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INDEX TO THIS VOLUME

(Important magazine articles or pamphlets may be listed for quick reference. Subjects may be divided into columns)

HOW RADIO TRAINING GREW WITH THE INDUSTRY

WHEN radio was used solely for marine communication and safety at sea, the school now known as R.C.A. Institutes was founded. It carried on through years of early developments in the art, training men for radio as the world experienced the exciting years of conflict and radio became an important factor in warfare. Expansion came as the dawn of broadcasting brought the possibilities of radio to world-wide popular recognition. On to the present when Television is promising to emerge from the laboratory and take its place beside sound programs, R.C.A. Institutes has progressed, keeping pace with the times in its improved methods of training men for the radio industry.

It was at 42 Broadway, New York City, in the year 1909, that radio's first instructor, Elmer E. Bucher, author of the first radio textbooks and now an executive of RCA, began his courses covering theory, maintenance, adjustment and repair of marine radio equipment—then commonly known as wireless.

Following the passage of this country's first radio law, the radio school room became a necessity. Experienced men as well as beginners had to prepare for the Government examination and obtain "Certificates of Skill."

In the Spring of 1912, the school was moved to larger quarters at Cliff and Fulton Streets, New York, when the Marconi Wireless Telegraph Company took it over and gave it the name of "Marconi School of Instruction."

Another federal law changed the "Certificates" to graded licenses and the examinations became more stringent. Two operators were required on most ships. As a result, the new school began to hum with activity. New instructors and more elaborate equipment were added.

Not long after that the school outgrew these quarters, necessitating another move to Duane and Elm Streets, New York, where its name was changed to the Marconi Institute.

In the latter part of 1919, when the Radio Corporation of America was organized, and the Marconi Company was absorbed, the school became known as The Radio Institute of America. About this time Mr. Bucher was called to fill an executive position for the Radio Corporation. In severing his connections with the Institute, he left behind a thoroughly organized corps of executives and instructors who took over its direction. M. L. Bergin, now with RCA Radiotron Company, became Director in charge.

In May, 1920, a move was made to the third floor of 326 Broadway, New York, and eventually these larger quarters were also outgrown. Practically the entire fifth floor of that building was then fitted for modern radio training.

In 1921 the home study division was inaugurated. This idea of studying radio at home grew steadily from the beginning. The courses were enlarged and special equipment was designed to assist the student. Evidence of its remarkable growth is seen in the fact that today there are students studying R.C.A. Institutes home study courses in every state of the United States and in many other countries throughout the world.

Following the advent of popular broadcasting, the need for expert service men became evident and a course in that subject was formulated.

Again the Institutes was a step ahead. As far as is known, there was no means up to that time of obtaining such instruction other than that in the service departments of manufacturers and their agents, limited to their particular products.

The service course was enlarged and extended in scope. It soon grew to be of value to the radio industry as a whole. Parallels to its value and timely start have since been seen in the inauguration of the Sound Motion Picture courses, the Broadcasting courses and, more recently, the course in Television.

Each successive year found the Institutes in a more important position. The industry now began to specialize. Following this program, the Radio Corporation of America formed several subsidiary companies, each with a particular function in the radio field. It was seen that in the industry there were the functions of manufacturing, research, merchandising and distribution, engineering and entertainment. Ranking with these functions was that of the training of personnel, a position well maintained by the Institutes.

This suggested a separate organization concentrating upon training and devoted entirely to it. Accordingly, in August [illegible], the R.C.A. Institutes was incorporated as a separate company. The New York school was greatly enlarged by adding to its personnel of supervisors, instructors and clerks and also through the occupancy of new, extensive quarters at 75 Varick Street, New York. At the same time there were taken into the organization the Philadelphia School of Wireless Telegraphy, founded in 1911, and the Eastern Radio Institute, which had been efficiently operated in Boston since [illegible]. A new school was organized in the city of Chicago.

Mr. D. O. Whelan became President of the R.C.A. Institutes in [illegible]. Since then he has not only caused the elaboration of the already existing radio courses, both in the resident schools and those for home study, but in adding several courses of instruction in the associated electronic arts. His former experience as a radio engineer and in training of men gives the Institutes an added advantage in retaining its position in radio training.

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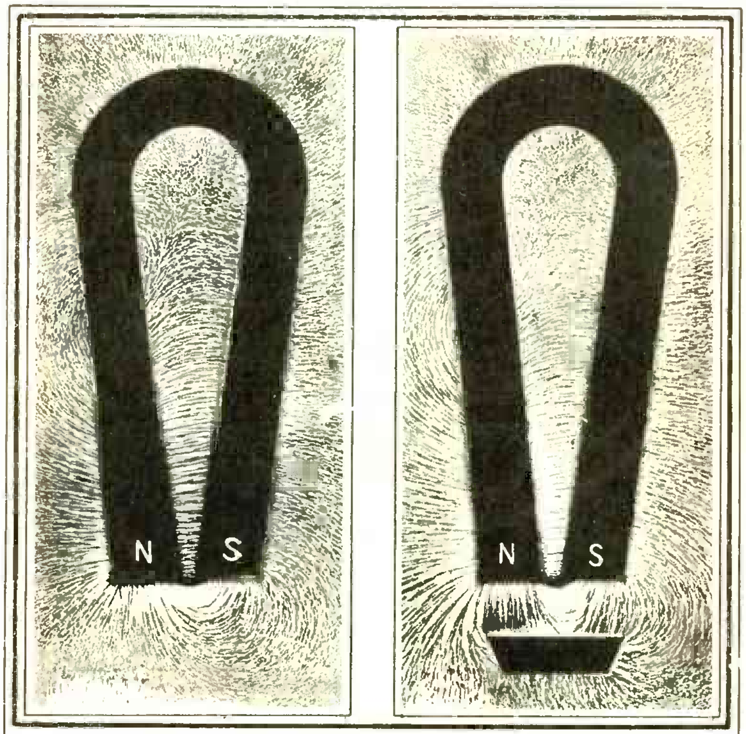
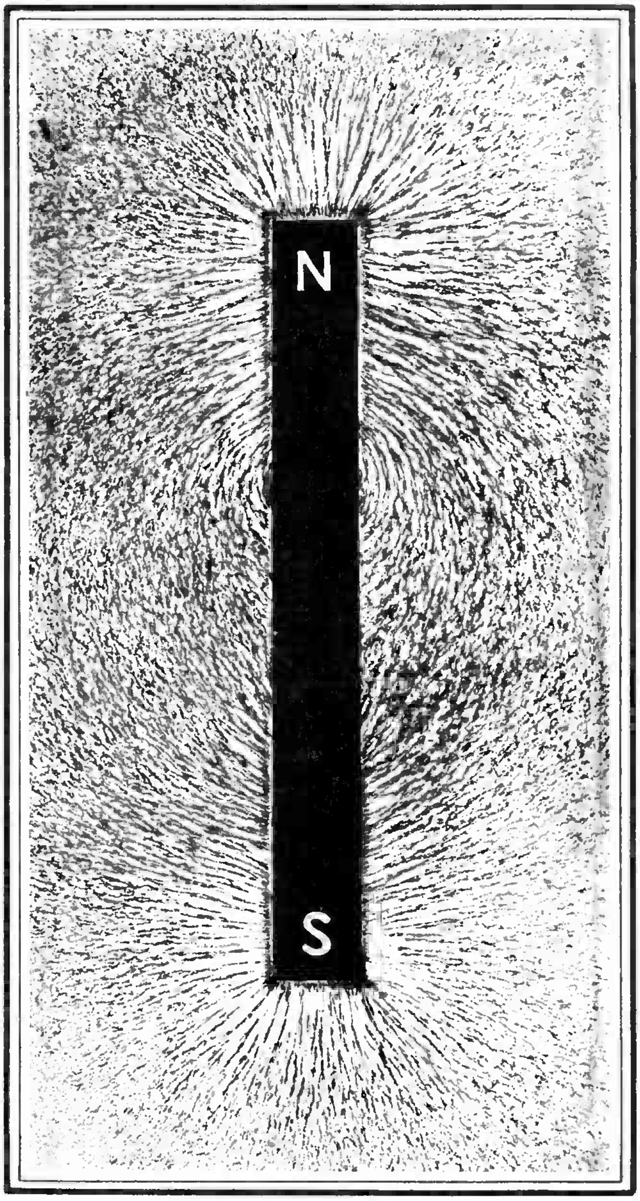


THE FIELD OF FORCE SURROUNDING EACH HORSESHOE MAGNET IS MAPPED OUT BY THE IRON FILINGS

THE THEORY OF MAGNETISM AND APPLICATION OF MAGNETS

VOL. 10 No. 2

DEWEY DECIMAL CLASSIFICATION R100



THE FIELD OF FORCE OF A BAR MAGNET

V-10 #2

America's Oldest Radio School

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THE THEORY OF MAGNETISM AND APPLICATION OF MAGNETS

MAGNETIC POLES. Many centuries ago in the mining regions of a small town in Asia Minor, named Magnesia, there was found a dark colored stone, which possessed a very peculiar property -- one that could be described as a sort of pulling force -- which gave this substance the power to attract small pieces of iron. It was then discovered that if a piece of this stone was suspended by a thread and allowed to move freely it would swing about slowly, and upon coming to rest would assume a position nearly due North and South. Early mariners used this stone as an aid in navigation, guiding their vessels according to its position, and for this reason the stone became known as "lodestone," which means "leading stone." Another name given to this stone (which is an ore of iron) is "magnetic oxide of iron," or "magnetite." The peculiar property we refer to became known as "MAGNETISM" and the substance itself which possessed the property was called a "MAGNET." The lodestone retains its magnetic properties indefinitely for it is the result of a natural condition within the ore itself.

In later years it was discovered that by an artificial process ordinary hard iron, or steel, could be made to take on the same property of magnetism as the lodestone. Thus, the magnetic property imparted to steel gave it the power to attract bits of iron, and morever, it was noticed that when a thin strip of magnetized steel was suspended, and permitted a free motion, it would swing about and come to rest in a position exactly similar to the lodestone with regard to the earth's North and South poles. The needle of the common magnetic compass, which is in widespread use, is nothing more than an artificial magnet; it is a magnetized piece of steel suspended so that it can turn freely. As most of us know, one end of the compass needle points in a general direction toward the North geographical pole of the earth and the other end points toward the South geographical pole. Convention, or custom in the past, accounts for the fact that the North (N) of a needle is so designated and used to identify the location of our North geographical pole in a general way as explained in the following paragraph.

In order to avoid any misunderstanding in our study of magnetism, let us explain now that the north end of the needle is actually attracted by the earth's magnetism set up by the South magnetic pole. This magnetic pole is located on the Boothia peninsula, in Canada, a distance of more than a thousand miles from the geographical North pole. Our earth is really a huge magnet with magnetic forces evident all over its surface, the forces being very pronounced and concentrated at the upper and lower extremities, or, as we would say, "at the poles." Hence, to be strictly accurate in our statement we should say that the "N" end of a compass needle points towards the South magnetic pole of the earth and the "S" end towards the North magnetic pole. The magnetic concentration is very evident from the behaviour of magnetic compasses when used by mariners and aviators in these regions.

To make certain that you have a perfect understanding about polarity as indicated by a compass let us look at the conditions this way: Consider that if the north (N) end of the needle points toward a magnetic influence, the region of this influence must be of opposite attraction, or a south (S) pole. If, on the other hand, the south (S) end of the needle points toward a magnetic influence the latter region must also be opposite, or a north (N) pole.

INDUCED MAGNETISM. Figure 1 illustrates the principle of magnetic induction and attraction. When a steel bar magnet is dipped into soft iron filings, it will be found that a large number of the iron particles will cling to one another and to the bar with great tenacity. Most of the filings will cluster near the ends of the bar with very few distributed along the surface and practically none at or near the middle. The iron particles which are in contact and closest to either end of the bar will seem to grip on with great firmness while those further out from the end are more feebly attracted to one another and seem to be less rigid. This indicates that the magnetism emanating from the end of the bar is strongest near its surface and as we proceed outward into space the magnetism becomes weaker.

We use the term "density" to express this difference in magnetism, saying that the magnetic density is greatest close to the bar. It simply means there is a greater concentration of magnetic force closer to the magnet's poles than at some distance away from it.

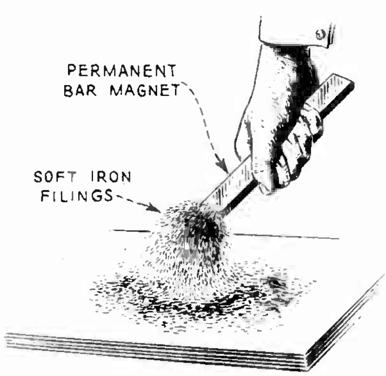

Figure 1

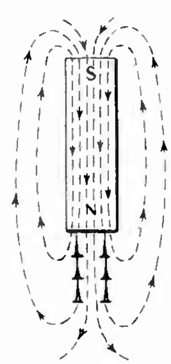

Figure 2

If a very strong steel magnet is used to attract the filings, and later you attempt to brush them off with your fingers, it will not prove an easy matter to remove absolutely every tiny iron particle from the magnet's surface. The manner in which these small iron bits cling to one another, and to the bar, indicates that regardless of the exact nature of this magnetic influence its force extends outward into the surrounding space which is called the "space medium." The iron tacks clinging to the magnet, in Figure 2, also serve to demonstrate the principles of induced magnetism.

The unseen influence around a steel magnet causes each individual filing in Figure 1 to become a tiny magnet possessing all of the properties of the large bar magnet itself. We usually express this action by stating that the large magnet induced magnetism into the iron filings. The filings would have magnetism induced in them whether they were in actual contact with the magnet, or merely in its presence. To prove the latter statement place the filings in a glass tube, or bottle, and then move the magnet against the outer surface of the glass and note how the filings are affected and shift around and cling to one another, assuming different positions according to the magnet's influence. Also, from this experiment we observe that glass is transparent to a magnetic force. Remember that each filing or tack assumes a position that enables it to accomodate the greatest amount of magnetism coming from the exciting magnet.

MAGNETIC PROPERTIES ALREADY EXIST IN IRON. The sketches in Figures 1 and 2 are intended to show that magnetism is not created but already exists in the iron tacks and filings. Nothing has been added to or taken from the iron to produce the results we have observed. It is simply a condition where this peculiar force (called magnetism) in the filings or tacks was made evident by the outside magnetic influence of the steel magnet. We know of several practical means for establishing magnetism and, also, ways to regulate its strength. This is a fortunate circumstance, indeed, because it permits us to utilize this invisible force in our electrical work.

Under ordinary conditions if we were to place materials like copper, paper, or wood, within the influence of a magnet we would not expect to observe magnetic effects such as the filings gave us in Figure 1. At first sight it might appear that any substance which is seemingly unaffected when subjected to a nearby magnetic force does not possess magnetic properties; but this is not the case. The phenomena of magnetism exists in all matter to a greater or less degree, only in some substances its detection becomes apparent quickly while in others it requires the most diligent research and delicate equipment to discover it. To make it pronounced in paper, wood, and all other so-called non-magnetic substances, would require an outside magnetic influence of considerable strength. If conditions were just right and if very strong magnetism was obtainable it could be shown that a piece of paper would be feebly attracted and would move toward the source of strong magnetism, whereas a piece of copper would be repelled.

We deal exclusively with iron and steel in our studies about magnetism because magnetic effects are especially pronounced in these metals, and for magnetic purposes they are the principal ones found in commercial use. However, it should be known that there is a certain compound consisting of iron and a small percentage of nickel that has magnetic properties superior to either iron or nickel alone. "Permalloy" is the name of one compound that can be magnetized about thirty times stronger than soft iron under similar conditions. "Perminvar" is the name of another magnetic compound.

TWO SOURCES OF MAGNETISM IN OUR PRACTICAL WORK. Let us mention at this point that the magnetic force set up by a fairly strong magnet is capable of not only attracting bits of iron and causing attraction or repulsion with other magnetic masses, but the force has the additional property of setting up a flow of current through coils, wires, and other elements composing an electric circuit. To produce a flow of current the magnetism which acts on the coils and conducting wires must be made to vary either in strength, or polarity, or both, and the circuit must be closed to form a complete conductive path for the current to flow. Or, if a magnetic force remains stationary and steady, a coil or conductor must be moved through it to produce a current of electricity therein.

It will be shown in a forthcoming lesson that an electric current passing through the turns of a coil sets up its own magnetic lines which completely encircle the coil. The lines set up by the current have precisely similar qualities in every way to magnetic lines produced by either a bar or horseshoe magnet. Bear in mind that magnetism, regardless of how or where it is made apparent (either through the use of magnets or from a flow of current) always exhibits the same general properties. Therefore, after having once mastered the fundamental principles outlined in this lesson, the student should find it easy to apply them to any action where magnetism and electric current are involved.

From these statements it is seen that there are two principal sources of magnetism:

1. Magnetic effects resulting from the use of magnets.
2. Magnetic effects resulting from the flow of electrical currents.

The first mentioned source is treated under the topic of "MAGNETISM" and the second, under "ELECTROMAGNETISM."

Just what takes place in the "space medium," or in a "material," when a magnetic force is present, or just what the nature of magnetism is we do not definitely know. But the results obtained when forces of this kind act upon magnetic substances, or upon conductors of electricity, have enabled scientists to formulate numerous laws and rules governing their behavior.

Very simple experiments can be performed to demonstrate "magnetic" and "electromagnetic" phenomena with a minimum of equipment, as for example, with the use of a small pocket-size magnetic compass, a bar or horseshoe magnet, iron filings, coils of wire and a battery, or dry cell.

KINDS OF MAGNETS. Magnetic substances are divided into two classes, namely:

(1) Natural magnets, and (2) Artificial magnets.

It should be quite obvious that a lodestone is a natural magnet and that all manufactured or man-made magnets are in the artificial class. The artificial kind are placed into the following two groups:

(1) Temporary magnets, and (2) Permanent magnets.

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Inasmuch as the soft iron filings in Figure 1, or the tacks in Figure 2, lose practically all of their magnetism when removed from the magnetizing force they are classed as temporary magnets. Suppose, on the other hand, that these filings, or tacks, after being shaken free from the bar were to retain their magnetic properties (assuming that even after a period of many months or perhaps years they still persist in clinging strongly to one another) they would be classed as permanent magnets. Assuming that a solid bar of iron or steel showed properties similar to the tacks and filings, as we have suggested above, the bar would also be called a "temporary" magnet, or "permanent" magnet, as the case may be. The point we wish to emphasize is that the size of a mass does not alter these conditions.

TYPES OF MAGNETS. There are in general three types of magnets. The path of the magnetic forces in each type is shown in Figure 3.

(1) Bar magnet........(Magnetic circuit consists partly of iron and air.)
(2) Horseshoe magnet..(Magnetic circuit consists partly of iron and air.)
(3) Ring magnet.......(Magnetic circuit consists only of iron; while seldom used it is given to aid explanations.)

SIMPLE WAY TO MAKE A MAGNET. Suppose that one-half of a bar of hardened iron or steel is repeatedly stroked with the "N" pole of a strong magnet, and each stroke is made the same way, beginning at the middle of the bar and stroking toward one end, then this end of the bar will presently become an "S" pole. Suppose the "S" pole of the magnet is now used to stroke the opposite half of the bar by the same process, then the latter end of the bar will become an "N" pole. If this bar, into which magnetism is being induced, is heated or slightly pounded during the process either treatment will assist the molecules in rearranging themselves in parallel rows (or in alignment) to make the bar a permanent magnet. It will be explained under the subject of "Electromagnetism" how a coil of wire through which current is flowing can be utilized to induce magnetism into a bar of hardened steel to make it a permanent magnet.

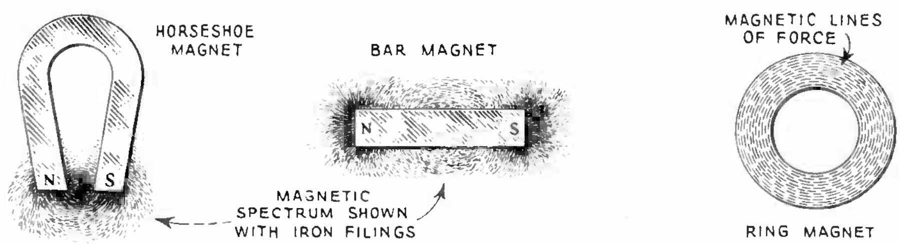

Figure 3

Magnets that are used for electrical measuring instruments and other devices requiring a constant magnetic flux must be aged. A permanent magnet becomes weaker with age but does not lose its strength uniformly with time. The strength decreases rapidly soon after the metal is magnetized and then falls off at a slower rate. The loss of magnetism is due to the haphazard arrangement of the molecules which will be discussed in detail later. In order to obtain a magnet which will lose very little strength over a long period of time we would ordinarily have to select a magnet which retained some magnetism although magnetized several years previously. However, manufacturers are able to obtain the effect of aging by a certain heating process. Heating a magnet to a red heat will, of course, destroy all magnetism but the application of a low temperature properly applied, will allow the molecules to hold their arrangement for an indefinite period.

FLUX - MAGNETIC FIELD - MAGNETIC LINES OF FORCE. To illustrate a "force" on paper is just like attempting to draw something one cannot see. For instance, you couldn't illustrate your "thinking powers" on paper, nor could you graphically show the "force" of an explosion. With this in mind you will appreciate why it has become the custom to merely draw a line to illustrate the line of direction of a force and then to place an arrow somewhere in that line to denote the exact direction in which the force is being applied. That is, the arrow shows the tension along the line. The magnetic forces which exist within a magnet and in the region surrounding it are, therefore, best illustrated by lines and arrows as shown in many of the drawings.

The total magnetic lines of force set up in a magnetic circuit (either by a magnetic material or by an electric current) are called magnetic flux, or simply flux. The flux is shown by dotted lines in our drawings. These lines take the form of ever-widening loops which may be thought of as a sort of magnetic whirl.

The field of force which is evident in the region outside a magnet is called the magnetic field.

The idea of presenting an unseen force graphically on paper is similar to that already used in our lesson on "Electrostatics." The difference is mainly that unbroken lines are drawn in the region where an electrostatic field of force exists, whereas, dotted lines are used to represent a magnetic field of force. Note particularly the formation of the magnetic lines of force in each of the different types of magnets in Figure 3. See how the majority of the lines come out at the region around one pole and go in at the region around the opposite pole, with comparatively few lines at or near the middle of the magnet. Of course, in the case of the ring magnet the lines are confined entirely within the iron mass because this magnet has no poles.

MAGNETIC LINES OF FORCE CAN BE VISUALIZED ONLY BY INDIRECT OBSERVATION. Magnetic forces cannot be seen, as you know, but their effects can be. In order that you may actually visualize the strain lines (lines of force) present about a magnetized substance it is suggested that the following simple experiment be performed. Obtain a small bar magnet or horseshoe magnet, a sheet of cardboard or glass, and a small quantity of soft iron filings. Someone connected with a machine shop in your neighborhood will no doubt give you the filings; a thimbleful or two will be plenty, or you may easily make them by filing part of an iron bolt, or any piece of ordinary iron for that matter.

Let the bar magnet be placed under the cardboard, or glass, and let the iron filings be sprinkled evenly over the flat surface. Then gently tap the surface a dozen times or more with a pencil and observe how the iron particles actually turn about and arrange themselves in lines or loops in a symmetrical formation according to the diagram in Figure 3. The energy in the magnet induces magnetism into the filings, causing each one to become a tiny magnet having its own "N" and "S" poles; the induced magnetism making the filings attract one another and causing them to form loops or whirls.

Each of the lines of force completes an independent circuit as shown by the continuous loops. The loops (or lines) tend to shorten themselves at all points, that is, they tend to take the shortest route in the space they occupy between opposite poles. However, the lines remain separated and spread out an infinite distance from the bar because of the strong repulsion which adjacent lines exert on one another. One line never crosses over, cuts through, nor merges into neighboring lines. See Figures 4 and 5.

The force lines exert a tension in a direction outward from the "N" end of the magnet as they pass around the bar through space and re-enter at the "S" end, the tension being continued on through the bar from "S" to "N," as indicated by the loops and arrows. When speaking about this characteristic of magnetism we say that lines of force are in a direction from "N" to "S" around a magnet and from "S" to "N" inside. (Note: The exception to this rule is a ring magnet which forms a closed iron circuit; in this type there are no open ends or poles and therefore the lines are confined within the iron. However, if a section of a ring magnet is cut out, the open ends thus made then become "N" and "S" poles respectively, with a magnetic field set up in the space between them.)

In the action explained in the foregoing paragraphs, where the force lines originating in the bar magnet exert their influence on the iron filings and cause their re-arrangement, it may be added that this action in turn places the filings in a position so that they exert their individual influences on one another. Keep in mind that each little filing becomes a magnet in this process. Consequently, we have a greater total magnetic force existing in the region around the magnet when filings are present than without filings, because the force lines set up by the filings when they are magnetized add to the force lines coming from the bar magnet.

<u>EXPLORING A MAGNETIC FIELD WITH A SMALL COMPASS</u>. Suppose we explore the magnetic strain set up in the region about a steel magnet by moving a compass in various positions as suggested in Figure 4. We will see that when the needle comes to rest at some particular location it will take up a definite direction acting along the lines of force at that point. The several positions of the compass in the drawing shows that the needle coincides with the lines of force in every case.

Hence, a magnetic compass is useful for detecting the presence of a magnetic field and determining the direction in which the lines pass. The diagram of the field about the magnet and the compass, in Figure 4, teaches you how to determine the polarity ("N" and "S" poles) of a magnet.

<u>MAGNETIC SPECTRUM</u>. In Figure 5 we observe a bar magnet and the region surrounding it placed under a strain by the force lines leaving at points toward one end of the bar and re-entering at similar locations toward the opposite end. This gives a symmetrical appearance to the formation of the lines as mapped out by the iron particles in the bar magnet in Figure 3.

The shape or image of the magnetic lines, as viewed with the aid of the filings, is called a "magnetic spectrum."

Since strain lines always exist around a magnet then for any change made in the position of a magnet the strain lines will move along with it. Try moving the bar magnet in Figure 1 slightly back and forth in different positions and note the effect on the filings.

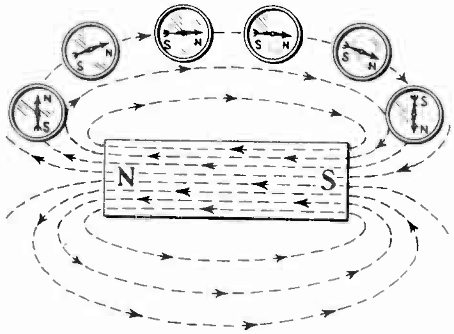

Figure 4

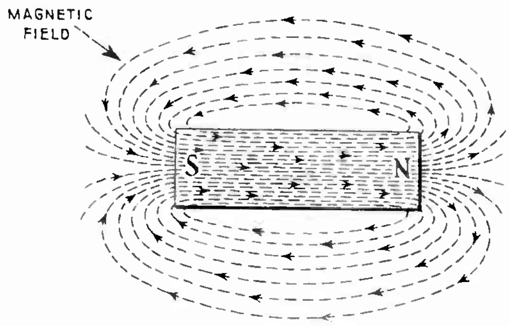

Figure 5

THE LAWS OF ATTRACTION AND REPULSION

(1) Magnetic poles of like kind repel each other.
(2) Magnetic poles of unlike kind attract each other.

To prove the laws just stated we will make use of two steel bar magnets whose "N" and "S" poles are known and marked as shown in Figures 6 and 7. One magnet is suspended by a thread so that it will move freely under the influence of the other magnet.

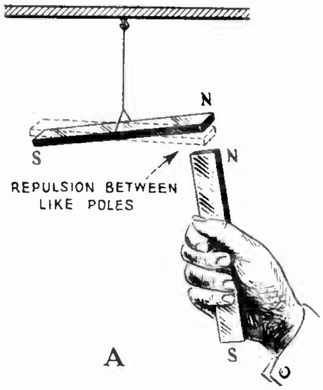

Figure 6

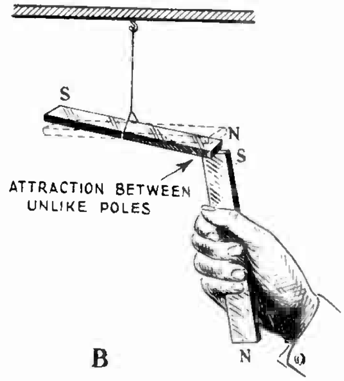

Figure 7

The conditions illustrated by Figures 6 and 7 are as follows:

(1) If one of the magnets is held in the hand and slowly moved, as shown in Figure 6, so that its north pole end is brought near the north pole end of the suspended magnet we will immediately see the latter move away and come to rest in a position as far as possible from the first magnet. This demonstrates the law of repulsion.

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(2) Now suppose the south pole end of the magnet in the hand is brought near the north pole end of the suspended magnet, as shown in Figure 7, then we will obtain an effect just opposite to the one observed in (1). This time the north end of the suspended magnet will swing toward the south pole of the approaching magnet, with the swinging magnet coming to rest in a position as close as possible to the magnet held in the hand. The ends of the magnets will actually come into contact if you permit them. This demonstrates the law of attraction.

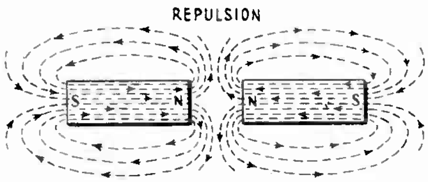


Figure 8

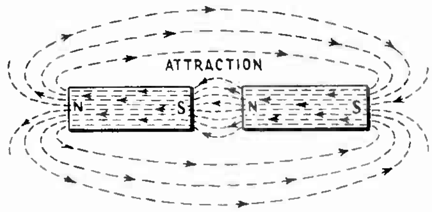


Figure 9

(1) The explanation for the action in (1) relating to repulsive effects will be understood after examining the sketch in Figure 8 and keeping in mind that the magnetic forces act along the lines and in the direction indicated by the arrows. Observe how the lines representing each field are distorted from the normal arrangement they occupy when not under the influence of each other. The shape of a normal field is shown in Figure 5. A similar effect of repulsion would be produced if two south poles were brought near to each other.

(2) The explanation governing the action in (2) relating to attractive effects will be understood by an examination of Figure 9 and reasoning as follows: The attraction or pulling effect between adjacent magnetic poles of unlike kind is caused by the lines coming out from the "N" end of the first magnet and going in at the "S" end of the second magnet, that is, the tension of the lines are acting along the same direction as shown in the drawing.

THEORY OF MAGNETISM IS BASED ON THE ENERGY STORED UP IN A MOLECULE AND ATOM. Now, examine the drawings in Figures 10, 11, and 12 for the purpose of studying the molecular action within an iron bar when it is demagnetized, or magnetized, or saturated with magnetism. Before we go into a detailed explanation of these drawings let us first mention a few facts about "energy" and the general conception that all magnetic effects in iron are thought to be due to an alteration in the position the molecules normally occupy. You should, at this point, recall some of the explanations given in a previous lesson about the composition of matter. You learned that all substances are composed of molecules, and that the molecules in turn consist of atoms, and finally the energy within the atom is a combination of positive and negative electrical forces. The negative forces are the rapidly vibrating electrons as previously explained.

Our explanations also stated that magnetism and electricity are inseparably associated in all kinds of "matter," and that energy in different forms is accounted for by the action of electrons in constant motion. It may be of more than passing interest to mention that according to the belief of scientists the many different kinds of substances found on our earth and the energy they possess were produced ages ago when our earth was in the process of cooling and formation.

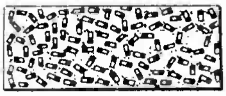


Figure 10

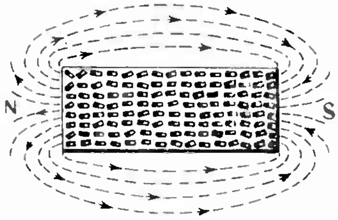


Figure 11

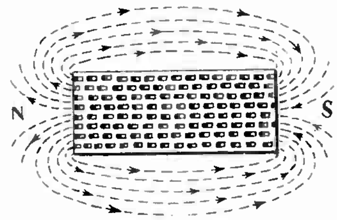


Figure 12

It is quite evident that energy already exists in iron and steel molecules and this energy is capable of doing "work" when properly directed. The results of the "work" performed by a magnetic force were observed in Figures 1 and 2 when iron particles and tacks were attracted toward a bar magnet and their weight was supported by it. Also, we saw that magnetic properties, similar to those of the steel magnet itself, were induced in the iron particles. This ability of iron and steel to become magnetized and to do work permits us to consider any material displaying such qualities as a storehouse of energy.

USE OF THE TERMS MAGNETIZED AND DEMAGNETIZED — ATTRACTION AND REPULSION. The power of either attraction or repulsion which one magnetized material exerts upon another was illustrated in the experiment with the bar magnets in Figures 6 and 7. Although these principles have been discussed before let us again repeat that each bar magnet has a north and south pole and, also, if two like poles, north poles for instance, are brought together the bars will move away from each other due to repulsion. Two south poles placed in the same neighborhood would also repel each other. On the other hand, if two unlike poles, north and south, are brought together the bars will move toward one another, and will touch if permitted to do so, due to attraction.

If you obtain some soft iron filings and actually try the experiment previously suggested in Figure 1 you will notice that after the filings are shaken off and removed from the magnet they cease to cling together; as far as all outward signs are concerned they have lost their individual magnetic properties. In other words, just so long as the filings are subjected to the magnetizing influence they continue to remain magnets, but when they are not subjected to this influence they lose practically all of their power to attract one another as you observed. In this process the filings were first magnetized and then demagnetized.

There are certain kinds of iron that, after being magnetized, will retain their magnetism for much longer periods than the soft iron filings which we used. This subject is treated under "Retentivity."

CONDITIONS IN A NON-MAGNETIZED IRON BAR. The energy contained in a magnet that enables it to perform work is stored up in the molecules of the substance, as we have previously explained. A single glance at the drawing in Figure 10 shows that every molecule (molecules are merely suggested by the rectangles) is a magnet in itself having its own "N" and "S" poles. Also, the dotted lines denoting the forces are seen to reach out through the void spaces between adjacent molecules thereby linking them together to form numerous closed and irregularly shaped groupings.

The extreme ends of each molecule are called "poles," and by convention they are known as "north" and "south" poles, respectively. The "N" pole ends of the molecules are indicated in the sketch by solid black squares and the "S" pole ends by white outlined squares.

Observe how there is a natural attraction between neighboring molecules which causes them to arrange themselves in a somewhat irregular order with their north and south poles practically together. When an iron mass is in this condition, that is, with its magnetic forces confined in closed paths by virtue of the closed molecular groups, the iron will not display any noticeable outward magnetic effects. The iron in this condition is said to be non-magnetized or demagnetized. In other words, although magnetism is present within the bar it is not evident in the region outside and, consequently there is no magnetic field produced.

CONDITIONS IN AND AROUND A MAGNETIZED IRON BAR. If a piece of soft iron is brought near a steel magnet the iron will become magnetized as mentioned in an early part of the lesson. The molecules of soft iron, when under the exciting magnet's influence, are forcibly turned about on their axes and rearrange themselves in a manner somewhat like the diagram in Figure 11. They form parallel rows with their "N" and "S" poles lined up end to end.

When this alignment of molecules is brought about the energy in each molecule adds to that of its neighbor with the result that the "N" poles point in the same general direction toward one end of the bar and the "S" poles toward the opposite end. Thus, the magnetized iron has all of the properties of a magnet, that is, it has a north pole and south pole of its own. We have, then, a condition where the magnetic energy in the molecules now exerts its influence in the region outside the bar, setting up strain lines in this region, the strain lines being called a "magnetic field." As indicated by the lines and arrowheads the force lines about a magnet leave at the north pole and reenter the south pole.

The magnetic circuit in the diagram in Figure 11 consists of air and iron. The air path is technically known as the "space medium." However, in practice you will find that a magnetic circuit may consist of air or iron alone, or a combination of both. Magnetic flux encircling a coil when current flows is an example of a complete air path, whereas, a ring magnet, such as the one in Figure 3, is an example of an all-iron path. A ring magnet may be employed where no external field is desired for special uses in certain types of meters and transformers.

From the facts stated heretofore the student should readily grasp the idea that a magnetic force is continuous. However, to make this point positively clear let us suppose that in Figure 5 there are 100,000,000 lines of force within the bar (we have shown only several strain lines for simplicity) then we would also have 100,000,000 strain lines acting on the space medium. In other words, for each line existing in the bar the space outside is subjected to the strain of one line for the simple reason that every line is continuous; it has no beginning or end. Moreover, the space about a magnet opposes being placed under a strain and, consequently, it exerts a constant effort to recover its normal state.

It is of utmost importance that the student should think of magnetic flux acting entirely around a magnetic circuit and not that the lines start or end at any particular point.

CONDITIONS IN IRON OR STEEL WHEN SATURATED WITH MAGNETISM. The drawing in Figure 12 shows several rows of perfectly aligned molecules. It is only natural to expect that such straight rows of molecules, when exactly end to end, will exert the greatest strain or tension in regions outside the magnet. In practice, however, molecules do not as a rule form absolutely straight lines but their rearrangement is more or less imperfect. In any event the extent of molecular rearrangement is dependent upon the kind of substance being magnetized and the strength of the inducing force. Each line contributes its individual magnetizing force to the total produced by the magnet. If all of the molecules of an iron or steel bar were rearranged as perfectly as those shown in Figure 12 then no further magnetism could be induced in the bar since there is nothing more that could be done to the iron to make it "take on" or "hold" more magnetism. In this condition the iron would be said to have reached the "saturation point," known as "magnetic saturation." Therefore, its magnetic strength could not be increased beyond this limit regardless of how strong might be the magnetizing force.

EFFECT OF BREAKING A MAGNET INTO SMALLER PIECES. The sketches in Figure 13 are intended to convey the idea that magnetism is due to a certain molecular arrangement and, also, that magnetic lines form a continuous circuit; they cannot be thought of as having any beginning

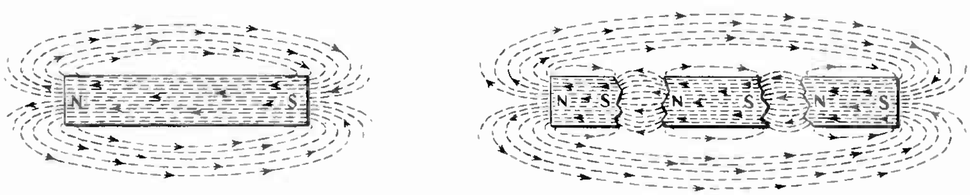


Figure 13

or end. Accordingly, if a bar magnet is broken into several pieces, as illustrated, each piece becomes a separate magnet with "N" and "S" poles of its own and with strain lines established in the surrounding space.

WHEN TWO MAGNETIC FORCES ACT SIMULTANEOUSLY IN THE SAME REGION. The purpose of showing the weather vane, in Figure 14, is to explain by a simple comparison with two air currents what would happen if two independent magnetic fields, established in the same region, acted on each other. Suppose we have the force of one air current, marked A, acting in the direction indicated by the arrows, and a second air current, marked B, acting from some other direction. If the two currents meet at a place where a weather vane is erected the vane will move about and finally come to rest pointing in a direction different from either of the oncoming air currents. The final direction assumed by the vane is a resultant effect of the two forces acting on each other. So it is with magnetic forces. If two magnetic fields are brought together in the same region the fields will be distorted and the final direction of the magnetic lines, or the resultant field, will be governed by the angle at which the fields meet and the relative strength of the forces acting.

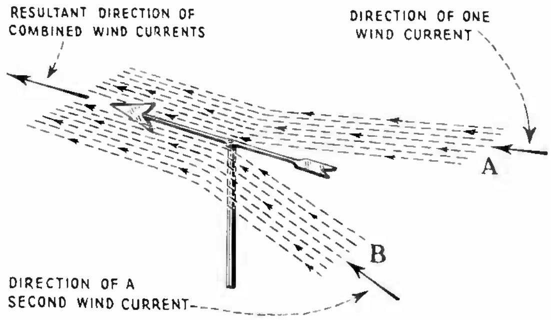


Figure 14

HYSTERESIS - MOLECULAR FRICTION. That molecules of iron actually do move and turn about on their axes when brought into the presence of a magnetic force can be proven in a practical way. If a magnetic force acting on an iron bar changes continuously in strength, or polarity, the iron molecules composing the bar will rearrange their positions in accordance with the changing force. The molecules, as they shift slightly back and forth, rub one another and in so doing they generate heat in the iron. The heat developed in the iron or steel parts of any electrical apparatus, which is built to function only when subjected to rapid changes in magnetism, represents one source of energy loss.

Therefore, if we wholly or partially magnetize and demagnetize a piece of iron steadily for a given length of time, which we can do by various means, the iron will become warm and under certain conditions it may even become very hot. The heat is said to be due to molecular friction between the iron particles, and note that all of this happens despite the fact that we can see nothing of the invisible forces that are acting. It is obvious that heat is a waste of energy when it is not desired, or when it is not put to some useful purpose.

It is more difficult and requires greater magnetic influence to alter the molecular arrangement of steel than iron, that is to say, steel naturally resists being magnetized or demagnetized to a greater extent than iron. The energy loss that occurs in iron or steel when subjected to rapid changes in their molecular arrangements is called "hysteresis."

RELUCTANCE EXPLAINED BY PLACING A BAR OF SOFT IRON BETWEEN TWO STEEL MAGNETS. The opposition which air, or iron, or any material used in a magnetic circuit presents to magnetic flux is called "reluctance." It will be recalled that in the case of an electrical circuit the opposition to current flow is spoken of as "resistance."

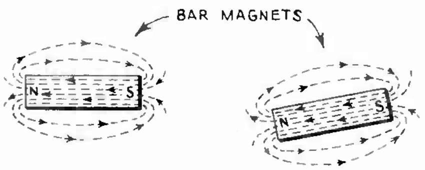


Figure 15

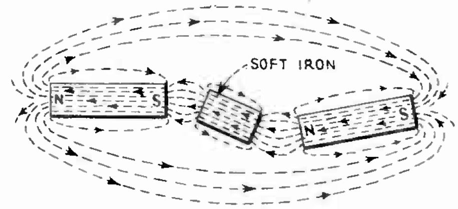


Figure 16

The reluctance of air is about a thousand times as great as the reluctance of ordinary iron. Because the reluctance of iron and steel is lower than air explains why lines of force will always take on iron or steel path in preference to an air path. Refer to Figures 15 and 16 which show that when a bar of unmagnetized soft iron is placed between two steel magnets a greater number of lines of force will be accomodated in the iron and a stronger flux will be set up in the magnetic circuit than would be the case if we simply had an air space separating the two steel magnets. The shape of the magnetic fields of the two magnets are normal when the iron bar is removed, as the drawing in Figure 15 shows. However, when the iron is inserted between the magnets, as in the drawing in Figure 16, their fields are distorted and the lines seek the path through the iron rather than through the air.

By moving the three bars closer together shorter air gaps will separate them and, of course, the reluctance of the complete magnetic circuit will be lowered accordingly with the result that more lines of force will be established. This will increase the attraction existing between the three bars and make the iron bar a stronger magnet. If, on the other hand, the three bars are moved farther apart the reluctance of the entire magnetic circuit will be increased due to the wider air gaps with the result that less lines will be established, and the iron bar will become a weaker magnet.

So long as the iron bar is kept in the presence of the steel magnets the iron will have magnetism induced in it and therefore will remain a magnet having "N" and "S" poles of its own. The polarity is due to the iron molecules being forced into alignment, a condition similar to that pictured in Figure 11. Note for one thing how the magnetic circuit in Figure 16 is formed and, also, that there is attraction between the three bars since their unlike poles are near each other.

In order to understand the reason for the results obtained in Figures 15 and 16 it is only necessary to bear in mind that air offers an infinite opposition to the setting up of magnetic lines, whereas, iron naturally offers an easier path for lines of force. This is why iron is attracted to a magnet.

The three factors governing the condition of any magnetic circuit are, namely: (a) the length of the complete magnetic path or circuit; (b) the cross-sectional area of the circuit; and (c) the permeability of the circuit, which varies according to the materials used and the length of any air gaps or spaces present through which lines of force must pass.

RETENTIVITY — PERMEABILITY. The term "retentivity" is used to denote the power of substances to retain or hold the greater part of magnetism imparted to them. The term retentivity should not be confused with permeability. The term "permeability" expresses the quality of a material that permits it to become strongly magnetized, or, in other words it indicates the ease with which a magnetic substance can be magnetized irrespective of how long the substance may retain magnetic properties afterwards.

A piece of hardened steel resists being magnetized, but after magnetism is once induced in the steel it will hold or retain this property for comparatively long periods. It requires a great magnetizing force (called coercive force) to completely demagnetize a steel magnet, that is to say, to return its molecules to such a position or arrangement that the steel will no longer show magnetic properties. So we find that molecules of steel are not easily moved out of their aligned positions after they once assume a certain arrangement. For this reason, steel is used in the manufacture of permanent magnets. A permanent magnet should always be handled with care; if dropped or subjected to shocks, jars, or heat, it is likely to lose a considerable part of its magnetism due to the breaking up of the molecular alignment.

On the other hand, soft iron is used where a temporary magnet is required because the molecules of this material will arrange and rearrange themselves with comparative ease when placed in and out of the influence of an outside magnetic force. It should now be apparent that soft iron acts as a magnet only at such times as when a magnetizing force is present.

DENSITY. It stands to reason that far more parallel rows of molecules can be packed into a given mass of iron when molecules form exactly straight lines and the lines are very close together as in Figure 12, than in the case where the molecules are more or less haphazard and partly in alignment as in Figure 11.

The number of lines that can be crowded into a given magnet determines its magnetic strength; the number of lines per unit area being known as the density. The strain at any point near a magnet is indicated by the density of the lines at that point. It then follows that a magnetic field of high density possesses great strength and is capable of doing considerable work while a field of lower density will be comparatively weaker.

Figure 17 shows how the density of a magnetic field varies with the distance from the source. The rectangle R is cut by many lines of force whereas the area designated as P is seen to have fewer lines traversing its boundaries. The exact relationship between distance and magnetic field intensity is expressed in the formula,

$$H \propto \frac{m}{d^2}$$

where: H = magnetic field intensity
m = the strength of the isolated magnetic pole
d = the distance from the pole

the symbol $\propto$ stands for the phrase "varies as."

From this relationship we can see that if 8 lines pass through R only one fourth of that number or 2 will pass through P or we can say that the magnetic field intensity varies inversely as the square of the distance from the pole. This is true providing P is twice as far from the end of the bar as R.

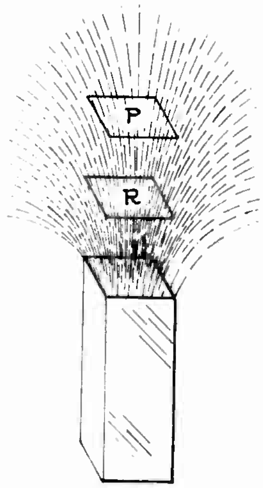


Figure 17

The magnetizing force H is the number of gilberts per cm.; a gilbert being the unit of magnetomotive force $\mathcal{F}$. The gilbert is numerically expressed in the relation,

$$\mathcal{F} = 0.4\pi NI$$

where: N = number of turns
I = current in amperes,

and the magnetizing force (H) is this result divided by the length of the magnetic path (l) or gilberts per centimeter,

$$\text{or, } H = \frac{0.4\pi NI}{l}$$

The number of lines of force in a unit area is called the flux density or field intensity. When one line passes through one square centimeter the field strength is said to be one gauss.

$$B = \frac{\Phi}{S}$$

where: B = flux density in gausses
Φ = total flux
S = total area in square centimeters

The total number of lines or flux in any given area is the product of the field strength and the area.

Due to the fact that magnetic lines of force are set up in iron much more easily than they are in air, the ratio of the number of lines that exist in iron to the number existing in air gives us a relationship known as permeability. Thus, if a single line passes through one square inch of air and one hundred lines pass through the same area of iron the iron is said to have a permeability of 100 divided by 1, or 100.

Figure 18 shows a number of lines of force passing through a unit area of air space; in this case 1 inch.

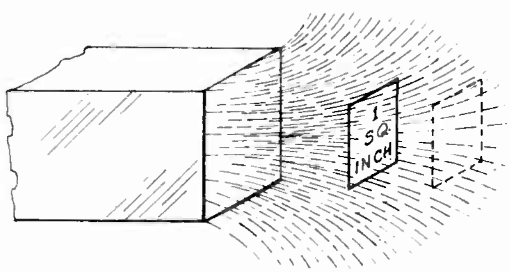


Figure 18

The ratio of the flux density (B) to the magnetizing force (H) likewise represents magnetic permeability (μ)

$$\mu = \frac{B}{H}$$

where: B = flux density in gausses
H = magnetizing force in gilberts per centimeter

If iron takes the place of air as a medium for magnetic lines of force the flux density B is increased. All kinds of iron, however, do not have the same flux density. Various specimens of iron and steel have been tested for use in magnetic circuits as well as for use in electrical machinery, and it has been found that the flux density or number of gausses set up by different magnetizing forces vary greatly. In order to show the relationship between the magnetizing force, (H), and the resultant flux (B), curves are plotted for all types of iron and steel. These curves are known as <u>magnetization-saturation</u>, or more commonly as <u>B-H curves</u>.

Figure 19 is a set of standard curves for several different materials used for magnetizing purposes. They represent the average for materials used by large commercial organizations.

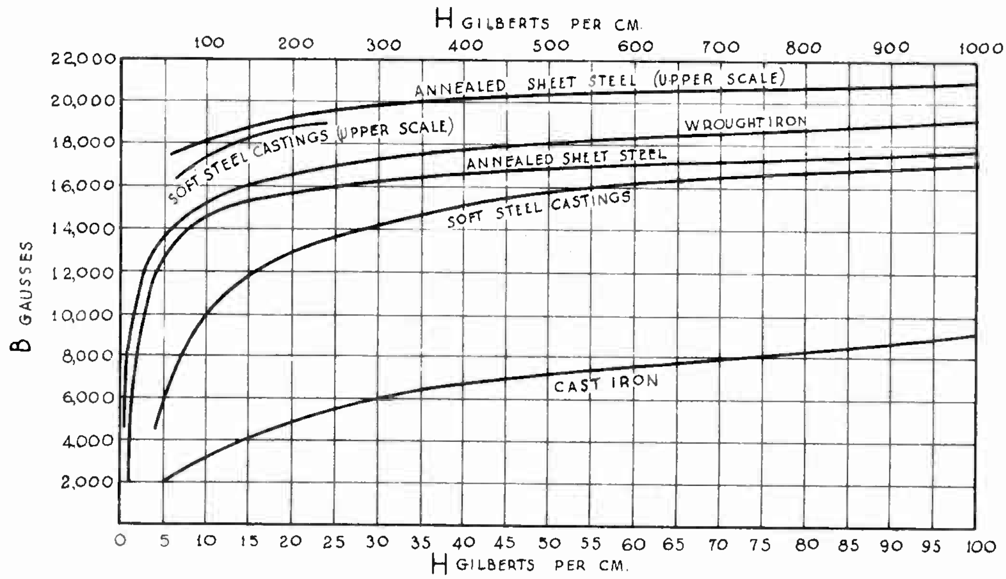


Figure 19

Now that we understand that permeability is the ability of a material to conduct magnetic lines of force we can expect that a unit representing the ability of a substance to oppose magnetic flux will be useful. The resistance to magnetic lines of force is called reluctance $\mathcal{R}$, the unit of which is known as the <u>oersted</u>. The difficulty with which a substance is magnetized is called its reluctivity and, as has been explained, reluctance is inversely proportional to permeability. This is the same as saying that if the permeability increases the reluctance decreases proportionally and if the reluctance is increased the permeability is decreased a corresponding amount.

$$\mathcal{R} = \frac{l}{\mu S}$$

where: l = length of magnetic circuit in centimeters
μ = permeability
S = cross section area in centimeters

<u>RESIDUAL MAGNETISM</u>. If an iron mass, after being subjected to a magnetizing influence, is removed from the exciting force and the iron then holds a perceptible amount of magnetism, the remaining magnetism is known as "residual magnetism." It simply means that the molecules do not all move back in the original positions they occupied before magnetization took place, but a certain number remain permanently

fixed in more or less irregular lines which produces a weak magnetism. "Remanance" is a term used when comparing the total number of lines of force of residual magnetism remaining in different kinds of iron and steel after the removal of the magnetizing force.

MAGNETIC SHIELD — AIR AND SPACE MEDIUM. We do not really consider air as the space medium in which magnetic lines are established around a magnet although the term air is frequently used to denote this region. Just what the medium is has never been ascertained, but it is known that it is something other than air. For instance, suppose we exhaust the air from a sealed glass chamber and suppose a compass occupies a position in the very center of the vacuous space. It would be found that if a steel magnet was brought near the chamber the magnetic lines emanating from the magnet would penetrate through both the glass wall and the vacuum and cause the compass needle to deflect.

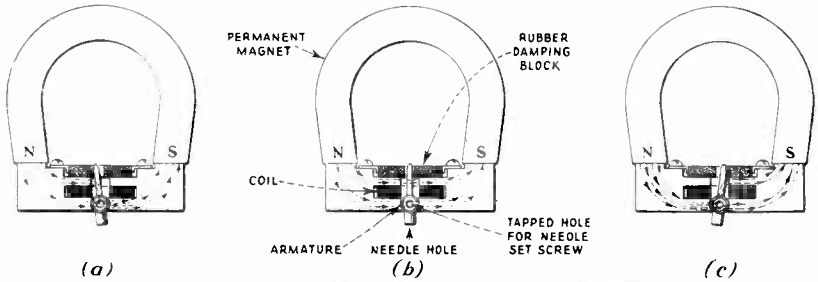
It is interesting to note from this test that neither glass nor a vacuum will act as a shield to block magnetism. Iron is used in practically all cases where a magnetic shield is desired. The principle of an iron shield is as follows: Magnetic lines from some source will not pass directly through and out on the opposite side of an iron shield, but rather the force of the lines act on the iron molecules tending to rearrange them and make the shield itself a magnet. What happens is this: the shield takes up the magnetism and in this way shunts the magnetic forces around the region which is to be protected or isolated from magnetic effects. Thus, when a shield is employed, magnetic lines cannot spread outward indefinitely into space, as the lines naturally would do otherwise. The principle explained here is one of magnetic induction, and it holds true in the case of any magnetic force acting on iron which tends to make the iron a magnet.

In a future lesson you will study a type of magnetism known as electromagnetism which produces effects similar to those studied in this lesson. Many electrical devices are operated on electro-magnetic principles and many depend on ordinary magnets for their action. Perhaps you are familiar with the difference between the two forces or perhaps you have learned the difference from the foregoing sentences. An ordinary magnet retains its magnetism at all times whereas an electromagnet is magnetic only in the presence of a current flow.

COMMERCIAL APPLICATIONS. Figure 20 shows various stages in the operation of a magnetic pickup device which is used to change the mechanical vibrations of a phonograph needle into electrical impulses, which can be increased by the amplifiers of a radio receiver or sound picture machine. This pickup contains a permanent magnet of the horseshoe type between the poles of which a light coil of wire is suspended. The needle is permanently connected to this coil and the wires of the coil are connected to the amplifier.

The coil of wire is located midway between the N and S poles of the permanent magnet as is shown in the illustration. The arrows indicate the path of the flux from the N to the S pole. If the coil moves through this flux due to mechanical vibration from the needle the flux will be affected or will be cut by the coil or conductor. When we study the subject of electromagnetism we will learn how this action produces an electrical current.

Permanent magnets are employed in a similar role in the magnetic type of loudspeaker and in ear phones or receivers. Instead of producing or generating a current, however, as does the pickup these sound producing devices receive electrical energy and change it to mechanical motion, which is the reverse action. The principle, however, is similar.



Operation of the magnetic pickup

Figure 20

Figure 21 illustrates a common type of magnetic speaker used whenever a medium amount of sound is desired such as is in the home or in the sound projection room of a theatre. When greater volume of sound is required a dynamic type of speaker must be employed. The magnetic

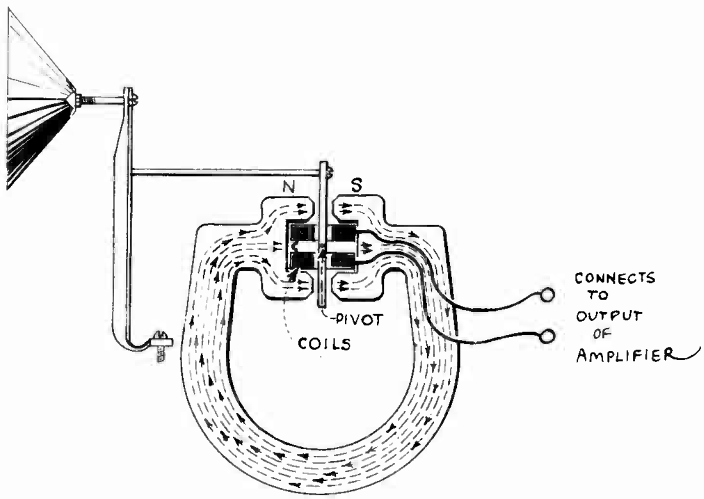


Figure 21

speaker contains a large permanent magnet and a coil of wire is located between its poles as shown. The arrows indicate the path of the magnetic flux.

The various parts which comprise a magnetic speaker are shown in Figure 22. The student should recognize that the main component parts are the permanent magnet and the coil or winding previously described.

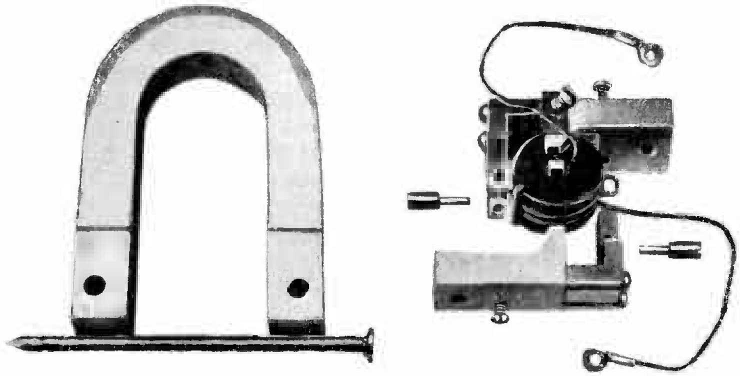


Figure 22

INCLINATION AND DECLINATION. The following terms do not have a direct bearing on our study of radio or sound pictures although many students will find them interesting and useful as magnetic disturbances often affect radio communication and navigation.

We mentioned in the first part of this lesson that a magnetic compass points towards the magnetic poles and that these poles do not coincide with the geographical poles of the earth. The angular deviation of the magnetic compass from the geographical north pole is called the angle of declination, or just declination. The first notice of this discrepancy of alignment between the magnetic and geographical north poles is accredited to Columbus who was unable to account for the phenomenon.

Lines connecting points on a map having the same declination are known as isogonic lines. The lines are very irregular due to magnetic deposits in the earth. A line connecting the geographical and magnetic north poles and running through Chicago is known as the line of zero declination as compasses located on this line point toward the true north. In northeastern Maine compasses point 20 degrees west of true north whereas in the state of Washington they point about 25 degrees east of north.

If a magnetic needle is balanced freely by means of a thread or pivot it will not lie parallel to the earth's surface but will dip towards the magnetic pole nearest to it. The angle of inclination, or dip varies from zero at the equator to a vertical position or 90 degree dip at the magnetic poles.

Navigators of both aeroplanes and ships must take these variations of the magnetic compass into consideration. A sensitive compass needle often swings back and forth three degrees on either side of its normal position when affected by a magnetic storm. Although the cause of such storms is unknown they are often accompanied by sun spots and auroral displays. Telegraph and telephone lines are inoperative during magnetic disturbances and radio signals become weak or fade out entirely.

The magnetic condition of the earth is continually undergoing changes. At the present time both the inclination and the declination are slowly increasing in the United States. Slow changes such as these are known as secular changes. That these changes have been going on for many centuries is evident from the fact that coal deposits are found in the extreme northern parts of the earth where no vegetation now grows. As coal is formed by tropical or semi-tropical vegetation the northern or arctic region of the earth must have been located in an entirely different position with respect to the sun than the present one. Such a change of the earth's position would no doubt shift the magnetic as well as the geographical poles.

SERIES AND PARALLEL MAGNETIC CIRCUITS.

Series Arrangement.

We shall see the advantage of connecting magnetic materials in series or in parallel with each other when we study electromagnetism, especially in connection with motors and generators. These machines have large magnetic cores composed of pieces of iron made in various shapes and sizes. The reluctance or opposition to lines of force offered by magnetic materials whether connected in series or in parallel depends on the length, the permeability, and the cross sectional area. This was expressed in the general formula for reluctance, namely,

$$\mathcal{R} = \frac{l}{\mu S}$$

The total reluctance offered by a series connection of magnetic circuits is equal to the sum of the individual reluctances, or

$$\mathcal{R} = R_1 + R_2 + R_3 + \text{------} \quad \text{etc.}$$

In the explanation dealing with electrical circuits resistance offered to the flow of current in an electrical circuit is handled in a similar manner.

Let us work out a typical problem in series magnetic circuits. Suppose we have a magnetic circuit composed of two pieces of iron with permeabilities and dimensions as given below and we wish to find the total reluctance of this magnetic circuit. If we compute the reluctance of each piece of iron and add the two values together the result is the desired total reluctance, or total opposition to the magnetic flux.

The first piece is 12 centimeters long, 5 square centimeters in area, and has a permeability of 400. The total reluctance is:

$$\mathcal{R} = \frac{l}{\mu S} = \frac{12}{400 \times 5} = 0.006 \text{ oersteds.}$$

The second piece is 30 centimeters long, 8 centimeters in area and has a permeability of 1000. Again we substitute and

$$\mathcal{R} = \frac{l}{\mu S} = \frac{30}{1000 \times 8} = 0.0037 \text{ oersteds.}$$

The total reluctance equals the sum of the two reluctances, or

$$0.006 + 0.0037 = 0.0097 \text{ oersteds.}$$

Parallel Arrangement.

When it is desired to find the total reluctance of several magnetic circuits placed in parallel or in shunt we employ the following relation:

$$\mathcal{R} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \text{------etc.}}$$

For example, suppose we have an iron ring with a circumference of 100 centimeters, a cross sectional area of 10 square centimeters, and a permeability of 180. Now if a ring of the same dimensions but of different material, and having a permeability of 90, is placed alongside the first ring the total reluctance is computed as follows:

Reluctance of first ring:

$$\mathcal{R} = \frac{l}{\mu S} = \frac{100}{180 \times 10} = \frac{1}{18} \text{ or } 0.0555 \text{ oersteds}$$

Reluctance of second ring:

$$\mathcal{R} = \frac{l}{\mu S} = \frac{100}{90 \times 10} = \frac{1}{9} \text{ or } 0.1111 \text{ oersteds}$$

The total reluctance of the two rings connected in shunt, or parallel is computed as follows:

$$\mathcal{R} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2}} = \frac{1}{\frac{1}{\frac{1}{18}} + \frac{1}{\frac{1}{9}}} = \frac{1}{18 + 9} = \frac{1}{27} \text{ or } 0.037 \text{ oersteds.}$$

Using the decimal equivalents instead of fractions we arrive at the same result.

$$\mathcal{R} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2}} = \frac{1}{\frac{1}{0.055} + \frac{1}{0.111}} = \frac{1}{\frac{2}{0.111} + \frac{1}{0.111}} = \frac{1}{\frac{3}{0.111}} = \frac{0.111}{3} = 0.037 \text{ oersteds.}$$

The above worked out problems are similar to those given in the examination questions.

PRACTICAL APPLICATIONS OF MAGNETS.

The photograph in Figure 23 shows the most recent type of dynamic loudspeaker which uses a large magnet to supply the permanent field in which the voice coil of the speaker is located. The mechanical design is clearly shown in this rear view photograph. The magnet

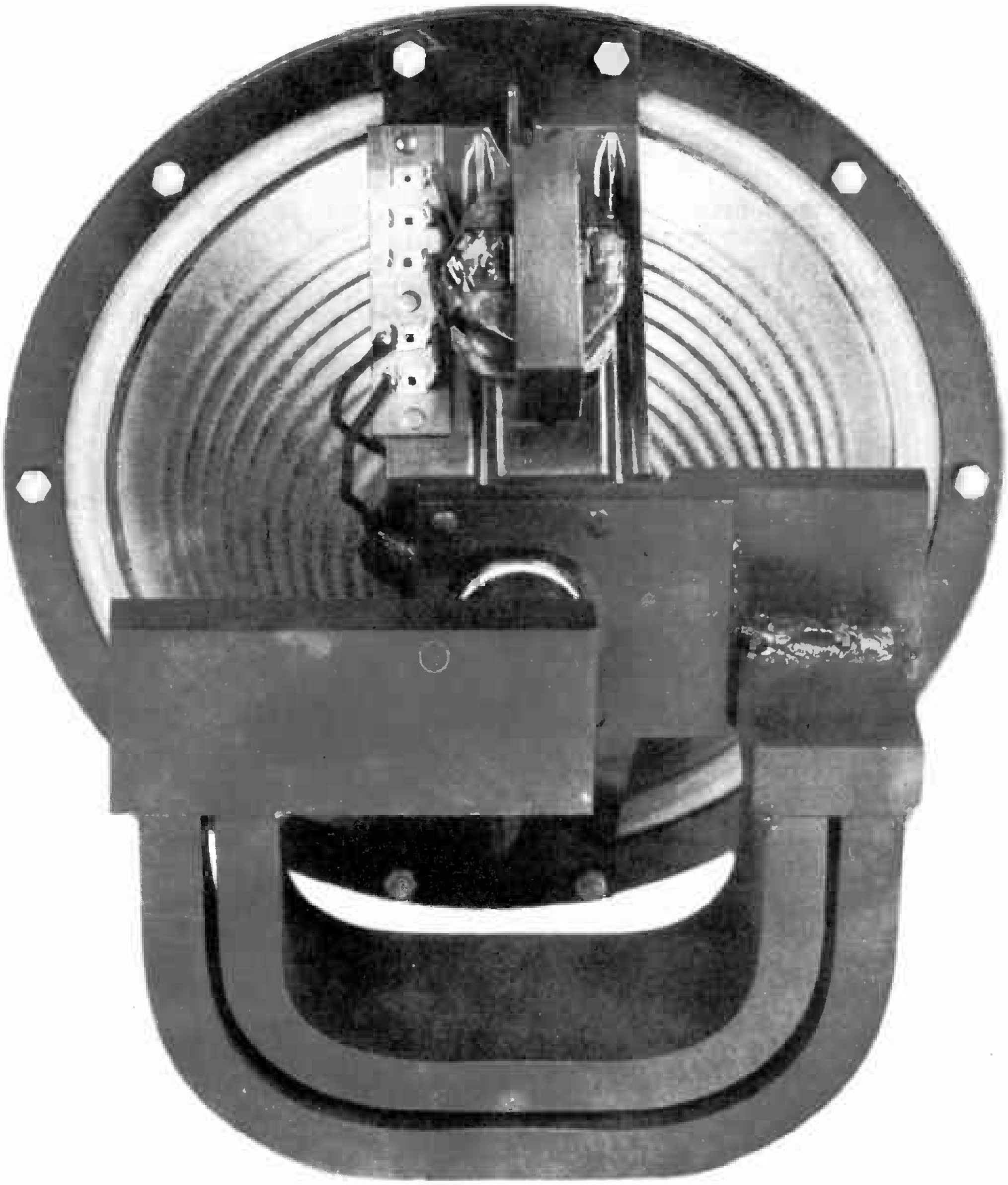


Figure 23

structure is formed from a high grade magnet steel or chromium steel which affords practically indefinite life or permanent magnetic strength unless the magnet is mistreated, such as by the application of demagnetizing fields, by severe mechanical shocks, by undue heating, or by improper contact with other magnetic materials. The yoke consists of two horseshoe type magnets which support all remaining portions of the assembly. One pole piece is formed from a solid cylindrical unit extending forward within a circular hole in the head or second pole piece to which both sections of the cone

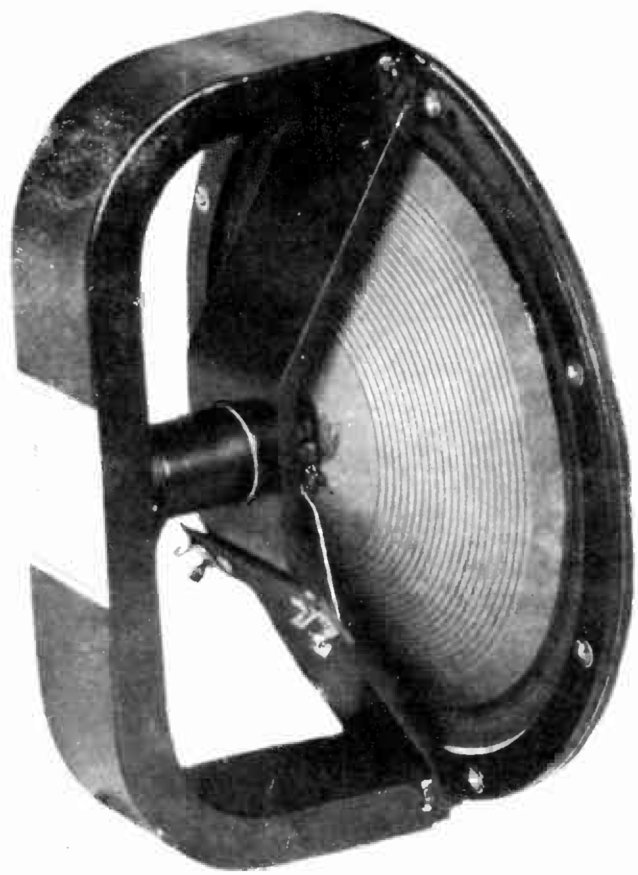


Figure 24

support are rivited. All joints between the various pole piece units and the magnet faces are electrically welded. This construction provides an annular air-gap in assembly within which the cone coil is suspended, the cone support being of non-magnetic material. In brief the action of the loudspeaker depends upon the magnetic lines set up around the cone coil when voice currents flow through it reacting on the magnetic lines of the permanent magnet. This reaction between the two magnetic fields causes the cone to move since the coil is mounted on the apex of the cone. The main feature in utilizing the permanent magnet for a dynamic type loudspeaker is for applications wherein either insufficient or no field supply power is available. The sound radiating surface is a paper cone which is corrugated to improve the reproduction.

There are many useful applications of a permanent magnet to be found in the electrical field such as in meters of various descriptions, in telephone receivers or headsets as they are often called, in devices used in connection with the visual indicating method employed in the reception of airplane beacon signals, in the pickup units used with self recording apparatus, and in the sound-on-disc system employed in sound picture equipment and so on.

Figure 25

Among the widely varied applications of a permanent magnet are the instrument relays designed for complex automatic testing devices incorporating vacuum tubes and photoelectric cells. The Jewell relay in Figure 26-A shows the horseshoe magnet, the moving coil and the contacts.

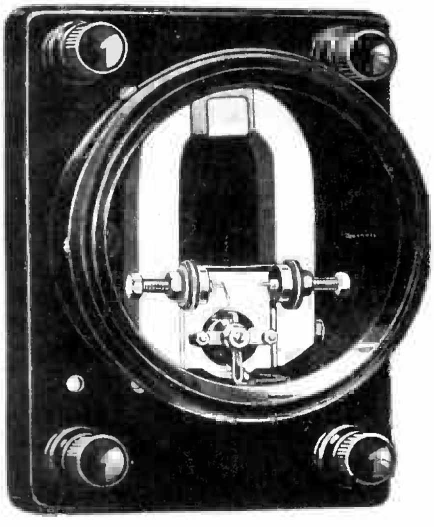


Figure 26-A

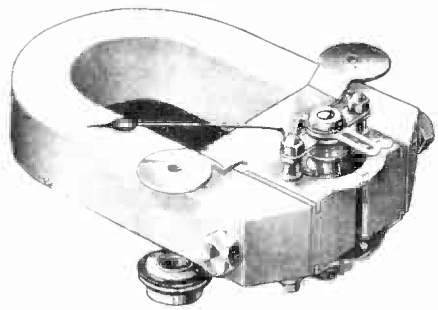


Figure 26-B

The permanent magnets used in direct-current instruments are of conventional shape as shown by the horseshoe magnet in Figure 26-B which is used in the d-c movement of a Jewell instrument. These magnets are designed to have the proper ratio of length to cross section in terms of the required flux and length of air gap and are forged from alloy magnet steel and heat treated.

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In Figure 27 you see a pickup unit about to be placed in the starting position on a record while the sketch in Figure 28 illustrates

Figure 27

the component parts and of particular interest at this time in our study of magnetism are the pole pieces and the magnet.

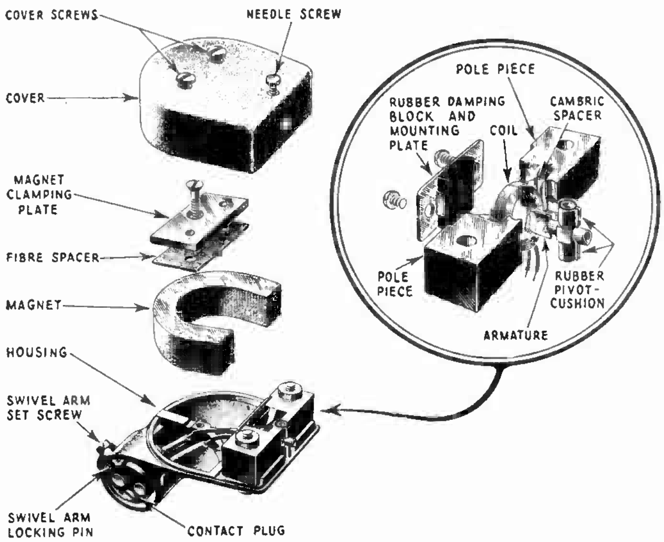


Figure 28

When the unit is assembled the pole pieces act as extentions to the poles of the magnet and hence, they carry the flux to the air gap in which the coil and armature are located.

EXAMINATION QUESTIONS

1. What would be the best material to use in the construction of:
   (a) A permanent magnet? Explain why this is true.
   (b) A temporary magnet? Why?

2. Name and illustrate three types of permanent magnets.

3. Why must great care be taken in the handling of a permanent magnet?

4. A steel magnet bar is broken into small pieces. What is characteristic of each particle?

5. What form does the magnetic spectrum of a horseshoe magnet assume? Illustrate by means of a diagram.

6. In your own words make clear the meanings of the following terms. (a) Reluctance, (b) Retentivity, (c) Permeability, (d) Magnetic saturation, (e) Hysteresis, (f) Residual magnetism.

7. Give an explanation of the laws of attraction and repulsion. How would you undertake to give a simple demonstration of these laws, to someone?

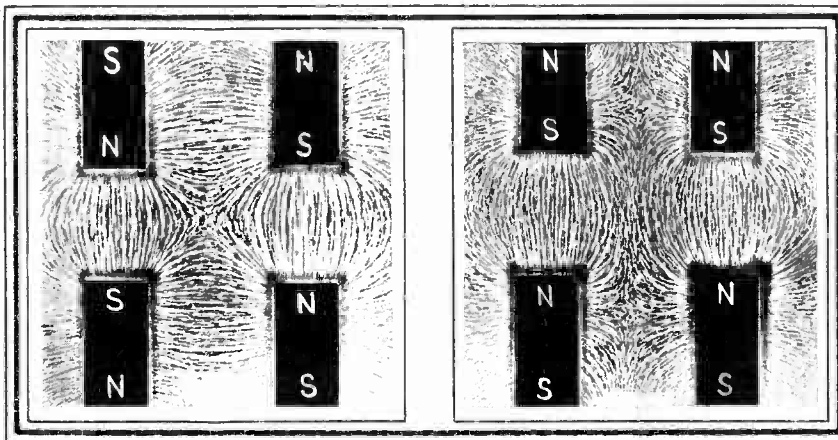
8. Answer briefly but clearly:
   (a) What is a magnetic field?
   (b) What is meant when one speaks of "density?"
   (c) What is induced magnetism?
   (d) What is meant by magnetic flux?

9. What are a few of the characteristics of "lines of force?"

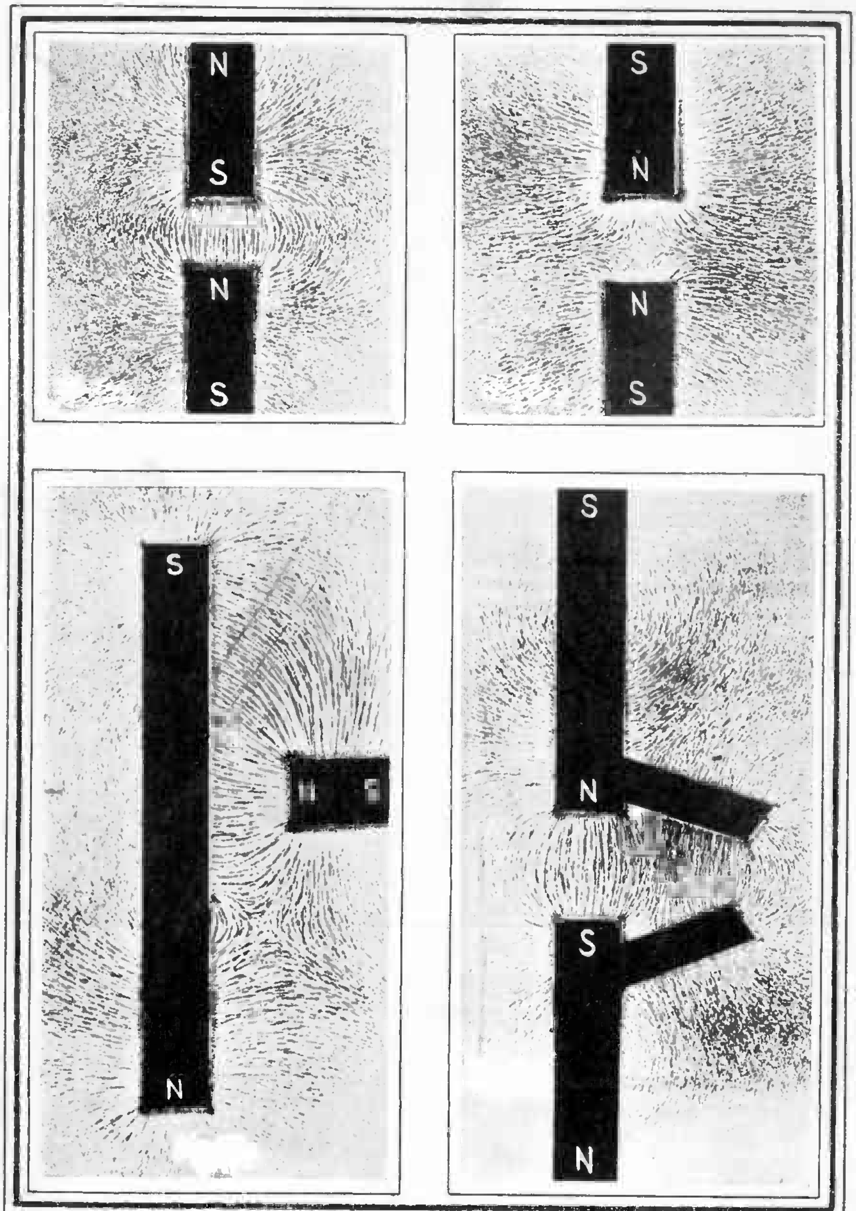
10. What is the arrangement of molecules in an iron or steel bar (a) When magnetized? (b) When demagnetized? (c) When magnetically saturated?

11. An iron bar 10 centimeters long, 5 square centimeters in cross section, and having a permeability of 100, is connected in series with another iron bar of the same dimensions but having a permeability of 80. A third piece of iron which is 4 square centimeters in area and 20 centimeters long is clamped alongside of the first two pieces so that the ends meet. If the third iron bar has a permeability of 100 what is the total reluctance of the three bars?

2



THE IRON FILINGS ARRANGE THEMSELVES INTO CURVED LINES BETWEEN THE UNLIKE POLES OF MAGNETS



IRON FILINGS INDICATE ATTRACTION AND REPULSION OF VARIOUS COMBINATIONS OF BAR MAGNETS

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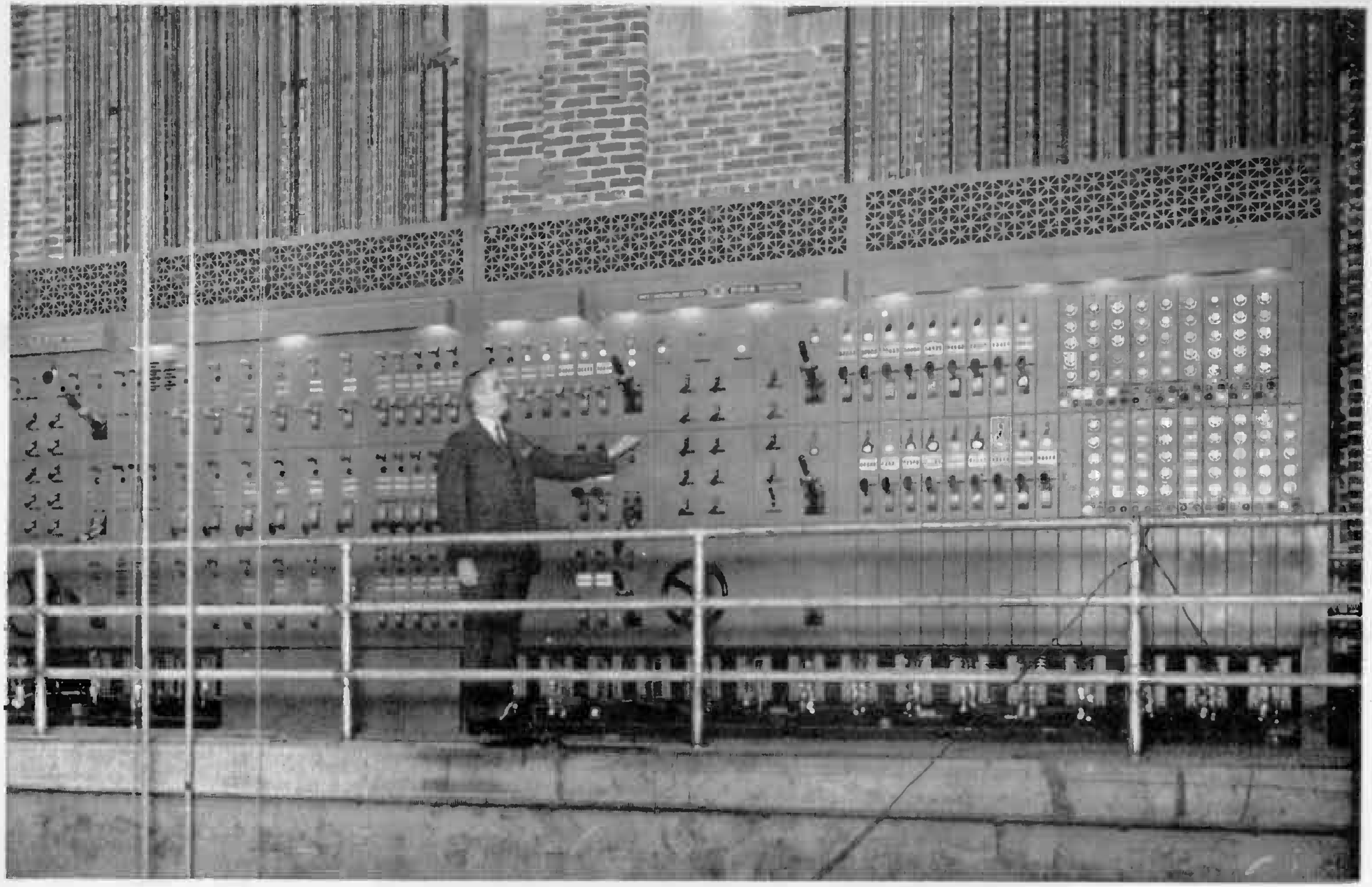
The dynamic speaker being assembled depends on electromagnetic forces for its operation.

Faraday's Discovery of Electromagnetic Induction. The Relation of Electric Current to Magnetism.

VOL. 10, No. 3

Dewey Classification R100



Electromagnets operate the switches and relays on this convention hall control panel.
These units distribute the sound currents to broadcast hook-ups.

Courtesy Westinghouse Elec. & Mfg. Co.

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ELECTROMAGNETISM — ELECTROMAGNETIC INDUCTION

A FLOW OF CURRENT PRODUCES MAGNETIC EFFECTS. With the invention of the magnetic compass man made use of a natural force about which he knew little. Since that time, however, steady progress has been made in finding practical uses for magnetic properties. Although the exact nature of magnetism and the medium through which it acts is still unknown we are able to produce magnetism and control its forces as this lesson will explain. From a study of the subject of "magnetism" one learns about the inherent properties of magnets and their effects. The same fundamental laws and characteristics governing magnetic lines of force of a permanent magnet are applied to all cases where electromagnetic lines of force are set up by a movement of electric current.

MAGNETIC EFFECTS ARE ALWAYS SET UP IN THE SPACE MEDIUM SURROUNDING A FLOW OF CURRENT. A stream of negative electrons moving from one place to another through any path which acts as a conducting medium is considered to be a flow of current. This is in accordance with the "Electron Theory." Therefore, a movement of electrons or current flow through a conductor (for example a wire) sets up in the region about that conductor electromagnetic lines of force which are in the form of a magnetic whirl beginning at the center of the wire and extending an infinite distance outward into space.

A review of the terms by which magnetic units are known and the origin of these terms are presented in the following paragraphs. You will notice from the explanations that magnetic units are named after some of the earlier investigators of electricity and magnetism. Two of these terms, the "Oersted" and the "Maxwell," have not as yet been officially recognized by scientific societies.

The MAXWELL, named after James Clerk Maxwell, a Scotch physicist, who expounded a mathematical theory of the existence of electromagnetic waves in the spectrum, is the unit of magnetic flux and represents the number of lines of force passing through each square centimeter of a field of unit density.

The total number of magnetic lines of force or flux in any given area is represented by Φ, or Phi, a letter taken from the Greek alphabet and pronounced "fe" as in feet, or "fi" as in fine.

<u>The OERSTED</u>, named for Hans Christian Oersted, a Danish scientist, is the unit of magnetic resistance and is defined as the reluctance offered by a cubic centimeter of vacuum.

$$\text{Reluctance} = \frac{\text{length in centimeters}}{\text{permeability x cross section in square cm.}}$$

<u>The GILBERT</u>, named after the English physicist, William Gilbert, is the unit of magnetomotive force or magnetic pressure. One ampere-turn produces 1.2566 units of magnetic pressure (0.4π). One unit divided by 1.2566 ampere-turns = .7958 ampere-turn, or one Gilbert.

Magnetic pressure = 1.2566 x turns x amperes, or

$$\mathcal{F}\,(\text{m.m.f.}) = 1.2566 \times N \times I$$

<u>The GAUSS</u>, named after Karl Friedrich Gauss, a German mathematician, is the unit of magnetic field strength, and is equal to one line of force per square centimeter. It represents the intensity of a field which acts on a unit pole with a force of one dyne.

In electricity Ohm's law states that the

$$\text{Current} = \frac{\text{Electromotive Force}}{\text{Resistance}}, \text{or } I = \frac{E}{R}.$$

Expressed in electrical units:

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

With electromagnetism we have a relation of quantities similar to Ohm's law. This relation between magnetomotive force, magnetic flux, and reluctance is expressed as follows:

$$\text{Magnetic Flux} = \frac{\text{Magnetomotive Force}}{\text{Reluctance}}, \text{or } \frac{\mathcal{F}}{\mathcal{R}}$$

In magnetic terms it is expressed as follows:

$$\text{Maxwells} = \frac{\text{Gilberts}}{\text{Oersteds}}$$

The magnetic field, or whirl, can be detected easily by means of a magnetic compass, or with the aid of iron filings, as shown by the experiment in Figure 1. It shows that a wire of suitable length (either insulated or bare wire) is thrust vertically through the center of a sheet of cardboard upon which is sprinkled a thin uniform layer of soft iron filings. The opposite ends of the wire are connected respectively to the positive (+) and negative (—) terminals of a dry cell which furnishes the electromotive force necessary to send current through the wire. The direction of current flow is indicated by arrows. With current flowing the cardboard is tapped lightly which causes the fillings to move and arrange themselves in concentric circles, each circle being a line of force. Of course, the filings cannot clearly map out all of the lines because of their

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vast numbers. An important fact to be remembered is that the lines of force exert their effort in a certain direction around the wire and at right angles to it.

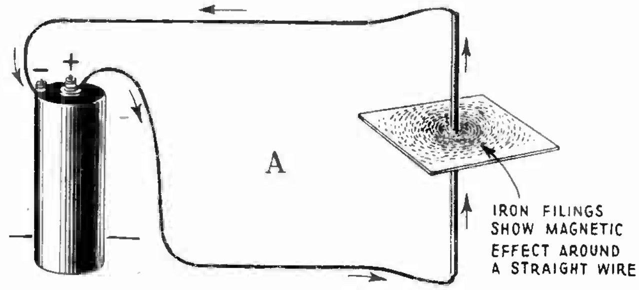

Figure 1

Our experiment offers a convenient means for indirectly observing how the passage of current through a wire sets up magnetic effects. Although these whirls of magnetic lines exist along the entire length of the wire circuit (whenever current flows) we are only visualizing them at one location on the wire, i.e., at the point where our cardboard is placed. To prove that the magnetism exists all along the wire move the cardboard up and down at the same time observing the behavior of the filings. The total number of lines encircling the wire is an indication of the magnetic field strength, or density, and in this case is chiefly dependent upon the number of amperes of current flowing. A current of low value will produce a comparatively weak field, whereas, a current of larger value will produce a relatively stronger field. The magnetic lines (or flux) around the wire have precisely every quality possessed by lines existing about a steel magnet. The lines act upon the space medium about the wire to place it under a strain as any magnetic flux would do.

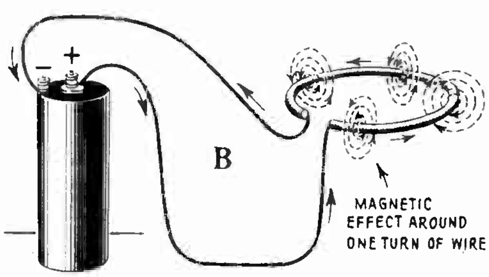

Figure 2

<u>THE MAGNETIC EFFECT ABOUT A "LOOP" OF WIRE WHEN CURRENT FLOWS.</u> Now let us bend the straight wire in Figure 1 into a loop as in Figure 2. It is seen that the magnetic lines are present but that by forming a loop we have obtained a condition where the direction of the lines are all upward inside the loop and all downward outside the loop. Stating this in a different way we could say that all of the lines set up by the current emerge from one end of the loop, surround the loop and re-enter at the opposite end, with the result

that a continuous magnetic flux encircles the single turn of wire. Figure 3 shows the magnetic flux set up by current flowing through a coil. The magnetic whirl around each turn is similar to the single turn in Figure 2, but by the coil arrangement the lines around one turn combine with those of an adjacent turn, and so on, throughout the length of the coil. This results in the lines assuming a similar direction around the coil and through the core, that is they emerge at one end and after continuing around the coil re-enter at the opposite end. Thus, a coil can be made to produce strong magnetic effects because the lines set up by each of its turns add up collectively.

You now see from the drawing in Figure 3 that a coil through which current is flowing is similar to a steel magnet insofar as each produces a magnetic flux and, consequently, each has "N" and "S" poles at its opposite ends. Since magnetic lines of force have similar characteristics, regardless of how they are produced, then any effects or work which a bar or other type magnet is capable of doing could likewise be done by any suitable coil of wire when current flows through its turns. The following important facts concerning a current-carrying coil should be remembered: (1) The current produces a magnetic flux; (2) the coil has definite "N" and "S" poles; (3) the end of the coil from which the lines of force leave is the "N" pole and the opposite end where they re-enter is the "S" pole.

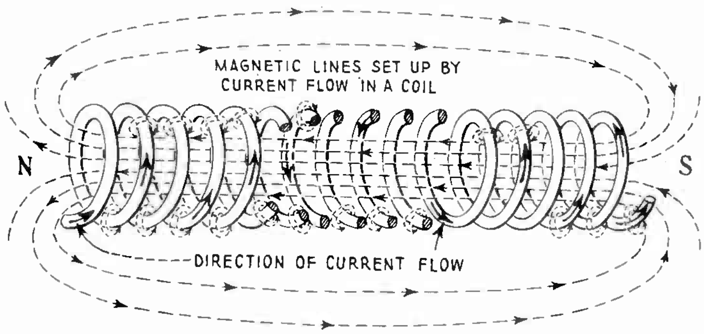

Figure 3

RELATION BETWEEN DIRECTION OF CURRENT FLOW AND MAGNETIC LINES AROUND A WIRE. The relation between the direction of current flow through a straight wire and the direction of the lines as they encircle it at right angles can be easily understood by the student after examining the diagram in Figure 4 and applying the following right-hand thumb rule:

FIRST RIGHT-HAND THUMB RULE: If a conductor is grasped with the right hand, with the thumb pointing in the direction of the current flow the fingers will encircle the wire in a direction similar to that taken by the lines of force. In other words, the fingers coincide with the direction of tension which the lines set up in space.

By placing a compass first above and then below a wire when current is flowing the direction of the force lines can be determined since they exist entirely around the wire in concentric circles. We have shown in Figure 4 how the compass needle points in a certain direction when it occupies a position over the wire, but, when under the wire, the needle points in the opposite direction. If we were to reverse the connections at the dry cell and cause current to flow through the wire in an opposite direction to that shown by the arrows the compass needle would indicate this change since it would point in directions just the contrary to those indicated for positions above and below the wire during the original connection.

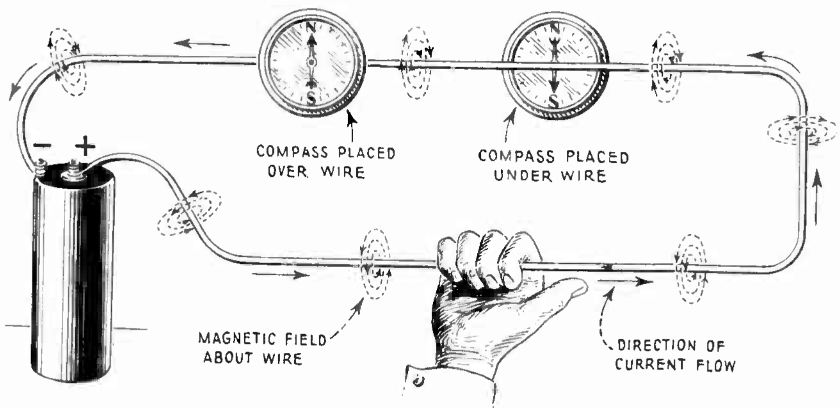

Figure 4

The drawings in Figures 5 and 6 are almost self-explanatory. Figure 5 shows the end view of a wire with the current flowing through it in a direction away from the reader (indicated by a cross) and the lines of force are in a clockwise direction about the wire. Figure 6 shows the same wire with the current reversed and flowing toward the reader (indicated by a heavy dot) and the lines are in a counter-clockwise direction about the wire. Figure 3 illustrates a coil with a cut-away section permitting you to readily visualize the magnetic effects around each turn and the total flux in and around a coil when current flows.

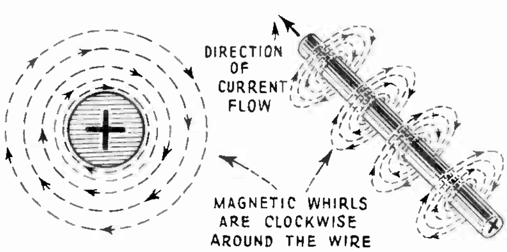

Figure 5

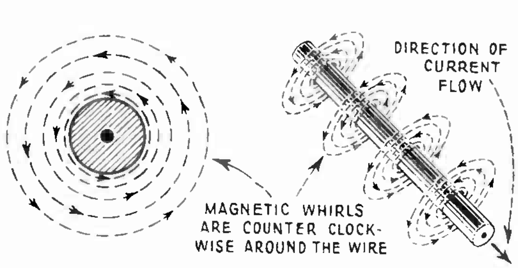

Figure 6

The attraction between the magnetic fields set by two parallel wires when the current flows through each one in the same direction is shown in Figure 7. The repulsion between two such fields when current flows in each wire in opposite directions is shown in Figure 8.

<u>RELATION BETWEEN DIRECTION OF CURRENT FLOW AND POLARITY OF A COIL.</u> The purpose of Figure 9 is to demonstrate how you could find the "N" and "S" poles of a coil providing you knew the direction of the current flow. This could be stated otherwise by saying that if you knew the polarity of a coil you could find the direction in which

the current passes through its turns. The polarity is determined by applying what is popularly known as the second right-hand thumb rule, as follows:

SECOND RIGHT-HAND THUMB RULE: TO DETERMINE POLARITY OF A CURRENT-CARRYING COIL. Grasp the coil with the right hand, place the fingers parallel with the turns, point them in the direction of the current flow and the thumb will point toward the "N" pole of the coil.

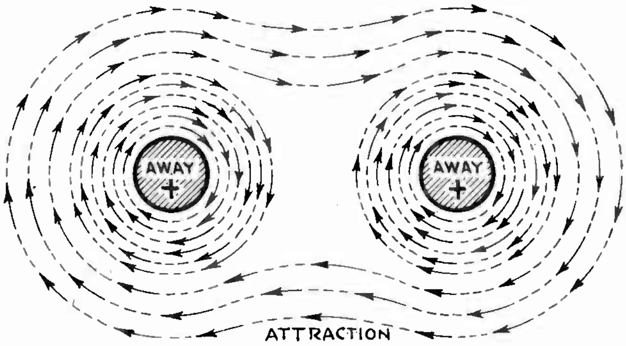

Figure 7

SOLENOID - HELIX. If a coil consists of but a few turns of wire it is usually called a helix (meaning spiral shaped) but a coil wound with a considerable number of turns is more often called a solenoid. In ordinary conversation coils are frequently referred to as "windings."

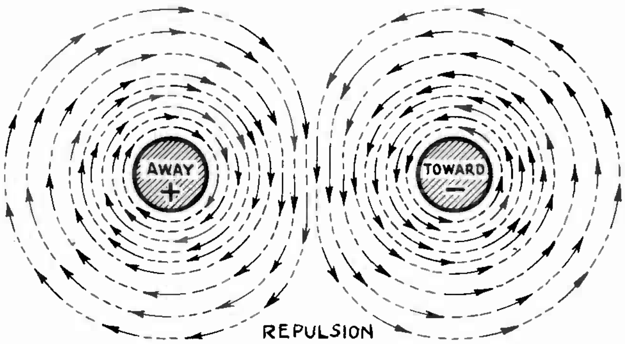

Figure 8

AIR CORE AND IRON CORE. When the inside of any coil consists merely of an air space the coil is said to have an air core, like the one in Figure 9. But, if we insert a bar of soft iron into the coil to fill the air space, as in Figure 10, the coil is then said to have an iron core and the whole unit is given the name "electromagnet."

ELECTROMAGNET. When current flows through the windings of an electromagnet the iron used in the core becomes magnetized by induction

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the same as would any mass of iron if brought into the presence of a magnetizing force. When the iron molecules are arranged in parallel rows the iron core itself sets up its own force lines and the latter are added to the lines established by the current in the coil. Thus, in any electromagnet the magnetic field strength is the sum of the lines set up by the iron core and those set up by the coil. By employing an iron core, as in figure 10, the magnetic flux set up around a particular coil by a certain current is multiplied many times over that of a similar coil with an air core.

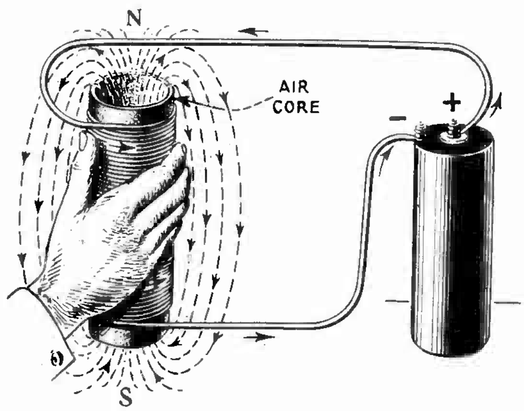


Figure 9

When iron is used and the iron protrudes beyond the ends of the coil it will be noticed that most of the lines pass entirely through the iron before they emerge and act upon the surrounding space medium. However, in the case of a coil with an air core the lines begin to spread out into space at the opposite ends of the coil itself, or where the turns end. This is due to the fact that iron has a higher permeability than air. See Figures 9 and 10.

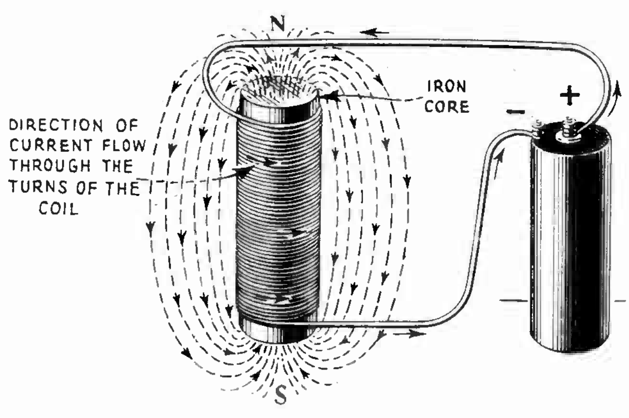


Figure 10

An example of how powerful an electromagnet can be made is given in the drawing in Figure 11 showing a modern lifting magnet moving large pieces of iron. The large pieces of iron are lifted by means of the strong magnetism produced when a very high current, perhaps 50 amperes or more, flows through coils consisting of a few thousand turns. A magnet of this kind often weighs over 5000 lbs. itself, has over 100,000 ampere-turns, and is capable of lifting iron pieces weighing thousands of pounds. By discontinuing the current in the coils the magnetism disappears due to the magnetic field collapsing inwardly to the center of each turn of wire making up the coil.

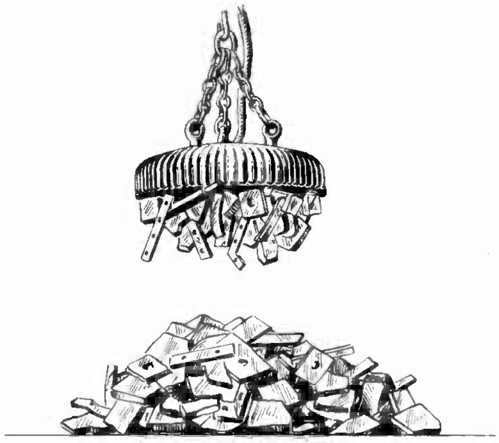


Figure 11

The fader relay in Figures 12-A and 12-B is another example of how the properties of an electromagnet are utilized to actuate an iron armature which moves the contact arms that switch the connections of the

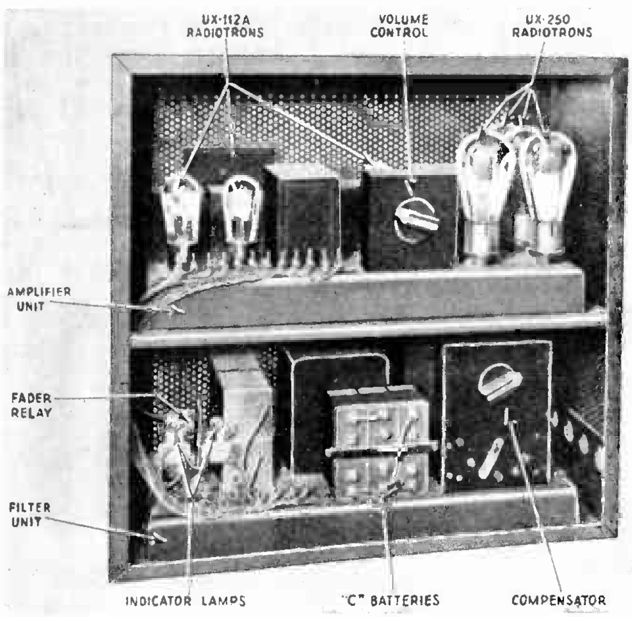


Figure 12-A

amplifier from one motion picture projector to the other, when the "changeover" switch is thrown. Figure 12-A shows the location of the fader relay in the amplifier housing of equipment for use in small theatres. Figure 12-B shows the wiring details of the relay. In operation current flowing through the magnet winding produces a magnetic field, the lines of force of which are greatly concentrated due to the soft iron core, thus forming an electromagnet. The magnetism attracts the armature, pulling it toward the magnet and by pivot action disengages the two long contact arms from the output connections of one projector which were shorted

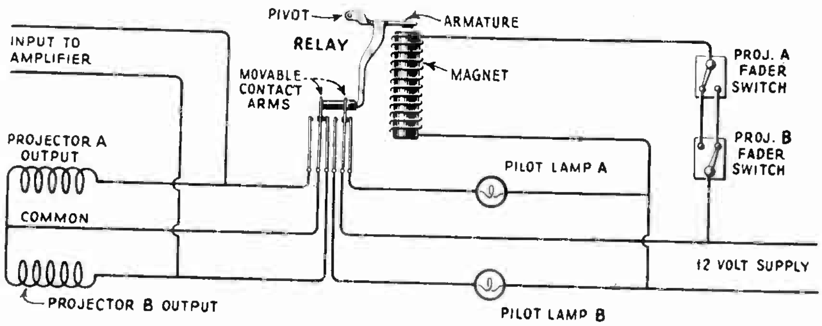


Figure 12-B

and moves them with the result that the connections to the other projector are shorted. It is known as the short-circuiting type of a fader relay. Keep in mind that the strength of an electromagnet or any current carrying coil depends mainly upon its ampere turns.

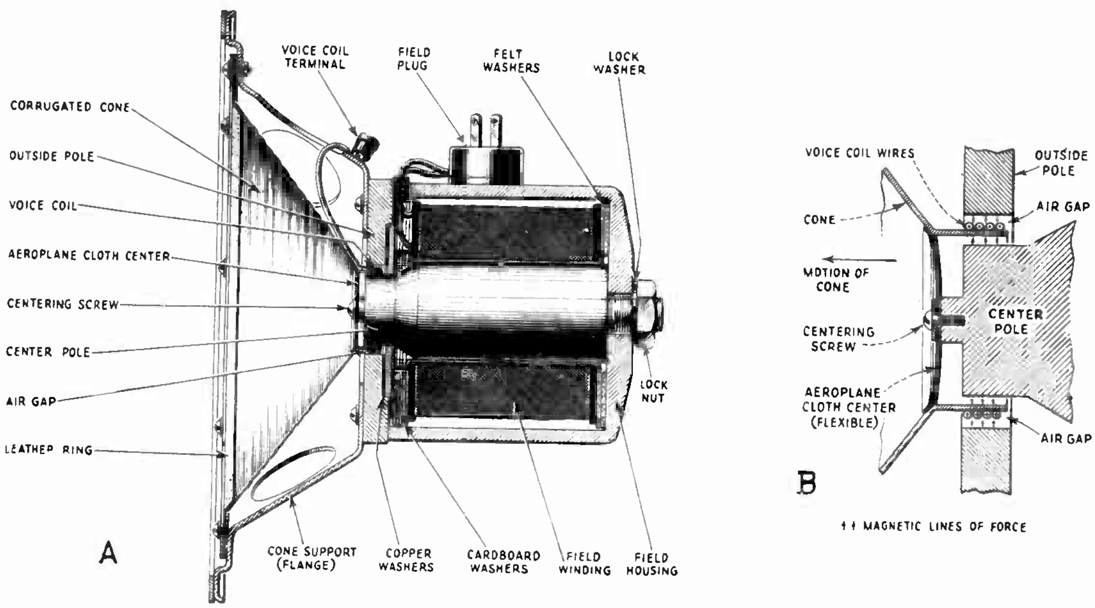


Figure 13

Another illustration of the use of an electromagnet is given in Figure 13, A and B, which is that of an electrodynamic speaker. Here the magnet or center pole is energized by a field winding receiving current from a direct current source. The magnet attracts and repels the voice coil, which is located at the neck of the cone, because of the alternating sound currents flowing through the voice coil from the output of the amplifier. In this manner the sound currents are converted into physical vibrations producing speech or music.

MEANING OF "AMPERE-TURNS." The magnetizing effect of a solenoid, or the number of lines of force produced by a given solenoid, are expressions which mean practically the same thing. The number of lines depend mainly upon two factors, namely: (1) the value of the current in amperes flowing through a winding and (2) the number of turns of wire comprising a winding. Hence, the term "ampere-turns" represents the product of the number of turns of wire on a coil and the number of amperes flowing in each turn. We can set down this relation for ampere-turns in a formula, thus:

AMPERE-TURNS = NUMBER OF TURNS x AMPERES

According to this formula a current of 0.2 amperes flowing through a coil consisting of 500 turns will produce exactly the same amount of magnetic strength as will a current of 20 amperes flowing through a similarly formed coil but which has only 5 turns. In both cases we have 100 ampere turns.

MAGNETOMOTIVE FORCE. (Abbreviated m.m.f.) This is the name given to the unseen force which is fundamentally the cause of setting up the magnetic flux in a magnetic circuit. It is essentially the same as electromotive force, meaning it is magnetic pressure. This force is an indispensable requirement for the establishment of magnetism in just the identical way that electromotive force is required before current will flow in an electric circuit. There is a definite relation between flux and magnetomotive force. For example, when iron is magnetized, demagnetized, and magnetized to an opposite polarity as is the case when alternating current flows through the magnet winding, part of the energy necessary to arrange the molecules in a polar alignment is converted into heat, due to friction between the molecules. The movement of the molecules either when magnetizing or demagnetizing, however, lags behind the magnetizing force. This lag of molecular arrangement is known as "hysteresis." In other words hysteresis is that property of the iron which helps the iron to maintain the magnetism it has acquired. The energy used in demagnetizing the iron to a zero point before it can be magnetized in the opposite direction to the other polarity is known as "hysteresis losses."

To exemplify this fact Figure 14 is given showing a hysteresis loop. Whenever iron is magnetized to the point of saturation, or a little beyond this point the magnetization curve flattens out as will be observed from the line OXA. If we remove this magnetizing force H the flux density does not follow the identical line it did during magnetization which marked its rise, but takes a different course as indicated by the line ALMP. Upon examination it will be noted that at point M the force H is zero but the flux density B is 10,000 gausses, represented in the ordinate from O to M. This value is termed the "remanence". To remove this remanence from the iron we are compelled to apply a magnetizing force H in the opposite direction of 9 gilberts per centimeter, represented by the line OP termed the "coercive force." By increasing the magnetizing force, minus H, (-H), a flux density, minus B, (-B), will be produced in the opposite direction. The magnetization curve of this operation is shown as line OC indicating a negative value at C equal in amplitude to A which is positive. (+). Going through the process of again diminishing the force minus H it will be noted from the course taken by curve CNA, that at N the density minus B, is 10,000 gausses and the force minus H is zero. In order to remove the remanence from the iron a coercive force Z must be applied in the positive direction which if continued will bring the curve up again to A. This cycle of events in the magnetization of iron is known as the "hysteresis loop."

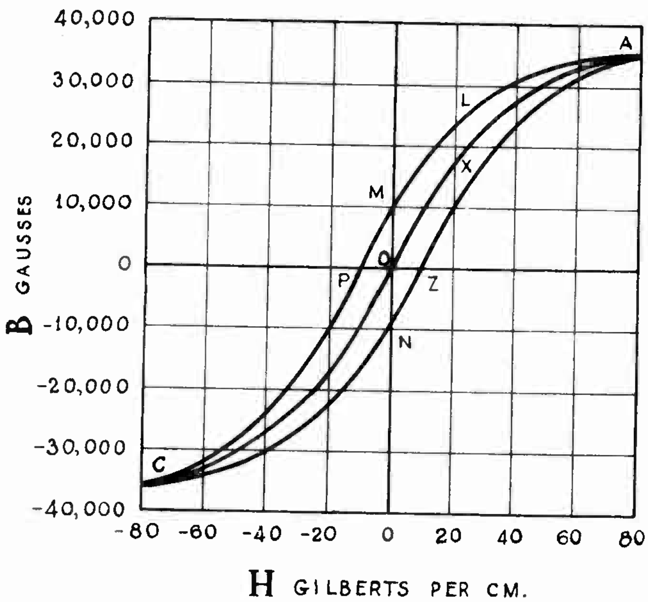


Figure 14

SUMMARY. The important facts to be remembered from the subject of "Electromagnetism," besides the two "right-hand thumb rules," are as follows:

(1) A magnetic field is always established in the region around a wire carrying a current of electricity.
(2) When current passes through a coil of wire each turn produces lines of force which extend outward into space and combine with the lines of neighboring turns to set up a magnetic flux encircling the entire coil. This effect is clearly shown in Figures 3 and 7.
(3) A coil carrying current exhibits "N" and "S" poles at its opposite ends, since a magnetic field is established in the surrounding space.
(4) Both a bar magnet and a coil through which current is passing produce similar magnetic effects.

ELECTROMAGNETIC INDUCTION

ELECTROMOTIVE FORCE AND CURRENT INDUCED IN WIRES BY LINES OF MAGNETIC FORCE. We learned in the earlier part of this lesson that an electric current moving through a wire, or any conductor, sets up a magnetic field surrounding the wire and, also, the lines of force comprising the field reach cut a considerable distance into space. The extent or magnitude (called density) of the field about a current carrying wire depends mainly upon the strength of the current for which the lines are responsible and, also, upon the material of the magnetic circuit, i.e., whether it be all air or partly iron. Other facts brought out were that if a conductor is wound in the form of a coil (helix or solenoid) it produces a magnetic field similar to that of a permanent bar magnet when current passes through the turns of the coil and that the coil will exhibit north and south poles at its opposite ends according to the direction of the current in the turns. We will repeatedly make use of these facts throughout our present discussion. However, we must now become familiar with principles which are the converse of the above statements, that is, magnetic lines of force are capable of producing a movement of electric current in conductors under certain conditions.

It was Michael Faraday who made this discovery in 1831 which is one of the most important in the entire electrical science because, from the application of these principles have sprung many forms of radio, sound picture equipment and power apparatus, such as generators transformers and so on. He noticed during one of his experiments that when a conductor was moved through a magnetic field in such a way that it cut across the lines of force an electrical pressure (e.m.f.) would be set up along the conductor, that is, induced in the conductor. That an e.m.f. or electric charge was made available was proved by attaching the conductor to the gold leaves of an electroscope and observing the movement of the leaves while the conductor was being moved. He also observed that if a conductor in which an e.m.f. was induced formed part of a closed electric circuit the induced e.m.f. would cause a movement of current through the entire circuit. "Induced e.m.f." is often called "induced voltage." Let us explain in regard to the latter statements that an e.m.f. is induced in an open conductor (this means a conductor whose ends are left free or disconnected) when acted upon by lines of magnetic force, whereas, an e.m.f. is induced and current flows in a closed conductor under similar conditions. When discussing the action occurring in a closed conductor we refer sometimes only to the induced current, keeping in mind, however, that we must first have the induced electromotive force.

Among several effects observed by Faraday one was that if a conductor after being placed in a magnetic field, remained at rest (that is, the conductor was not moved with respect to the lines of force) no induced e.m.f. could be obtained. Nor could an induced e.m.f. be obtained if the conductor was moved in the magnetic field in such a way that its direction of motion was parallel to the direction of the lines of force. In other words, in the latter motion the conductor would not cut or pass through the field, it would merely travel along and coincide with the direction of the lines. But, he found that if a conductor remained in a stationary position and the magnetic lines were made to move so that they passed through or cut across the conductor an e.m.f. would be induced in the wire under such conditions.

Notice particularly that in all cases involving induced e.m.f. and current we have to consider the relative motion of the conductor and the magnetic lines since either may remain stationary. That is, we must take into account the following conditions, namely: (1) Whether a conductor is moved through a stationary field, or (2) Whether magnetic lines move past or cut across a stationary conductor.

The foregoing statements form the basis of the study of "Electromagnetic Induction." As we now see, this subject deals with the production of electrical pressures and currents in conductors by making practical use of the invisible force that is always present in the space where a magnetic field exists.

CURRENT INDUCED IN A CONDUCTOR BY A MAGNET AND AN ELECTROMAGNET. In the following explanations it will be shown that the principles of electromagnetic induction remain the same regardless of the source of the flux. The flux may be obtained from the use of a permanent magnet, as in Figure 15, or from an electromagnet, as in Figure 16. In our practical work we find coils of both the air-core and iron-core type in use. The design of a coil is governed by its particular function in the circuit. We do know, however, that when iron is used for the core material it sets up a magnetic flux which is hundreds of times greater than could be obtained from a given coil when operated with only an air core.

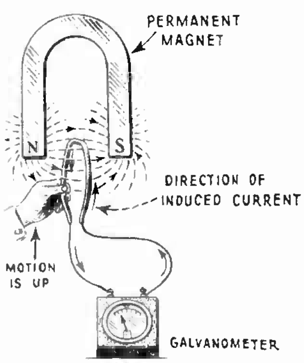


Figure 15

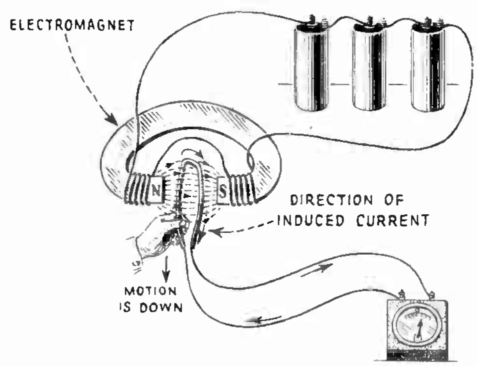


Figure 16

In the experiment in Figure 15 the induced e.m.f.'s and currents for movements of the loop of wire will be detected by the deflections of the pointer of a sensitive galvanometer. Before continuing with our subject let us first give a brief explanation of this instrument. It consists of a small movable coil carrying a pointer, the coil being mounted on a bearing and placed in the magnetic field of a horseshoe type magnet, and it operates on the principle that a passage of current through the coil causes it to rotate, one way or the other, due to the force of the magnetism set up by the current in the coil acting upon the force of the magnetism of the magnet. A spring holds the coil and pointer in a zero, or center position. The pointer will move right or left of the zero mark according to the direction of the current supplied to the coil through the connections at the two binding posts on the top of the meter case. The amount of the pointer deflection is taken as the measure of the strength of the current induced in the circuit when the loop of wire moves across the lines of force as illustrated.

Let us know proceed with the experiment. If the loop is suddenly moved vertically downward a deflection of the galvanometer pointer will be seen, indicating that current momentarily flows through the closed circuit consisting of the loop, the coil in the galvanometer, and the connecting wires. The pointer will move a certain distance across the scale and immediately drop back to its natural position of rest. Assume that the pointer moves to the right. If the loop is suddenly moved upward the pointer will momentarily deflect in a direction opposite to its first movement and, accordingly, it will move a certain distance across the scale to the left of zero. It is evident that when the loop stops cutting the lines the induced current dies out. Bear in mind that the induced electromotive force is generated only momentarily, or while the conductor is actually moving and cutting lines.

The galvanometer readings indicate that the induced current in the loop alternates with each reversal of its movement through the field. If the loop is moved quickly across the lines a higher deflection will be read on the galvanometer than if only moved slowly. Also, if instead of moving the loop perpendicular to the direction of the lines we now move it from left to right, or right to left, either way (that is, parallel to the direction of the lines) no lines will be cut and, therefore, no e.m.f. or current will be obtained. A person performing an experiment of this kind could easily move the loop up and down so rapidly that the pointer, due to its weight, could not follow the variations or reversals of the induced current and, therefore, the pointer would remain at zero, or possibly it might make a slight quivering motion without giving any definite reading.

There are two more important points to be mentioned in regard to Figures 15 and 16. If the loop is held stationary and either the magnet or electromagnet is moved up and down so that the lines are made to cut through the loop the same results will be obtained as for conditions outlined in the foregoing paragraphs where the loop is made to cut through the lines. And if the magnetic fields were reversed, with "N" to the right and "S" to the left, the induced pressures would then be set up in the reverse directions for the same motions of the loop relative to the field.

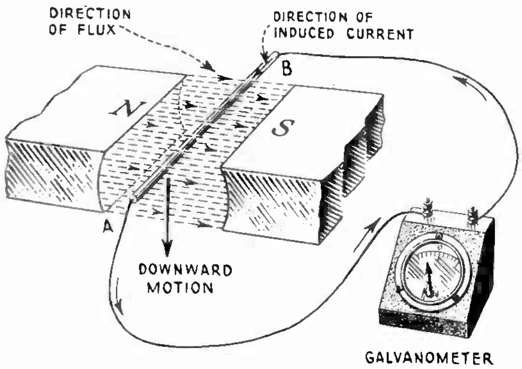


Figure 17

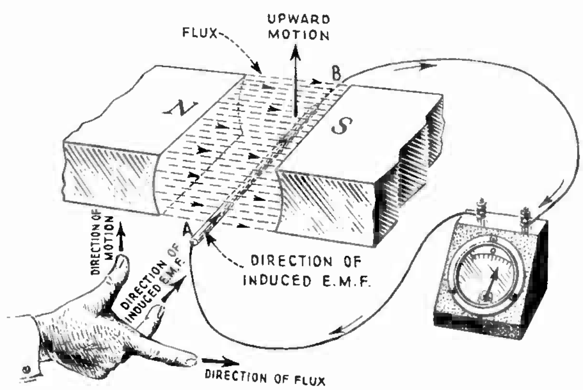


Figure 18

<u>FLEMING'S RULE FOR DETERMINING THE DIRECTION OF INDUCED E.M.F. IN A CONDUCTOR.</u> To explain the rule it is best to perform the experiments in Figures 17 and 18 with a straight copper rod. It is easy to understand the inductive effects set up in a rod and then later you can apply the same rule to any number of conductors, or turns of wire. A galvanometer is again used to indicate the strength and direction of the induced current, the instrument being shown connected to the ends of rod AB.

The laws relating to the direction of the e.m.f. induced in a conductor when it cuts through a magnetic field must be learned in order to understand the principles of the electric generator, which will be dealt with in one of our forthcoming lessons. The diagrams in Figures 17 and 18 are drawn expressly to illustrate one method for determining the relation between the direction of the induced current, the direction of the motion of the conductor, and the direction of the lines of force. In the following paragraphs we will consider two cases: (1) The effect when the rod is moving downward, (2) The effect when the rod is moving upward.

Case (1). If rod AB is moved down across the magnetic flux, as in Figure 17, the induced pressure in AB will be in the direction from B to A as indicated by the arrow in the rod. This e.m.f. sends current through the rod and the galvanometer coil and, thus, a momentary deflection of the pointer is seen. Let us assume that the pointer moves to the left of zero and drops back immediately.

Case (2). Now, if rod AB is moved up across the flux, as in Figure 18, the induced e.m.f. will be set up in the opposite direction, or from A to B, as indicated by the arrow drawn in the rod. This reversal of induced pressure with a reversed movement of the rod sends current through the rod and galvanometer coil in the opposite direction to that obtained during the down movement as in case (1) above. During the up movement of the rod the pointer will deflect momentarily to the right and return to zero.

Hence, we find that the direction of the induced electromotive force depends upon the direction of the lines of force and the direction of motion of the conductor with respect to the lines. An easy way for remembering these relative directions and particularly to find the direction of the induced e.m.f. is to apply a rule, known as Fleming's Right-Hand Rule, as shown in the diagram in Figure 18 and explained as follows:

With the THUMB, FOREFINGER, and MIDDLE FINGER of the right hand all held at right angles to one another, let the THUMB point in the direction of the motion, the FOREFINGER in the direction of the lines of force, and the MIDDLE FINGER will point in the direction of the induced e.m.f.

Carefully examine the hands in the diagram in Figure 19 which clearly show the application of Fleming's rule to the effects set up in a rectangular loop of wire when it is being rotated on its axis in a clockwise (or right-hand direction) through a magnetic field. Current will circulate entirely through the loop when it cuts through the lines because the loop forms a closed metallic circuit. It will be noticed, however, that for the set of conditions we have shown in the drawing (that is, with the N pole to the right, and the S pole to the left, and the right side of the loop moving downward through the field, and the left side of the loop moving upward through the field) the induced pressure and current will be in a direction away from the reader on the right side of the loop and toward the reader on the left side.

It will be noticed that whenever the rod is moved in a vertical direction across the lines, either up or down, the galvanometer will deflect a certain amount first to one side and then to the opposite side of zero. If the rod were moved across the lines in such a way that it followed a diagonal path then lesser amounts of current would be obtained as indicated by small deflections of the pointer, providing, of course, that for all cases the same rate of movement of the rod is maintained. Or, if the rod is moved parallel to the lines and, therefore, does not cut through the lines, no induced current will be obtained nor will any deflection of the pointer be observed. The facts just mentioned explain, in general, the results to be expected for various changes in the path which a conductor could be made to take across a magnetic field.

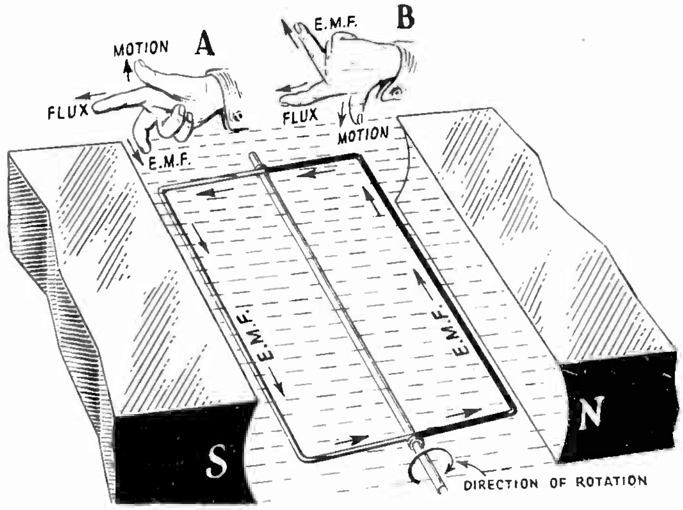


Figure 19

WHEN A CIRCUIT IS "CLOSED" AND "OPENED" THE CURRENT DOES NOT RISE FROM A ZERO TO MAXIMUM VALUE INSTANTLY - NOR DOES THE CURRENT FALL FROM MAXIMUM TO ZERO INSTANTLY - A SHORT INTERVAL OF TIME IS REQUIRED FOR THESE CHANGES TO OCCUR. The purpose of the several views in Figure 20 is to illustrate pictorially three conditions, namely: (1) How current gradually rises in strength on the "make" or closing of a circuit by throwing a switch (views A and B). (2) How the current flows at a steady value an instant or two after a circuit is closed and does not vary in intensity if the circuit remains closed, provided the circuit conditions remain unchanged (view C). (3) How the current gradually decreases in strength from its steady value and drops to zero, on the "break" or opening of a circuit by pulling a switch (views D and E).

Since every change in current strength will produce a corresponding change in the number of lines of force produced by the current then we can assume that while current flows through a wire, and progressively increases in value, the lines of force build up and expand outward into space for some distance.

When the current flow becomes steady or constant the lines remain stationary, i.e., they do not vary in number, or density. A "constant current" is an unvarying current. When current in a wire progressively decreases the lines gradually diminish in number, contract back on the wire and, finally, when the current ceases to flow the lines disappear entirely.

Thus, from Figure 20, we learn that on the "make" and "break" of a direct current circuit the rise and fall in the intensity of the current causes a corresponding change in the magnitude of the magnetic field and, also, that the changes in current strength and variations in flux strength are only momentary.

HOW AN E.M.F. IS INDUCED IN A SECONDARY CIRCUIT BY VARIATIONS OF THE MAGNETIC FLUX SET UP BY A CHANGING CURRENT IN THE PRIMARY. The principles already explained relating to the setting up of a current in a conductor by causing a flux to cut across it will again be used, but this time the results will be obtained without moving either one of the wires. The circuit arrangement is shown in Figures 21 and 22.

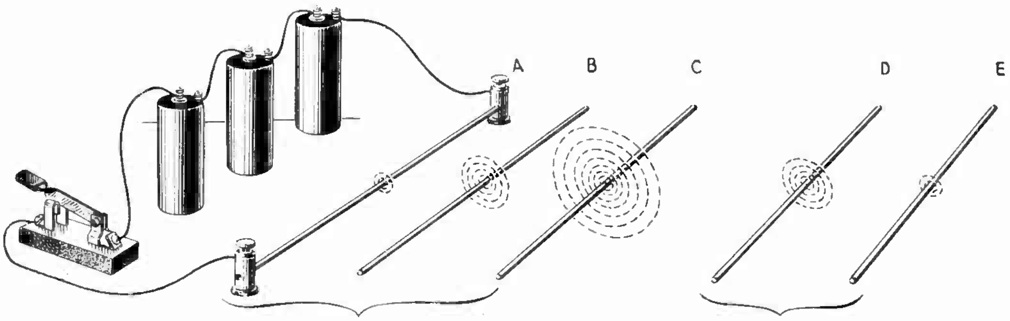


Figure 20

Figure 21 shows the action during the "make" of the primary. At this instant the current begins to rise and the lines of force it produces also increase in numbers and in another instant they will have reached out sufficiently far to cut through the secondary conductor. This effect of the primary on the secondary induces an e.m.f. in the secondary in the direction designated by the arrows, and the lines set up by the momentary flow of current are shown as small magnetic whirls along the secondary.

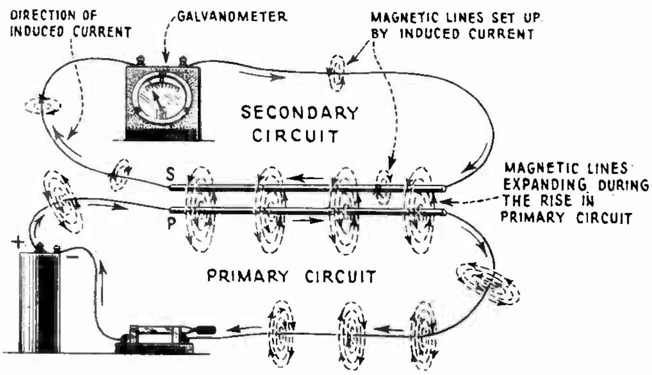
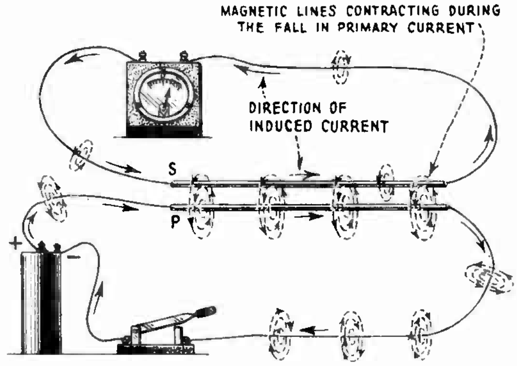


Figure 21

Figure 22 shows the action during the "break" of the primary. At this instant the primary current begins to fall and the lines, as they contract and fall back on the primary, cut through the secondary conductor in a direction opposite to their movement during the "make" of the primary. The cutting action of the lines this time induces an e.m.f. in the secondary in the opposite direction to the previous induction. This change in direction is denoted by arrows. Observe that the secondary e.m.f. and primary e.m.f. are now in the same direction, and also that the magnetic whirls assume similar directions.



ACTION DURING THE "BREAK" OF THE PRIMARY

Figure 22

The above two actions illustrate the fact that the secondary opposes the induction of current in it by the direction that its lines take when compared to the primary's field, and the secondary also opposes the stopping of the current induced in it the second time by the change in direction of its magnetic lines. In brief, in one instance the primary and secondary fields are opposed and in another instance they aid each other.

The effect of magnetic lines expanding and contracting for increases and decreases in current through one circuit is made use of to produce an e.m.f. and current in some other circuit. Both circuits, or their parts, although usually independent are in close mechanical relationship, i.e., coupled to each other but with no physical connection between them. Stated in a few words the principle is simply one where a changing magnetic flux set up by the conductors of one circuit reach out and link through, or cut through, the conductors of a neighboring circuit. Coils are employed to provide this coupling between two such circuits so that the proper magnetic effects will be set up by one circuit and the desired amount of voltage will be available from the other circuit. This principle is illustrated in the diagrams in Figures 21 and 22. This is one method for generating an e.m.f. by electromagnetic induction without the necessity of moving wires of coils, as we have heretofore been doing in our experiments.

<u>LAW RELATING TO THE AMOUNT OF INDUCED E.M.F.</u> Suppose in Figure 18 that the magnetic flux consists of 100,000,000 lines of force. It would be found that if rod AB was made to cut these 100,000,000 lines in exactly one second, the pressure set up along the ród (that is, between its opposite ends, or between A and B) would be one volt. This relation between the amount of the induced electromotive force measured in volts, the strength or density of the flux. and the rate of cutting the lines should be learned.

All of the following conditions have a direct bearing on the amount of the pressure induced in a conductor when cutting, or being cut, by lines of force:

(A) The strength or density (number of lines per unit area) of magnetic flux at the point where the conductor is acting at any instant.
(B) The number of turns in the coil or length of the conductor actually being acted upon by the lines.
(C) The angle which the conductor makes with the direction of the lines, as determined by the path through which the conductor moves as it cuts across the lines.
(D) Rate of motion, or the number of lines cut per second.

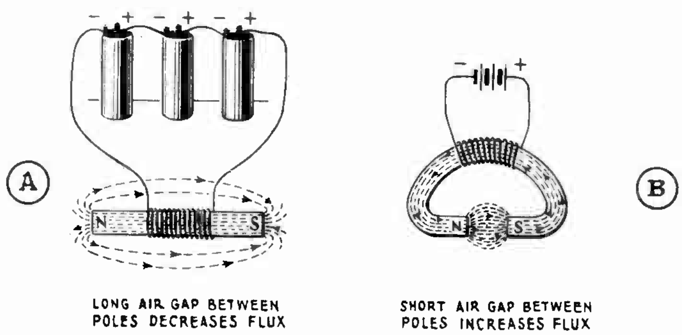


Figure 23-A

THE STRENGTH OF THE INDUCED E.M.F. DEPENDS SOMEWHAT ON THE SHAPE OF THE MAGNETIC CIRCUIT AND ITS MATERIAL. The three electromagnets in sketches B, C, and D in Figures 23-A and 23-B each have a more efficient form of magnetic circuit than the electromagnet in sketch A because the length of the air gap through which the lines must

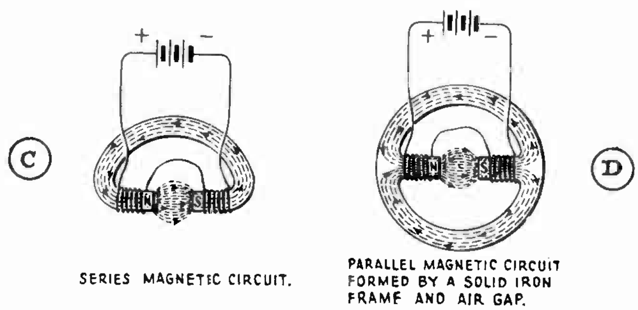


Figure 23-B

pass is longer in A than in the other cases. A short air gap strengthens the magnetic field for a given set of conditions and, thus, for certain movements of a loop of wire through the flux more lines of force will be enclosed or cut by the loop. In some types only one electromagnetic winding is mounted on the iron core while in the other types more than one winding is used, this being done to increase the ampere-turns. The distance between the poles which governs the size of the air gap is carefully considered in practical machinery to keep the reluctance of the magnetic circuit minimum. The coils are connected in series so that current flowing through one must also pass through the other and their turns are so wound as to make the adjacent ends of the windings north and south poles, respectively.

LENZ'S LAW. This law in a condensed manner states that the direction taken by the current caused by the induced e.m.f. is such that the magnetic field produced offers a repelling force to the motion which produced it. Explaining this law further, since we are conversant with the effects occasioned by magnetic lines of force, is that current always flows under pressure of the induced e.m.f. and sets up magnetic lines of force in such a direction, they oppose any change in the initial magnetic lines responsible for the production of the induced e.m.f. The induced e.m.f. is also termed counter electromotive force, meaning the pressure of this force retards the flow of the applied current which produced it. The application of this property is credited with the successful use of alternating current apparatus.

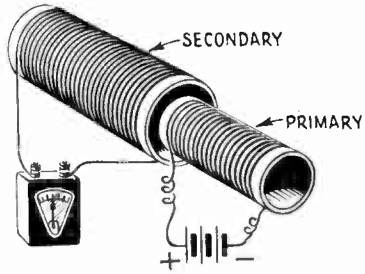


Figure 24

Refer to Figure 24 showing two coils, one a primary and the other a secondary; together they constitute a transformer. A practical explanation of Lenz's law is given below with references made to the diagram: Let us assume that the current in the primary coil is such that it makes the polarity at the left-hand end north. When the primary is moved into the secondary the flow of induced current in the latter coil makes its polarity at the right-hand end also north. Thus, the adjacent ends of both coils when the primary is fully inserted, have opposite polarity and, therefore, the effect set up between them is one of repulsion. However, when the primary is withdrawn from the secondary the induced current in the latter is reversed and reverse polarity will be set up at the right-hand end of the coil. We now have a condition where the left-hand end of the primary is north (note that the polarity of the primary does not change because it is supplied with a steady source of e.m.f. by the dry cells) and the right-hand end of the secondary is of south polarity. A magnetic attraction now exists between the coils that tends to oppose their separation. It is only while the coils are moved with respect to each other and the induced current flows and reversed magnetism is set up about the secondary that we have these effects of attraction and repulsion. It is seen in every case that the magnetic attraction and repulsion tends to oppose the motion of the primary coil.

SELF-INDUCTION. This is the name given to that property of an electric circuit wherein it tends to oppose any change (increase or decrease) in the strength of the current in the circuit. The effects of self-induction are present only at such times as when a current is changing in intensity. The magnetic lines which always accompany a current begin in a wire at the very center of its core. Thus, when current rises the lines build up outward and pass through the very wire which is producing them. On the contrary, when current falls the lines recede inward on the wire and cut the wire in the opposite direction to the first instance cited. This cutting action on a conductor by its own lines induces an e.m.f. in the conductor first in one direction for an increase in current and, secondly, in the opposite direction for a decrease in current. Thus, we see that the induced e.m.f. at one time tends to oppose the establishment of a current in a conductor and at another time it tends to prevent the current from dying out. The induced e.m.f. is known as the induced e.m.f. of self-induction. The student must understand that the e.m.f. of self-induction is another e.m.f. acting on a circuit and separate from the usual e.m.f. which is applied to any conductor in order to make current flow in the first place.

MUTUAL INDUCTION. Current flowing in a secondary circuit, by reason of the induced e.m.f. set up by the varying flux produced by current changes in the primary circuit, establishes a secondary flux which cuts the conductors of the primary and induces in the primary an e.m.f. which exerts a pressure in the same direction as the flow of the applied primary current. Therefore, when two independent circuits are so associated that the effects produced by their respective magnetic fields, results in inducing e.m.f.'s and currents in these circuits, that is, the primary induces an e.m.f. in the secondary and the secondary induces an e.m.f. in the primary. Two such circuits are said to react on each other. This reaction is known as mutual induction and the circuits involved are said to possess the property of mutual inductance.

These effects explain the fundamental action of transformers and illustrates why more current is drawn by the primary when the load on the secondary is increased. Figures 21 and 22 show two independent fields reacting on each other. One magnetic field is due to the applied or inducing current, flowing in the primary (P) and the other is due to the current flowing under pressure of the induced e.m.f. in the secondary (S). The strength of the current flowing in the secondary is determined principally by the load placed upon it.

INDUCTANCE. The unit of inductance, called the "Henry," is designated by the symbol "L." Inductance may be defined as that property possessed by an electric circuit (when current flows) which stores up energy in the form of electromagnetic lines of force. The total lines represent the magnetic flux. Self-induction is the result of inductance in a circuit, and is that property which induces a reverse, bucking or counter voltage, always acting to oppose any change in the value of the current flowing through the circuit. The resulting field when current flows expands outwardly cutting the conductors and induces this reverse or bucking voltage which tends to maintain the dormant state, or the existing conditions before the change from no current flow to current flowing, took place. When the current flow is interrupted the magnetic field collapses but this time it cuts the conductors in an inward direction toward the center of the conductors, and induces a current which takes the same direction as the applied current and, hence, attempts to keep the applied current flowing. This effect can be noticed by the spark which appears at the switch blades whenever a circuit is broken, the spark being the result of self-induction.

The amount of inductance, as measured by the unit henry, is determind by the amount of voltage that will be induced in a coil or circuit by the current changing at a given rate. Thus: "A circuit is said to have an inductance of one henry when a current changing at the rate of one ampere per second will induce therein an electromotive force of one volt."

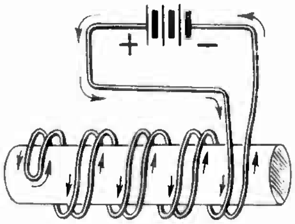


Figure 25

NON-INDUCTIVE CIRCUIT — HOW EFFECTS OF SELF-INDUCTANCE WITHIN A CIRCUIT MAY BE NEUTRALIZED. The fields set up along the turns of a coil can be made to neutralize one another if the turns of the coil are wound so that the field around each turn opposes in direction the field around an adjoining turn. The current in each turn must be equal, and adjacent turns should be close together. A coil wound to produce this result is shown in Figure 25. The coil is said to be non-inductive because practically no field is established around the coil when current flows. Coils of this general type are employed for resistor units in instruments such as Wheatstone bridges, meters and in any circuits where resistance is required but inductive effects are undesired.

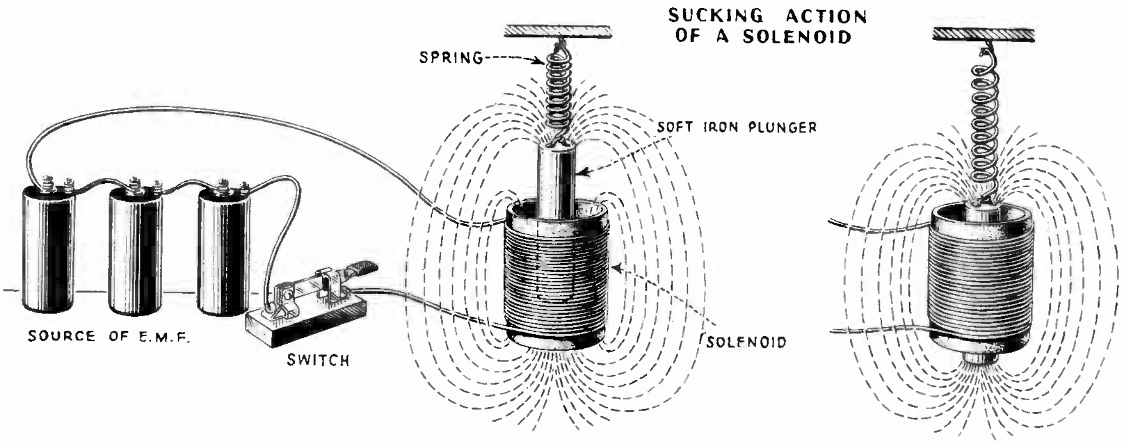


Figure 26

Figure 27

SUCKING ACTION OF A SOLENOID. Since all magnetic fields possess similar properties a solenoid will attract iron when current flows through it in the same way a bar magnet will attract iron as shown in Figures 26 and 27. The flux seeks the path through the iron plunger in preference to passing entirely through air and this magnetizes the plunger, causing it to be attracted by the coil. The plunger is drawn into, or sucked into the coil, and does not stop moving until it centers itself in a position where it will accomodate the greatest amount of flux. It remains unmoved in the coil so long as the current flows at the proper value to provide the requisite amount of flux to hold the plunger from being pulled back by the spring. This principle is utilized commercially in the operation of protective devices called "circuit breakers." These devices automatically trip, open a circuit and shut off the power when the spring is adjusted to the proper tension so that the plunger is sucked into the coil only under extreme conditions. This idea can be used for relay operation, or any form of tripping device.

PRACTICAL APPLICATIONS. Practical applications of the use of electromagnets are both numerous and varied. The electromagnets in the automatic oscillograph, shown in the photograph in Figure 28, play an important part in the operation of this device which is used to investigate current and voltage conditions in an electrical circuit. Oscillograms may be taken of chance transients, surges and also normal voltage and current characteristics of circuits under observation. The records are traced by means of light directly on a strip

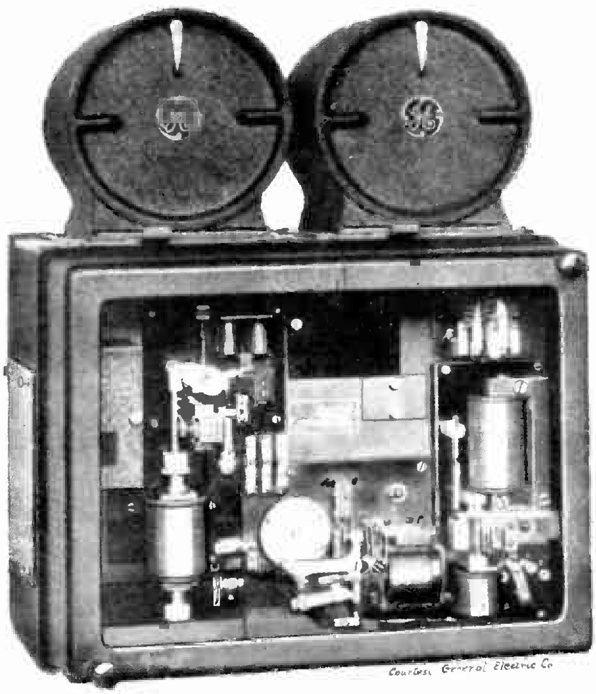


Figure 28

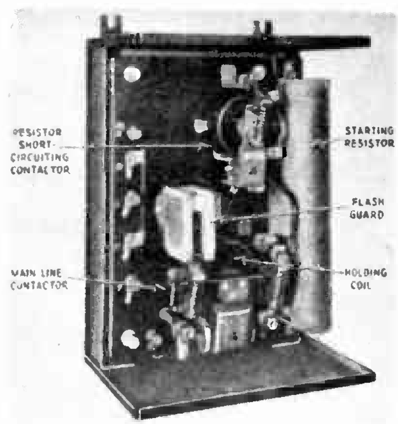


Figure 29

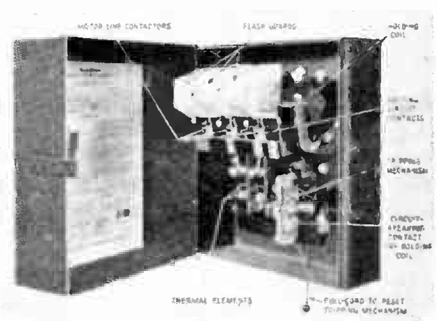


Figure 30

of sensitized paper so after the development process the current and voltage characteristics appear directly as wavy lines on the strip of paper. The records obtained show wave shapes and phase relations instead of merely envelopes of these waves. Two typical examples of the use of electromagnets are given in Figures 29 and 30 which show two types of line switches for motor-generator sets used in motion picture equipment. One type is for d-c operation and the other for a-c operation. The holding coils and electromagnet for the resistor short-circuiting contactor are clearly shown in the photographs. In operation they become energized and attract the iron armature to which the operating mechanism is attached.

EXAMINATION QUESTIONS

1. What phenomenon always exists when current flows?

2. State the right-hand thumb rule for determining the polarity of a solenoid and draw a simple sketch illustrating same.

3. State the right-hand thumb rule for determining the direction of a magnetic flux around a current-carrying wire.

4. What is Fleming's right-hand rule?

5. If an air-core is carrying a current and a bar of soft iron is inserted into the coil what effect will be produced?

6. (a) What happens when an "open" conductor moves across a magnetic field?
   (b) What happens when a "closed" conductor moves across a magnetic field?

7. Explain the principle of the sucking action of a solenoid.

8. Explain briefly what is meant by the following terms: (a) Self-inductance, (b) Mutual inductance, (c) Ampere-turns.

9. What does Lenz's law state?

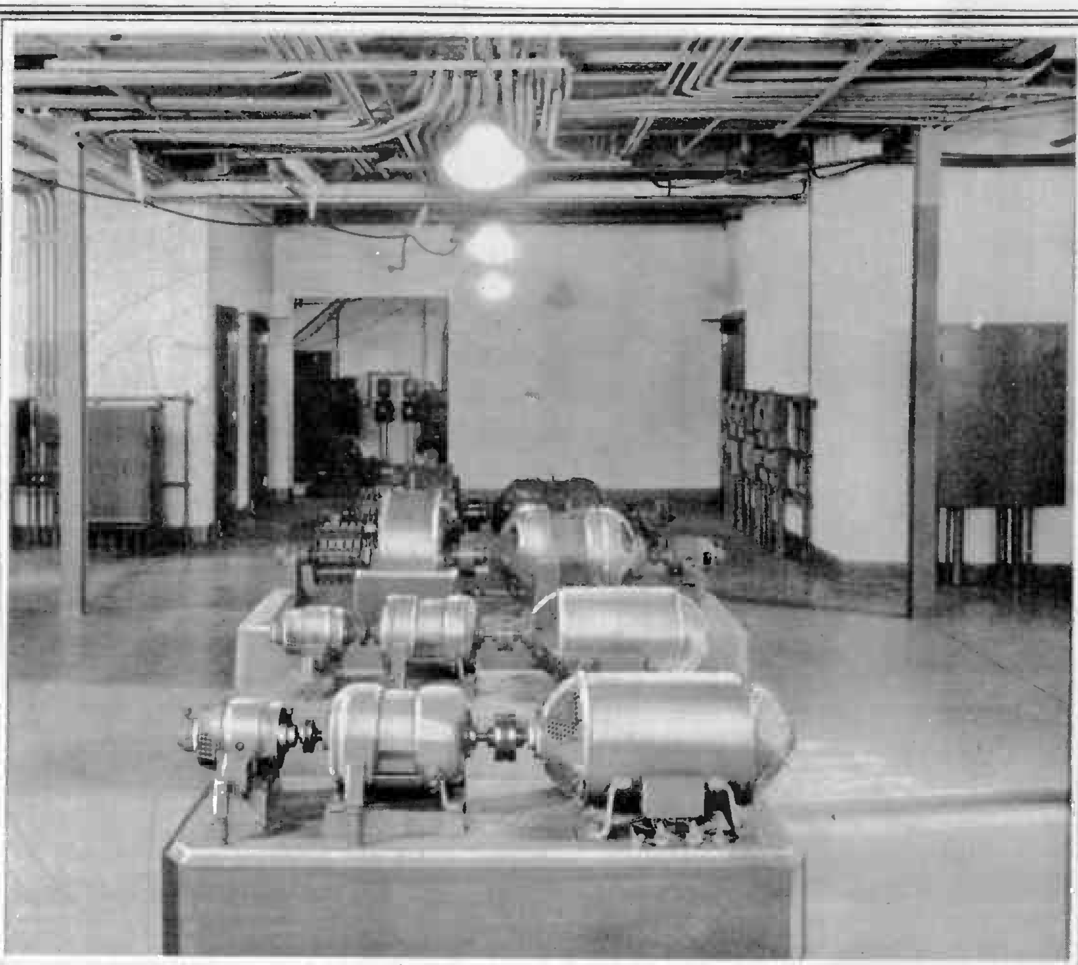
10. (a) Give the definitions of the gauss, gilbert, oersted and maxwell.
    (b) What does the Symbol Φ represent?

11. Either one of two conditions must be satisfied before an e.m.f. can be induced in a wire or circuit. What are these conditions?

12. If 5 amperes circulate through a magnet winding of 30 turns, how many turns are required to produce an equal m.m.f., with only 1.5 amperes flowing?

13. What does the line OXA in Figure 14 represent? The line OM? The line OP?

14. What coercive force is required to remove a remananence of 10,000 gausses? Refer to Figure 14.



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VOL.10 No.3

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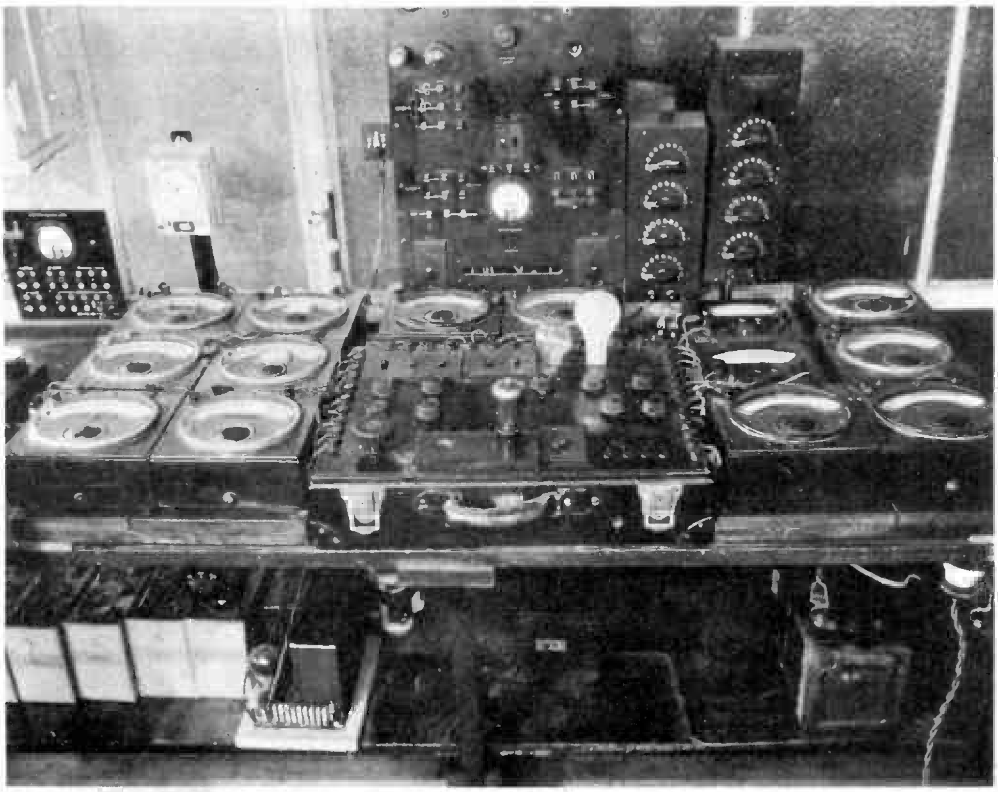
THE MEASUREMENTS OF VARIOUS ELECTRICAL QUANTITIES ARE MADE BY MEANS OF CALIBRATED INSTRUMENTS

UNITS OF MEASUREMENT AND SYMBOLS

VOL. 10 No. 4

DEWEY DECIMAL CLASSIFICATION R 100



METERS ARE THE YARDSTICKS OF ELECTRICAL MEASUREMENTS

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ELECTRICAL UNITS AND TERMS

Many of our students have found it to their advantage at the beginning of their work to study the various electrical units in a single lesson although these units are again given along with their related subjects. It is with this idea in mind that we present this lesson. Everyone who studies electricity or one of its associated subjects, such as radio, television, sound motion pictures, aviation radio, and so on, should at least be familiar with the system which forms the basis of electrical computation as given below. The balance of this lesson consists of abbreviations, symbols and electrical units and terms in common use. If you review this work several times as you progress through your course it will be easy for you to understand and apply the various units and terms.

The three FUNDAMENTAL UNITS of measurement are:

(1) the centimeter, or unit of length,
(2) the gram, or unit of mass or weight,
(3) the second, or unit of time.

These three quantities are combined and expressed below in a simple relation known as the centimeter-gram-second, or C.G.S. system.

The C.G.S. unit of velocity is the kine, representing a distance of one centimeter covered in one second. 1 centimeter = 0.01 meter = 0.3937 inch.

$$\text{UNIT OF VELOCITY} = \text{cm/sec}$$

The C.G.S. unit of force is the dyne, representing the force required to move a mass of one gram one kine per second. 1 gram = 1/28th of an ounce.

$$\text{UNIT OF FORCE} = \frac{\text{gm cm/sec}}{\text{sec}}, \text{or } \frac{\text{gm cm}}{\text{sec}^2}$$

The C.G.S. unit of work or energy is the erg, representing the work accomplished by a force of one dyne working over a distance of one centimeter.

$$\text{UNIT OF WORK} = \text{dyne x cm, or } \frac{\text{gm cm}}{\text{sec}^2} \text{ x cm, or } \frac{\text{gm cm}^2}{\text{sec}^2}$$

DEFINITION OF ELECTRICAL UNITS AND TERMS

THE VOLT is the unit of electrical pressure. This pressure is known as "electromotive force" and, also, as "difference of potential." Electromotive force is abbreviated by letters (E.M.F.) or (e.m.f.).

<u>One volt is defined as that amount of electromotive force necessary to cause a current having an intensity of one ampere to flow through a circuit having a resistance of one ohm</u>.

In electrical practice you will hear references made to this unit by any one of the following names: Volt, Voltage, Electromotive Force, Pressure or Difference of Potential, all of which have the same meaning. The unit volt is denoted by the symbol (E).

In an electrical circuit we express the amount of the electromotive force as a certain number of volts. To illustrate the proper use of the terms "e.m.f." and "volts" let us consider the simple circuit drawn in Figure 1 where a 6 volt battery is connected to a 6 volt lamp. When speaking about the pressure in this circuit it would be the customary thing to say: "The e.m.f. of 6 volts, applied to this circuit by the battery, forces a certain amount of current through the filament of the lamp, thus causing it to light."

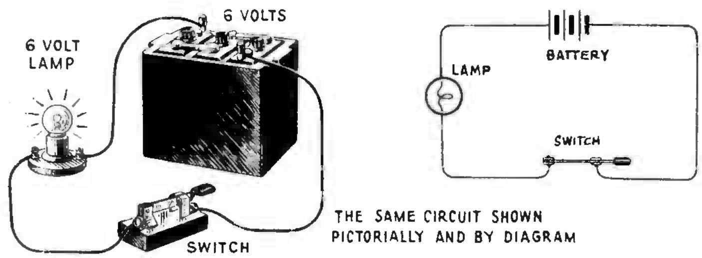


Figure 1

Electrical pressure is analogous to water pressure. To illustrate this let us suppose you connect up your garden hose to a faucet and open the valve. Providing there is water supply available in the mains we know that water will run through the hose. The <u>pressure</u> in the pipes was necessary in order to get this flow of water. Just how water pressure in pipes is obtained in our homes and buildings should be quite obvious to most anyone since there are practically only two sources; one source is the result of mechanical work done by a pumping machine of some type, while the other is the result of natural gravity provided by a head of water, or water supply originating at some level higher than the outlet where the hose is attached.

You will find that the water analogy is used to explain many phases of radio or electrical theory. It may be used to illustrate the action of a condenser or the action of a resistance or even the radiation of electromagnetic waves from a broadcasting station, but in no case is it more applicable than for illustrating the relation of pressure (E.M.F.) and the current which flows as a result of this pressure.

To point out the idea that pressure is always essential before a movement or motion of any kind can be produced we have shown a small tank partly filled with water in sketch (A) of Figure 2. Notice that to the bottom of the tank there has been connected a short pipe, bent into a U shape, the open end of which is arranged exactly level with the tank connection.

The valve acts in a manner similar to a switch in an electrical circuit in controlling the flow. If the valve in the pipe is closed the water pressure is not utilized although the pressure is always present by reason of the height and volume of water in the tank. But, if we open the valve, the pressure will immediately act and water will flow through the pipe and gush out at its open end. The flow will continue just so long as there is any water in the tank or any pressure. Finally when the tank is emptied it will be seen that the pipe still holds a quantity of water which does not flow out of the open end because both ends of the pipe are level, as shown in sketch (B). This result shows that while the water remaining in the pipe has a potential force due to its own weight, yet it cannot be made use of in this case. Thus, we see that it requires a difference of pressure level to obtain force by which the water may be made to flow even though water may be at hand. However, by merely bending the open end downward, as in (C), the water confined in the pipe will begin to flow out, since we have set up a condition where the force due to the weight of water is now acting. The higher the water level in the tank the greater will be the available pressure.

Although we can see the water we cannot see the "pressure." Nevertheless, it is easy to measure water pressure in pounds with a suitable pressure gauge. When we refer to pressure in the electrical sense, we also deal with an unseen force which may be generated in one of several ways. We know how to regulate the intensity of this

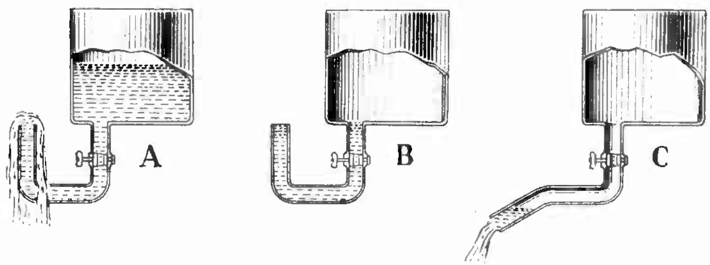


Figure 2

electrical pressure according to certain requirements so that it may be applied to a circuit to set up a flow of current. It is also easy to measure electrical pressure by means of a suitable instrument, called a "voltmeter." Two common sources of electrical pressure are batteries and generators.

THE AMPERE is the unit of electric current which represents a certain amount of current flowing at a given rate.

> One ampere is defined as the intensity (or strength, or value) of the current that will flow through a circuit whose resistance is one ohm, when the applied electromotive is one volt.

Another definition of the unit of current strength, based on the amount of chemical decomposition taking place in a given period of time, and stated in terms of quantity and rate of flow is, "One ampere is that steady flow of electric current which when passed through a standard solution of nitrate of silver in water will deposit silver at the rate of 0.001118 gram per second."

 4

The quantity of electricity is measured by the unit "COULOMB." Although this unit is defined in a subsequent paragraph let us at this time show the relation between "coulomb" and "ampere" as follows: "When one coulomb of electricity passes a given point in a circuit, every second of time, one ampere of current is said to flow." Hence, if 2 coulombs of electricity pass a given point in a circuit per second the strength of the current is 2 amperes. In a given circuit, therefore, to find the total quantity of electricity expressed in coulombs we must take the product of the current in amperes and the length of time in seconds that the current flows. "Product" is the mathematical expression for the result of multiplication.
Note: The underlined definition of an ampere just given is the one that should be learned for our practical work.

Current is denoted by the symbol (I) and is measured by an instrument called an "ammeter." Small values of current are measured by a "milliammeter" or "microammeter."

Again refer to the drawing in Figure 2 to be sure that you have a clear understanding of the difference between "quantity" and "rate of flow." Water flowing through a pipe at the rate of a certain number of gallons per minute can be compared to coulombs passing through a circuit. In a water system "gallons" represents the quantity and "gallons per minute" the total amount for a given time, or rate of flow; whereas, in the electrical circuit "coulomb" is the quantity and "amperes" is the rate of flow of a given quantity.

An important point to be mentioned in this discussion is that throughout the whole length of the pipe there are oppositions set up which prevent a free movement of the water. These oppositions are due principally to friction by contact of the water with the inner walls of the pipe, bends in the pipe and the length and size, or cross section, of the pipe. In any of its forms, opposition must be met and overcome by the pressure before water flows and, of course, the oppositions will govern to some extent the amount of water that flows in a given time under a given pressure. It is easy to see that any opposition presented by the pipe itself will retard the water flow.

This opposition is comparable to that which is present at all times in electrical circuits because the wires or other metallic parts do not permit current to flow freely. The current must be forced to flow through the materials used to construct the circuit under pressure of the applied voltage. Each different kind of metal has its own specific resistance. For instance, current flows more readily through silver than through copper, and more readily through copper than iron. Thus, if we have two circuits consisting of the same length and cross-section of wire, and if one circuit uses copper wire and the other iron wire, and if exactly the same voltage is applied to both circuits it will be found, under these conditions, that about six times as much current will pass through the copper wire as compared to the iron wire circuit. This is because the relative resistance of copper is 1.075 as compared to 6.37 for iron. In the case of the electrical circuit this opposition of the material itself, which governs to a large extent the intensity of the current flow, is known as the "resistance."

For all practical purposes, copper wire is used because of its low resistance. Silver has a resistance lower than copper but its cost is prohibitive except for special purposes.

THE OHM is the electrical unit of resistance. Resistance is the natural opposition which all materials offer to the flow of current, and since this opposition is inherent in all matter it must be overcome by the electromotive force before current will flow.

> One ohm is the resistance of an electrical circuit when an electromotive force of one volt is required to force a current of one ampere through it.

The following is a definition of the unit resistance based on a physical standard: One ohm is the amount of resistance offered to a steady flow of electric current by a column of mercury of uniform cross-section, 106.3 cm. long, 14.4521 grams in weight at a temperature of 32 degrees Fahrenheit, or 0 degrees Centigrade. (Note: One centimeter is a little less than a half inch. One ounce is equal to 28 grams.)

The ohm is denoted by the symbol (R) and is named after the German scientist George S. Ohm. He was responsible for recognizing the relation existing between the "voltage," "resistance" and "current" in all electrical circuits and formulating this relation into what is probably the most important and widely used law in electricity, known as "OHM'S LAW."

One megohm equals one million ohms.
One microhm equals 1/1,000,000th of an ohm.

THE COULOMB is the unit of electrical quantity used to express the total quantity of electric current passing through a circuit in a stated time.

> One coulomb is the quantity of electricity that will flow in one second through a circuit having a resistance of one ohm when the applied e.m.f. is one volt.

We are now dealing with "quantity" in electricity in about the same way that ordinary standards, a pound or gallon for instance, are used to measure supplies such as sugar, milk, etc. Thus, if we wish to know the number of "coulombs" or "quantity of electricity" passing through a circuit in a given time we must multiply the number of amperes by the number of seconds the current continues to flow.

The following example shows how to apply this rule: Suppose the rate of current flow for a particular circuit is 8 amperes and the current continues to flow steadily for 4 seconds. The total quantity of electricity passed will be 8 x 4 or 32 ampere-seconds, or 32 coulombs of electricity. Also, if 2 amperes flow for 16 seconds we would have 32 ampere-seconds or 32 coulombs.

The unit "coulomb" is frequently applied in electrostatics with reference to placing an electrostatic charge on a condenser and in this usage it is defined as follows: "One coulomb is the quantity of electricity necessary to raise by one volt the difference of potential between the plates of a condenser whose capacitance is one farad."

The coulomb is denoted by the symbol (Q), and this unit is equal to one ampere-second. Mathematically expressed this statement takes the form of Q = IS.

THE HENRY is the unit of inductance. Inductance is a certain property possessed by every electrical circuit which establishes an electromagnetic field about its conductors and windings (coils) when current passes through it. Inductance is also applied to the peculiar property of all conductors and windings (coils) which tend to oppose any current change produced by a circuit within itself by virtue of the changing magnetism which is set up whenever current varies or tends to vary in strength. The effect is pronounced in any circuit in which the current is continually changing in intensity, as for example, in a circuit carrying pulsating direct current or alternating current. The net result of inductive effects is the generation of a second, or counter e.m.f. (C.E.M.F.) separate from the applied e.m.f. which causes the current to flow.

This property of "inductance" exists in all portions of an active circuit because the electromagnetic lines of force (flux) set up by the current will vary in magnitude according to every change in current intensity. These electromagnetic lines of force are continually acting upon the very wires (or conductors and coils) which comprise the circuit. The term "self-inductance" is commonly used to express this peculiar property exhibited by a circuit due to the action of its own magnetic lines upon itself. The tendency of a circuit to prevent changes in current intensity and spoken of as the "self-inductance" of a circuit, as just mentioned, represents one kind of opposition and it must not be confused with a circuit's "resistance."

Resistance is always present whether the current varies in strength or whether it flows steadily. However, "inductance effects" are not present in a circuit when a steady direct current flows, for in this case the magnetic lines are also steady and consequently do not act upon the conductors.

> A circuit is said to have an inductance of one henry when an electromotive force of one volt will be induced in the circuit by a current varying at the rate of one ampere per second.

The letter (L) is the symbol used to denote inductance.

THE FARAD is the unit of electrical capacity and is abbreviated "fd." This unit relates to the amount of charge that can be stored up in a condenser in electrostatic form under a given e.m.f. measured in volts.

> A condenser is said to have a capacitance of one farad if the potential difference between its plates will be raised one volt by a charge of one coulomb.

From this definition we see that a condenser, when connected in a circuit and supplied with voltage will store up a definite amount of electricity in static form.

The farad is considerably too large to be applied in practical work. We therefore have two sub-multiples of the unit in common use. They are:

Microfarad (abbreviated mfd. or μfd.)

Micro-microfarad (abbreviated mmfd. or $\mu\mu$fd.)

One microfarad is equal to one-millionth part of a farad.
One micro-microfarad is equal to one-millionth part of a farad again sub-divided into a million parts; that is to say, a micro-microfarad is one-millionth of one-millionth part of a farad. Picofarad, although not an approved unit, is an expression sometimes used for micro-microfarad.

<u>EXAMPLE.</u> Either unit, microfarad or micro-microfarad, may be used to express a certain numerical value according to one's own preference. As a rule values in the order of 1000 mmfd. and higher are expressed in microfarads (mfd). Here are a few examples of how a value may be written in terms of either unit:

1 mmfd. = 0.000001 mfd.
250 mmfd. = 0.00025 mfd.
1000 mmfd. = 0.001 mfd.

A simple condenser is shown in Figure 3. It consists of a thin piece of suitable insulating material, such as mica, on either side of which is glued a sheet of tinfoil. The tinfoil sheets are called the "plates" and the mica the "dielectric." If two wires are connected from a source of voltage to the respective plates the e.m.f. thus provided will cause an electrostatic charge to be stored up by the mica. In Figure 5, the dry cell of 1.5 volts causes a difference of potential of 1.5 volts to be set up between plates "A" and "B" of the air type condensers; the electrostatic lines in this case are stored up in the air but in Figure 3 they are stored in the mica. The condensers in Figures 3 and 5 are called fixed condensers because no provision is made to alter their capacitances.

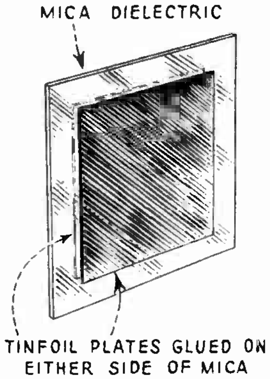


Figure 3

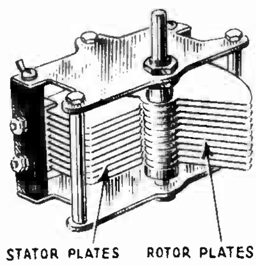


Figure 4

The multi-plate variable air type condenser in Figure 4 consists of a set of fixed and movable plates; this type is in general use in radio work for tuning purposes. The capacitance of this condenser is varied by rotating one set of plates, which acts to change the effective relationship between both sets of plates. The dielectric medium, which possesses the property of storing up electrostatic lines of force in a condenser of this kind, is the air which separates the plates. We will explain later how the particular kind of dielectric used, whether it be air, mica, paper or any other suitable material, has an important bearing upon the amount of charge the condenser will take on. The dielectric material also governs the amount of voltage that can be applied to the condenser without placing the insulating qualities of the dielectric under an excessive strain that would eventually result in a breakdown.

Capacity is designated in all of our writings and formulas by the letter (C).

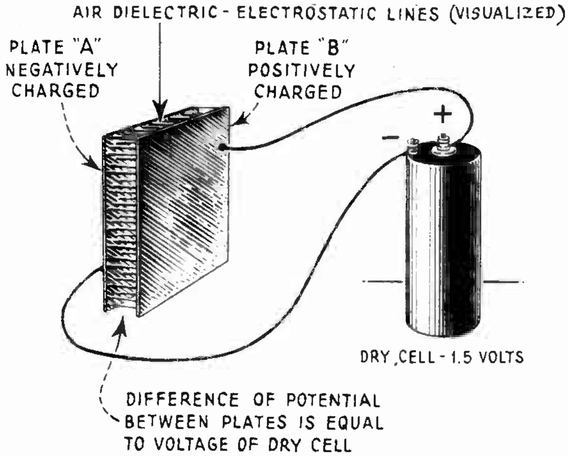


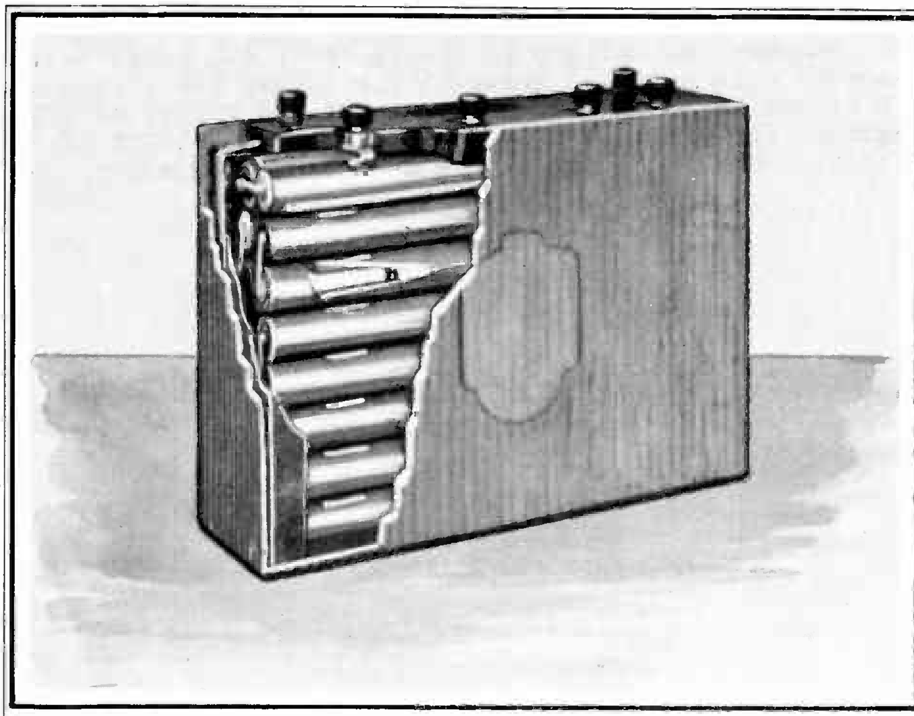
Figure 5

<u>ELECTRICAL WORK AND POWER.</u> In our radio subjects we deal considerably with work and power. Through experience we find that very often the terms, <u>force</u>, <u>power</u>, <u>energy</u> and <u>work</u> are not thoroughly understood by everyone. To avoid any confusion between these terms we will explain their meanings in the following paragraphs, also giving a practical example of their use.

There are different kinds of force that will produce work when properly directed. For instance, we apply muscular force whenever we exert ourselves in the performance of certain tasks. Also, we have mechanical force derived from various types of motors and engines which may be operated with compressed air, gas, water, steam, gasoline and so on. There is also chemical force and electrical force. Other examples of force could be cited, but electromotive force is the force most frequently dealt with in our work. It will be repeatedly mentioned that an electromotive force, when properly applied, will cause or tend to cause a flow of electrical current.

<u>FORCE</u>. Force is an unseen agent which acts to cause some change in the existing motion of a body, or mass, or it may cause a change in direction of motion, or it may in some cases alter the physical shape of the body acted upon.

At this time let us review a few of the possible conditions relating to force. If a body is at rest and force is applied, it will tend to set the body in motion; or if the body is already in motion a force may be applied in such a way as to cause the body to accelerate (move faster), or slow down, or perhaps come to a complete stop; or if a body is moving in a certain direction a force applied in some other direction will tend to cause the body to change its original course of direction.



A COMBINED "B" AND "C" BATTERY FOR AIRCRAFT RADIO

RCA INSTITUTES INC

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VOL.10 No. 5

The e.m.f. across each series connection is 4.5 volts. In a parallel combination of cells the e.m.f. is the same across the component parts hence, the e.m.f. across the three groupings is 4.5 volts as marked on the diagram.

SERIES-PARALLEL COMBINATION. The circuit illustrated in Figure 16 consists of 12 cells connected in a series-parallel arrangement. Observe that there are three separate parallel groups each of which consists of 4 cells connected in parallel, and the three parallel groups are joined in series. Hence, a series-parallel combination is a series connection of a number of parallel arranged cells.

The e.m.f. across the battery in Figure 16 is 4.5 volts because the e.m.f. across each parallel group is 1.5 volts, i.e., the total e.m.f. of the 3 groups in series is their sum, or 4.5 volts, as marked on the diagram. Figure 17 is a diagram of the connections of "B" and "C" batteries for use in a sound-motion picture installation.

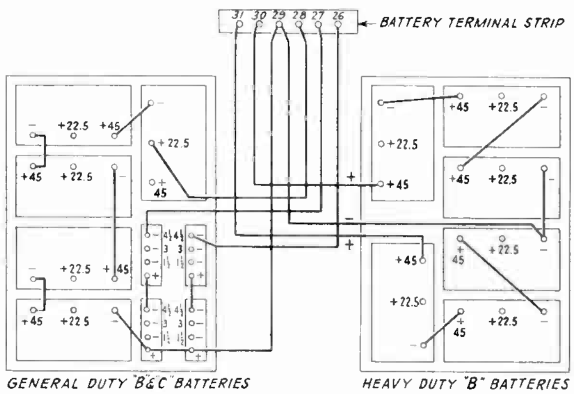


Figure 17

EXAMINATION QUESTIONS

1. What is a primary cell?
2. Name the materials used in some one type of primary cell.
3. (a) What determines the e.m.f. of a dry cell?
   (b) What determines the useful life of a primary cell?
4. (a) What is polarization?
   (b) How may polarization be reduced?
5. (a) What is meant by local action?
   (b) Do you know of any remedy for local action? Explain.
6. Can a primary cell be charged and used again like a storage cell? Why?
7. What is the difference between a cell and a battery?
8. (a) When would you use a series connection of cells?
   (b) What is the advantage of connecting cells in series?
   (c) How is the total e.m.f. of a series combination of cells computed?
9. (a) When would you use a parallel grouping of cells?
   (b) What is the advantage of a parallel connection of cells?
   (c) How is the total e.m.f. of a parallel combination of cells figured?
10. If you were given 15 dry cells and asked to connect them in a group which would supply a certain circuit with an e.m.f. of 4.5 volts,how would you do it? Draw a schematic diagram using symbols.

Figure 14 shows two parallel combinations of cells. The e.m.f. of the left-hand battery is 1.5 volts, which is the e.m.f. of any one of the cells. Likewise, the e.m.f. of the right-hand battery is 1.5 volts, or the e.m.f. of any cell in the group.

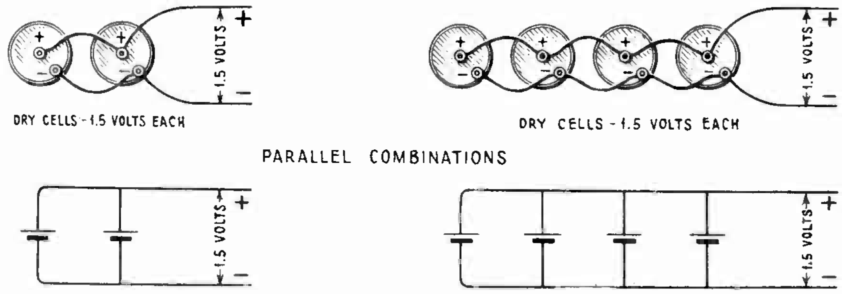
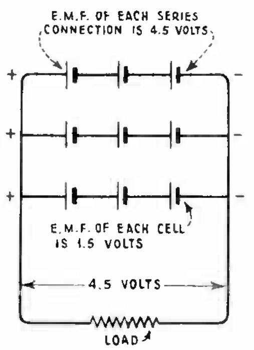


Figure 14

Hence, suppose the battery in Figure 13 consisting of 3 cells in parallel is connected to a circuit which is passing 2 amperes, then each cell of this group would contribute one-third of 2 amperes, or 0.66 ampere to the circuit. Thus, the load would be divided equally among the cells. If all of the cells were forced to pass 2 amperes steadily to energize such a circuit the cells would deteriorate very rapidly. In Figure 13 suppose the actual current passing through the bell is 0.15 ampere ; each cell then would furnish one-third of this amount, or $0.15 \div 3$ equals 0.05 ampere.

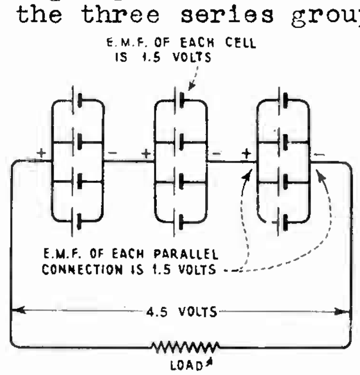
An <u>application of the parallel connection</u> may be easily understood by the following: Suppose we connect a small lamp to a single cell. The lamp will continue to remain lighted until the cell becomes exhausted which at the end of say, ten hours. If we connect another cell in parallel to the first and both are fresh cells, the lamp will remain lighted for twenty hours or twice as long as for one cell. With three lamps the lamp will remain lighted for thirty hours and so on. Each cell adds its current value to an adjacent cell with the additive current continually feeding the lamp as long as it is in the circuit. In any case, the voltage applied to the lamp would not be greater than that furnished by any single cell used.

<u>PARALLEL-SERIES COMBINATION</u>. The schematic diagram in Figure 15 shows 9 cells connected in a parallel-series arrangement. In this circuit we have three separate series groups each of which consists of 3 cells connected in series, and the three series groups are



PARALLEL-SERIES COMBINATION

Figure 15



SERIES-PARALLEL COMBINATION

Figure 16

joined in parallel. The diagram shows that a parallel-series combination is a parallel connection of a number of series arranged cells.

From the foregoing explanations we learn that to find the resultant voltage, or e.m.f., of any number of cells connected in a series combination it is only necessary to multiply the voltage of any one of the cells, providing they are all alike, by the number of cells in the group. Also, to find the internal resistance of all of the cells taken together in a series combination we must multiply the internal resistance of one of the cells, providing they are all alike, by the number connected in the group.

PARALLEL COMBINATION. Figure 13 is a picture diagram of a parallel or multiple grouping of cells where the e.m.f. or voltage of the whole combination is only the e.m.f. of a single cell. The drawing shows that all of the negative terminals (—) are connected together and, therefore, we have but one lead coming from the negative side of the cells that is common to all of negatives. The positive terminals (+) are also all connected together which provides only one common lead coming from the positive side of the cells. Observe that the connecting wires are put on according to the following system: The zinc of cell 1 is joined to the zinc of cell 2; the zinc of cell 2 is joined to the zinc of cell 3; and from this point a lead is carried to the bell. Next we have the carbon of cell 1 joined to the carbon of cell 2; the carbon of cell 2 joined to the carbon of cell

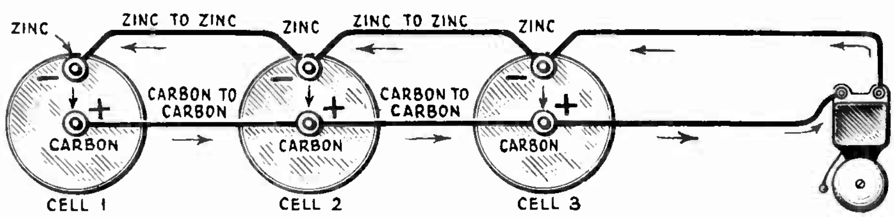


Figure 13

3; and then a second connection is carried from this point to the other terminal on the bell. Thus, we have completed the continuity of this parallel arrangement of cells. The path of the currents furnished by the individual cells and the total current flowing to the bell is represented by the arrows.

In this arrangement the internal resistance of the battery is reduced if cells are added to the group. For example, the internal resistance of the 3 cells in the battery in Figure 13 is one-third that of any single cell. If there are two cells in a parallel grouping the internal resistance is one-half that of either cell.

We learned in the first part of this lesson that the amount of zinc exposed to the action of the electrolyte determined the amount of current that would be delivered by the cell and that the voltage of all cells are exactly alike, relardless of their size, when the same combinations of materials are employed. Hence, in a parallel grouping of cells we have the effect of increasing the area of the plates since the zincs of all the cells are connected together; but we do not obtain an increase in the e.m.f. according to the consideration that certain combinations of materials give a known e.m.f. and the size, or area, of the materials has no influence on this voltage. The advantage of connecting cells in parallel is that each cell contributes an equal amount of the current delivered by the battery.

Example: Suppose we have a battery consisting of 12 cells, each rated at 1.5 volts, with the cells in series. What is the total voltage available? The answer is 12 x 1.5, or 18 volts. Example: If the internal resistance of each of the cells in a group of 12 connected in series is 0.5 ohm, what is the total internal resistance of the cells? The answer is 12 x 0.5 ohm , or 6 ohms.

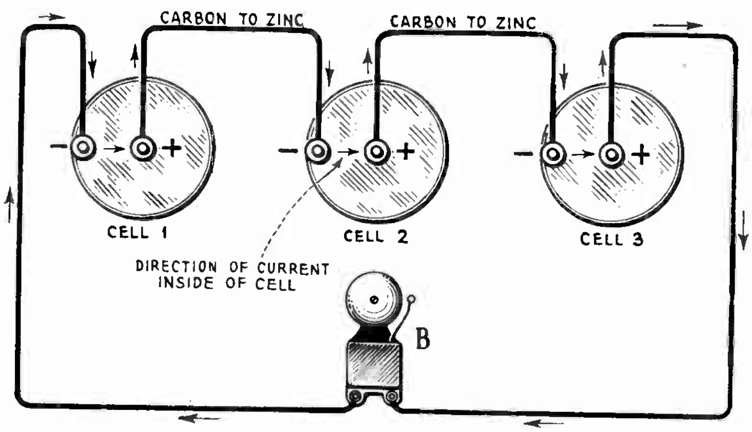


Figure 11

An illustration which clearly shows just how a series combination increases pressure is given by Figure 11. Assume that bell B requires a pressure of 4½ volts before its clapper will move and strike the bell. With one cell in the circuit, the clapper would probably not move; with two cells connected in series to the bell the clapper may vibrate but not to its greatest extent; and with three cells connected in series, the clapper attains its maximum vibration. This increase of electrical pressure exists in every series circuit due to the fact that the voltage of every cell in the series group contributes its pressure additively and since a larger voltage is made available, a larger current can be forced through a given circuit to perform a certain amount of electrical work.

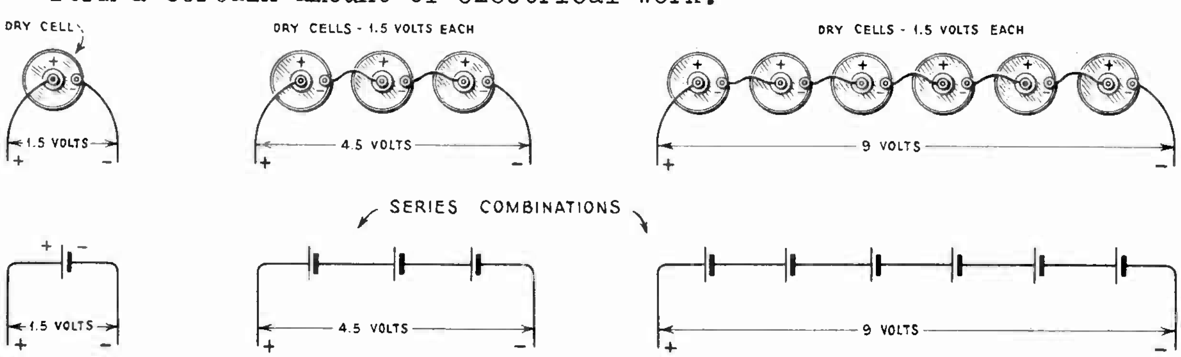


Figure 12

Figure 12 illustrates groupings of cells in series arrangements and is marked to show that the voltage of the cells is always additive in such a combination. The single cell at the left is shown to point out the relation between a cell and its symbol.

that a dry cell has two terminals, one a positive and the other a negative. The small sketch to the right in Figure 8 is one way of drawing the top view of a cell and indicating the amount of electromotive force in volts that the cell is rated at, or in this case, the cell is seen to have a "terminal" e.m.f. of 1.5 volts. Instead of drawing a picture of a dry cell each time we desire to indicate one on a diagram we make use of the standard symbol as shown in your lesson on "Symbols." The long thin line represents the positive pole, whereas, the short heavy line represents the negative pole.

There are two ways in which the cells of a battery may be arranged to vary the current output of the cells; (1) by a series combination: and (2) by a parallel combination.

(1) By the series method the e.m.f. of the battery is increased because the single cells are connected in a way that permits the sum of all of their e.m.f.'s to be available. When cells are joined in series the internal resistance of the combination is equal to the sum of the internal resistances of the individual cells. In Figure 9 three cells are shown joined in series and connected to a bell.

(2) By the parallel method the e.m.f. of the battery will not be greater than that of a single cell but the internal resistance of the battery decreases with each addition in the number of cells used. Refer to Figure 10 showing three cells joined in parallel and the combination connected to a bell and controlled by a push button.

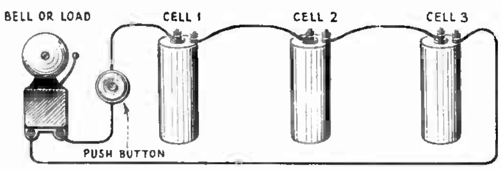


Figure 9

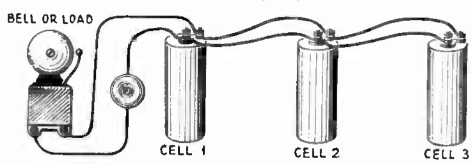


Figure 10

SERIES COMBINATION

Both Figures 9 and 10 are pictorial diagrams drawn to assist you in understanding just how the cells are actually connected. Notice that in the series combination in Figure 9 the connecting wires are put on according to the following system: The negative terminal post of cell 1 is joined to the positive of cell 2; the negative of cell 2 is joined to the positive of cell 3; the negative of cell 3 is joined to one terminal on the bell; the other bell terminal is joined to one terminal on the push button; the other terminal on the push button is connected to the positive terminal of cell 1. Thus, we have made a complete circuit, beginning at cell 1 and returning to it. In this arrangement the same amount of current that flows through one part of the circuit must also pass through all other parts since there is only one continuous circuit formed. Now refer to the diagram in Figure 11 which illustrates the circuit of Figure 9 in slightly different form. The purpose of Figure 11 is to show that when we connect two cells from positive to negative we are in reality connecting the carbon of one cell to the zinc of the adjoining cell. It is a simple matter to trace out the "continuity" of this circuit. The word "continuity" expresses just what we were doing, that is, tracing out a circuit from beginning to end to see that it is continuous and unbroken so that we may be sure that current will flow through all of its parts. The course of the current is shown by the arrows.

to keep a dry cell in a cool place whenever possible where the temperature is not much higher than 70° F.

A dry cell is a very convenient means for obtaining an electromotive force but it is adapted only for use on intermittent work such as, ringing door bells, telephone installations, or where the service demands only a small continuous current such as for supplying current to heat the filaments of small receiving type vacuum tubes in radio circuits, and other uses too numerous to mention.

Because of its low internal resistance a dry cell in good condition will deliver a current of about 18 to 30 amperes, or more, when measured on momentary short circuit by means of a low resistance ammeter. Short circuit tests should not be made often on the same cell as it places a heavy drain on the active materials. A voltage test can be made by using a good high-grade voltmeter with a low reading scale. The average e.m.f. of all new dry cells in good condition is about 1.5 or 1.6 volts. In certain classes of work after a cell has dropped to about 1 volt it is removed from active service and a new one is substituted. Also, if two or more cells are used in conjunction with one another their individual voltages should be measured frequently to ascertain whether they are nearly alike, or whether one cell is considerably lower than the rest in which event the operation of the circuit would be seriously impaired.

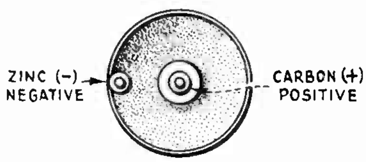


Figure 7

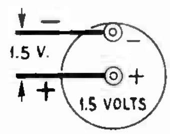


Figure 8

LECLANCHE CELL. The standard dry cell is practically a Leclanché cell made up in a different form — both employ similar materials in their construction. The Leclanché cell consists of two cylindrically shaped plates, one of zinc and one of carbon placed in a sal ammoniac solution, the carbon plate being corrugated in shape to form a porous cup in which the manganese dioxide and powdered coke are placed. When delivering current the sal ammoniac solution attacks the zinc and, as in the case of the simple dry cell, bubbles of hydrogen gas are liberated and collect on the surface of the carbon. The gas combines with the manganese dioxide and is removed, thus preventing polarization of the cell. A cell of this kind will keep in good working condition for years and practically the only attention it needs is an occasional filling with water and sometimes with a fresh supply of sal ammoniac.

METHOD OF CONNECTING CELLS

A top, or plan view, of a common dry cell is shown in Figure 7. The center terminal connects to the carbon rod and this terminal is called the "positive pole" of the cell; the (+) sign is used to denote positive polarity. We do not as a rule call this a "plus" sign in this work; we most generally say "positive" sign. The terminal at the outer edge of the cell connects to the zinc can, or shell, of the cell and this terminal is called the "negative pole"; the sign (—) is used to denote negative polarity. We do not call this a "minus" sign as a rule but rather a "negative" sign. Hence, we say

We will attempt to make the following explanation as easy to understand as possible although it is not necessary that you learn this explanation. When chemical action sets up in the cell each molecule of sulphuric acid separates into two oppositely charged parts; namely, positive ions which are the H_2 or hydrogen part of the acid, and negative ions which are the SO_4 or sulphuric part of the acid. The negative ions are made up of a certain number of negative electrons. Also, a portion of the zinc separates into electrons and positive ions with the latter uniting with the negative sulphate ions, the SO_4 mentioned above. But the electrons just made available by the zinc do not unite with other parts and, therefore, they move through the circuit. The repulsive force which electrons exert upon one another (this is because all electrons possess a negative charge of equal amount and have similar characteristics otherwise) causes them to move through the zinc electrode, and through the conductors forming the external circuit, and thence through the copper electrode and the action just described continues on so long as the cell is connected to the external circuit and the materials used in the cell are in good condition. (The external circuit consists of the connecting leads and the load as indicated by the resistance symbol.) The fact that each one of the two parts of the electrolyte go to opposite plates when it separates as stated above (that is, the H_2 positive ions go to the copper plate and the SO_4 negative charges go to the zinc plate) causes the respective plates to become charged electrically to positive and negative potentials. This results in the setting up of a difference of potential between the plates, or terminals, of the cell and the movement of the electrons through the external circuit in the direction from negative to positive.

The arrows in the drawing in Figure 6 are not to be associated with the movement of the electrons in the explanation just given. The arrows merely indicate the direction of current flow according to the usual convention or custom in practical use for many years. Note that the current arrows are in a direction in the external circuit from the positive to the negative electrode and in the internal circuit from the negative to the positive electrode.

CONSTRUCTION AND OPERATION OF THE COMMON DRY CELL. The interior view of a typical dry cell is plainly marked in Figure 2 to identify all of the parts that enter into its construction. Dry cells of this type are usually 6 inches high and $2\frac{1}{2}$ inches in diameter. The zinc cylindrical can is the negative electrode. The terms electrode and plate are used interchangeably. The zinc can holds the moist black paste into which is embedded a large carbon rod that forms the positive electrode, or plate. The paste usually consists of a mixture of ammonium chloride (or sal ammoniac, the chemical name of which is NH_4Cl), plaster of Paris, powdered coke, a small quantity of graphite, zinc chloride ($ZnCl_2$), and a depolarizing agent, such as manganese dioxide (MnO_2). Enough water is added to the electrolyte to moisten the absorbing paper which lines the zinc can and separates the zinc from the paste. After the paste and carbon rod are firmly packed in, the whole assembly is covered with sand and on top of this is placed a sealing compound to make the cell moisture proof and thus prevent evaporation.

The great advantage of this type of cell is that it can remain on open circuit for long periods without appreciably shortening its useful life. After a period of a year, or more, it will begin to deteriorate rapidly if unused and the drying out of the cell will be hastened if it is kept in a very warm atmosphere. It is always best

LOCAL ACTION. If a cell, like the one pictured in Figure 6, is left on open circuit (which means that there is no conductor of electricity connected to its respective plates) then there should be no chemical action occurring between the materials composing the cell. If the zinc plate is absolutely pure, (i.e., without foreign matter or impurities) an internal action cannot be set up and current cannot be produced by the cell's own materials. However, ordinary commercial zinc contains many foreign particles, such as carbon, tin, iron, and so on, and these small foreign particles act with the zinc to set up tiny electrical currents that flow in a short-circuit path as shown in Figure 5. This local action causes the zinc to be eaten away continuously and in time it will affect the normal output energy of the cell. To prevent this consumption of the zinc when the cell is not used to operate a circuit it is customary to rub a small quantity of mercury into the surface of the zinc. This process is called amalgamation. Amalgamation, therefore, stops local action when a cell is left on open circuit because the mercury does not combine with the carbon, or other foreign particles, but it does act chemically with the zinc to form zinc-mercury amalgam that works its way over the zinc plates and covers up the particles.

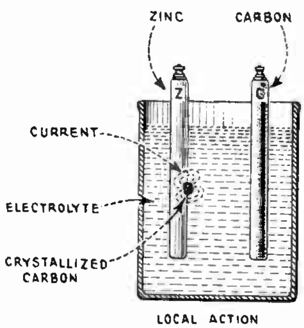


Figure 5

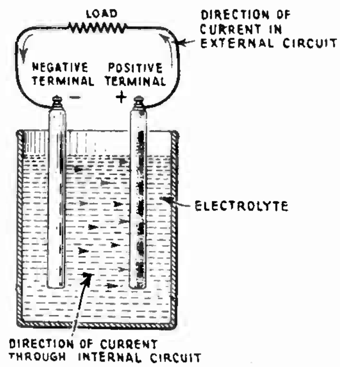


Figure 6

ACTION OF A SIMPLE PRIMARY CELL. Suppose the simple cell in Figure 6 is composed of a positive copper (Cu) electrode, a negative zinc (Zn) electrode, and diluted sulphuric acid. In this combination of materials the acid unites more readily with the zinc than with the copper. The chemical symbol for sulphuric acid is H_2SO_4 which denotes that a molecule of this liquid consists of two atoms of hydrogen, one atom of sulphur, and four atoms of oxygen.

The action is explained according to the "electron theory." The important thing to bear in mind is that atoms consist of an aggregation of electrons and if some of these electrons can be set free by chemical means the free electrons will move through the conductors forming the external circuit around the cell. As we have just stated the movement of current through the load circuit connected to the cell is simply a movement of electrons. Their direction of flow in the external circuit connected to a cell is from the negative terminal to the positive terminal of the cell. This is in accordance with the theory as explained in our lesson on "Static Electricity." It was stated that at a positively charged electrode there is a deficiency of electrons and at a negatively charged electrode there is a surplus of electrons.

by a sal ammoniac electrolyte solution. When a cell of this type is connected in a circuit and current flows the zinc is slowly dissolved, or eaten up, by the chemical action of the sal ammoniac (ammonium chloride). It is the combining of the electrolyte chemically with the zinc and the amount of the intensity of the action for this particular set of materials that makes the cell capable of developing an e.m.f. between its plates and, also, to furnish a given amount of current to a circuit for a given time.

While the chemical action goes on and current flows through the cell a quantity of fine bubbles of hydrogen gas are liberated which immediately form around the carbon. The bubbles collect very rapidly if the cell passes a current of high value continuously for any length of time and their presence on the positive carbon plate causes a very noticeable reduction in the current strength. Thus, we see that the hydrogen gas has a detrimental effect on the amount of electrical energy supplied by the cell. This weakening of the cell is called <u>polarization</u> and if allowed to continue the cell will cease functioning entirely.

The falling off of the current caused by the hydrogen gas is due to two conditions set up within the cell; first, the gas being a non-conductor of electricity acts as an insulator and increases the internal resistance of the cell and, therefore, actually tends to block the flow of current; secondly, the gas layer on the carbon reduces the amount of active surface material that the carbon can present to the electrolyte, that is to say, the gas acts to separate the carbon from the electrolyte. Moreover, if a cell of this kind is strongly polarized it sets up a small opposition e.m.f. because the character of the plates are altered inasmuch as the carbon plate virtually becomes a hydrogen plate. So far as the chemical action of the cell is concerned,it will behave as though it had zinc and hydrogen plates and not zinc and carbon. It has been mentioned before that different combinations of the materials of which a cell is composed will cause the e.m.f. produced between its plates to also change, hence, the e.m.f. of the cell is considerably lowered by the polarized condition.

<u>Polarization</u> is prevented in a cell when it is operated to give an intermittent current of average value for the particular type of cell in question. In the type already under consideration a strong oxidizing substance, such as manganese dioxide, is used for this purpose as it combines readily with the hydrogen and, therefore, removes the gas from around the carbon. It is to be understood that if an excessively large current is delivered steadily by the cell the chemical action between the oxidizing material and the hydrogen may be too slow to prevent polization and the cell will become inactive in a short time. However, if a cell when in this condition is disconnected from the circuit and permitted to remain on open circuit for a brief interval it will rapidly <u>recuperate</u>, or recover, which means that it will be restored to normal by the cleaning up of the hydrogen by the depolarizing agent. The carbon then is once more left free to act as a plate and conductor for the passage of current.

Have you ever noticed when using a pocket flashlight that the light suddenly became dim, but after allowing the switch to remain in the "off" position for a half minute or so the lamp when next lighted would glow with its former brightness? This dimming of the light was caused by the falling off of the current through the cell due to polarization. The same weakening effect is often noticed in the ringing of a door bell, or in the operation of a buzzer, especially when they are operated <u>steadily</u> for a time.

necessary to pass current again through the storage cell to restore the materials to their original condition. With intelligent care a storage cell will last for years since it only requires charging and the adding of water at periodic intervals to maintain it in a proper condition. The life of a dry cell, on the other hand, is a more or less fixed condition because it is governed by the rate at which the active material, zinc for instance, is consumed and this in turn depends upon the amount of electrical energy delivered by the cell. For the reasons just advanced a dry cell is called a primary cell and a storage cell is called a secondary cell. A lesson is devoted to storage batteries and storage cells later in our course. Primary cells are also known as galvanic cells.

Another important thing to mention is that a dry cell is not really dry as the name would lead most anyone to believe. The use of the word "dry" no doubt became popular owing to the fact that all of the materials in the cell are sealed up in a moisture-proof container without any outside evidence of a liquid solution in it like in a "wet" battery, for example. During the manufacture of a dry cell a certain amount of water is added to the materials and the liquid is therefore retained in the moist pasty filling which we could see if we broke open a good cell.

WHY AN ELECTROMOTIVE FORCE IS PRODUCED BY A DRY CELL. It is a known fact that there is always an e.m.f. of a certain number of volts set up between any two pieces of metal of dissimilar kind when immersed in a liquid. When certain combinations of materials are used, and the liquid is a chemical solution of a particular kind, e.m.f.'s as high as 2 volts and more can be obtained. The metal pieces referred to are called "plates" and the chemical solution the "electrolyte." The e.m.f. or voltage of a cell is determined solely by the kind of materials used for the plates and the nature of the electrolyte. The theory is that the electrolyte acts more readily on one material than the other and it is this chemical action that causes both plates to possess an electric potential, but because of their difference in character one plate will have a higher potential than the other. The higher potential plate is called the positive plate and the lower potential plate is the negative plate. The difference of potential is electrical pressure and it is capable of sending current through a circuit. The size of the plates, their actual surface area in contact with the electrolyte, or the amount of separation between plates have no bearing whatsoever on the voltage of the cell. However, these factors do have some effect on the internal resistance of the cell and this in turn will govern to some extent the amount of current that the cell will be capable of delivering.

Hence, if we have one very large cell and one very small cell and each one is made up of a similar combination of materials and electrolyte it will be found that the voltage reading taken between the plates will be alike for the two cells. This would prove our statement that only the materials and the electrolyte govern the e.m.f. or voltage across the plates. A cell consisting of a zinc plate and a copper plate immersed in a liquid of dilute sulphuric acid gives an e.m.f. of approximately 1 volt regardless of the size of the elements (elements means the materials). Another cell, however, having a different combination of materials, for instance, zinc for one plate, carbon for the other, and a sal ammoniac electrolyte, sets up an e.m.f. of approximately 1.5 volts between its plates.

POLARIZATION. To explain this term let us consider that we have a cell consisting of a zinc plate and a carbon plate being acted upon condition. Several cells may be connected to form a battery as follows: Suppose we have 3 cells of this type connected together to form a battery then the total e.m.f. at the terminals would be 3 x 1.5 or 4.5 volts. Again, suppose we had 30 cells of this kind connected to form a battery;then,the total e.m.f. available at the battery terminals would in this case be 30 x 1.5 or 45 volts. In many dry batteries there are connections taken from different cells in order to provide several different voltages from the same battery for convenience.

A battery consisting of three small dry cells connected together in series is shown in Figure 3. Notice that three terminals are supplied so that the e.m.f. (or voltage)of one or two cells may be used separately, or the voltage of three cells may be used by making connections to the outer two terminals. A dry battery containing thirty small cells compactly arranged in a container is shown in Figure 4; the e.m.f. at the outside two terminals is 45 volts. In this battery a tap taken between the 15th and 16th cells is brought to the center terminal on the top so that one-half of the total voltage, or 22½ volts, is available either between the first and second terminals, or between the second and third terminals.

The dry cell and batteries illustrated are typical of the kind found in widespread use for radio and electrical work. A battery similar to the one in Figure 3 is mostly used for a specific purpose in radio circuits to supply a negative voltage to the grids of vacuum tubes and it is, therefore, known as a "C" battery. The battery in Figure 4 is exactly the same as the one just mentioned so far as its principles of construction are concerned, except that it has more cells than the one in Figure 3. The larger battery in Figure 4 is employed principally to furnish the plate voltage to operate vacuum tubes in certain types of equipment and is known as a "B" battery. If several cells of the type shown in Figure 2 are used to furnish an e.m.f. to the filaments of vacuum tubes in receiving sets, to provide the heating current, the cells are then referred to as an "A" battery. Later on in your work you will become accustomed to using the terms "A," "B," and "C" for identifying batteries of any type according to their particular duty. It should now be clear that the terms battery and cell are not to be used interchangeably and, therefore, in your conversation and writing be careful to make the correct distinction between them. Say "cell" when you mean cell and "battery" when you mean battery.

DISTINCTION BETWEEN PRIMARY AND SECONDARY CELLS. There are two types of cells in general use, namely: dry cells and storage cells. A dry cell is one that depends for its operation upon the consumption of one of the materials by the chemical action of the solution on it when current flows through the cell and through the circuit to which it is connected. While current flows the material is gradually eaten up and in due time it will be entirely consumed,and as a result of this action the voltage (or e.m.f.) of the cell will drop so low that the cell becomes useless for all practical purposes. When this happens the cell must be discarded and replaced by a new one. A storage cell, on the other hand, is one that must first be charged by passing a current through it in a certain direction so that its materials will be put into the proper condition that will enable them to produce an electrical pressure. After the storage cell has been on circuit and delivers a certain amount of current in a stated time, its e.m.f. will fall below the proper working value because the chemical relations of the cell are then altered. Since the materials merely undergo a change and are not eaten away, as in a dry cell, it is only

In the case of the generator the electromotive force is obtained by making practical use of the laws of electromagnetic induction. According to the explanations in our preceding lesson on this subject one law stated that when a coil of wire is moved through a magnetic field an electromotive force is produced across the terminals of the coil; this is exactly the principle upon which the generator works since it is constructed to provide a strong magnetic field through which a number of coils are rotated by mechanical means and from these coils we are able to get an electromotive force, or electric power.

In the case of the battery, however, the electromotive force is obtained through the electrochemical action that occurs between the combination of materials that are used. We learn, therefore, that a generator transforms mechanical energy into electrical energy and a battery transforms chemical energy into electrical energy.

Hence, insofar as we are concerned at the present, a generator and a battery both produce similar results, that is, either one will provide an electromotive force. Of course, you will understand that many practical and economical considerations determine whether a generator or battery will be used to furnish power for the operation of certain types of equipment. In many of the modern radio broadcast, commercial telegraph, sound picture, television, and aviation radio installations it has been found necessary to employ both generators and batteries to obtain the best electrical results.

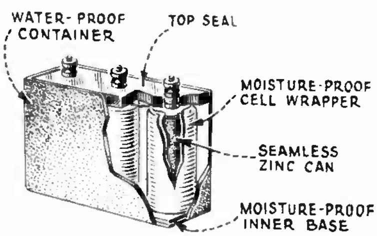


Figure 3

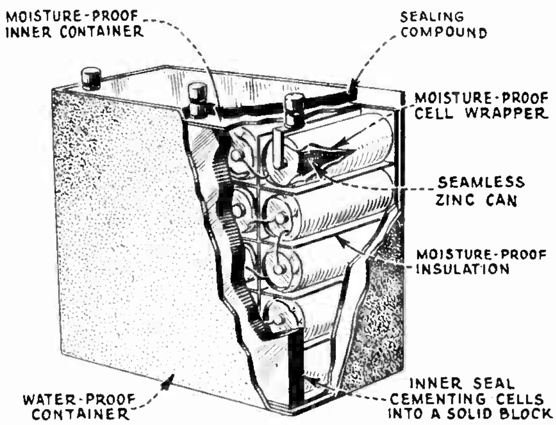


Figure 4

CLASSIFICATION OF BATTERIES AND CELLS. Let us first explain the distinction between the terms "battery" and "cell." A cell is a complete unit consisting of a chemical solution into which is placed two different kinds of materials which are not allowed to touch each other and from which an electromotive force can be obtained by the chemical action set up between the solution (electrolyte) and the materials. When two or more cells of similar kind are connected together in a combination that permits their individual e.m.f.'s to be utilized all at the same time, the whole combination is known as a "battery." Hence, a battery is a number of cells all functioning in conjunction with one another to provide a certain amount of electrical pressure, measured in volts, from its terminal binding posts.

A single cell of the dry cell type is shown in Figure 1, while its interior construction is pictured in the cross-sectional view in Figure 2. This cell has an e.m.f. of approximately 1.5 volts when in good

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A Radio Corporation of America Subsidiary

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75 Varick Street, New York
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PRIMARY CELLS

SOURCES OF ELECTRIC POWER. The principal sources of electric power that are utilized in practically every radio, sound picture, television, and aviation radio power installation, including recorders, reproducers, transmitters, receivers, auxiliary equipment and types of apparatus of unlimited varieties, are the electric generator and the electric battery. When we say source of electric power we mean a source of electromotive force. It is customary for some persons to think that a generator or battery stores up electricity and supplies current to any device to which it may be connected, but this is not a fact. A generator or battery merely furnishes an electromotive force (or pressure) which when applied to any device, or circuit, will set electrons in motion and cause them to flow through the device, or circuit. Always keep in mind that the movement of electrons through wires (and all conductors of electricity) is the so-called current flow. Now, since electrons already exist in the wires and other elements that form a circuit then it cannot be said

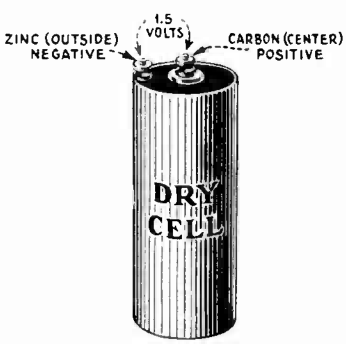

Figure 1

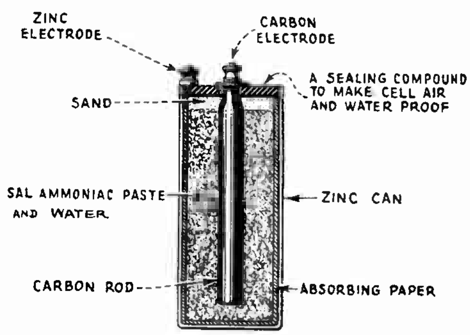

Figure 2

that a generator or battery supplies them; what the generator or battery does is to force these electrons to move through the wires from one place to another, that is, the electrons which constitute the current are forced to flow through a circuit by the e.m.f. (or pressure) applied to the circuit. Thus, it is evident that current will not flow in any circuit unless an electromotive force is applied to it from some source.

RESULTS OBTAINED FROM VARIOUS CELL COMBINATIONS

VOLTAGE - RESISTANCE - CURRENT

SERIES ARRANGEMENT OF CELLS

VOLTAGE......The total e.m.f. of a series combination of cells is the sum of the e.m.f.'s of the individual cells.

RESISTANCE...The combined resistance of cells in series is increased by adding cells. The total resistance is the sum of the internal resistances of the individual cells.

CURRENT......In practice cells are usually connected in series (to increase the e.m.f.) when the resistance of the load circuit (or external circuit) is high in order to obtain the proper current.

PARALLEL ARRANGEMENT OF CELLS

VOLTAGE......The total e.m.f. of a parallel combination of cells is equal only to the e.m.f. of any cell in the group providing they are of similar kind.

RESISTANCE...The combined resistance of cells in parallel is decreased by adding cells. The total internal resistance is equal to the internal resistance of one cell divided by the number of cells.

CURRENT......In practice cells are generally connected in parallel when the resistance of the load circuit is low so that each cell contributes its share of the total current in the circuit.

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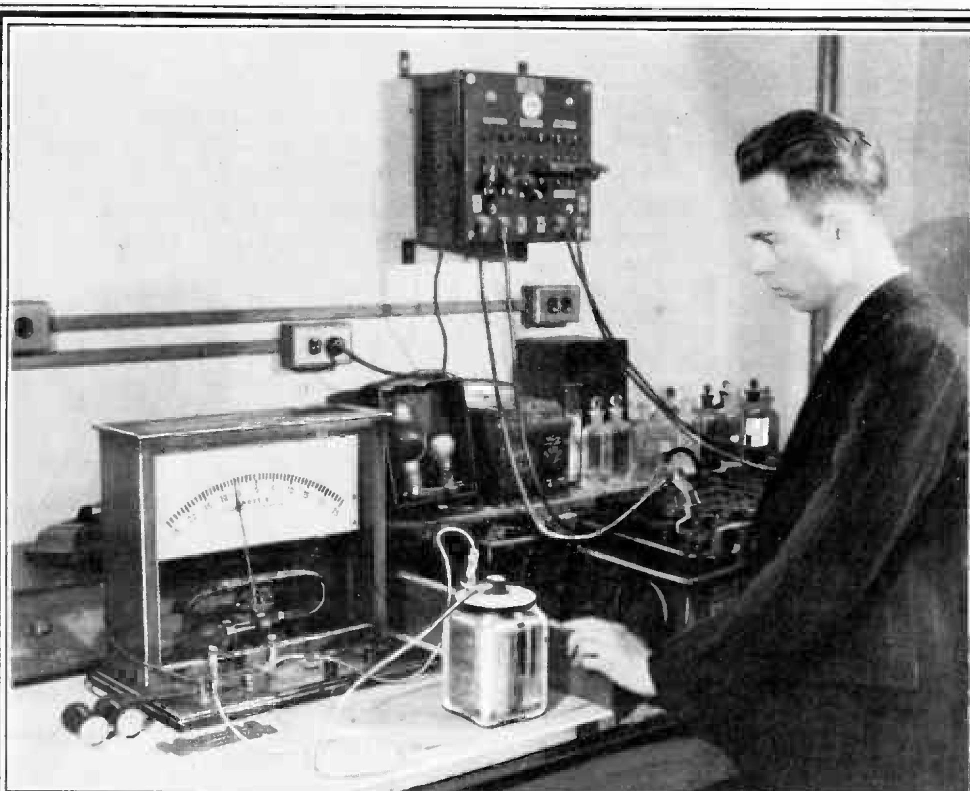
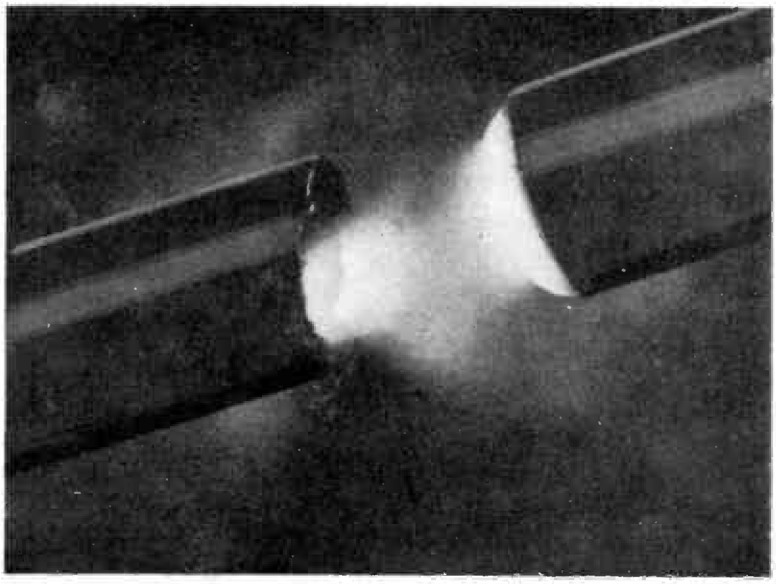


THE DEFLECTION OF THE METERS' POINTER INDICATES THE ELECTRICAL PRESSURE (E.M.F.) PRODUCED BY THE PRIMARY CELL OR JAR

HOW ENERGY IN ELECTRICAL FORM IS PROVIDED BY THE PRIMARY CELL

VOL. 10 No. 5

DEWEY DECIMAL CLASSIFICATION R100



AN ARC CHANGES ELECTRIC ENERGY INTO LIGHT AND HEAT

RCA INSTITUTES INC. P.O. 1183

VOL. 10 NO. 4 PRINTED IN U.S.A.

AN ELECTRICALLY OPERATED MAGNETIC CRANE CONVERTS ELECTRICAL ENERGY INTO MECHANICAL ENERGY

(Problems cont'd from previous page)

Note: Solve the following problems which relate to direct current circuits. Use the form suggested in worked-out examples in this lesson where the formula is written first, the known values substituted next, and so on.

7. If 3 amps. pass through the lamp in Figure 6, and the line voltage at the wall outlet is 110 volts, what power is being expended?

8. Suppose an electrical heater, rated at 350 watts, is placed in operation and by measuring the current strength with an ammeter, we find it to be 3 amps. Find the line voltage.

9. If the load on a generator supplying an electrical circuit is such that a current of 200 amperes flows at a pressure of 120 volts, what is the capacity of this machine in watts? Also, in kilowatts?

10. In this problem you are given the following data: The e.m.f. is 120 volts, the current drawn is 20 amperes and the generator is maintained in operation 12 hrs. Find kilowatt-hours of energy expended.

EXAMINATION QUESTIONS

1. Give the definitions of the following units, expressing them in your own words. Do not use the exact wording given in the lesson.

   (a) volt
   (b) ampere
   (c) ohm
   (d) coulomb
   (e) watt
   (f) henry
   (g) farad
   (h) kilowatt-hour
   (i) ampere-hour

2. (a) What is a megohm?
   (b) Microhm?
   (c) Kilowatt?
   (d) Micro-microfarad?
   (e) Microfarad?

3. (a) Can energy be created?
   (b) Name two practical sources for obtaining electrical pressure.
   (c) What must we first have in an electrical circuit before current will flow?
   (d) What unit of time is electrical measurement based on?
   (e) Write 35 mmfd. in the unit mfd.

4. Suppose the capacity of a generator when carrying a load is 3500 watts. Express this value in kilowatts and horse-power. Show your work.

5. What is the difference between work and power? What is force and energy? Use an analogy, if you wish, in order to explain the meanings.

6. (a) Write the formula you would use if the power and current of a circuit were known and you were asked to find voltage.

   (b) Write the formula you would use to find current strength if the voltage and wattage of a circuit were known.

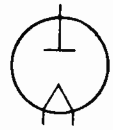
   (c) Write the formula you would use to find the wattage of a circuit if the voltage and current were known.

(Problems cont'd on next page)

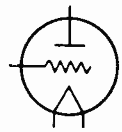
STANDARD RADIO SYMBOLS

Vacuum Tubes

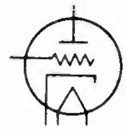
Diode
(or half-wave rectifier)



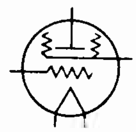
Triode
(with directly heated cathode)



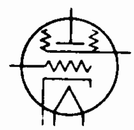
Triode
(with indirectly heated cathode)



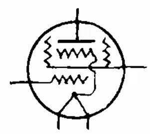
Screen Grid Tube
(with directly heated cathode)



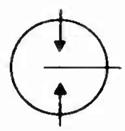
Screen Grid Tube
(with indirectly heated cathode)



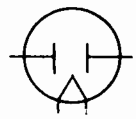
Pentode
(with directly heated cathode)



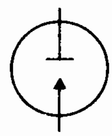
Rectifier Tube, Full-Wave
(Filamentless)



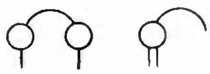
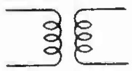
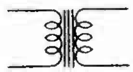
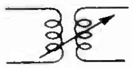
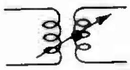
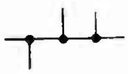
Rectifier Tube, Full-Wave
(with directly heated cathode)



Rectifier Tube, Half-Wave
(Filamentless)



STANDARD RADIO SYMBOLS

Resistor	
Resistor, Adjustable	
Resistor, Variable	
Spark Gap, Rotary	
Spark Gap, Plain	
Spark Gap, Quenched	
Telephone Receiver	
Thermoelement	
Transformer, Air Core	
Transformer, Iron Core	
Transformer, With Variable Coupling	
Transformer, With Variable Coupling (With moving coil indicated)	
Voltmeter	
Wires, Joined	
Wires, Crossed, not joined	

Part III

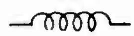
STANDARD RADIO SYMBOLS

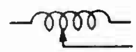
Frequency Meter (Wavemeter) 

Galvanometer 

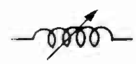
Glow Lamp 

Ground 

Inductor 

Inductor, Adjustable 

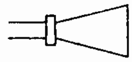
Inductor, Iron Core 

Inductor, Variable 

Jack 

Key 

Lightning Arrester 

Loud Speaker 

Microphone (Telephone Transmitter) 

Photo electric Cell 

Piezoelectric Plate 

Part II

STANDARD RADIO SYMBOLS

Courtesy, Institute of Radio Engineers

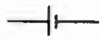
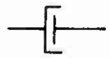
Aerial	
Ammeter	
Arc	
Battery (the positive electrode is indicated by the long line)	
Coil Antenna	
Condenser, Fixed	
Condenser, Fixed, Shielded	
Condenser, Variable	
Condenser, Variable (with moving plate indicated)	
Condenser, Variable, Shielded	
Counterpoise	
Crystal Detector	

CHART OF THE TYPICAL UNITS OF WORK AND POWER

WORK = Force x Distance, or $W = FD$

UNITS OF WORK

Joule = Watt second, or $J = PS$

$= EIS$

$= EQ$

$= I^2RS$

$= \frac{E^2S}{R}$

$= 10^7$ ergs

Erg = dyne centimeter

$= \frac{gm\ cm}{sec^2} \times cm$

$= \frac{gm\ cm^2}{sec^2}$

POWER $= \frac{Work}{Time}$, or $P = \frac{W}{T}$

UNITS OF POWER

Watt = Volt ampere

$= EI$

$= I^2R$

$= \frac{E^2}{R}$

$= \frac{joule}{second}$, or $P = \frac{J}{S}$

$= \frac{1}{746}$ H. P.

$= \frac{550\ \frac{ft\ lbs}{sec}}{746}$

Key To Abbreviations

cm = centimeter

D = distance

E = volt

F = force

ft = feet

gm = gram

H.P. = horse-power

I = ampere

J = joule

lb = pound

P = watt

Q = coulomb

R = ohm

S = second

T = time

W = work

GREEK LETTERS, SYMBOLS AND MATHEMATICAL SIGNS

Greek alphabet

Letters		Names	Letters		Names	Letters		Names
A	α	Alpha	I	ι	Iota	P	ρ	Rho
B	β	Beta	K	κ	Kappa	Σ	σ ς	Sigma
Γ	γ	Gamma	Λ	λ	Lambda	T	τ	Tau
Δ	δ	Delta	M	μ	Mu	Υ	υ	Upsilon
E	ϵ	Epsilon	N	ν	Nu	Φ	ϕ	Phi
Z	ζ	Zeta	Ξ	ξ	Xi	X	χ	Chi
H	η	Eta	O	o	Omicron	Ψ	ψ	Psi
Θ	θ	Theta	Π	π	Pi	Ω	ω	Omega

Symbols

μ = permeability (B/H)
π = 3.1416
ρ = volume resistivity
τ = thickness
κ = susceptibility
λ = wavelength in meters
δ = logarithmic decrement
ϵ = 2.7183 (base of Napierian logarithms)
η = efficiency (per cent)
θ = phase angle (degree or radian)

ϕ = angle
ψ = difference in phase
ω = $2\pi f$ (angular velocity in radians per second);
Φ = magnetic flux
Ψ = electrostatic flux.
Ω = ohm
Υ = electric conductivity
$\mathcal{E}$ = electric field intensity
$\mathcal{F}$ = magnetomotive force
$\mathcal{R}$ = reluctance

Signs

$\propto$ proportional to; varies as
$=$ equal to
$\times$ multiplied by
$+$ plus; addition
$-$ minus; subtraction
$\div$ divided by
$\odot$ circle

$\angle$ angle
$<$ is less than
$\ll$ much less than
$>$ is greater than
$\gg$ much greater than
∞ cycle

ABBREVIATIONS FOR RADIO TERMS
Courtesy, Institute of Radio Engineers

Term	*Abbreviation*
Alternating-current (adjective)	a-c
Alternating current	spell out
Ampere	a
Antenna	ant.
Audio-frequency (adjective)	a-f
Continuous waves	CW
Cycles per second	~
Decibel	db
Direct-current (adjective)	d-c
Direct current	spell out
Electromotive force	e.m.f.
Frequency	f
Ground	gnd.
Henry	h
Intermediate-frequency (adjective)	i-f
Interrupted continuous waves	ICW
Kilocycles (per second)	kc
Kilowatt	kw
Megohm	MΩ
Microfarad	μf
Microhenry	μh
Micromicrofarad	μμf
Microvolt	μv
Microvolt per meter	μv/m
Millivolt per meter	mv/m
Milliwatt	mw
Ohm	Ω
Power Factor	p.f.
Radio-frequency (adjective)	r-f
Volt	v

ABBREVIATIONS FOR METRIC PREFIXES

Prefix	*Abbreviation*
centi	c
deci	d
deka	dk
hecto	h
kilo	k
mega	M
micro	μ
milli	m

points is one wavelength. Let us try to visualize a wave motion occuring in space, set up by unseen forces. Suppose that an electromagnetic wave is projected from an active transmitting antenna and this energy consists of a succession of rapidly recurring impulses in space, due to the disturbance set up in the space medium. The length of each individual wave or complete impulse of the electromagnetic wave motion is considered from a similar viewpoint as each water wave.

The metric unit of measurement is used to compute such length. Thus the wavelength of an electromagnetic wave sent out by a radio transmitter may be 300 meters, or it may be 1,500 meters or 14.5 meters or any desired length which is governed by the electrical adjustments of the transmitter. One meter equals approximately 39.37 inches. The student must not confuse the distance which a radio wave will actually travel to be intercepted and heard in the receivers (which may be several thousand miles in some cases) with the wavelength of each individual impulse in the complete wave motion.

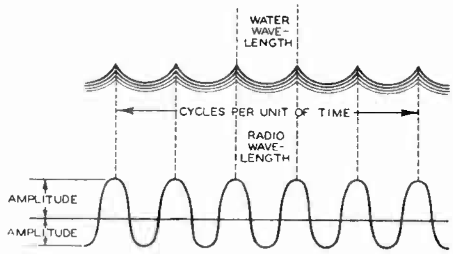


Figure 13

The length of a wave is the distance from the crest of one wave to the crest of the next wave as shown in Figure 13. The variations passed through during one such occurrence are said to constitute one cycle. 1000 cycles are equivalent to one kilocycle. The total number of these cycles which occur in one second is called the frequency.

Figure 14 shows the frequency range or spectrum of all the known forms of vibratory motion. Classifications are not sharply defined as much of the spectrum remains to be fully explored.

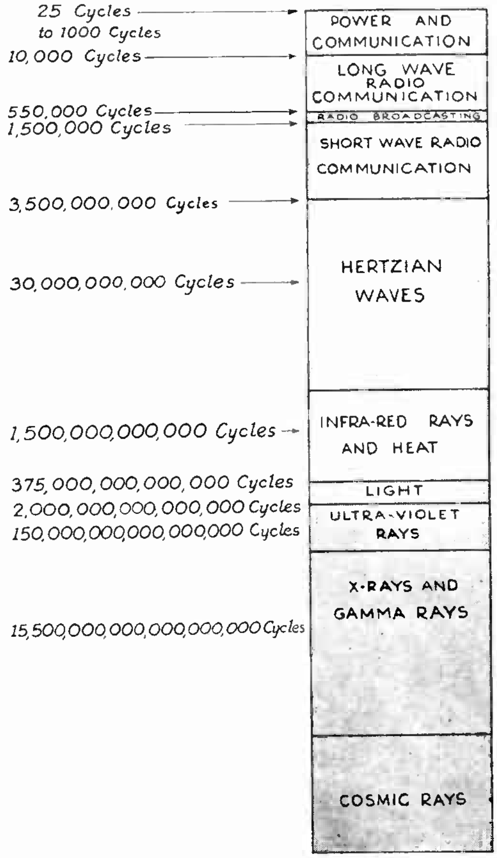


Figure 14

The balance of this lesson contains charts and symbols which are followed by the examination questions.

We have already given an equation which states that 550 foot-pounds per second is equivalent to 1 mechanical horse-power. The electrical equivalent of this, or 1 electrical horse-power, would be

$$1 \text{ ELECTRICAL H.P.} = \frac{550}{0.7375} \text{ or, 746 watts.}$$

The above derivation of the number of watts per electrical horse-power is the same as,

$$1 \text{ ELECTRICAL H.P.} = 550 \times 1.356 \text{ or, 746 watts.}$$

The value .7375 is the reciprocal of 1.356, or 1 divided by 1.356, that is,

$$\frac{1}{1.356} = .7375$$

THE METER IS THE UNIT OF MEASUREMENT FOR WAVELENGTH. Wavelength can also be expressed in terms of frequency. These terms are used in connection with electromagnetic wave motion in space, by this we mean radio waves in space. The terms can be interchangeable, it being a simple matter to convert wavelength to frequency and vice versa. This is explained in a subsequent lesson. Refer to Figure 12, which shows a regularly recurring wave motion set up on the surface of water by striking it with equal intensity at regular intervals with a wooden block.

The term wavelength can best be explained with the aid of a drawing of this kind and after once understanding the meaning of wavelength it can be applied to any form of motion that occurs and reoccurs at regular intervals.

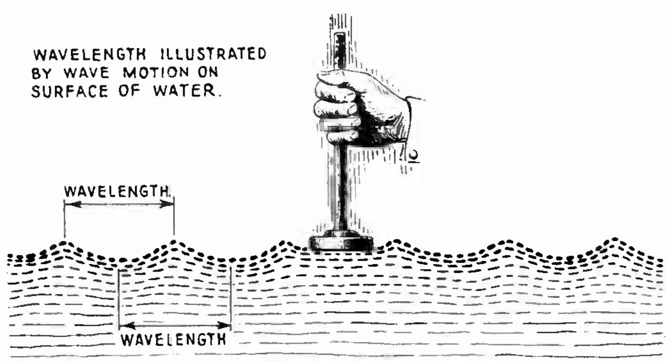


Figure 12

One wavelength is the distance from crest to crest of the wave in Figure12, or it may be the distance from trough to trough, which naturally would be the same. Moreover, we could consider any point on one wave impulse and compare it to a similar point on an adjoining wave impulse and say that the distance between these two selected

Now, in order to find the rating of an electrical machine, in the unit of horse-power, we have simply to know its capacity in volts and amperes; to find the horse-power multiply the volts by amperes and divide by 746. This is the same thing as saying that the number of watts are divided by 746. Hence, we have.

$$\text{ELECTRICAL H.P.} = \frac{\text{VOLTS x AMPERES}}{746} = \frac{\text{WATTS}}{746}$$

The following worked out example is given to aid you in solving problems of this kind. The results can be expressed either in the unit watt, kilowatt or electrical H.P.

PROBLEM: Suppose the current drawn by the motor in Figure 11 is 20 amperes and the line voltage is 220 volts. Find the number of watts of energy consumed?

SOLUTION:

(1) Write formula: WATTS = E x I

(2) Substitute known values: WATTS = 200 x 20

(3) Solving, we get: WATTS = 4400 watts. Answer

If we wish to express the above answer in horse-power maintained by the motor, simply divide 4400 by 746 as follows:

$$\text{ELECTRICAL HORSE-POWER} = \frac{\text{WATTS}}{746} = \frac{4400}{746}$$

Hence, ELECTRICAL HORSE-POWER = 5.8 H.P. Answer.

This answer expressed in kilowatts is 4400 ÷ 1000 = 4.4 kw.

THE BASIS OF COMPARISON BETWEEN MECHANICAL AND ELECTRICAL H.P. The basis for comparing an equivalent amount of mechanical energy measured in "foot-pounds" and electrical energy in "watts" was worked out mathematically many years ago by Dr. Joule. He made a direct comparison between both kinds of energy in performing exactly the same work which consisted of heating a given quantity of water until its temperature was raised to a certain value. In the case of mechanical energy the heat was obtained from the friction set up when paddle wheels were rotated through the water. The amount of power required was figured from the number of foot-pounds of work per second obtained from a certain arrangement of pulleys and weights used in the experiment. In the case of the electrical circuit the power was computed from the amount of current consumed at a certain voltage and the time required in generating the specified amount of heat. Dr. Joule estimated that 1 foot-pound per second = 1.356 watts.

hour, one-half hour or five minutes, or any other interval of time, will determine the "time rate of doing the work," or "the power." Mechanical power is usually estimated in foot-pounds per minute, but in some practical work it may be more convenient to use foot-pounds per second. Hence,

1 MECHANICAL H.P. = 33,000 FT. LBS. PER MINUTE
or, 1 MECHANICAL H.P. = 550 FT. LBS. PER SECOND.

We obtain the 550 in the lower equation, for expressing so many foot-pounds per second, by dividing 33,000 foot-pounds per minute by 60 seconds, that is, $33{,}000 \div 60 = 550$.

In commercial practice the power is estimated according to the amount of work done in horse-power and the period of time involved in hours.

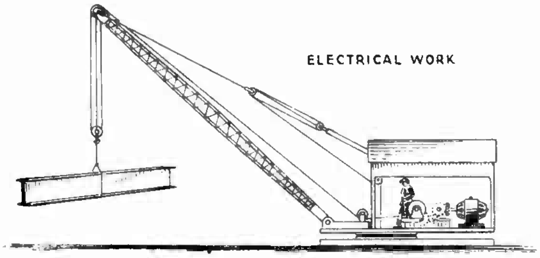


Figure 11

Electrical H.P. Electrical power is measured in watts, the measurements being based upon the second of time and not the minute which is chiefly used in mechanical work.

Let us suppose the horses in Figure 10, are replaced by an electric motor as the source of power as in Figure 11. You will recall that power is estimated according to the amount of work done during a certain period of time. Accordingly, in our computations it will be necessary to know the amount of power that a motor is supplying and length of time it is kept in operation.

In one of the paragraphs in this lesson, under the unit "Joule," it was explained that one joule per second is the unit of electrical power, or the watt. Furthermore, it was explained that the rate in watts at which electrical energy is expended is equal to the voltage of a circuit times the number of amperes of current flowing. Putting these statements together should give you an understanding of the significance of the watts formula; where

$$\text{WATTS} = E \times I$$

Where large amounts of power are handled it is often inconvenient to use a unit as small as the watt, as we previously mentioned and so in the practical work of rating electrical machinery the larger unit "electrical horse-power" is employed. It will be recalled that one electrical horse-power equals 746 watts.

The work done is the result of the force exerted, or power expended, by the horses in overcoming any opposition or resistance which the load presents. The heavy iron beam is the load. The power is the rate at which the work is done, that is, whether it takes the horses 15 minutes, or 1 hour, or any given time to lift the load. The total work includes the power expended and the time.

In summarizing the foregoing facts we can say in a few words that the energy possessed by the horses was converted into mechanical pulling or lifting power. This gives us a good illustration of the laws governing the "conservation of energy." Conservation relates to the transference of energy from one state to another. There is nothing lost, practically speaking, in the transference of energy from one state to another so long as our purpose is fulfilled; that is, so long as the work we desire to be performed is actually completed.

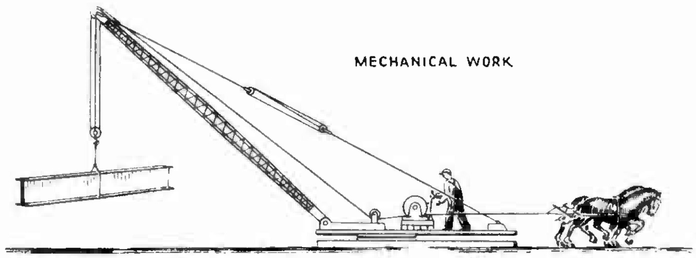


Figure 10

ELECTRICAL AND MECHANICAL HORSE-POWER DEFINED

Mechanical H.P. In the illustration in Figure 10, we have shown two horses lifting a heavy iron beam by means of a hoisting crane. The power in this case is the rate at which the work of lifting the beam is accomplished. Mechanical work is measured in "foot-pounds" or "pounds multiplied by feet." Thus, if a weight of 3 lbs. is raised to a height of 5 ft. we have an equivalent of 15 foot-pounds of work. Suppose a $7\frac{1}{2}$ lb. weight is lifted only 2 feet we would have exactly the same amount of work done as when 3 lbs. is raised 5 ft., or 15 foot-pounds in both cases.

Now, to explain the meaning of mechanical horse-power let us suppose that the iron beam in Figure 10 weighs 33,000 lbs. and is to be raised one foot against the force of gravity, and suppose further that the horses take one minute to do this. Here we have a set of given values. Let us repeat them: 33,000 lbs. is to be raised one foot in one minute. This combination of values is the basis for the rate of doing work which is equal to one mechanical horse-power. If twice this weight, or 66,000 lbs., is raise one foot in twice the time, or two minutes, the "rate of working" would still be the same as in the preceding case, or one mechanical horse-power.

If the horses were replaced by a stronger team that could lift the same beam, the same distance, in just half the time, or let us say, in one-half minute, then it is logical to assume that one team is twice as powerful as the other. Thus, if 33,000 lbs. is lifted one foot in 30 seconds it would give us 2 mechanical horse-power. We see that both teams of horses perform exactly the same total amount of work, but, depending upon whether the work is completed in one

The watt-hour is the unit of measurement that is applied in the calibration of electric meters installed in our homes, factories, office buildings and so on, for indicating the amount of electricity consumed; the meters used for this purpose are usually equipped with several dials for recording and are called watt-hour meters.

Since a watt is equal to a <u>volt</u> multiplied by an <u>ampere</u>, it is easy to see that watt-hours must equal <u>volts</u> multiplied by <u>amperes</u> and <u>time</u>; or stated in a formula, we have

$$\text{WATT-HOURS} = E \times I \times \text{HOURS}$$

In many cases the unit "watt-hour" is too small for practical computations, and for convenience a larger multiple of the unit is employed, called a "kilowatt-hour." Remember that one kilowatt equals 1000 watts. Therefore, a kilowatt-hour is found by first multiplying volts by amperes by hours, and then dividing the product found by 1000. From this we derive the following formula.

$$\text{KILOWATT-HOURS} = \text{KILOWATTS} \times \text{HOURS}$$

$$\text{or, KW-HRS} = \frac{E \times I \times \text{HOURS}}{1000}$$

<u>One kilowatt-hour is defined as the equivalent of one kilowatt (1000 watts) of electrical energy expended in one hour.</u>

<u>EXAMPLES OF HOW THE TERM KILOWATT-HOUR IS USED.</u> Suppose that a generator in a power plant is kept in operation to furnish light and power for a factory. If the output of this generator indicates that one kw. of electrical work is maintained for one hour the factory will use 1 kilowatt-hour; or if 2 kw. is maintained for one-half hour ($2 \times \frac{1}{2} = 1$) the factory will likewise use 1 kilowatt-hour; but, if 4 kw. is maintained $2\frac{1}{2}$ hours the factory will use 10 kilowatt-hours.

An <u>AMPERE-HOUR</u> is the unit in general use in battery charging service; it represents a continuous flow of current of 1 ampere for 1 hour.

<u>ILLUSTRATING THE PROPER USE OF THE TERMS:</u> <u>POWER</u>, <u>FORCE</u>, <u>WORK</u> and <u>ENERGY</u>. Let us refer to the drawing in Figure 10 where a team of horses is at work raising a heavy iron beam. This illustrates how force applied through a certain distance causes or tends to cause a body to be set into motion. In this instance, motion is actually produced because the horses are strong enough to perform the task imposed upon them. In this action the <u>force</u> might be defined as the physical exertion put forth by the horses in accomplishing the work. The capacity which these horses possess for doing work of this kind is the <u>energy</u>. (Note: The energy cannot actually be created, it is a natural condition existing within the horses.)

formula and the other two is easily found by use of the simple circular chart containing letters W, E, and I shown below in Figure 7. The explanation is as follows:

To use this convenient aid for learning the different forms of watts formula, it is simply necessary to cover one member of the formula, and its relation to the other two members is apparent.

Suppose we desire to know the relation of voltage to current and watts. We cover (E) which designates voltage and find that (E) is equal to $W \div I$, which is exactly what the formula ($E = \frac{W}{I}$) tells us. This procedure is shown in Figure 8.

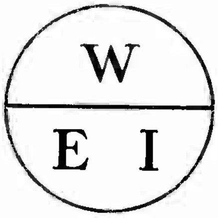


Figure 7

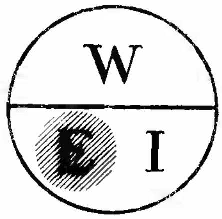


Figure 8

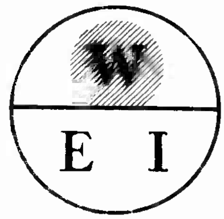


Figure 9

Now, suppose we desire to know the relation of watts to current and voltage. We cover (W) which stands for watts and find that (W) is equal to E x I, which is the equivalent of the relation expressed by the formula ($W = EI$). See Figure 9. The relation of current to watts and voltage may be found in the same way by covering (I).

This same arrangement of the parts of a formula may be applied to any equation having three members. The expression EI means the same as E x I, or E times I.

Another practical example in the use of the watts formula is worked out below.

PROBLEM: Let the rated power of a circuit be 660 watts and the line voltage 110 volts. What is the value of the current passing through this circuit?

SOLUTION: The formula is written first and the computation completed as follows:

(1) Write formula: $I = \frac{W}{E}$

(2) Substitute known values: $I = \frac{660}{110}$

(3) Solving, we have $I = 6$ amperes. Answer.

THE WATT-HOUR AND KILOWATT-HOUR. The watt-hour is a convenient unit to use in practical work for denoting the amount of energy expended in a given number of hours.

One watt-hour is equal to one watt of electrical energy expended in one hour.

Supposing now, that we were required to find the wattage of a circuit without knowing the applied voltage. The problem and its solution is presented to illustrate the second wattage formula, ($W = I^2R$).

PROBLEM: Find the number of watts expended in the circuit of Figure 6 when the EMF is unknown, the current is 0.5 amperes and the resistance of the lamp is 240 ohms.

SOLUTION:
(1) Write the formula: $W = I^2R$
(2) Subsitute known values: $W = 0.5^2 \times 240$ or, $(0.5 \times 0.5 \times 240)$, or,
(3) Squaring 0.5: $W = .25 \times 240$
(4) Multiplying: $W = 60$ watts. Answer.

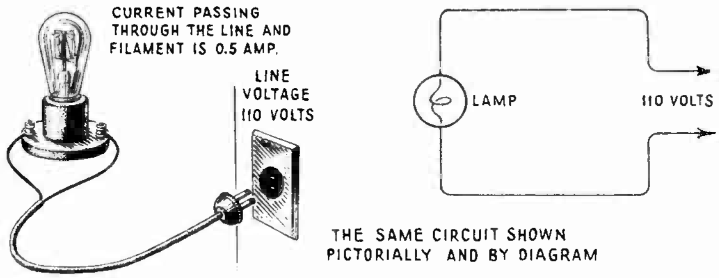


Figure 6

The number of watts may be expressed in the larger unit "horse-power," abbreviated "H.P." In terms of horse-power, one watt is equal to 1/746th of an electrical horse-power. This is equivalent to saying that one electrical horse-power equals 746 watts, or writing this in the form of an expression, we have

1 ELECTRICAL H.P. = 746 watts.

Another unit in common use is the "kilowatt." One kilowatt, abbreviated "kw," is equal to one thousand watts, or

1 kw = 1000 watts.

PRACTICAL USE OF WATTS FORMULA. The watts formula for direct current can be stated in three ways as shown below for convenience in working out practical problems. Exactly similar relations are represented between the quantities in each of the formulas. An inspection of these formulas show that if the value of any one of the three quantities is unknown it may be easily found providing the other two quantities are known. Using the symbols, we have

$$W = E \times I$$

$$\text{or,} \quad I = \frac{W}{E}$$

$$\text{or,} \quad E = \frac{W}{I}$$

The relation which exists between any one component of the watts circuit. The same formula is repeated below but using the electrical symbols in their proper relation.

$$W = E \times I$$

From previous instruction of this lesson we have learned that the volt is the pressure required to force a current of one ampere through a circuit having a resistance of one ohm. This expressed mathematically takes the shape of,

Volts = Amperes x Ohms

$$\text{or,}\quad E = I \times R$$

Substituting (E) of this formula for the voltage in the watts formula ($W = E \times I$), we have

$$W = I \times I \times R$$

$$\text{or,}\quad W = I^2R$$

It is clear that if we wish to ascertain the number of watts of power in a direct current circuit, or in the parts which form the circuit, we have simply to multiply the volts by the amperes, or the current squared (I^2) by the resistance. However, in our lesson on alternating current (a-c) we will learn that another factor, called power factor, enters into the computation of the wattage of an alternating current circuit or its parts.

The power or watts formula for an alternating current circuit is:

$$W = E \times I \times \text{POWER FACTOR}$$

The following definition of a watt should be learned:

> <u>One watt is the power expended when one ampere of current flows steadily through a circuit under a pressure of one volt.</u>

The symbol (W) is used to denote the watt as used above in the formulas.

A practical example is worked out below showing how to find the wattage of a simple circuit.

<u>PROBLEM</u>: Find the number of watts expended in the circuit of Figure 6 when the e.m.f. (E) is 120 volts and the current (I) drawn by the lamp is 0.5 amp.

<u>SOLUTION</u>: The wattage for this circuit is computed as follows:

(1) Write the formula: $W = E \times I$

(2) Substitute known values: $W = 120 \times 0.5$

(3) Perform the work as shown at the right:

$$\begin{array}{r} 120 \\ \underline{0.5} \\ 60.0 \end{array}$$

(4) Write the answer: W = 60 watts. Answer.

An illustration of electrical work is where an electric flatiron is connected to a 110-volt house-lighting circuit. The work or energy expended in the electrical case is represented by the heat developed in the coils, called heating element, mounted within the iron. In order for this work to be done successfully we know that the voltage on the line was effective in overcoming all the oppositions of the circuit, with the result that a certain value of current was forced through the coils. This teaches us how electrical energy is transferred into heat energy.

The total amount of work done is calculated by multiplying the amount of a force and the distance through which it acts (or is applied) in overcoming resistance which results finally in a transference of energy from one form to another.

The accomplishment of a certain piece of work is independent of time. That is to say, it may require different amounts of time, as for instance a day, a week or perhaps longer to complete a given work. When the element of time is associated with the work we must make reference to the term power.

POWER. Power is the time rate of doing work. It represents both the expenditure of a certain amount of energy and the length of time during which it is maintained. Since the term power includes the element of time we must not confuse it with the total amount of work actually performed. The two terms "power" and "work" are frequently confused. Therefore, we are presenting their relation with a mathematical equation.

The relation of "power," "work" and "time" can be set down as follows:

$$\text{POWER} = \frac{\text{WORK}}{\text{TIME}}$$

THE WATT is the unit of electrical power. From a little consideration of the three explanations previously given in regard to the joule (or unit of work), and the ampere (or the unit of current), and the volt (or unit of pressure) it is evident that the amount of "power" in any electrical circuit must be a combination of these three factors.

Thus, one watt is defined as that unit of power equivalent to one joule divided by one second. This relation may be written as follows:

$$\text{WATTS} = \frac{\text{JOULES}}{\text{SECONDS}}$$

Now we already know that a joule is the amount of work resulting when one ampere of current is maintained for one second under an applied e.m.f. of one volt. Therefore, combining this relation into one expression we have the well-known watts formula:

$$\text{WATTS} = \text{VOLTS} \times \text{AMPERES}$$

The watts formula which we have just given is for a direct current

It is to be understood that force does not always produce motion. This is a fact with which you are perfectly aware. For a simple illustration consider what would happen if you pushed against the side of a house with all your strength; you know that the energy expended would not result in the house being moved regardless of how hard you may have worked to accomplish this purpose. These natural laws are true in the case of electricity; an electromotive force does not in every case act to cause a movement of current but it tends to do so. Thus, it may be said that a force acting over a distance or through space is a factor of work but the action does not necessarily produce motion.

THE JOULE is the unit of electrical energy or work.

> One joule represents the amount of work performed or energy expended, including that consumed in generating heat, when an electromotive force of one volt is applied to a circuit and a current of one ampere flows for one second of time.

At this point, it may be well to stress the difference between the COULOMB and the JOULE. From previous instruction you know that a coulomb is equal to one ampere-second. Now, from the above definition we learn that the joule is the equivalent of one watt-second, since a watt is equal to a volt-ampere as will be explained later.

We can express electrical work as the product of the "electro-motive force" in volts and the "quantity of current" in coulombs. Now, since an ampere is equal to one coulomb of electricity multiplied by a time period of one second, then this entire relation can be stated as follows:

ELECTRICAL WORK (JOULES) = VOLTS x AMPERES x SECONDS, or,

$$J = E \times I \times S$$

The symbol (J) is used to denote the joule.

WORK. Work is performed whenever a force overcomes opposition or resistance, in causing a body upon which it acts to be set into motion. The amount of work done can be conveniently measured whether it is the result of mechanical, chemical, electrical or heat effects. This statement, no doubt, is plainly obvious to everyone and is intended to point out the fact that to do work does not necessarily mean that a weight must be lifted. For instance, work is done by compressed air acting upon a piston in a rivet machine; an explosion of a charge of gasoline vapor acting on one or more pistons provides the power in a gasoline motor for use in boats, automobiles and so forth; steam engines utilize the expansive force of steam on the heads of large pistons as a source of power. Steam may be used in a plant to drive electric generators which are in turn used to supply light, heat and power. We could go on indefinitely citing examples of how power is obtained to do different kinds of work.

A simple illustration of mechanical work is one in which a team of horses is in action, exerting energy in pulling up a very heavy weight by means of suitably arranged pulleys and lines.

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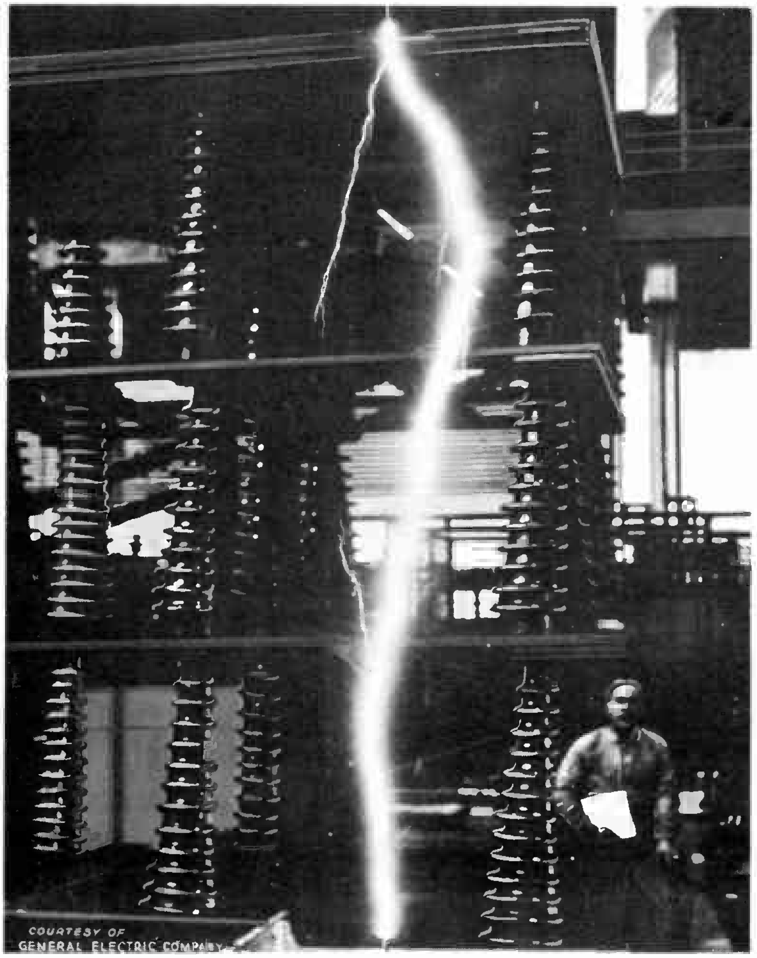
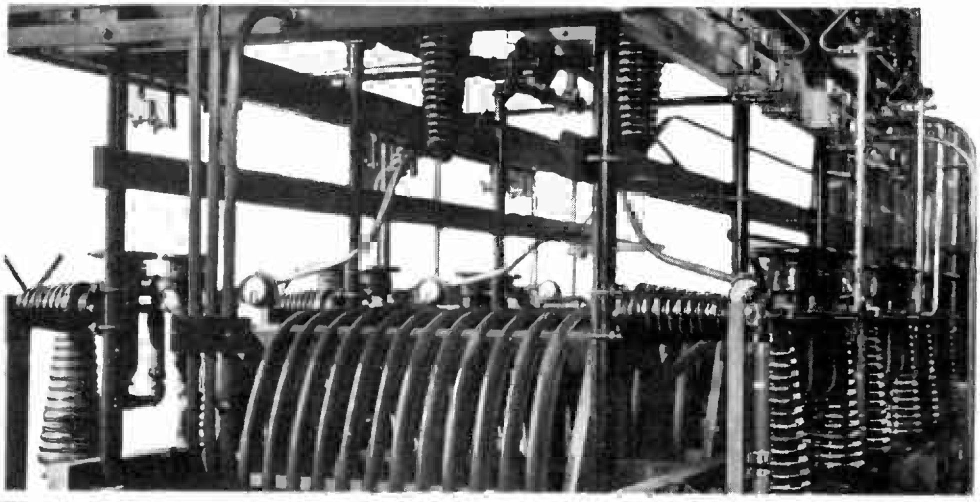


A 5,000,000-volt artificial lightning discharge breaks down the resistance of 15 feet of air.

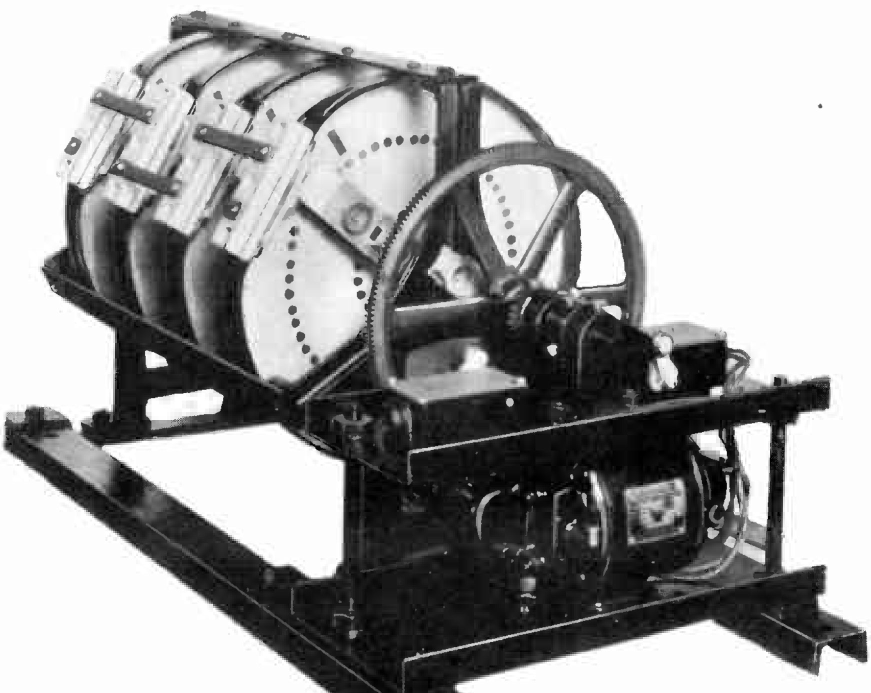
How Current Flow depends on Resistance and Conductance

VOL. 10, No. 6

Dewey Classification R100



Many long corrugated insulators are used to prevent electrical conduction between the parts and framework of this high voltage rectifier.



Resistance of these units is varied by means of an electric motor.

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RESISTANCE AND CONDUCTION

It is absolutely necessary in the study of any electrical subject to have a complete understanding of the three important quantities that govern the operation of every electrical circuit. These quantities are current, electromotive force and resistance. However, before one can really say he understands the relation between the amount of current flowing in a circuit, or part of a circuit, to the amount of electrical pressure that forces the current to flow he must also have a good working knowledge of the quantity "Resistance".

Hence, in this lesson we will deal chiefly with resistance and conduction, the latter being the inverse of resistance. The subjects pertain to explanations about different materials and their characteristics with regard to the ease or difficulty with which current will flow through them; also, how a change in temperature will change the resistance of a material; and the calculation of the resistance of wire, and so on. Our next lesson will explain in detail about the electrical circuit itself and how the three quantities mentioned above, current, electromotive force and resistance, are always associated together in a definite relationship which was discovered by George Simon Ohm, who gave to electrical science the famous and invaluable Ohm's Law.

It will be seen that resistance has to do with different kinds of materials that are used in the construction of an electrical circuit and the opposition that such materials offer to the progressive movement of its electrons, from atom to atom through the material, whenever pressure is suitably applied. It is to be remembered that the electron in motion is the electric current and that the value of the current is measured in the unit "ampere".

Also, the pressure or electromotive force that is responsible for causing the electron movement is measured in the unit "volt", and the resistance of the material which hinders the free movement of the electrons is measured in the unit "ohm". These units have already been defined in a previous lesson.

The word "resistance" should be familiar to everyone since it is frequently encountered in our every day life, and wherever the word is used it generally has one meaning which expresses an "opposition" of some sort.

Many examples could be given showing how this applies but the following ones are sufficient. If you undertake to do any kind of work, and regardless of whether the task requires mental or physical effort, there are oppositions in one form or another that must be met and overcome before the work can be accomplished. Just what these oppositions are will depend, of course, upon the nature of the work. When you walk or run there are oppositions or resistances constantly present that retard your action. No doubt you have had the experience of rowing a boat through rough water, or against the tide, and found that a much greater effort was required to make the boat move forward than if the water were smooth and calm. Even in the latter case, that is, with the water smooth, the pull on the oars (which represents the energy expended in overcoming the opposition of the water which otherwise would prevent the forward movement of the boat) is often sufficient to tire out, in a short time, anyone but a strong person.

A good analogy is always at hand in the case of hydraulics, or water running through a pipe under a certain head pressure, to illustrate the relation existing between <u>pressure</u>, <u>rate of flow</u>, and <u>opposition of resistance</u>. It is easy to understand that water will flow fast or slow according to the pressure, but the oppositions in any particular system also have an important bearing on the rate of the flow as we will explain. Water running through a pipe, even under a strong head pressure, is retarded to some extent because as it rushes along it is constantly in contact with the inner walls of the pipe and this creates a certain amount of friction. If the pipe has a fairly large diameter, and its inner surfaces are clean and smooth the water will then flow with comparative ease, but if rust and silt are allowed to collect in the same pipe, either along its length, or at bends, elbows or joints, it will require more pressure to force the same quantity of water through than in the first case, or when the pipe was clean.

Thus we see that rust and silt form an <u>obstruction</u>, or <u>resistance</u> to the movement of water and this must be added to other oppositions in the pipe line. In general, the various oppositions in a water supply system would include the inner wall resistance as determined by the total length of the pipe and its inner surface condition, that is, whether smooth or rough, the pitch of the pipe at different locations, the area of cross section, and the size of the pipe at the end where the water flows out, the latter usually being regulated by a valve.

Now suppose that instead of thinking of the opposition or resistance presented to the flow of water by any piping system we thought of this system only in terms of the <u>ease</u> with which water was <u>conducted</u> through it. We could then compare two different systems and say that one conducted water more readily than the other. Here we have the use of the word "conducted" and it is evident that we have simply another way of looking at the same conditions. So, whether we say that the latter system has a higher resistance to water flow than the former we would in either case have conveyed the same idea. This illustrates the practical use of the terms "resistance" and "conduction".

<u>ELECTRICAL RESISTANCE.</u> Similar conditions of <u>resistance</u> and <u>conduction</u> are met with in the case of an electric current flowing

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<u>ELECTRICAL RESISTANCE.</u> Similar conditions of <u>resistance</u> and <u>conduction</u> are met with in the case of an electric current flowing

through a circuit. First will be discussed the subject of resistance, and following that the subject of conduction.

Although the amount of current passing through a circuit depends primarily upon the amount of pressure that causes it to flow, yet the fact remains that the current strength is limited by the resistance of the circuit. Resistance is a property possessed by all substances that opposes the free movement of electricity through them. All materials have this property, but in some it is more pronounced than in others, and as a result substances are classified under two heads, namely: conductors and non-conductors or insulators.

After all, the resistivity of substances is only comparative and, therefore, it can be said that conductors are those materials which offer relatively low resistance to current flow and insulators are those which offer a very high resistance as compared to conductors. For all practical purposes an insulator is supposed to completely block the flow of current, and high grade insulators come very near doing this even when subjected to excessively high voltages.

Just how much a certain material will oppose current flow depends in general upon its natural properties, its physical dimensions, or size, and its temperature.

DEFINITION OF A STANDARD OHM. The unit in which resistance in measured is the OHM, as heretofore stated. Resistance is represented by the letter (R) and the electrical unit "ohm" is designated by the symbol (Ω) which is the Greek letter Omega.

The standard value of an ohm is defined as that resistance offered to an unvarying electric current by a column of pure mercury 106.3 centimeters long, of uniform cross-sectional area, and weighing 14.4521 grams at a temperature of melting ice, or 0 degrees Centigrade, which is the same as 32 degrees Fahrenheit.

Although the following does not strictly define an ohm, and only expresses the relationship of an ohm to voltage and current, yet it is often called a definition. "An ohm is said to be that resistance possessed by a circuit which allows one ampere of current to pass when an electromotive force of one volt is applied to the circuit".

RESISTANCE IN A D-C CIRCUIT. In a direct-current circuit resistance can be calculated very easily inasmuch as the only opposition presented to the current is by the materials which comprise the circuit and since all circuits are made up mainly of wire of some kind or other then the opposition is due principally to the wire. It is only at the closing or opening of a direct current circuit that oppositions other than the resistance of the wires are introduced which affect the flow of current. When the current reaches its steady value and flows without interruption in a d-c circuit, then only the resistance of the materials limits the current.

RESISTANCE IN AN A-C CIRCUIT. Current flow in an alternating current circuit is affected similarly by the materials and wires as in a d-c circuit, and also by another form of resistance due to the inductance of the circuit. This is explained as follows: In an a-c circuit the current is constantly changing in intensity and this current produces magnetic lines of force which likewise change in magnitude. Hence, in an a-c circuit an electromotive force is induced in the wires and coils which make up the circuit, this being accounted for by the action of the changing lines of force cutting the very wires in and around which they exist. In every case the induced e.m.f. opposes any change in current strength.

The induced e.m.f. may reach comparatively high values and seriously retard the current if coils are used which have too many turns of wire which would set up an excessively strong varying magnetic field around the coil for the particular circuit in question. Thus, we say that an a-c circuit contains inductance due to the wires used in the construction of apparatus and the wires used to supply power and connect the parts. We particularly think of inductance in the use of a coil because of the greater concentration of the lines of force in a given space when the conductors are wound in the form of a coil.

The e.m.f. induced in an a-c circuit (because of changing current and consequent action of the magnetic lines on the conductors and which tends at all times to oppose the changes in current as just explained) is a form of resistance called inductive reactance, which is measured in the same unit "ohm" as is the usual resistance presented by the wires or materials.

Now if an a-c circuit contains capacitance, such as could be easily provided by inserting a condenser in a circuit, there still will be another form of resistance present, because the a-c current will charge this condenser. Suppose the condenser used mica between its metal conducting plates. The mica will take on an electric charge but in so doing the current does not actually pass through this material as in the case of a copper wire. This is because the atoms of the mica (the mica is an insulating material) do not possess the necessary free electrons that can be forced to move progressively from atom to atom of the material, but rather what happens is the electrons in the mica atoms are merely pushed to one side, or shifted slightly from their usual positions in the atoms by the e.m.f. in the circuit. It requires an expenditure of force, or a certain amount of e.m.f. to cause this displacement of electrons in the atoms of the mica, and when in this stressed condition, the condenser is said to be charged. This form of resistance is called capacitive reactance, and it is also measured in the unit "ohm".

The student should know right from the start that current does not flow through insulating materials because such materials are lacking in free electrons which are the conductors of electricity, but an insulating material used in a condenser gives the effect of current passing through it since it can be charged and discharged by the action of its electrons being displaced in one case, and returning to their normal or unstressed positions in the other.

Thus, if an alternating current circuit contains coils and condensers, or as we would ordinarily say, inductance and capacitance, there will be three different forms of resistance present and acting at the same time. To sum up our statements, the three resistances are as follows:

(A) Resistance presented by the materials.
(B) Resistance due to inductive reactance.
(C) Resistance due to capacitive reactance.

Combining these resistances and knowing that they all affect the flow of current we have a term which expresses the sum total of the oppositions; this term is impedance. In our a-c circuits we will again come to this subject of impedance.

From these preliminary facts it is apparent that resistance is a factor to be considered in all alternating and direct current circuits. In a d-c circuit resistance is found in only one form, but in an a-c circuit it is present in more than one form as just outlined. The reason for again referring to this is because we often want to distinquish between resistance that materials of the circuit offer from other resistances due to the presence of inductance, or capacitance, or both. The resistance due to natural physical properties of materials or wires used is referred to as ohmic resistance.

It should now be clear that no electrical circuit could be designed without having some resistance. In some cases an excessive amount of resistance is undesirable and in other cases resistance is inserted purposely to limit the flow of current. Keep in mind that all substances have this property and that metals in general have by far less resistance than other substances. Therefore, it is obvious why metals serve best as carrying agents of electricity.

ELECTRICAL CONDUCTANCE. Conductance is just the inverse of resistance as we explained before, and its unit of measurement is the MHO, which is OHM spelled backwards. It expresses the ease with which current will flow in a conducting medium, that is, it indicates the ease with which electrons can be made to move in a progressive order between the atoms of a material when an electrical pressure is supplied.

EXAMPLES. If a certain conductor, or circuit has a resistance of (R) ohms, its conductance will equal unity (1) divided by (R), that is, $1 \div R$. For example, if the resistance of three resistors were respectively 10 ohms, 400 ohms, and 5 ohms, the conductance for each would equal 1/10 mho, 1/400 mho, and 1/5 mho.

The unit "mho" is not used to any great extent in our work and when used it is in the calculation of the resistance of a divided circuit. To find the resistance of a divided or parallel circuit in terms of conductance the following rule should be used. Add the conductances of the several branches in order to first obtain the total conductance of the combination, and this result when inverted will give the total resistance of the combination.

Other examples of the use of the term conductance are as follows:

> EXAMPLES. Inverted means that if the conductance of a combination were found to be 1/15, this fraction inverted would become 15/1, and 15 ÷ 1 equals 15, and the combination would have a resistance of 15 ohms; or, if we had 3/16 mhos as the conductance, this fraction inverted would be 16/3, and working this out, we would get 5.3 ohms as an answer. Additional explanations are given about parallel circuits in the lesson dealing with Ohm's law.

THE USE OF THE TERMS "RESISTANCE" AND "RESISTOR". Resistance is a property of all materials which opposes the free flow of an electric current, as we already know, but considering only the word itself, or "resistance", it is common knowledge that is is used loosely to indicate or identify any device made especially to be inserted in a circuit to limit the current flow. The proper term to apply to a piece of equipment intended for this purpose is "resistor". The term resistance, in its more correct use, is the inherent opposition offered by all substances to the flow of electrical current.

Three names in general use which designate resistance units are Resistor, Rheostat, and Potentiometer. You will become very familiar with these terms as you advance in your studies. Resistance devices are made up in innumerable sizes and shapes to meet any practical condition.

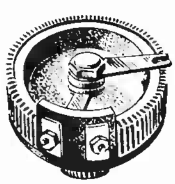

Figure 1

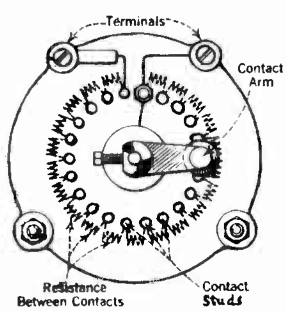

Figure 2

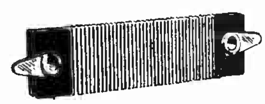

Figure 3

Figure 4

RHEOSTAT. When a resistance unit is constructed to permit the amount of resistance it contains to be altered, it is called a "rheostat". Two terminal connections are provided for such a unit; one of the connections goes to the movable contact arm which is firmly pressed against the wire by a spring, and the other to one end of the wire. By simply moving the arm across the wire it makes contact on different portions and, hence, more or less of the resistance wire will be included in the circuit in which the device is connected. This action is expressed by saying that resistance is cut in or cut out of the circuit. Thus, by the use of a rheostat current in a circuit can be controlled.

One form of rheostat is shown in Figure 1. Figure 2 illustrates a commercial type rheostat for regulating current in the field coils of a motor or generator. It is made with tap connections taken from different portions of the wire, and these taps terminate at brass studs or segments. In this type, when the contact arm or handle is moved over the studs, from one end to the other, sections of the wire are successively cut in or out, and the change in resistance causes the current supplied to the fields to be increased or decreased as the case may be. The resistance of the rheostat in Figure 2 is varied in sections, or, as we usually say, in steps, but the resistance of the rheostat in Figure 1 is continuously variable since the contact on the arm slides along the wire itself.

Resistor-Fixed Type. If there is no need for varying the current during the operation of a circuit, then resistors of the fixed type can be used to control the flow of current. The resistances of fixed resistors cannot be altered since no mechanical means are provided for doing so. An exception to this is in the case of fixed resistors wound with special wire which changes its resistance with changes in current strength, and these are used to provide automatic regulation for certain kinds of work. Figures 3 and 4 show fixed resistors.

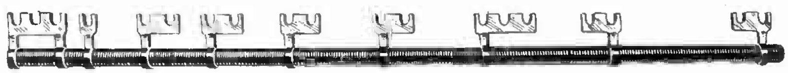

FIG. 5 — WIRE WOUND FIXED RESISTOR.

Potentiometer. The long narrow resistor in Figure 5 consists of many feet of resistance wire wound on a rod of insulating material with tapped connections taken from the wire at certain intervals. A unit of this kind is called a "potentiometer" and its function in

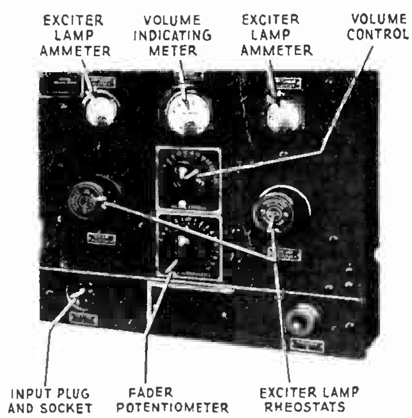

FIG. 6 — EACH CONTROL KNOB SHOWN IS USED TO VARY RESISTANCE.

a circuit is different from that of either a rheostat or fixed resistor. Although a potentiometer is physically a resistance device it is not used to limit current flow in a circuit but is used as a convenient method to supply voltages of different amounts to one or more circuits that may be suitably connected to the various terminals. Suppose for the sake of explanation that a battery having an e.m.f. of 30 volts was connected to the extreme ends of this potentiometer, then certain intermediate values of e.m.f. between 0 and 30 volts could be obtained at the taps. Since a potentiometer is primarily a voltage dividing device it is not referred to as a resistor. Potentiometers are built with resistances ranging all the way from a hundred ohms or less to several hundred thousand ohms.

PRACTICAL APPLICATIONS. A few examples of typical resistors built for various purposes are now given. Bear in mind that all of these resistors function in a similar way insofar as the electrical circuit is concerned.

Figure 6 is the front view of an input control panel made for use in certain types of sound picture equipment. In this view is seen the controls, while the resistors themselves are shown in the rear view in Figure 7. There are two rheostats of the continuously variable type used to control the amount of current passing through the exciter lamps. One of the two potentiometers is used to control the output current to the loudspeaker when changing from one projector to the other. It is so arranged that when the current from one amplifier to the loudspeaker is decreased, the current from the second amplifier is increased, which keeps the sound volume from

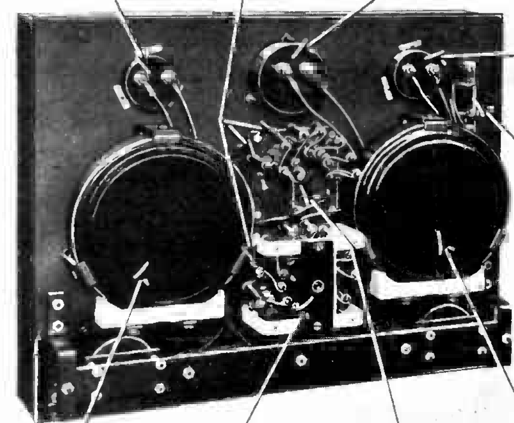

FIG. 7 — VARIOUS TYPES OF RESISTORS FORM PART OF THIS INPUT CONTROL PANEL.

the loudspeaker at the same level while the change is being made. This is called a "fader". The other potentiometer is used for the volume control. A fixed resistor is employed to control the current flowing in the photo-cell circuit.

The schematic diagram in Figure 8 illustrates the manner in which the rheostats are connected in the circuit. Figure 9 shows the volume control connections, while the fader connections are given in Figure 10.

The partially completed rheostat shown in Figure 11 is constructed along the lines of the rheostat in Figure 2. This particular type made by the Ward Leonard Co. is a Vitrohm dimmer plate before the application of the protective enamel coating to the resistance wire and the contacts.

The large motor-driven rheostat illustrated on one cover is used in theatres for dimming the stage lights. To provide the necessary changes in light a rheostat of this kind must be capable of handling hundreds of amperes and, therefore, it is very rugged in construction as the photograph indicates.

In Figure 12 are two illustrations showing a more recent application of resistors in the ignition systems of automobiles equipped with radio sets. Small resistors of the order of 25,000 ohms are used with each spark plug and the main high tension wire from the distributor head to suppress radio-frequency current which otherwise would seriously interfere with the clarity of the broadcast heard in the loudspeaker.

MATERIALS USED FOR RESISTANCE PURPOSES—ALLOYS. All electrical pieces of equipment built to give a predetermined amount of resistance are constructed, for practical and economical reasons, with the least amount of material and made into a unit of suitable physical proportions as governed by the use to which the part will be put.

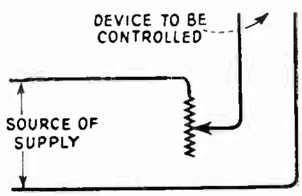

FIG. 8 — SCHEMATIC OF A RHEOSTAT CONNECTION.

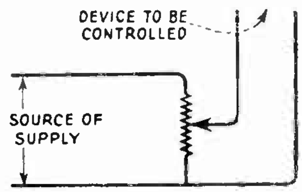

FIG. 9 — A CIRCUIT ARRANGEMENT FOR VOLUME CONTROL.

To grasp the importance of the idea of size in devices of this kind, just consider for a moment how much copper wire would be required to give a resistance of some comparatively low value, let us say 100 ohms. This can best be explained if we suppose that the resistor shown in Figure 3 has a resistance of 100 ohms. To construct a resistor of equivalent value, or 100 ohms, would take about 10,000 feet of copper wire, provided we used a No. 20 B. & S. gauge wire, and the copper would weigh approximately 30 lbs. A No. 20 wire has a diameter of 31.961 mils or .03196 inch. These figures are based on the data given in the "Wire Table" at the end of this lesson.

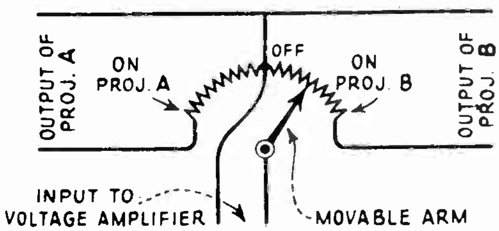

FIG. 10 — VARIABLE RESISTANCE IS USED IN A FADER UNIT.

It is easy to see that copper wire, because of its low resistivity, is not suited for use as a resistance material and, furthermore, the high cost of such a large bulk of copper would make its use prohibitive for this purpose. Copper is, however, the most widely used material for electrical conductors because of its low resistivity. Iron wire and aluminum wire are extensively used for conductors, the iron having a resistivity of about 7 times that of copper and the aluminum about 1.6 times. Galvanized iron wire is used on many telegraph lines.

Since pure metals such as copper, iron, aluminum and so on have comparatively low resistivity it is necessary to use materials which are alloys to obtain high resistances with reasonably small amounts of material. Alloys are combinations of different materials and are manufactured expressly to give high resistances. The resistance of an alloy can be made much higher than the resistance of the pure metals alone, that is, when not in the combination. Of course, the resistance of any alloy will depend upon the nature of the metals and the percentage of each used. Moreover, alloys are prepared with great care to obtain non-corrosive materials that will remain practically without change in resistance at different temperatures. Materials in this class should remain as nearly constant as possible under normal working conditions. There are some alloys used for the specific purpose of automatically limiting the current in a circuit; the resistance of such materials changes considerably for changes in temperature. This kind of alloy is used to make the photo-cell protective resistor shown in Figure 7.

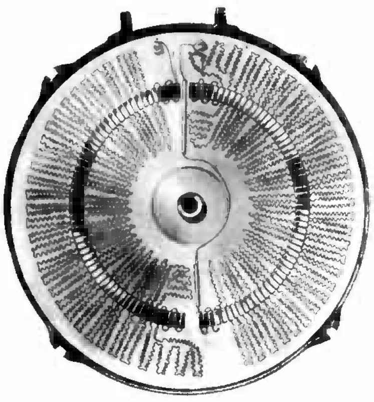

FIG. 11— RESISTANCE WIRE IN PLACE BEFORE PROTECTIVE ENAMEL IS APPLIED.

The resistivity of an alloy is greater than pure metals like copper, iron, aluminum, nickel, zinc, chronium and so on. This is explained y the following example. An alloy, such as manganin, consists of three metals, namely: copper, nickel, and iron-manganese and when combined in certain proportions the alloy can be made to have a resistance of three or four hundred ohms for each foot of wire when the wire is drawn to a diameter of .001 inch. Alloys of some of the materials mentioned above are made to give a resistance of more than 600 ohms per foot when in the form of a wire .001 inch in diameter. Notice that a foot of wire of .001 inch diameter is used as a unit for comparison of materials. This is known as a "milfoot". Monel metal is an alloy of approximately 71 per cent nickel, 27 per cent copper, and 2 per cent iron. Constantan, another alloy used in rheostats and measuring instruments, consists approximately of 60 per cent copper and 40 per cent nickel. In commercial practice we find rheostats and resistors constructed of rods, disks, strips of the resistance material, and resistance wire wound in coils, and so on. One type consists simply of a metallized deposit on a form of insulating material.

The wires wound on the parts shown in Figures 1, 2, 3, 4, and 5 are alloys of different kinds. A resistor of one type may use iron wire and another may use carbon ground up and placed in tubes shaped in different forms, and so on. Since some heat is developed by these units the resistance wires on the parts in Figures 1 and 3 are wound on forms of a non-inflammable fibre material while porcelain is used to hold the wires in Figures 2 and 4.

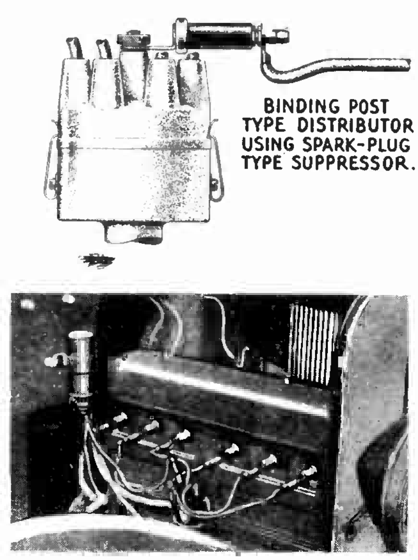

FIG. 12 — RESISTORS USED IN AUTOMOBILE IGNITION SYSTEM TO ELIMINATE INTERFERENCE.

Engineers who design electrical equipment for heating and other purposes take a great deal of care in selecting the proper material so that it will have the desired resistance and, not only that, the material must have sufficient cross-sectional area to be capable of radiating from its surface whatever heat is generated in the material by the current, at a rate that will never permit the temperature to rise high enough to damage the wire or insulation if this is used.

The dissipation of heat is measured in watts since the heat is due to the power supplied which in turn is represented by the voltage and current in the circuit. You will recall that a watt equals a volt multiplied by an ampere, the watt being the unit of electrical power. Every wire has its safe current-carrying capacity and if operated within the current limits specified excess temperature conditions will not exist.

RESISTANCE OF MATERIALS CHANGES WITH TEMPERATURE. In any of its forms a resistance material, or any conductor of electricity, dissipates a certain amount of heat proportionate to the current strength and resistance of the material. This relation of current (I) and resistance (R) is referred to as the "I R" loss, or heat loss. Changes in temperature of a material alter its resistance, but so long as the temperature remains constant the resistance will remain unchanged.

In general, the resistance of metals increases with a rise in temperature. Carbon is an example of a material that decreases in resistance with an increase in temperature. Other substances that exhibit this same peculiarity are porcelain, glass, and electrolytes. The latter name refers to solutions of water and various salts and acids. A solution of sulphuric acid and water such as is used in lead-acid type storage batteries is called an "electrolyte".

Another curious fact is that a certain substance will have the property of an insulator when cold, but that of a conductor when heated. This property exists to a very small degree in the carbon lamp filament which has a resistance when cold about twice that which it has when heated to incandescense.

Since in every wire or conductor the electrical energy consumed in setting up a flow of current (that is, in overcoming the resistance of the conducting materials) is turned into heat, then it can be said that some heat is produced in all kinds of electrical apparatus when current is flowing. The heat generated in overcoming electrical resistance is comparable to heat generated by mechanical friction in the moving parts of machinery.

Certain types of electrical equipment are made expressly for heating purposes such as electric soldering irons, toasters, percolators, electric heaters and so on. In all equipment of this kind the heat generated is put to a useful purpose. On the other hand, when heat is generated where it is not needed it is wasteful and represents a loss of energy. For instance, in an electric lamp which is used only to produce light the heat set up is a loss, and in an electric motor which is used to produce mechanical motion the heat developed by the parts is just so much energy wasted. The function of any resistor or rheostat which is used to regulate the flow of current is to absorb a certain amount of electrical energy applied to a circuit and this energy will be transformed into heat in this part, and this reduces the amount of energy available to other parts for performing useful work. In any resistance device used for limiting current the energy is wasted in heat instead of performing useful work.

Most of the electrical energy in a circuit may go into heat energy, or less of it may go into heat and more into other forms of energy. In an electric lamp, as just mentioned, heat and light energy are both present. In an active antenna system of a broadcast or commercial transmitter the electrical energy in the conductors is transformed into heat energy and, besides, energy is given off in the form of electromagnetic waves radiated into space. We can neither feel nor see the effects of radio waves in space but our senses permit us to detect the presence of heat and light energy.

Special care is exercised in manufacturing electrical apparatus to keep the heat produced down to a safe value and in many installations provisions are made to carry off excessive heat in certain parts by various means, as for instance, by employing special insulating oil, fan blowers, cooling coils through which water circulates, and so on. These precautions are necessary to prevent an excessive rise in temperature of the parts that might be the possible cause of a breakdown of the equipment.

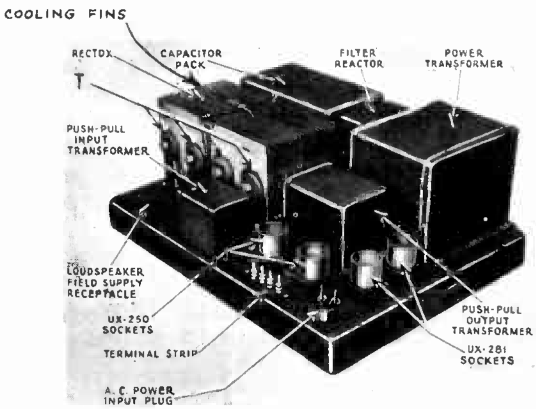

FIG. 13 — HEAT IS DISSIPATED BY MEANS OF THE COOLING FINS.

Figure 13 shows the units "T" of a dry metallic type rectifier used in sound picture installations to change alternating current into direct current. The passage of current through the unit causes considerable heat to be developed, and the "fins" shown in the photograph are used to quickly dissipate this heat by means of the large surface which they present to the surrounding air.

Friction — Heat and the Electron. In support of the fact that conductors do become warm when current flows and more heat is developed in some substances than in others, we have the electron theory which tells us that there is friction between electrons and the atoms among which they circulate in travelling through a material. It is thought that heat is produced in a wire or other conductor when current flows because of the countless numbers of collisions that occur between the electrons and atoms as the electrons are forcibly moved from atom to atom by the e.m.f., or pressure. Thus, an electron encounters friction and wherever there is friction present a certain amount of heat will be generated. Also, if a comparatively small current passes through a large sized wire then only a very small amount of heat will be produced, perhaps not sufficient to be noticeable. The same current in a much smaller wire might produce considerable heat. If the electrons had to travel through a long path rather than a short one it would increase the total friction and the total resistance, hence, more heat would be generated.

Keep in mind that there is friction encountered by each electron as it becomes attached to, and detached from, the large number of atoms which make up the conducting materials in circuits. The possible differences in the number and arrangement of the electrons gives us a plausible reason why the friction set up between the moving electrons and atoms is greater in some substances than in others. In this instance we are considering, of course, only the property of a substance and not its size, or cross-sectional area, as in the case of wires of different gauge.

Now consider the heat effects in two wires of equal length but one having double the cross-section area of the other and the same number of electrons moving in each wire. For the purpose of explanation assume that the electrons travel not only in the same direction but in sort of parallel rows. Electrons will be packed more closely together in the small wire than in the large one, consequently the total friction resulting in the large wire will be only half as great as in the small one.

EXAMPLES OF LOSS OF POWER DUE TO HEAT. Suppose a power transformer (which has no moving parts and is used merely to transform an a-c voltage of one value to an a-c voltage of either a higher or lower value) is supplied with 50 kilowatts of electrical power at its input side, and suppose that the transformer delivers from its output side only 48.8 kilowatts of electrical power. For this particular transformer operating under certain conditions the electrical power in kilowatts that is lost in producing heat which is not wanted, is 50 — 48.8 or 1.2 kilowatts.

Hence, we can conclude that in all electrical apparatus there is a certain amount of wastage due to heat which is unavoidable and this must be kept down to a minimum by careful design and proper operation of the equipment.

CONDUCTORS AND INSULATORS

If we consider from the viewpoint of the electron theory what happens in a material when it is subjected to an electric pressure it will make it fairly easy for most anyone to understand what causes the difference in electrical action between conductors and insulators. It will also help to further impress one with the convenience of this theory in accounting for the actions that go on unseen in electrical circuits. Once again, let us state that a movement or so-called drift of electrons from one place to another through any medium, whether it be a metal, a liquid, or air, in every case the electron flow constitutes an electric current.

According to the electron theory the atoms of one material naturally possess more or less free electrons than the atoms of some other material. Although the free electrons revolve rapidly about the positive nucleus of the atom they are not so firmly bound to it as are another group or inner circle of electrons which also whirl constantly about the same nucleus and remain associated with it. In each atom there are perhaps but one or two free electrons that can be forced out of their usual positions away from their parent atom by an e.m.f. After being detached from their parent atom these electrons will be moved to some other atom and in turn one or two electrons will be detached from that atom and will move to another atom, and so on. This movement or exchange of electrons from atom to atom occurs in the same direction as the pressure or e.m.f. which is forcing them to move.

Since the electron itself is electricity then the conduction of current through any substance is brought about by the movement of electrons. Thus, it is easy to figure out that if the atoms of a certain material have a sufficient number of free electrons available, then under a properly applied pressure there will be a flow of current. That is to say, electrons will move progressively from atom to atom through the material from one end to the other, or between the points where the pressure is applied. Hence, any material that is said to pass an electrical current is called a conductor. Also, that is why we call any metallic path, or other medium through which an electrical current can be made to flow, a conductive circuit.

Now, on the contrary, if the atoms of a certain substance have practically no free electrons for the conduction of electricity then it is reasonable to suppose that such a substance will offer a comparatively high opposition to the flow of current, or in other words its resistivity will be high. In certain materials there is no conduction for all practical considerations, and such materials are called non-conductors or insulators. Materials vary greatly in the amount of requisite electrons for conduction purposes. This is what classifies materials with regard to their resistivity. A chart is shown in the back of this lesson which gives the properties of materials used for conduction.

From the foregoing statements you can easily reason out that conductors form one group of substances offering relatively low resistance, whereas, insulators form another group that offer high resistance as compared with conductors.

When speaking in relative terms about the differences between materials and in a case where the resistance of a certain wire is low and its ability, therefore, to conduct electrons will be good, then in referring to this wire we would say, "it is a good conductor." Conversely, if the resistance of some other kind of wire is high its conductance will not be so good and for the latter wire we would say, "it is a poor conductor."

An examination of the chart giving the resistivity of different materials will show that silver is the best conductor while copper is almost as good. However, German silver has a much greater specific resistance than that of silver. The resistance of German silver, which is an alloy consisting of a mixture of copper, zinc and nickel, varies according to the method of manufacture and the materials used. Depending upon the percentage of nickel used in this alloy it can be made to have a resistance of from about 13 to 30 times, or more, the resistance of copper.

To give a reason for this difference in materials, and to review what we have already stated, we will compare silver and copper. It is assumed that when an e.m.f. is applied to silver and copper, the electrons are detached with less difficulty from the atoms to which they belong in the case of silver, and will move more freely from atom to atom than would those electrons that are detached and moved from atom to atom in the copper. Thus, if an e.m.f. of 1 volt is applied across two faces of a piece of silver having a mass an inch cube, the rate of flow of electrons will be greater from face to face in this metal than if the same voltage were applied to a piece of copper of similar size and tested under like conditions.

Furthermore, let us make it clear that there is no fixed line of distinction between conductors and insulators; it is simply a question of a material having the required electrons that can be forced to move from atom to atom by a pressure, or that something which we call electromotive force. Whether a material is called a conductor, a partial conductor, or an insulator is merely relative. Nothing but a perfect insulator could block completely a flow of current. Tests prove that an infinitesimal amount of current, so small as to be measureable only with the most sensitive laboratory meters, pass through even the highest grade insulators known. At the present time there is no substance known that has perfect insulating qualities any more than there is a perfect conductor, or one without resistance.

CONDUCTORS. Carbons, all the metals, solutions of salts and acids are conductors. A few substances are arranged below in the order of their conductivity. Silver heads the list since it is the best conductor.

Silver	Zinc	Lead	Acid solutions
Copper	Platinum	Mercury	Sea water
Aluminum	Iron	Carbon	Moist earth

INSULATORS. Some of the well-known insulators are given in the following list.

Dry air	Shellac	Wool and silk	Oils
Glass	Rubber	Dry paper	Slate
Mica	Paraffin Wax	Porcelain	

Water, dry woods and the human body are examples of partial conductors.

EXAMPLES OF THE USE OF INSULATORS. All types of insulators are made for the purpose of preventing either short circuits or loss of electrical energy through leakage to the ground. The first requisite of an insulator is that it must block the passage of current at the e.m.f. it will be subjected to under working conditions and, besides, there should be a certain margin of safety for abnormal conditions. We find insulators made in various shapes and forms and of different materials. Just what particular type insulator is selected is determined by the amount of voltage in the circuit in which it will be used and whether it will be installed outdoors or indoors.

An insulator might be located at some point in a circuit where higher voltages are apt to be encountered than would be found in ordinary service. Because of the abnormal conditions possible in any circuit insulators for a particular use should be capable of preventing disruptive high voltages from breaking down the insulating qualities, of course, within certain limitations.

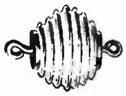

FIG. 14 - CORRUGATIONS INCREASE EFFECTIVE LENGTH OF INSULATOR.

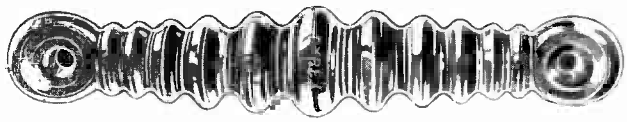

FIG. 15 — PYREX GLASS INSULATOR.

The insulators shown in Figures 14 and 15 are two popular types used in the erection of antennas, the latter type being Pyrex glass made by the Corning Glass Works. Insulators of this kind for receiving antennas are comparatively small, being only a couple of inches or more in length and an inch or so in diameter. The small insulators prove adequate because of the feeble signal currents that are carried by receiving antenna conductors. However, when intended for use in transmitting antennas they are made in large sizes of a foot or more in length and several inches in diameter. This is necessary because of the high voltages present in commercial radio transmitting antennas and because of the weight of the heavier wires which they must support.

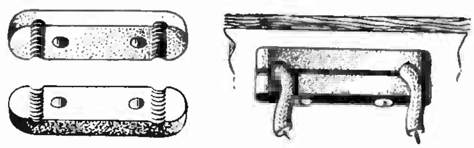

FIG. 16-PORCELAIN CLEATS USED TO SUPPORT WIRES.

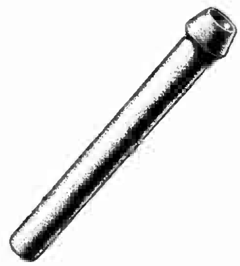

FIG. 17-TYPE OF PORCELAIN TUBE.

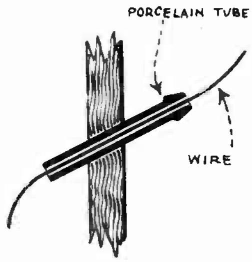

FIG. 17-A—TUBE SHOWN INSERTED IN WALL.

Observe that the corrugations on the surfaces of the insulators make their lengths along the outside much greater than the actual lengths of the insulators measured from end to end. The increased surface length gives an insulator better insulating qualities which is particularly advantageous when moisture or dampness collects on its surface. Since water is more or less a conductor of electricity a certain amount of "surface leakage" occurs in damp and stormy weather.

Figure 16 shows a pair of porcelain cleats and how they are used to hold two rubber covered wires in place, the cleats being screwed or nailed to a ceiling, wall or support of some kind. Another type of insulator is shown in Figure 17. This is a porcelain tube which allows a wire to be passed through it as illustrated in the sketch where the tube is shown installed in a wall or partition; 17-A.

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Figure 18 is a typical receiving antenna installation between an outbuilding and the house where the radio set is located. Notice that insulators of the types in Figures 14 and 15 are supporting the long horizontal antenna wire at its opposite ends and an insulator tube of the type in Figure 17 is used at the window casing where the lead-in wire enters the house.

Figure 19 is a Pyrex glass deck insulator, the metal rod to which the antenna conducting wire or lead-in is connected is carried through the cup shaped glass and the assembly is provided with a flange for mounting the insulator and making it watertight.

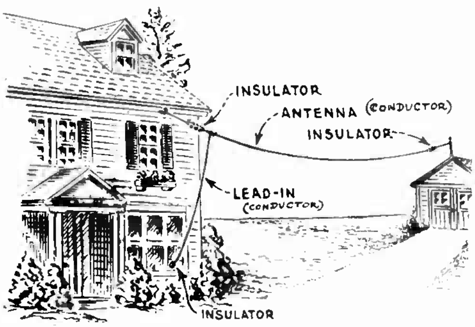

FIG. 18 — SHOWING USE OF CONDUCTORS AND INSULATORS IN A RECEIVING ANTENNA.

Insulators of the type in Figures 20 and 21 are employed in commercial radio transmitting equipment. These are made to be installed in decks, bulkheads, or at any place where the lead-in wire from the antenna is carried indoors. These types, in general, are called "deck insulators" and they are manufactured in various sizes to resist puncture or breakdown by e.m.f.'s which reach as high as 30,000 volts in some antenna systems. In radio transmitter antennas the working conditions are quite severe because of the high frequencies at which the electric stresses alternate. Also, at times there may be considerable heat developed by the high frequencies and this will have some effect on the insulating qualities of the insulator.

Moisture reduces the dielectric strength of any insulating material. Hence, when materials like porcelain are used they go through a special process of baking in hot furnaces that gives them a smooth glassy surface. If the glazed surface should become cracked or chipped the material will absorb moisture and its effectiveness as an insulator will be materially lowered and this will result in a reduction of the voltage at which a "flash-over" might occur. This simply means that the insulation will be weakened to the extent that it will allow current to pass through it at some particular voltage.

The insulator in Figure 20 consists of a heavy brass rod moulded into the insulating material with connection terminals at either end. The insulator is threaded at (A), and the upper half (B) carrying this threaded portion is inserted in a hold of proper size cut in the deck or bulkhead. The flange part (C) rests on rubber gaskets and when collar (D) is slipped over the lower part and drawn up tightly with a wrench a water-tight joint is provided. The type shown in Figure 21 serves the same purpose as the one in Figure 20.

MEASUREMENT AND CALCULATION OF RESISTANCE

Since the greater portion of radio and power circuits consists of wire to conduct the electrical current we will devote the balance of our lesson to the subject of wire.

WIRE GAUGE TABLES. There are several standard wire gauge tables, differing somewhat from one another, in general use for wire calculations. The B. & S. gauge originated by the Brown & Sharpe Manufacturing Co. is the one in most common use in this country and therefore it is often called the American gauge. The B.W.G. table (Birmingham Wire Gauge) is considered the standard in Great Britain. The table for the B. & S., or American gauge, will be found in the back of this lesson. There it will be seen that a few relations are given such as, diameter, area, weight, etc., for each size wire from No. 0000 (pronounced "four naughts") to No. 40, the latter being a very fine wire not much larger than a coarse human hair. Notice that the largest wire is given the smallest number and the numbers increase up to 40 as the wire sizes decrease.

MICROHM. In measuring resistances it is often convenient to use as a unit of value the one-millionth part of an ohm, which is called the microhm. If any value of resistance is stated in ohms the same value may be expressed in microhms by multiplying the given value in ohms by 1,000,000. For example: If a certain conductor has a resistance of 0.0058 ohms its equivalent value in microhms is 0.0058 x 1,000,000 or 5,800 microhms.

FIG. 19 — PYREX GLASS DECK INSULATOR.

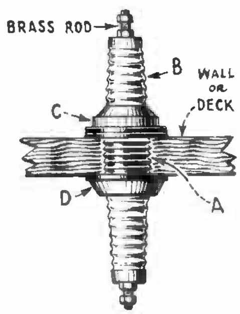

FIG. 20 — PORCELAIN TYPE DECK INSULATOR.

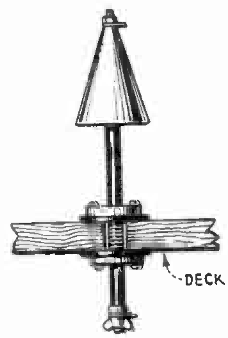

FIG. 21—A CANOPY PROTECTS INSULATOR FROM ELEMENTS.

MEGOHM. When very high resistances are measured the unit called a megohm is used. One megohm equals 1,000,000 ohms.

TEMPERATURE COEFFICIENT OF RESISTANCE. Refer to the table at the end of the lesson headed "Properties of Metals". In order to compare different metals in making up a table similar to this one a standard unit is necessary and for this the Bureau of Standards has adopted the resistivity of annealed copper standard which has a temperature coefficient of 0.00393 at 20° Centigrade. You will see this value in the second column opposite copper. Although "temperature coefficient of resistance" appears to be a big term yet it is easy to understand for it merely indicates a value which tells us how much the resistance of a material will increase for every degree rise in its temperature. The values of the temperature coefficients are based upon a change in resistance from 20° C. If the original temperature of the metal were something other than 20° C. when compiling a table then the temperature coefficient values would not be the same as those given in this table.

SPECIFIC RESISTANCE. Let us first mention that the opposition to current flow by a substance is called its "resistivity" and the total opposition offered by an electrical circuit is called its "resistance" or "total resistance".

The resistivity of a unit length of material (as measured by the distance the current must travel in passing between opposite faces of the material) and a unit cross-sectional area at the predetermined temperature is known as its "specific resistance". The table shows that the resistivity values vary for different metals. Either a unit centimeter, or a unit inch, may be used as the basis for this measurement. If we have a block of copper 1 inch on all sides it is said to be an "inch cube" in dimensions, and if it is 1 centimeter on all sides it is a "centimeter cube".

CIRCULAR MIL. A circular mil is the area of a circle whose diameter is one mil, or one-thousandth of an inch. (Note: 1 mil = .001 inch and 1,000 mils = 1 inch. Hence, mils ÷ 1,000 = inches.)

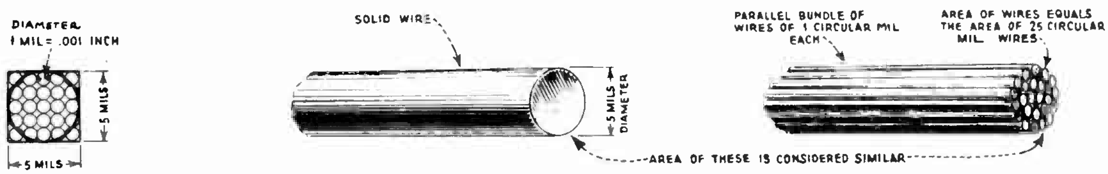

FIG. 22 — SHOWING RELATION BETWEEN AREA IN SQUARE MILS AND CIRCULAR MILS.

SQUARE MIL. A square mil is the area of a square whose sides are 1 mil. long. A circular mil is used in measuring cross-sectional area of a round wire instead of a square unit of area. In Figure 22 we have drawn a large circle inside of the square to show the relation between area which is represented by square mils or by circular mils.

Let us explain this relation in the following way: Suppose the diameter of each small circle is 1 mil, or 0.001 inch. It is seen that the length of each side of the square is 5 mils since there are 5 circles on each side. The area of the square, with sides measuring 5 mils, is 5 x 5, or 25 square mils. Now, the area of the large circle is equal to the diameter multiplied by itself, or d^2. Since there are 5 small circles, 1 mil each, in the diameter of the large circle then its diameter must be 5 mils, and the area of the large circle expressed in circular mils is therefore, 5 x 5, or 25 circular mils. Knowing that the area of the large circle equals the sum of the areas of the 25 small circles it can be said that the area of a wire in circular mils is equal to the diameter squared expressed in mils.

To cite examples: If a certain wire measures 3 mils in diameter it will have a cross-sectional area of 3 x 3, or 9 mils. A wire with a diameter of 162.02 mils has an area of 162.02 x 162.02, or 26,250 circular mils. Refer to Wire Table.

Keep in mind the following difference: The area of a circle in square mils is equal to the diameter squared multiplied by 0.7854 (or d^2 x 0.7854), whereas, the area in circular mils is equal only to the diameter squared (or d^2). Since we use 0.7854 (which is a value less than 1) in our calculation to find the area of a circle but not of a square, it follows that the area of any circle is 0.7854 of the area of a square.

From this it is evident that the square mil is slightly larger than the circular mil and, hence, there will always be a greater number of circular mils in any given area than there are square mils. Therefore, to convert a circular mil area into a square mil area we have merely to multiply the circular mil area by 0.7854 and the result will be in square mils.

(A) Area of a circle in circular mils = d^2

(B) " " " " " square mils = $d^2 \times 0.7854$

(C) Since 1 circular mil = 0.7854 square mils, then

(D) An area in square mils = circular mil area x 0.7854

In the expressions given in this work the letter "d" stands for diameter in mils.

<u>HOW 0.7854 IS DERIVED:</u> Area of a circle = radius^2 x π, (π = 3.1416). If a circle has a diameter of 1 mil, its radius is .5 mil. Hence, the area of such a circle is equal to $r^2 \times 3.1416$ = .25 x 3.1416, or 1/4 x 3.1416 = 0.7854.

<u>MEANING OF THE LETTER (K) USED IN FORMULAS.</u> The letter (K) is used to represent the quality of a material as a conductor. A certain volume of the material must be considered, as for instance the volume of a <u>mil-foot</u>. A mil-foot is the <u>volume of a wire which is one foot long with a uniform sectional area equal to 1 circular mil.</u> For commercial copper the resistance of this particular volume, or 1 mil-ft., is 10.4 ohms at a temperature of 20° C. Hence, the (K) value for copper at this temperature is 10.4. There are different values for the constant (K) for various materials depending on their qualities as conductors, as just explained, and on the temperature selected as the basis for measurement. The (K) value for iron is 63.35 at a temperature of 68° F.

<u>HOW TO FIND THE RESISTANCE OF WIRE.</u> The resistance of a conductor varies with the kind of material used, directly as the length and inversely as the cross-sectional area. The letter (K) is the symbol that represents the kind of material and its resistivity, or specific resistance as mentioned before.

(1) <u>TO FIND THE RESISTANCE OF A WIRE:</u> Multiply the length in feet by the specific resistance (that is, the resistance per mil-foot) and divide this result by the cross-sectional area in

circular mils. Writing this down in the form of an equation it would read:

$$R = \frac{K \times L}{d^2}, \text{ or } \frac{KL}{d^2}$$

(Note: When two quantities are written together, as KL for example, the multiplication of these quantities is understood, hence, K x L and KL are the same.)

In the above equation let
R = resistance in ohms.
L = length of wire in feet.
d = diameter in circular mils. Therefore, d^2 = circular mil area.
K = specific resistance of the material. Commercial copper at 20 C. has a specific resistance of 10.4 ohms.

PROBLEM. What is the resistance of 1,000 feet of copper wire having a cross-sectional area of 5,000 circular mils?

SOLUTION. Substituting all of the known values in the above formula, and solving, we have

$$R = \frac{10.4 \times 1{,}000}{5{,}000} = \frac{10{,}400}{5{,}000} = 2.08 \text{ ohms. Ans.}$$

(2) TO FIND THE LENGTH OF A WIRE WHEN THE RESISTANCE AND AREA IN CIRCULAR MILS ARE KNOWN: Apply the following formula:

$$L = \frac{R \times d^2}{K}$$

PROBLEM. If the size of a certain iron wire conductor is a No. 17 B. & S. gauge and its resistance is 15 ohms what is its length?

SOLUTION. Substitute the known values in the formula just given after first finding the value of d^2 from the wire table for a No. 17 wire. The value for d^2 is 2048, as given in the column marked, "Area—Cir. mils".

Let K = 63.35 for iron.
d^2 = 2048.

$$\text{Hence, } L = \frac{15 \times 2048}{63.35} = \frac{30{,}720}{63.35} = 484 \text{ ft. Ans.}$$

(3) TO FIND THE CIRCULAR MIL AREA OF A WIRE WHEN THE LENGTH AND RESISTANCE ARE KNOWN. Apply the following formula:

$$d^2 = \frac{L \times K}{R}$$

PROBLEM. Suppose the length of a coil of copper wire is 2,000 feet and its resistance is 20 ohms, find the circular mil area of the wire.

SOLUTION. Substitute the known values in the above formula and solve:

$$d^2 = \frac{2000 \times 10.4}{20} = \frac{20,800}{20} = 1,040 \text{ circular mils. Ans.}$$

(4) TO FIND THE AREA OF SQUARE OR RECTANGULAR CONDUCTORS. Some conductors are made square or rectangular in shape and these are measured in square mils. Suppose a certain conductor is rectangular then it will be a simple matter to find its area in square mils by multiplying its width by its thickness, or if the wire is square its area is found by squaring its sides. The dimensions, of course, must be expressed in mils.

EXAMPLE. If a conductor is square and 2 mils on each side its area will be 2 x 2, or 4 sq. mils. Or, if rectangular and 2 mils on one side and 4 on the other its area will be 2 x 4, or 8 square mils.

HOW TO CONVERT SQUARE MILS TO CIRCULAR MILS AND VICE VERSA.

(5) If it is desired to change,the area of a wire when given in square mils to an equivalent area in circular mils multiply the square mil area by 1.2732 as illustrated in problem worked out below.

PROBLEM. A flat ribbon wire is 1/5" thick on one side and 1/2" wide on the other. Find its equivalent area in circular mils.

SOLUTION. Since the measurements are given in inches instead of mils you must first change 1/5" and 1/2" to mils. Thus, 1/5 x 1000 = 200 and 1/2 x 1000 = 500. The square mil area is next found by taking the product of these values, or 200 x 500 = 100,000 square mils. Now multiply the square mils just found by 1.2732 as follows:

100,000 x 1.2732 = 127,320 circular mils. Ans.

(6) If it is desired to convert the area of a wire expressed in circular mils to an equivalent area in square mils multiply the circular mil area by 0.7854 as shown in the following worked out problem.

PROBLEM. Find the square mil area of a wire having a diameter of 1/5 inch.

SOLUTION. First, change 1/5 inch to mils, or 1/5 x 1000 = 200 mils. The circular mil area is equal to the diameter in mils squared, or 200^2, or 200 x 200 = 40,000 C.M. (C.M. is the abbreviation for circular mils). Now multiply the circular mil area by 0.7854 as follows:

40,000 x 0.7854 = 31,416 square mils. Ans.

HOW TO FIND THE CIRCULAR MIL AREA WHEN DIAMETER IS GIVEN IN INCHES AND VICE VERSA.

(7) If the diameter of a round wire is expressed in inches its circular area can be found by squaring the diameter when expressed in mils. The following equation represents the relation.

Area in C.M. (circular mils) = d^2 (diameter in mils squared)

PROBLEM. What is the circular mil area of a wire having a diameter of 1/5 inch?

SOLUTION. The first thing to do is to change 1/5 inch to mils as follows: 1 inch = 1,000 mils, then 1/5 inch equals 1/5 x 1000, or 200 mils. Now find the area as follows:

$C.M. = d^2 = d \times d = 200 \times 200 = 40,000$ circular mils. Ans.

(8) If the circular mil area of a wire is known and it is desired to find its diameter expressed in mils you have simply to extract the square root of the known area. Thus:

$$d = \sqrt{C.M.}$$

PROBLEM. What is the diameter in inches of a wire having an area of 4107 C.M. (circular mils)? (Area of a No. 14 gauge wire is 4106.8 as given in Wire Table).

SOLUTION. Work out the problem by finding square root of 4107, thus:

$d = \sqrt{C.M.} = \sqrt{4107} =$ 64 mils, or 0.064 inch, approximately. Ans.

EXAMINATION QUESTIONS

1. What is the function of a resistor?

2. What is the difference between a fixed resistor and a rheostat?

3. What is the difference between an insulator and a conductor?

4. (a) What are the three forms of opposition or resistance in an a-c circuit?
   (b) Is there more than one form of resistance in a d-c circuit? Explain.

5. What does the coefficient of temperature mean?

6. (a) Is it possible for current to flow in a wire without producing some heat and why?
   (b) What is an alloy and why is it used in the manufacture of certain kinds of wire?
   (c) Name one alloy and give its composition.

7. How may the effective length of an insulator be increased?

8. If the resistance of a certain coil is known to be 0.06 ohms what is its resistance expressed in microhms?

9. Find the resistance of 1500 feet of copper wire having a cross-sectional area of 10,000 circular mils.

10. What is the square mil area of a wire 1/4 inch in diameter?

11. What causes substances to differ in their ability to conduct or insulate?

12. Give two reasons why resistors are connected in electrical circuits.

13. (a) How would you find the circular mil area of a square bus bar which measures $\frac{1}{4}$ inch on each side?
    (b) Show how you would change the circular mil area of 2,400 feet of #40 copper wire to square mils.

14. Give the weight, circular mil area and resistance of two miles of #6 copper wire.

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Resistance of International Standard Annealed Copper
American Wire Gauge (B. & S.)

B. & S. gauge, No.	Diameter in mils, d	Area in circular mils, d^2	Ohms per 1000 ft. at 20° C. or 68° F.	Pounds per 1000 ft.
0000	460.00	211,600	0.04901	640.5
000	409.64	167,810	0.06180	508.0
00	364.80	133,080	0.07793	402.8
0	324.95	105,530	0.09827	319.5
1	289.30	83,694	0.1239	253.3
2	257.63	66,373	0.1563	200.9
3	229.42	52,634	0.1970	159.3
4	204.31	41,742	0.2485	126.4
5	181.94	33,102	0.3133	100.2
6	162.02	26,250	0.3951	79.46
7	144.28	20,816	0.4982	63.02
8	128.49	16,509	0.6282	49.98
9	114.43	13,094	0.7921	39.63
10	101.89	10,381	0.9989	31.43
11	90.742	8,234.0	1.260	24.93
12	80.808	6,529.9	1.588	19.77
13	71.961	5,178.4	2.003	15.68
14	64.084	4,106.8	2.525	12.43
15	57.068	3,256.7	3.184	9.858
16	50.820	2,582.9	4.016	7.818
17	45.257	2,048.2	5.064	6.200
18	40.303	1,624.3	6.385	4.917
19	35.890	1,288.1	8.051	3.899
20	31.961	1,021.5	10.15	3.092
21	28.462	810.10	12.80	2.452
22	25.347	642.40	16.14	1.945
23	22.571	509.45	20.36	1.542
24	20.100	404.01	25.67	1.223
25	17.900	320.40	32.37	0.9699
26	15.940	254.10	40.81	0.7692
27	14.195	201.50	51.47	0.6100
28	12.641	159.79	64.90	0.4837
29	11.257	126.72	81.83	0.3836
30	10.025	100.50	103.2	0.3042
31	8.928	79.70	130.1	0.2413
32	7.950	63.21	164.1	0.1913
33	7.080	50.13	206.9	0.1517
34	6.305	39.75	260.9	0.1203
35	5.615	31.52	329.0	0.0954
36	5.000	25.00	414.8	0.0757
37	4.453	19.83	523.1	0.0600
38	3.965	15.72	659.6	0.0476
39	3.531	12.47	831.8	0.0377
40	3.145	9.89	1049	0.0299

PROPERTIES OF METALS

(Courtesy of the U.S. Bureau of Standards.)

Metal	Microhm-centimeters at 20° C	Temperature coefficient at 20° C	Specific gravity	Tensile strength, lbs./in.²	Melting point, °C
Advance. See Constantan.					
Aluminum	2.828	0.0039	2.70	30 000	659
Antimony	41.7	.0036	6.6	....	630
Bismuth	120	.004	9.8	....	271
Brass	7	.002	8.6	70 000	900
Cadmium	7.6	.0038	8.6	....	321
Calido. See Nichrome.					
Climax	87	.0007	8.1	150 000	1250
Constantan	49	.00001	8.9	120 000	1190
Copper, annealed	1.7241	.00393	8.89	30 000	1083
Copper, hard-drawn	1.771	.00382	8.89	60 000	....
Eureka. See Constantan.					
Excello	92	.00016	8.9	95 000	1500
German silver, 18 per cent	33	.0004	8.4	150 000	1100
German silver, 30 per cent. See Constantan.					
Gold	2.44	.00342	19.3	20 000	1063
Ia Ia. See Constantan.					
Ideal. See Constantan.					
Iron, 99.98 per cent pure	10	.0050	7.8	....	1530
Iron. See Steel.					
Lead	22	.0039	11.4	3 000	327
Magnesium	4.6	.004	1.74	33 000	651
Manganin	44	.00001	8.4	150 000	910
Mercury	95.783	.00089	13.546	0	−38.9
Molybdenum, drawn	5.7	.004	9.0	....	2500
Monel metal	42	.0020	8.9	160 000	1300
Nichrome	100	.0004	8.2	150 000	1500
Nickel	7.8	.006	8.9	120 000	1452
Palladium	11	.0033	12.2	39 000	1550
Phosphor bronze	7.8	.0018	8.9	25 000	750
Platinum	10	.003	21.4	50 000	1755
Silver	1.59	.0038	10.5	42 000	960
Steel, E. B. B	10.4	.005	7.7	53 000	1510
Steel, B. B	11.9	.004	7.7	58 000	1510
Steel, Siemens-Martin	18	.003	7.7	100 000	1510
Steel, manganese	70	.001	7.5	230 000	1260
Superior. See Climax.					
Tantalum	15.5	.0031	16.6	....	2850
Therlo	47	.00001	8.2	....	....
Tin	11.5	.0042	7.3	4000	232
Tungsten, drawn	5.6	.0045	19	500 000	3000
Zinc	5.8	.0037	7.1	10 000	419

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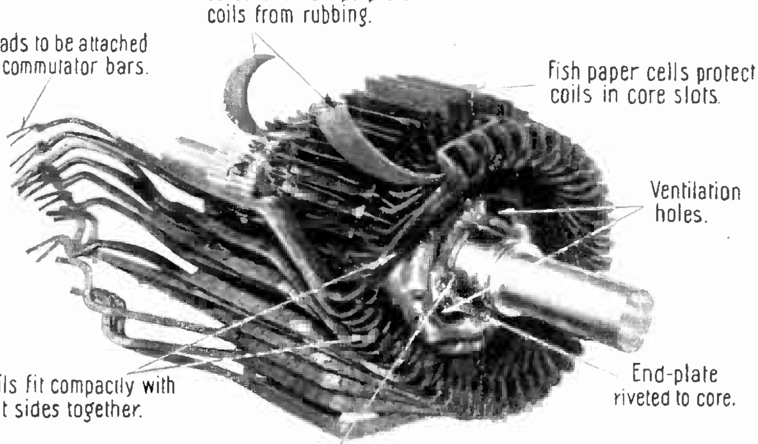
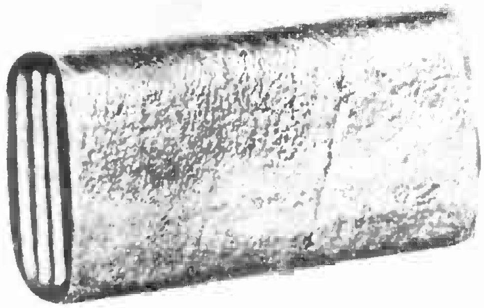


Partially Wound Armature

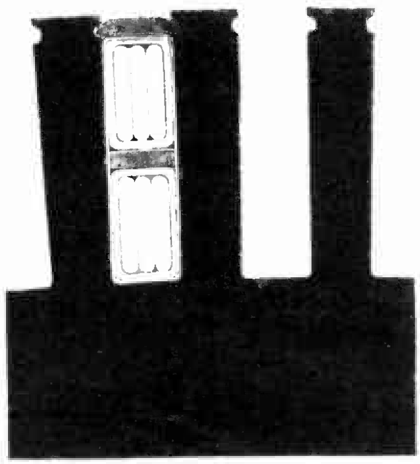
D-C MOTORS

VOL.10,No.8

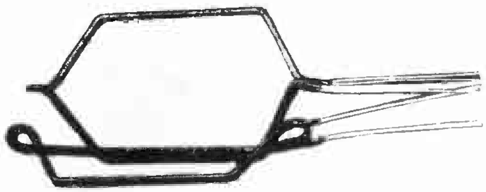
SECTIONAL VIEWS OF ARMATURE COILS
IN D.C. MOTORS



Section Through Armature Coil



Section Through Coils
and Slots



Complete Armature Coils

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D-C MOTORS

A study of the action of d-c motors is largely a study of magnetic and electromagnetic principles and, therefore, if the student is not thoroughly familiar with these subjects it is suggested that they be reviewed at this time.

THE PURPOSE OF THE D-C MOTOR

What is an electric motor and what is its purpose? The motor is a machine so designed and constructed that the electric power applied to it will be changed into mechanical power. Just what does that mean? Suppose we explain it as follows, taking for our explanation a trolley car. Over the track on which the car runs you notice a wire which is stretched from pole to pole. From this wire the trolley car pole collects current, as shown in Figure 1, and conducts it to the electric motor of the car causing the motor armature to revolve. The armature is geared to the wheels of the car.

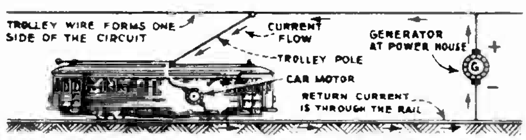


Figure 1

The current, after passing through the motor, is conducted through the wheels and passes into the rails, thence to the ground where it returns to the powerhouse generator. This simple explanation will serve to show you that electrical energy is converted into mechanical energy when the car moves.

THE PARTS OF A D-C MOTOR

In the electric motor there are three essential parts. The first part is the field pole, which is a piece of soft iron made into a particular shape for a definite purpose. On this field pole is wound a certain number of turns of wire making it an electro-magnet. The second part, known as the armature, is another electro-magnet made so that it can be revolved between the field poles. The third is a device called a commutator which leads the current into the armature windings.

In Figure 2 is shown a motor having four field poles of alternate north and south polarity. The armature bears a number of individual coils of wire which carry the current for magnetizing it.

That we may better understand the theory of why this armature revolves when placed in a magnetic field we are going to consider an armature coil of a single turn of wire, placed in the simple magnetic field provided by two magnet poles of opposite polarity.

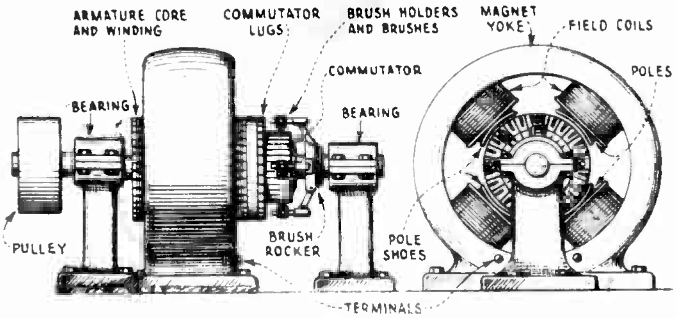


Figure 2

Referring to Figure 3, we show what is, in effect, a single electromagnet formed by the frame of a motor and the field poles. This magnetic structure is the first essential part of the motor. When current flows through the coils which surround the field poles a strong magnetic field is created (as shown by the dotted lines) which fills the space between the two pole pieces. The magnetic lines of force complete their circuit through the frame of the motor, which we see in this case provides two parallel paths.

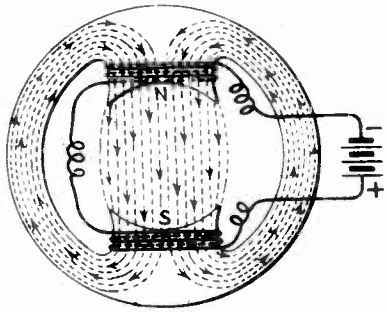


Figure 3

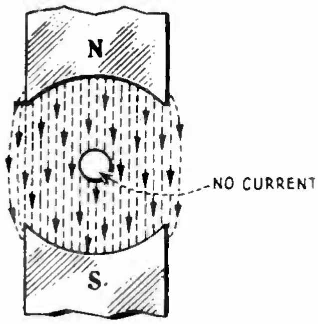


Figure 4

To further aid us in studying the motor action we will use only the field magnets and the space where the armature revolves, as in Figure 4. Here you notice a circle in the center of a field which represents only one side of an armature coil. Note carefully that the lines of force of the field are moving from the N to S pole of the magnets in a uniform manner, that is, they appear to be moving in straight lines ending on the S magnet very nearly opposite to the point at which they left the N magnet. This proves to us that although the armature coil is in the center of the field, the field has not been influenced by the presence of the coil.

This is the natural course a magnetic field assumes; it tends at all times to move in a straight line and should anything happen to divert it from this course it will endeavor to regain its natural state at the expense of whatever attempts to change it.

Now consider what happens if we remove the battery from the field windings; the magnetic lines of force cease to exist between the two pole pieces. Now let us connect the battery to the ends of the armature conductor which is shown between the poles in Figure 4. A magnetic field springs up at once about the armature conductor. In Figure 5 the circle marked with the cross indicates the conductor, and denotes that the current is moving through the wire away from you with its resultant field indicated by the arrowed lines.

Keeping the armature wire connected to the battery, let us now reconnect the field windings to the battery. As shown in Figure 6, the field of the armature wire is opposing the field of the magnets on the left side and moving with the magnet field on the right side of the wire. The lines of force between the north and south poles of the magnet are effective in a downward direction as shown in the figure. On the left side of the wire, they meet the lines of force caused by the current in the wire, and these are effective in an upward direction. This tends to neutralize or weaken the field at the point A.

At point B, to the right side of the wire, the lines of force due to the magnet poles are effective in the same direction as those due to the current in the wire. This causes a concentration or bunching of the lines of force at the right side of the wire, which is an increase in the field strength there. These distorted or

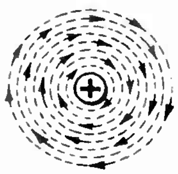


Figure 5

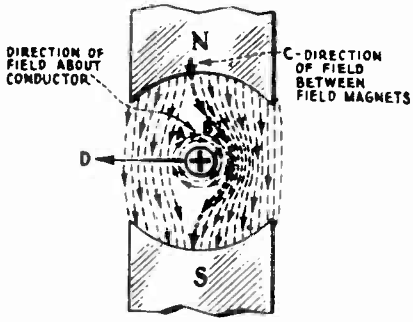


Figure 6

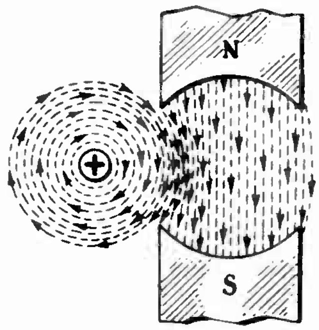


Figure 7

bent out lines of force act as taught rubber bands and at any instant tend to straighten themselves. This can only happen by the current-carrying wire moving away from the point where the lines of force are most concentrated, and toward the point where they are less concentrated. The wire will move in the direction shown by the arrow D.

This movement will continue until the wire has moved out of the magnet field as shown in Figure 7, or until it has moved so far that the pushing force which remains is too weak to overcome the natural friction between the wire and whatever supports it in position.

LEFT HAND RULE

There is a very handy rule for determining in just what direction the armature wire will move. Turn Figure 6 so that the normal left side of the page is toward you, and it is flat on a table with the Figure 6 exposed. Place the middle finger of the left hand on the crossed circle representing the current flow away from you. With the middle finger perpendicular to the paper, extend the forefinger in the same direction as the lines of force of the magnet, that is, toward the pole marked S. Keeping the thumb horizontal, stretch it out. You will find that it points in the direction of motion as shown by the arrow D in Figure 6. This rule should be practiced and memorized. It will help you somewhat to use the following memory trick:

Center finger	Forefinger	Thumb
Current direction	Flux direction	Toward?

The three fingers used are to be held at right angles to each other during this practice.

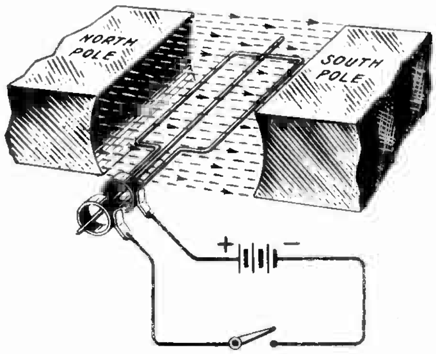


Figure 8

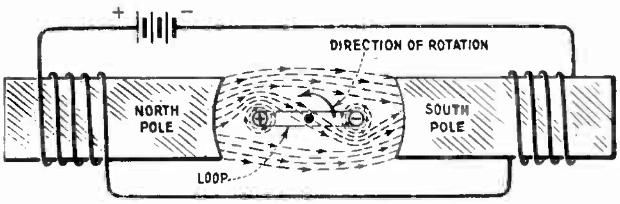


Figure 9

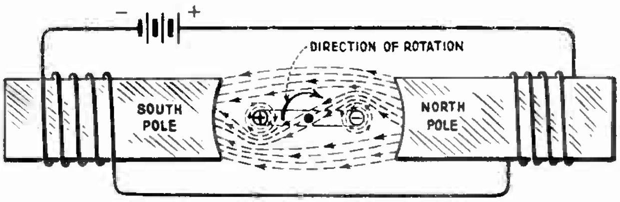


Figure 10

Let us study Figure 8 in order to understand more thoroughly how rotation of an armature takes place. You recognize the field magnets at once. A complete loop of wire (armature coil) has been drawn to show why a rotating movement is secured from the previously described simple displacement to one side (Figure 6). The loop is secured to an axle which passes through the center line of the loop, and centrally located with respect to the pole pieces. The loop is free to rotate about the axle, but not able to move in any other direction. Study the field as it leaves pole N in Figure 9. The small arrows show a bunching of lines of force over the top of the left wire of the loop, thus the magnetic field of the wire has added itself to that of the field magnets, making a strong concentration of lines above the wire. Underneath that wire its field is moving against the field of the magnets, thus weakening the field at this point. At the right-hand wire of the loop the opposite effect is evident. The concentration of lines of force is below the wire. We have stated that the loop is free to rotate on its axis. Applying the left-hand rule to both sides of the loop, we find that the left wire of Figure 9 will move downward and the right wire move upward. It is apparent that the loop will then turn in the direction shown by the arrow, or counter clockwise.

CONTROL OF DIRECTION OF ROTATION

Remembering the left-hand rule and the fixed relations between the fingers, it is seen that the direction of motion can be reversed by a reversal of either the field flux direction or the armature current direction, but not both. In Figure 10, the direction of current flow in the armature loop is the same as for Figure 9. The connections of the field windings to the battery have been reversed, and this reverses the polarity of the field magnet. The rotation is now clockwise as shown.

In Figure 11, the current in the armature wires has been changed in direction. Figure 12 has the same field polarity as Figure 9, but opposite armature current direction, so the directions of rotation are opposite. Figure 13 has the same field polarity as

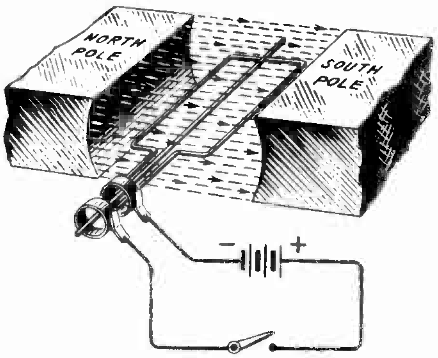


Figure 11

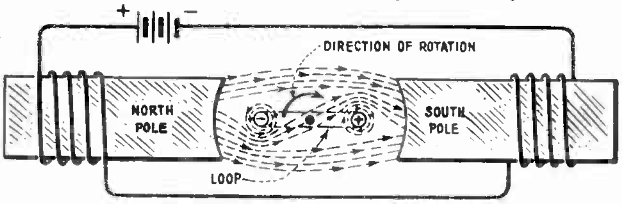


Figure 12

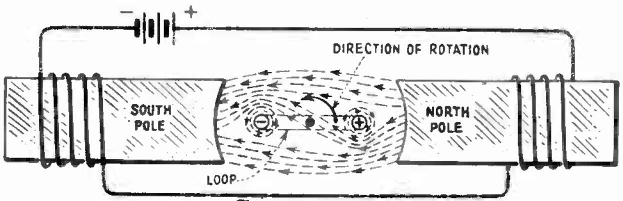


Figure 13

Figure 10, but opposite armature current direction, so the directions of rotation are opposite.

LIMIT OF ROTATIONAL MOVEMENT

The illustrations so far have shown merely in what direction the armature loop will turn when current passes through it in the presence of a separate magnetic field. To understand how far the loop will go we must return to the fundamental principle shown in Figure 6. We see here that the force exerted on the wire moves it out of the field of the poles, if it is free to move. In Figure 12, etc., the forces exerted on the two sides of the loop are such as to try to move the two sides of the loop out of the field and in directly opposite directions. But they are bound together at a fixed distance by their mechanical construction. Therefore, each wire will move as far from the center line of the field flux as it can. The limit of this movement is reached when the plane of the armature loop is perpendicular to the direction of the field flux. Then each wire is as far as it can go, with the arrangement disclosed to you up to this point. Maybe the rotational movement of the loop will have given it a certain momentum which carries it beyond that point. The wires will have then been carried on around a little way into the more intense sections of the field, and will be pushed back until they are in the neutral position; in Figures 12 and 13, for instance, the loop would come to rest in a vertical line.

COMMUTATION

In explaining the theory of the motor up to this point, we have used illustrations in which the armature received current from the battery through two wiping contacts resting on two separate rings (Figures 8 and 11). In Figure 14 we show a single ring split into two parts. These parts, called "segments", are insulated from the shaft and from each other. Each segment is connected to one end of the armature loop. The segmented ring is known as a "commutator". Pressing against opposite points of the commutator are two conducting strips, making a wiping contact with the commutator, and they are generally called "brushes". These are so mounted that each changes contact from one segment to another when the loop is at right angles to the lines of force. It will be remembered from our

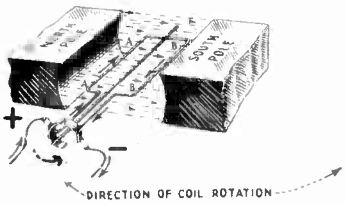


Figure 14

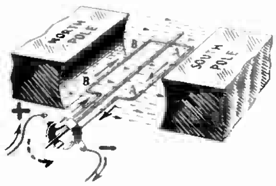


Figure 15

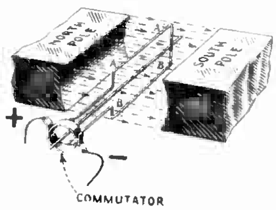


Figure 16

previous discussion that this is the limit to which the loop can turn with the armature current unchanged in direction. The momentum of the loop carries it across the neutral position a little ways. If the original direction of armature current were maintained the loop would then be thrust back into the neutral position. However, the direction of the armature current through the loop was changed by the commutator and brush arrangement when the loop crossed the neutral position. So instead of being pushed back, the loop is pushed forward in the same direction in which it started. (You may check this statement by applying the left-hand rule to Figure 15). It is now due to make a half-turn before coming into the next neutral position which is shown in Figure 16, and here again its momentum carries it across until the commutating action has again changed the direction of the armature current. This continuous pushing in one direction causes the armature loop to speed faster and faster until a steady speed has been reached.

COUNTER ELECTROMOTIVE FORCE

If we forget for the moment that the motor we are studying is rotating because of an electromotive force applied to the armature windings, we can consider the machine as though it were being rotated by some external source of mechanical power, such as a steam engine. In this case the machine becomes a generator, which is treated fully in a separate lesson. It is sufficient for our present purpose to state that when the armature loop is made to rotate in the magnetic field provided, the cutting of the lines of force by the two sides of the loop causes electromotive forces to be generated in them. The direction of these electromotive forces is opposite, as considered from the point of an observer outside the machine; the direction is the same considered from the standpoint of the series path provided by the loop itself. The electromotive forces generated in the two sides of the loop are, therefore, additive in their effect at the terminals of the loop (commutator segments). By the application of Fleming's Right-Hand Rule for the determination of the direction of an electromotive force induced in a moving conductor, we find that this is opposite in direction to the applied electromotive force from an external source which supplies the armature current and makes the rotation possible. The generated e.m.f. is, therefore, known as the counter e.m.f., sometimes called the back e.m.f. Its effect is very important in motor operation; it causes the effective or working electromotive force to become considerably less than the applied electromotive force. Just what the difference is, of course, depends on the numerical value of the counter e.m.f., and this depends on a number of factors, among which we can mention (1) the strength of the field, (2) the length of an armature conductor measured perpendicular to the field, (3) the number of complete turns in the loop, and (4) the rotating speed of the loop.

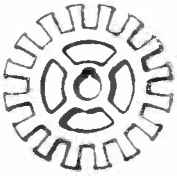


Figure 17

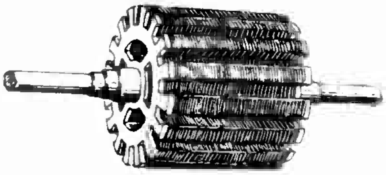


Figure 18

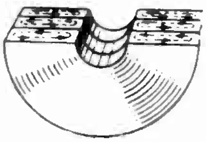


Figure 19

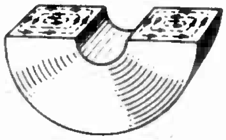


Figure 20

ARMATURE CONSTRUCTION

The armature core of the motor is made up of thin stampings of a good grade of soft iron or steel as shown in Figure 17. A number of these stampings are used to make up the armature core, and this core is then called a "laminated" core. Figure 18 will serve to show you how the armature core looks when all these individual discs have been placed, one against the other, making the completed core. The discs are held in place by various methods. In small motors, bolts are sometimes employed which run through the discs; in others, lock nuts which are threaded to the shaft, and in some makes a collar is shrunk on the shaft holding the discs in place under great pressure.

The armature is made up of laminations to reduce eddy current losses brought about when the armature revolves in a magnetic field. The induced currents within the revolving metal represent a part of the energy being used to operate the motor and do no actual good. In fact an armature constructed of one solid piece of metal would have eddy currents produced in it of such magnitude as to cause the armature to become very hot. This heat represents a large waste of energy. The armature coils absorb a considerable portion of this heat which causes damage to the insulation and overheats the bearings. It is then advantageous to see that such eddy currents are kept to a minimum. The losses are very materially reduced by building up the armature of thin discs of soft iron. By using laminations the magnetic conductivity of the core is reduced and the circulating eddy currents are confined to each disc, thus preventing these undesirable currents from becoming large enough to heat the armature excessively. The insulation between laminations is merely the coating caused by oxidation.

Figure 19 represents an iron core cut in half with the laminations purposely enlarged to show how the eddy currents are confined to each disc. Figure 20 represents a solid iron core showing how the eddy currents would move through the entire core.

when the armature coil is passing under one magnetic pole the eddy currents flow in one direction, but as soon as the armature comes under the influence of a magnetic pole of opposite polarity these currents are reversed in direction.

When the armature is revolving at high speed the eddy currents are rapidly reversed in direction thus causing friction between the molecules of the iron. Friction creates heat which, if allowed to become excessive, not only raises the temperature of the copper conductors, but may cause the insulation of the conductors themselves to burn. This rapid reversal of the molecules creates what is known as "hysteresis losses" and is considered as one of the harmful effects to be avoided in armature design and construction.

The slots along the outside of the laminated core carry the coils of wire on the armature, held in place by small pieces of wood which fit into the slots in the core, preventing the coils from being thrown out of the slots by centrifugal force. A cross section of how this is done is shown in Figure 21.

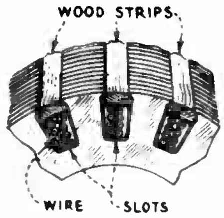


Figure 21

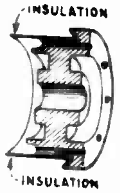


Figure 22

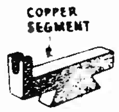


Figure 23

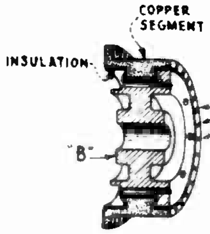


Figure 24

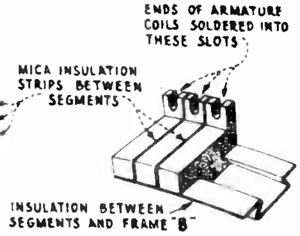


Figure 25

COMMUTATOR CONSTRUCTION

The commutator, the next and third essential part of the motor, is a very ingenious device. First we will see how the commutator is constructed. Figures 22 to 30 inclusive show the construction of the commutator. Figure 22 shows a locking ring which holds the segments in place. It is one solid piece of iron or steel cast in the shape shown. The commutator requires great care in assembling even though the principle of assembly is simple. The following building up process will give you the idea of how the parts are assembled. Figure 22 shows the part we begin with, the first requirement being to insulate the part. On this insulated section are then placed the copper segments which are insulated from each other; Figures 24 and 25 illustrate the alternate arrangement of mica strips and copper segments. After the required number of segments have been placed on the section and insulated perfectly, both from the holder and from each other, the locking ring, Figure 26 is moved into place as shown in Figure 27. The segments are locked into place by tightening the threaded studs which run through the locking ring, into the section, as shown in Figure 28. Figure 29 illustrates the segments as they would appear with a section cut out of a finished commutator, while Figure 30 is the finished commutator ready for fitting to the armature shaft and connection to the armature windings. The beginnings and ends of the armature coils are brought out and soldered into the slots of the segments as shown in Figure 25.

This completes the three major parts of the motor. Our next problem is to assemble these parts into a completed machine.

COMPLETE ASSEMBLY

Now let us consider one armature coil wound on an actual armature. In Figure 31 we can trace the position of this coil from the copper segment on which the top brush rests, across the armature core around the back of the core (as illustrated in Figure 32) into the armature slot on the opposite side of the core; and finally out where the end is taken to a copper segment of the commutator diametrically opposite the segment from which the coil started. Ordinarily coils are wound in all of the slots, but they have been omitted here to enable you to easily trace the position occupied by the one shown on the core. The continual rotation and speed of the motor is dependent upon a great number of coils as you will learn later.

In Figure 33 is shown a typical brush holder and brush, which rests on the rotating commutator and is connected to the power line used to supply the armature with current. For a view of a complete machine you are referred back to Figure 2 at the beginning of the lesson which shows a four-pole machine having four brushes. Two poles at opposite sides of the armature have North polarities; the other two poles, also opposite each other and in between the first

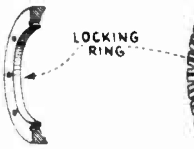


Figure 26

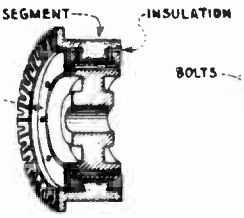


Figure 27

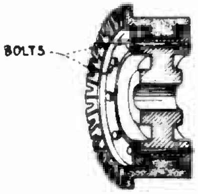


Figure 28

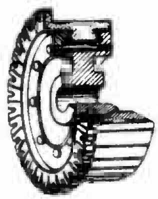


Figure 29

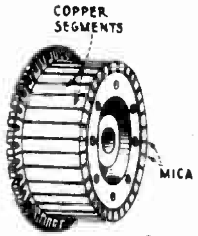


Figure 30

pair, have South polarities. We find also that the brushes are grouped into pairs, each brush being cross-connected to the one on the opposite side of the commutator. The positive power lead is, therefore, connected to the commutator at two places by two of the brushes; the negative lead to two other places on the commutator by the remaining brush pair.

A motor of this type may have six or any other <u>even</u> number of poles, and there will always be the same number of brushes as there are poles, if the power is supplied by a two-wire line.

TYPES OF ARMATURES

Armatures may be divided into three classes according to the core shape and the method of winding the wire on it. The classes are as follows:

1 - Drum Armatures
2 - Disc Armatures
3 - Ring Armatures

DRUM ARMATURES

This type is distinguished by having the entire winding external to the core, as shown in Figures 31 and 32. The core is of a cylindrical or drum shape. Each of the active wires is wound on the external surface of the drum in a direction parallel to the shaft. Such a wire is connected to another active wire by means of a connecting wire which is also external to the core.

DISC ARMATURES

The core for this type consists of a disc, and the active armature conductors are spread out radially on the flat sides of the disc. Armatures of the disc type are very seldom met with in modern practice.

RING ARMATURES

A ring-shaped core is used, and it is wound with a number of coils. Each coil consists of a number of turns of wire wound in and out aroung the ring. Figure 34 gives approximately the placement of a winding consisting of eight coils. This illustration is convenient for us to review the commutator action which it is so necessary for you to understand.

Tracing the current from the battery we see that it flows from the positive side to brush A, thence to commutator segment #1. At point K the current divides; part goes through coils 7-8-1-2 to point K1, thence to segment #5, and through brush B returns to the negative side of the battery. The other part of the battery current goes from point K through coils 6-5-4-3 to point K1, and hence to the negative side of the battery through segment #5 and brush B.

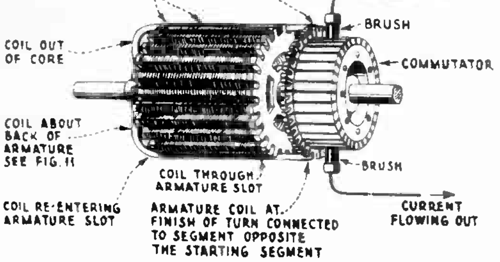


Figure 31

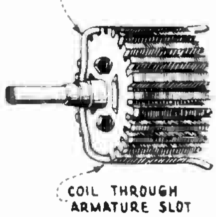


Figure 32

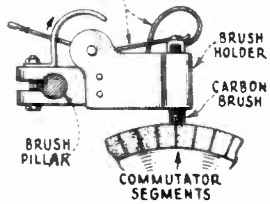


Figure 33

While the illustration does not show it, let us state that all the coils are wound around the armature ring in the same direction. When current enters coil 7 it sets up a North pole in the core ring near point K, and a South pole at that end of coil 7 which is next to coil 8. The current in coil 8 sets up a North pole at the end adjacent to coil 7, and a South pole at the end adjacent to coil 1. Likewise coils 1 and 2 set up magnetic poles in the same direction. This actually means that all the coils 7-8-1-2 and each turn of them works in the same direction to establish magnetic lines of force which make a North pole in the ring at point K, and a South pole in the ring at point K1. Taking the other path from K, the current through coil 6 goes through it in the opposite direction from that through coil 7,and sets up at point K a North pole also, making a South pole in the core on the side toward coil 5. The current passing through coil 5 sets up a North pole on the side toward coil 6, and a South pole on the side toward coil 4. This principle holds for coils 4 and 3. Therefore, the magnetizing effects of the coils 6-5-4-3 are additive, and the lines of force in that half of the ring are concentrated. Their direction is such as to also establish a North pole at K and a South pole at K1. We see then that the magnetizing effect of all the coils combined is the same as though a strong permanent magnet were used with its axis practically at right angles to the line of direction of the flux between the two field poles.

In accordance with your previous study of magnetism, such a magnet would tend to turn and get in line with the direction of the field poles, the North pole of the armature being attracted to the South field pole, and vice versa. But since we are using a commutator on a wound armature we get a more continuous effect. As segment #1 turns up to the right, and segment #5 turns down toward the left, we find that segments #2 and #6 have come under brushes A and B respectively. The current through coil 7 has been reversed and it now has a North pole at its left end where it previously had a South pole. Likewise coil #3 now has a South pole at its right end, where it previously had a North pole. We see then that the North pole of the armature ring has been shifted to a point between coils 7 and 8, and the South pole to a point between coils 3 and 4, with the armature rotated one-eighth of a turn. Therefore, the relation between the direction of the field flux and the armature flux is the same as before, and the turning effect continues.

The commutator is of course the secret of the continual motion produced. It keeps the directions of the current through the various coils such that the combined effect of all the coils is the same at all times as far as directions of magnetic forces are concerned.

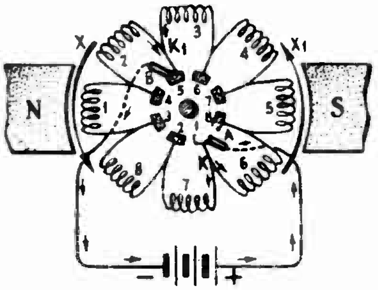


Figure 34

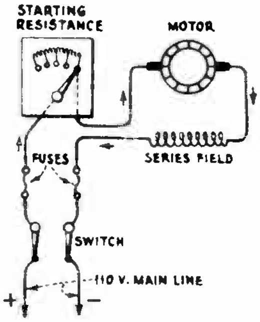


Figure 35

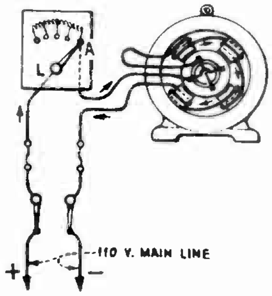


Figure 36

TORQUE AND SPEED

The motor is designed to produce a turning motion as a result of a twisting force which we call TORQUE, and on this torque depends the work the motor is capable of doing. We are interested not only in the work which can be done, but also in the SPEED of the motor in revolutions per minute. The formulas for these are as follows:

Speed: $n = \dfrac{E_a}{\Phi Z'} = \dfrac{V - I_a R'}{\Phi Z'}$ revolutions per minute

Torque: $T = 7.05\, Z' \Phi I_a$ lb. - ft.

where: E_a = counter e.m.f.

V = line voltage

Φ = field strength or flux

Z' = a factor which depends on the number of poles, the length and the number of the armature conductors.

I_a = armature current

R' = the sum of the armature resistance and any other resistance in series with the armature and the line.

These equations are important for our understanding of the operating conditions of various types of motors.

TYPES OF MOTORS

There are three types of direct current motors used in radio practice. They are the series, shunt, and compound.

The different types are used according to the work they have to perform.

The series motor, although not found extensively in radio use, will be briefly explained here in order to enlighten you on the field winding connections. This motor is used mostly in electrical hoisting equipment and in electric traction work. It derives its name from the fact that the field coils are connected in series with the armature.

The series motor connection is shown in Figures 35 and 36; it is noted that all the current for the motor flows through the armature circuit and the field circuit in succession. Inspection of the equation for the speed of a motor shows that the speed of the series type must decrease rapidly with increasing load. When a load is thrown on the motor the twisting force or torque must increase, and from an equation above this can happen only through increasing either the field flux or the armature current. In the

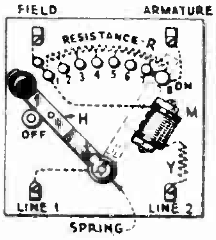


Figure 37

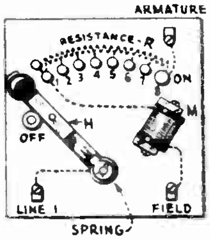


Figure 38

series motor the field flux is proportional to the armature current, so we see that the current will increase to supply the additional power required. Now look at the equation for speed; we have decreased the value of the numerator (above the line) by increasing the IR which is to be subtracted from the line voltage V; we have increased the denominator (below the line) because the field flux is increased in proportion to the current. These two things combine to make an appreciable decrease in the motor speed.

On the other hand, if the machine is designed to run at a certain speed when connected to some minimum load which can be increased, if that minimum load is entirely removed, as by the slipping of a pulley belt off the pulley of the motor, the decrease in work performed will so decrease the armature current that the machine will speed up to a dangerous extent. We, therefore, find a series motor should be coupled to its load either by direct shafting or by sturdy gears, and never by a belt.

SHUNT MOTOR

This type of motor is used where a close regulation of speed is required under loads which are constantly varying. The field coils of the shunt motor are wound with many turns of fine wire, thus making the resistance of the field coils high. This allows only a small current to flow of more or less constant value no matter how much current is flowing in the armature circuit. This is illustrated in Figures 39 and 40. When a load is thrown on such a motor we can interpret its action also in terms of the two equations given you. Looking at the equation for speed, we find again that the IR drop in the armature is increased, decreasing the value of the numerator, and the motor, therefore, slows down slightly under load. This decrease in speed is appreciably less than it would have been for a series motor, in which the field strength would also have been increased by an increase in armature current.

Caution should be exercised in the operation of this type of motor regarding the speed control; the regulation of the speed may be accomplished by the use of a variable resistance in series with the field coil, or by a resistance in series with the armature circuit. The field circuit must not be opened thereby cutting the current off suddenly. If the field circuit suddenly opened the field would become very weak and the motor would operate by the residual magnetism in the field magnets. The armature would increase its speed because sufficient counter e.m.f. could not be generated to reduce the applied e.m.f. and the armature might possibly be torn apart if abnormally high speed were attained. Precautions to guard against an open field will be described later under motor control.

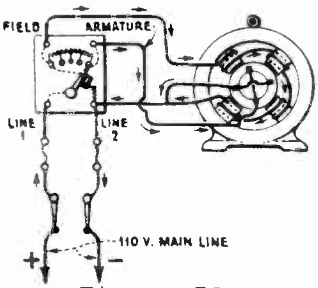


Figure 39

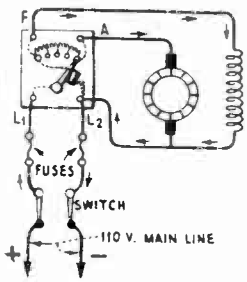


Figure 40

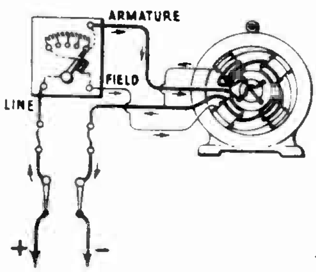


Figure 41

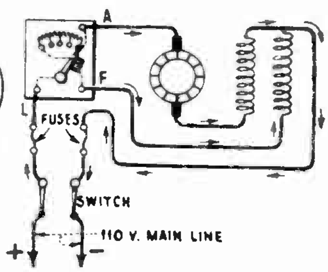


Figure 42

COMPOUND MOTOR

The purpose of this type of motor is to obtain constant speed under all load conditions. It differs from the two types just described because the field is composed of two sets of windings, a series and a shunt winding, as shown in Figures 41 and 42. Most of the field flux is due to the shunt winding. The series winding is so connected that its field flux opposes that due to the shunt winding. Under this condition, when a load is applied the armature current increases, and from the speed equation we see that this decreases the numerator (top part) of the term. At the same time the armature current flowing through the series field winding has increased its opposition to the field flux created by the shunt winding. The net result is a decrease in the strength of the field, which is part of the denominator (lower part) of the term in the speed equation. By design, the decreases in the upper and lower parts of the term are made proportional, and the speed of the motor remains constant. It is even possible to so proportion the strengths of the shunt and the series fields that the speed of the motor is increased somewhat when a load is applied.

When the field due to the series winding bucks the field due to the shunt winding, the motor is said to be differentially compounded. It is, of course, possible to change the connections of either the series or the shunt field winding which will make the two fields add. The motor is then said to be cumulatively compounded. With this type the speed falls considerably with increasing load. Its characteristics may be said to be intermediate between those of the shunt and the series motor. One particular advantage of the cumulatively compounded motor over the series motor is that the former will not "run away" when the normal load on the machine is suddenly removed, but will instead increase its speed to a definite safe limit.

In a compound motor the shunt winding may be connected across the line, in which case it is called a long shunt. It may, on the other hand, be connected right across the armature terminals, (short shunt) and in this case the shunt field current passes first through the series field winding where it has little extra effect as it is small compared to the full armature current passing through the series winding. One terminal of the shunt winding always connects to that side of the armature which goes straight to the line. The other terminal of the shunt winding may connect to the side of the armature which goes to the series winding, or it may pass over the series winding and connect to the second line wire. The first of these methods is the short shunt and the second is the long shunt.

STARTING A MOTOR

The resistance of an armature coil is very low and to place the line voltage, of say 110 volts, on an armature coil when it is not in motion would be the same as connecting a short wire around the terminals of a battery; that is to say, the armature would cause a short-circuit on the 110-volt line. In our study of the motor, however, we discovered that as soon as an e.m.f. was applied to the commutator segments through the brushes, current moved into the armature coil and the coil at once was forced to move.

In this starting of the motor armature the current taken by each coil is more than is required to drive it. If you connect an ammeter in the circuit it may read 25 amperes at first, but as the armature gains speed, you will see the ammeter needle gradually drop back until, when the armature is revolving at full speed, the meter may only read 4 or 5 amperes.

Now why did the current drop from 25 to 5 amperes? At the start the armature coils were practically a short circuit, which allowed an excessive current to flow; but as this excessive current flows in the coils for a very short period of time no damage is done in the case of a small motor.
As the motor armature begins to revolve its coils act similar to those of a generator, that is, an electromotive force is developed in the coils, called counter e.m.f. This counter e.m.f. opposes the current which is causing the armature to revolve, and by virtue of this opposition limits the amount of current flowing in the armature. As the speed increases this back or counter e.m.f. becomes greater and greater, allowing less and less current to flow into the coils.

This continues until the full speed is reached when the back e.m.f. may, for instance, reach a voltage of 105 volts. If there is 110 volts applied and 105 "bucking" or opposing it then, $110 - 105 = 5$ volts, which will be the total e.m.f. forcing current through the armature coils. Suppose the resistance of the armature is one ohm. By Ohm's Law $I = \frac{E}{R}$. $I = 5 \div 1 = 5$ amperes, or the total current flowing in the armature when it is up to full speed. By Ohm's Law figure out what the current flow would be in the armature coils if the armature did not rotate.

$$I = \frac{E}{R} \text{ or } I = \frac{110 \text{ volts}}{1 \text{ ohm}} = 110 \text{ amperes.}$$

This would certainly place a short in the line and cause the fuses to blow, thus protecting the armature coils from burning. Therefore, you can realize the importance of ç.e.m.f. as applied to the motor; it acts to regulate the current.

So far the motor has merely been revolving without driving any machinery. Suppose now the motor is connected to a load; the motor will momentarily slow down and the counter e.m.f. will at the same time become less, and more current will flow into the armature windings. Now disconnect the load; the speed of the armature increases and so does the counter e.m.f. thus reducing the current flowing into the armature. Any variation in the speed of the armature will cause a variation in the counter e.m.f.

This counter e.m.f. then acts to automatically regulate the flow of current into the armature when the load on the motor is varied.

Motors such as we are going to use require some means of controlling the e.m.f. applied to the armature at the time of starting the motor, therefore, a resistance is placed in the motor line to regulate the current flow to the armature coils. When the normal speed of the motor is reached this resistance is cut out of the circuit.

This regulating device is called a starting box and is shown in Figures 35 and 36. Further explanation of starting boxes will be taken up later in this lesson.

MOTOR STARTING BOXES

Controlling the start and stop of electric motors and generators is accomplished by either the manual type of control or by the automatic or remote control. The modern radio transmitter is equipped with the latter type so that the operator may start and stop the apparatus from the operating table. Other methods require that the motor generator sets be started and stopped by manipulating the lever of the starting rheostat.

The starting resistance of direct current motors, as explained, controls the current flowing in the armature of the machines. A further control of this applied current to the armature is effected by the counter e.m.f. developed by the armature after it begins to rotate. The starting resistance may be cut out of the circuit gradually as speed is attained. As the resistance of the armature is low the starting resistance is necessary to limit the current to a safe value until the armature has attained its full speed.

Figure 37 illustrates what is known as a four-terminal starting box while Figure 38 shows the three-terminal box.

The difference between the two starting boxes is in the connection of the holding magnet in the circuit. In Figure 37 the holding magnet is connected in series with the resistances Y and R and across the 110-volt circuit as shown. The starting box of Figure 38 has the holding magnet connected in series with the shunt field of the motor and resistance R.

Figure 39 illustrates the method of connecting a shunt motor to a four-terminal starting box. Figure 40 is a schematic diagram of the same motor and box.

Figure 41 shows the proper connections for a compound wound motor and a three-terminal starting box with a schematic diagram shown in 42. when it is desired to start a motor with this type of control the starting arm H, Figure 38 is moved slowly across the contacts. When the armature is on contact Number 1 current flows from line 1 to the starting arm through the arm to resistance contact 1, through all the resistance coils to contact 8 where it is led to the terminal marked armature and from there to the motor armature. As the arm is slowly moved over the contacts the resistance is gradually cut out. When arm H reaches the holding magnet M and rests on contact 8 all the resistance is out and current flows directly from line 1 to the armature.

The magnet M holds the arm H which is made of soft iron, in the running position as shown by the dotted arm in Figure 37. This magnet is connected to the first contact and it receives full voltage at first, but as the arm moves over the contacts less e.m.f. is im-

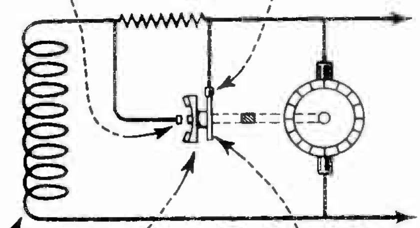


Figure 43

pressed across the magnet windings due to the increased resistance through R as the arm is moved to full running position. Hence, when the arm is in full running position, just enough current flows through the magnet windings to attract and hold the arm. The resistance protects the magnet winding from heating.

If the shunt field circuit or the line switch is opened for any reason the magnet current is cut off and the arm is pulled back to the "off" position by a spring located in the shaft supporting the handle.

AUTOMATIC SPEED CONTROL

In some uses of motors an evenness of speed is desired which must be better than can be achieved merely by the design of the motor itself. Mechanical principles are then brought to bear on the problem, as in the case of a small motor which is used to move the film in a sound picture projection machine. Steadiness of speed is essential here as any speed change will change the musical pitch of the sound program being picked off the film.

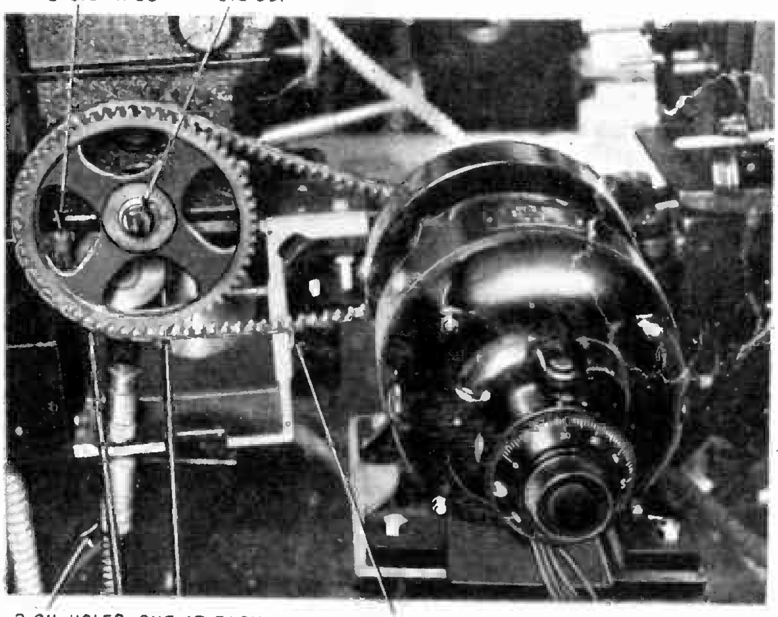
In Figure 43 is shown the schematic wiring of such a machine. It is shunt wound, and a resistance is placed in the lead from one side of the line to one side of the field winding. The effect of the resistance is to decrease the current which would otherwise flow through the winding. At one end of the motor shaft is a centrifugal device consisting of two fly-weights secured by hinges to a disc on the end of the shaft. At the center of the spring which joins the fly-weights there is a contact, connected to a slip ring on which rests an ordinary brush. When the motor is not running the spring holds the fly-weights in toward the shaft. As the motor picks up speed, the centrifugal force tends to throw the weights out away from the shaft, which action is resisted by the spring holding the weights together.

Opposite the contact which is central to the fly-weights, there is another contact and this latter can be adjusted by means of a dial so that its distance from the moving contact can be changed. The two contacts will touch when the machine has reached a certain speed which is sufficient to extend the fly-weights away from the shaft enough to thrust the moving contact over against the fixed one. This operation places a short across the resistance which is in series with the field winding, the field strength is increased and the motor slows down, as previously described. The slowing down of the motor makes the fly-weights draw in closer to the shaft and this opens the contacts again. The resistance is once more inserted in series with the field winding, weakening it so that it speeds up again slightly.

The success of such a device depends on a very accurate design and a sturdy construction, so that very small changes in speed will operate it to cause an effect which will be opposite to the change.

EXAMINATION QUESTIONS

1. What are the principles underlying the operation of electric motors?
2. What is the function of an electric motor?
3. Name the essential parts of a d-c motor.
4. (a) What is the purpose of the armature?
   (b) How is it constructed?
5. What is the meaning of torque?
6. Give an equation for torque, and explain what each symbol represents.
7. What advantage has a cumulatively compounded motor over a series motor?
8. What is the purpose of the commutator? How is it constructed?
9. How is the speed of a shunt motor regulated?
10. Explain the action of a motor starter.



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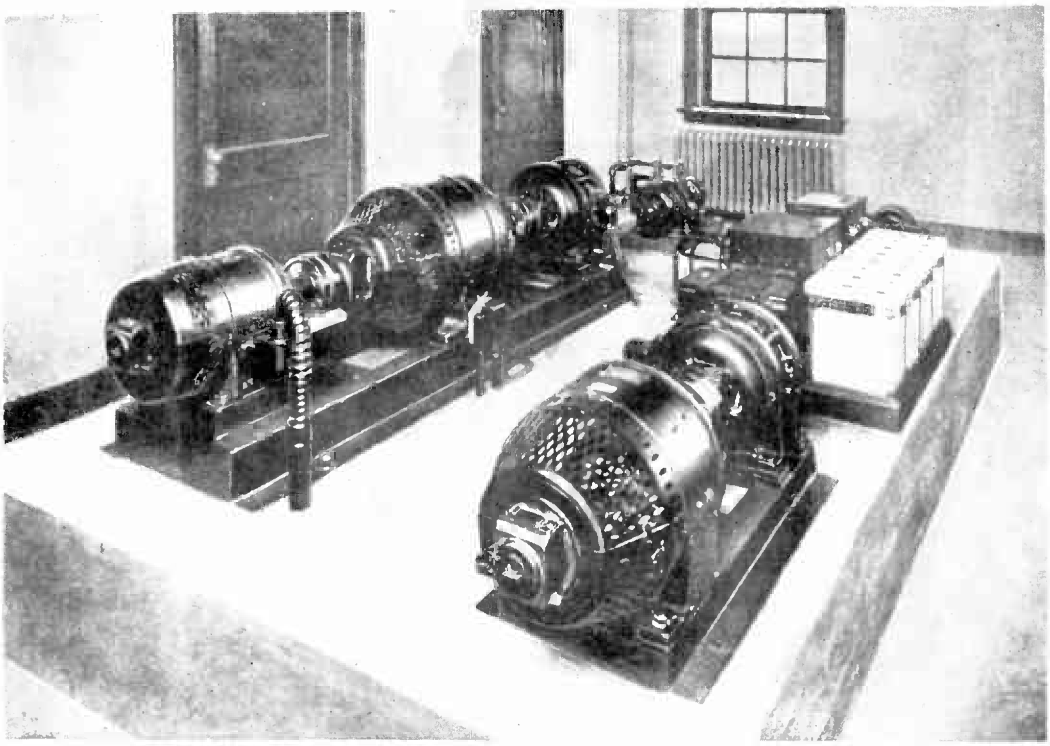
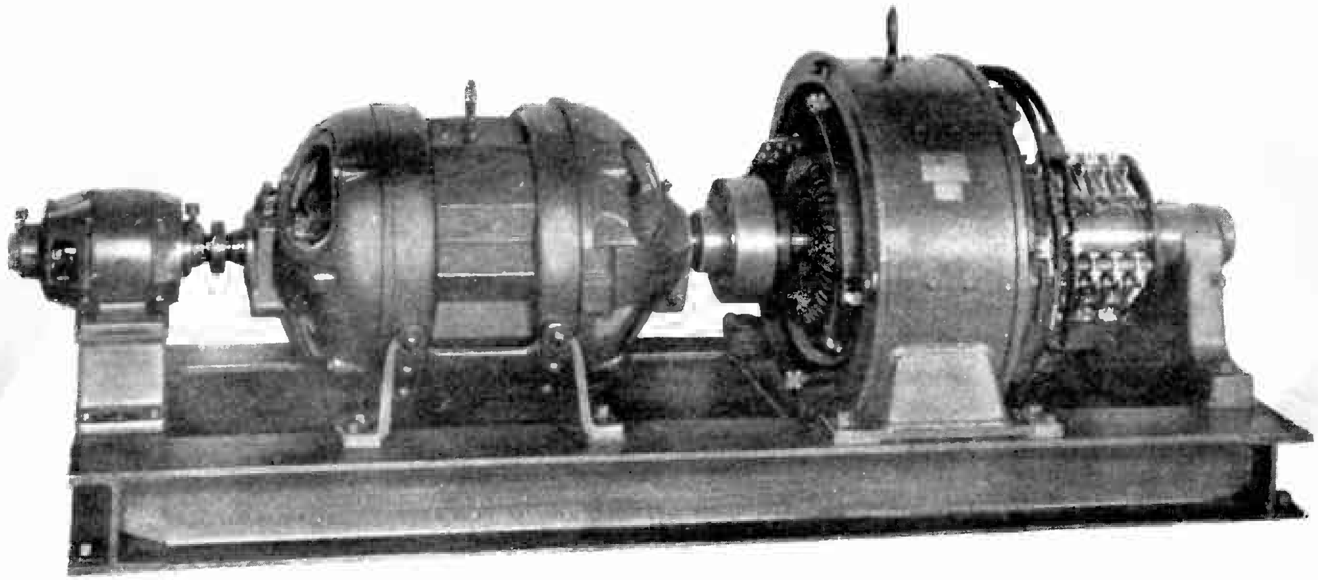


Typical Broadcast Station Power Room

D. C. GENERATORS

VOL.10,No.9 Dewey Classification R100



Filament Motor Generator Set
The unit is capable of furnishing 600 amperes at 35 volts. Exciter is shown at left

D.C. GENERATORS

The theory of the electric generator and the electric motor are very closely related and the construction of both is practically the same.

The action, however, of the generator is opposite to that of the motor. The generator, or dynamo, as it is sometimes called, converts mechanical energy into electrical energy while, the motor converts electrical energy into mechanical energy.

Electrical energy is taken from a generator when it is driven by an electrical motor or by other means such as a steam or gas engine, or by a water turnbine.

The dynamo can be used either as a generator or motor. The term used to designate a machine depends upon whether it is to be used as a motor or as a generator. In shop practice this method of having one machine which can be either used as a motor or generator is employed to some extent.

HISTORY OF THE GENERATOR

We have to look backward a good many years to find when the first generator was used. In 1821 Michael Faraday, an English scientist, found that he could produce rotation of a magnetic needle when it was brought near a conductor carrying an electric current. He did this while experimenting and applying the discoveries of Oersted in electromagnetism. In 1831 Oersted's great discovery of electromagnetic induction was made and, from that date, you might say the electric generator was born, for it was on this principle that the dynamo was founded. Since then many men have contributed to this discovery and it has taken years of constant study and application to bring the generator to its present-day perfection.

THE PRINCIPLE

Generator:—From the name many people think the dynamo generates electricity. To entertain this idea, however, is wrong. A dynamo can no more generate electricity than a water-pump can generate water. The water is there; the pump merely forces it out of the well. Electricity is already there, and the dynamo only generates a pressure which moves the electric current through a wire.

In your earlier lessons you spent some time with electromagnetic induction, learning how an E.M.F. was induced in a wire when it moved through a magnetic field. You were then acquiring knowledge which will now enable you to understand the principle of the generator.

If you make a loop of wire and bring the ends out to two "collector" rings as shown in Figure 1, and place this loop in a magnetic field, and so arrange the loop that it may be rotated in this magnetic field, you will have an experimental device suitable to illustrate the principle of a simple generator.

If this loop is now revolved so that the lines of force between the two magnets are cut, an E.M.F. will be induced in the loop and current will flow through the loop "AA" and "BB". The current which is being forced around this loop by the induced E.M.F. will

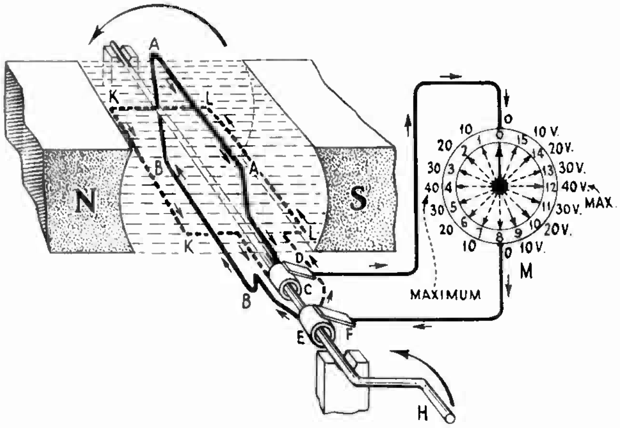


Fig.1-Diagram illustrating the operating principle of a simple generator

flow to the collector ring "C", to the brush "D", and through the meter "M" to brush "F", to collector ring "E" and return to side "BB" of the loop. The current has caused the meter needle to move so we know that current flows in the loop.

If the loop is turned from the position as shown in the diagram by the handle "H" to the left, the side "A.A." of the loop will begin to move through and cut the lines of force at an angle.

As the side "AA" moves in the direction shown by the large arrows the induced E.M.F. will cause current to flow through the loop as shown by the small arrows on the loop. More lines of force are cut as it moves toward the dotted lines "KK", which represents the loop at the point where it cuts the greatest number of lines of force or at right angles, and when it reaches this position the maximum E.M.F. is induced and the greatest current flow naturally results.

As the loop moves out of this point of greatest field strength toward position "BB" less and less E.M.F. is induced as the loop gradually approaches the point "BB"; at point "BB" the loop moves parallel to the magnetic field and no lines of force are cut consequently no E.M.F. results.

While side "AA" has been moving down, side "BB" has been moving up, and the induced E.M.F. in side "AA" is in the opposite direction to that in side "BB".

We said that when the top of the loop moved downward from point "AA" to point "KK" E.M.F. was induced in that side of the loop which increased in strength until at point "KK" the maximum E.M.F. was reached. As the loop continued beyond position "KK", the induced E.M.F. gradually became less until, at point "BB", it dropped to zero.

The induced E.M.F. gradually increased from zero at point "AA", to a certain point and then decreased again to zero.

Suppose we study Figure 2 and see what we can get out of that picture to help us understand this E.M.F., or voltage rise and fall.

Here we have something that looks like a cart wheel; at the center is a hub and from this hub are radiating lines or arrows which point at figures around the rim of the wheel. Start at the hub now and

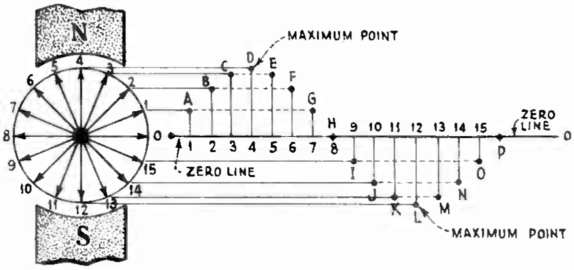


Fig.2-Diagram illustrating voltage increase and decrease in a simple generator

study the arrow which points to zero. Just opposite zero you will see a line which we will call the zero line; this zero line extends, we will say, for 15 inches, and the numbers, 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, will then be at intervals of an inch.

The arrow above and to the left of arrow 0 points to 1, the next arrow above and to the left of arrow 1 points to 2, and so on around the rim of the circle until we return to arrow zero.

We are going to let the arrow which points to zero represent the position of side "AA" of the loop in Figure 1.

We want you to follow this very carefully for you are going to construct a curve which is the method used by all electrical men to show how electric current moves in an A.C. circuit. It is important for you to know this for you are going to see many similar curves before you finish this work and we want you to understand how the curve is obtained.

The loop will be rotated through the magnetic field. Before moving the loop, however, let us look over the special meter we have arranged at M, Figure 1, to indicate the amount of the induced voltage as it increases and decreases in the loop during its journey through the lines of force.

On the inner circle of the meter you find numerals 0 to 15; these correspond to the movement of the loop. On the outer circle 10v (10 volts) 20v, 30v, 40v appear and, following the circle around, 40v, 30v, 20v, 10v, 0 volts appear. Now let us start the loop and, if it were possible to observe the individual readings as the loop is turned, the following results would be noted.

The loop moves from point zero, the neutral or zero position, to point 1, and has cut lines of force for a distance of one inch. Glancing quickly at the meter M, Figure 1, we find that the voltage has increased from zero volts to 10 volts. At this position, or point "A", Figure 2, place a dot. The loop moves on, and our next point of observation is at point 2. Again reading the meter we find the voltage has increased to 20 volts, so at point "B", Figure 2, another dot is placed. As the loop revolves, and arrives at point 3, Figure 2, we take our reading of 30 volts, and another dot is placed at point "C", (Note that the voltage is increasing as the loop approaches the point where it is cutting more lines of force at right angles). At point 4, another reading is taken and we find the meter reads 40 volts. So we place a dot at "D".

The arrow pointing to Number 4, Figure 2 represents the loop in position "KK", of Figure 1.

As the loop moves downward from point "KK" in Figure 2 to point "BB", the resulting positions are shown in Figure 2 by numbers 5, 6, 7, 8. We find that at point 5 the voltage has dropped to 30 volts, or 10 volts less than at point 4, and a dot is placed at point "E". Our next reading is at 6. The meter reads 20 volts and a dot is placed at "F"; at point seven the voltage has dropped to 10 volts and a dot is placed at "G" and, as point 8 is reached, the meter shows zero volts and a dot is placed at "H".

The foregoing is called one alternation; the voltage at the start was zero and it gradually increased until the maximum of 40 volts was reached when it receded again to zero value.

As the portion of the loop "BB", Figure 1, continues it begins to travel upward through the lines of force inducing an E.M.F. opposite in polarity to that induced on its downward travel. Naturally the current will change its direction of flow. We will show you how to plot this by using Figure 2.

The loop is now moving from position "BB" towards "LL", Figure 1 and as it leaves point 8, Figure 2, and reaches point 9 we find that the meter reads 10 volts. Following out our line to point "I" another dot is placed. (Note that the voltage is increasing again, but in the opposite direction). Point 10 is now reached in the upward travel of the loop as it comes under the influence of the "S" pole of the magnet, and our meter reads 20 volts; another dot is placed at "J". when 11 is reached the meter reads 30 volts and another dot is placed at "K"; point 12 is next with a meter reading of 40 volts or the maximum voltage of the alternation.

The voltage now begins to drop and, as points 13, 14 and 15 are passed, we read a voltage of 30, 20 and 10 volts respectively, with dots placed at "L", "M", "N" and "O". Finally when the loop reaches zero, the starting point, the voltage has dropped to zero and, with a final dot at "P", a cycle of values has been completed, i.e., two alternations.

Now starting with the dot at zero draw a continuous line through A, B, C, D, E, F, G, H, I, J, K, L, M, N, O, to P and you will have a curved line as shown in Figure 3. Draw a straight zero line beginning at zero through "H" to "P" and a true sine curve is the result, shown in Figure 4.

From this study it is seen as the portion of the loop leaves the point "AA", Figure 1, it moves downward and cuts the lines of force under the influence of the magnet "N", (north polarity) and the

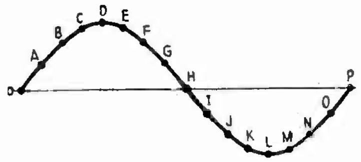


Fig.3-Voltage curve diagram

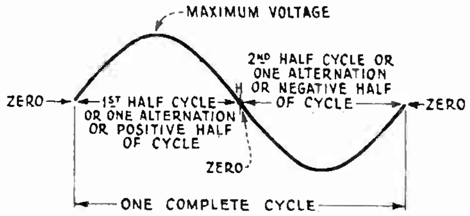


Fig.4-A true sine curve

induced E.M.F. is in one direction while the loop leaving the position "BB" is cutting the lines of force under the magnet "S" (south polarity) upwards, inducing an E.M.F. in the opposite direction.

To lead this induced alternating current out of the loop two collector rings "C" and "E" are mounted on the shaft, insulated from each other, to which are connected the ends of the loop and on which rest the brushes "D" and "F" as shown in Figure 1. Leads connect the brushes to the meter and, as just explained to you, as the loop

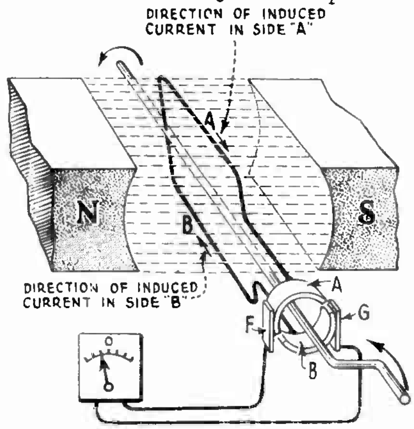


Fig.5-Diagram of a simple direct current generator

revolves, the needle of the meter indicates the rise and fall of induced current at the various parts of the revolution or cycle. These results may be plotted similar to the curve you have just made.

Alternating current is used to a great extent, and we will discuss that in another lesson. However, at this time we are dealing with direct current dynamos, therefore it is necessary to provide some means for changing alternating current to a direct current, or a current which flows in the external circuit in one direction.

This may be done by removing the collector rings, shown in Figure 1, from the shaft and substituting a commutator about which you have alreadv studied. This is shown in Figure 5. Here only one loop is used. Therefore only two segments are needed. The metallic ring is split into two segments A and B and, where they are split insulation is placed, which is flush with the outside face of the segment. The ends of the coil are soldered to each segment as shown in Figure 5. The loop "A" and "B", as shown in the diagram is parallel with the magnetic field and this is the position where no E.M.F. is induced as indicated by the small meter. (Also note the brushes short circuit both segments; that is the neutral or no voltage position).

Now by turning the handle in Figure 5 so the loop revolves counter-clockwise, or to the left, side "A" of the loop begins to cut the magnetic field of the magnet under the "N" pole inducing an E.M.F.

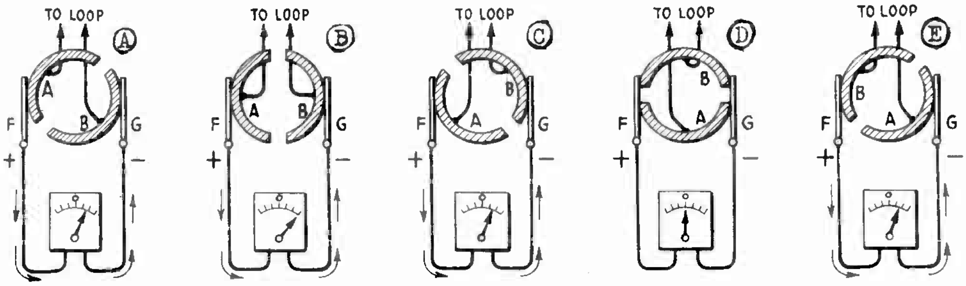


Fig.6-Diagrams of various commutator positions in the simple direct current generator

which causes an induced current to flow in this half of the loop as shown by the arrow. The commutator segments which are secured to the shaft have moved into the position as shown in Figure 6A, and the induced current is flowing to segment "A" and out brush "F" through the meter to brush "G", into segment "B", and to the "B" side of the loop.

At the same time, the "B" half of the loop has moved upward, as shown by the arrow in Figure 5, cutting the magnetic field of magnet "S", inducing an E.M.F. in this half of the coil causing an induced current to flow through "B" half of the loop, as shown by the arrow, which is opposite in direction to that of side "A".

The coil has now taken the same position as shown in Figure 7 by the arrows 2 and 6.

As the loop rotates it reaches the position 3 and 7, Figure 7, with the commutator as shown in Figure 6B. Position 4 and 8, Figure 7, is the next position of the loop with the commutator in position Figure 6C.

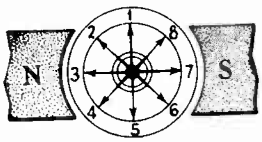


Fig.7-Loop positions

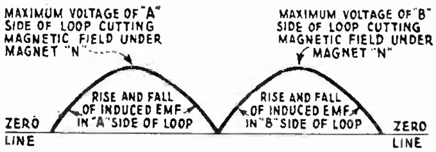


Fig.8-A direct current sine wave

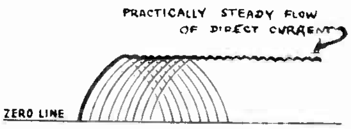


Fig.9-A pulsating direct current graph

At position 1 and 5, Figure 7, the "A" side of the loop in Figure 5 is at position 5, while "B" side is holding the position that "A" formerly held at the start. The loop is again in the neutral plane, at which point no E.M.F. is induced in the loop.

The "A" side of the loop and the "A" segment of the commutator could be considered positive at this point, and the "B" side of the loop and "B" segment of the commutator negative. The commutator is shown short circuited at 6D and in this position the loop is parallel to the magnetic field at which time no current flows.

Continue to rotate the loop (Figure 5), however, and side "B" and segment "B" now becomes positive, while side "A" and segment "A" are negative, Figure 6E, and the same cycle of events take place over and over again as the loop continues to rotate.

Thus, you can readily see that at each half revolution the current changes direction in the loop as it comes under the influence of the different magnetic poles. The commutator, however, keeps the current flowing in the external, or meter circuit, always in the same direction, thus supplying direct current to the external circuit.

Thus, with only one coil on the armature and using a commutator the current would rise and fall, but would not reverse its direction. This condition is shown in the curve Figure 8, and is called a pulsating direct current. This condition is not desirable, because if a lamp is connected in the circuit instead of the meter the lamp would appear dim at first then bright at the point of maximum voltage, then grow dim again and at each half revolution of the loop the lamp would go out. In order to eliminate this undesirable feature of alternate increase and decrease of the E.M.F. a great number of loops are used with a correspondingly great number of segments.

With more loops revolving in the magnetic field the pulsating current becomes as shown in Figure 9, giving a greater number of pulsations per second of time.

The loops are so arranged that each coil replaces the preceding loop coming into the magnetic field so rapidly that the E.M.F. is practically constant. One coil no sooner passes out of the maximum voltage point than another is arriving at the same point.

However, even with a large number of armature coils, and a correspondingly large number of segments, these slight fluctuations of the current will still be present. Such fluctuations of the current are known as "commutation ripples," but are so small in value that, as far as ordinary circumstances are concerned, they are of no importance.

If we revolve the armature through the magnetic field and the armature coils are self supporting, the reluctance which the air gap between the poles offers to this magnetic field will materially reduce its strength.

All armature coils are wound on a soft iron laminated armature core. This iron core practically fills the space between the magnetic field poles, reducing the reluctance offered to the magnetic field and therefore a greater number of lines of force may be cut. The distance between the revolving armature core and the field magnet pieces is usually 1/64 of an inch.

FIELD POLES

The field magnets of motors and generators are generally large electromagnets. The core in most cases is either cast iron, wrought iron or soft steel. In some types of small motors the frame and pole pieces are permanent magnets and these require no field winding.

In the larger types that we are dealing with the field magnets are electro-magnets and are made up separately and bolted to the frame of the motor or generator. The field pole is machined carefully to fit closely to the frame, because a tight joint reduces magnetic leakage. The field pole, "A" in Figure 10, is soft iron cast into shape, and then machined as shown. Holes are drilled for the holding bolts and provisions made to countersink the heads of the holding bolts into the shoe of the pole piece.

The form wound field coils are next prepared as shown in B. In series wound motors the field coils consist of heavy insulated wire. As each turn is wound on the form, shellac is applied. Upon completion of the winding as shown at "B", Figure 10, it is wrapped with cotton tape shellacked again and baked. The completed winding is then ready for the pole piece, which is removed from the frame, and the field coil is slipped over the pole piece fitting close up to the shoe of the core, as shown at "C", Figure 10. The completed field coil is then placed inside the generator frame, bolted into place and the terminal of each coil connected as shown at "D", Figure 10. The placing of the pole pieces as to polarity, together with the path of

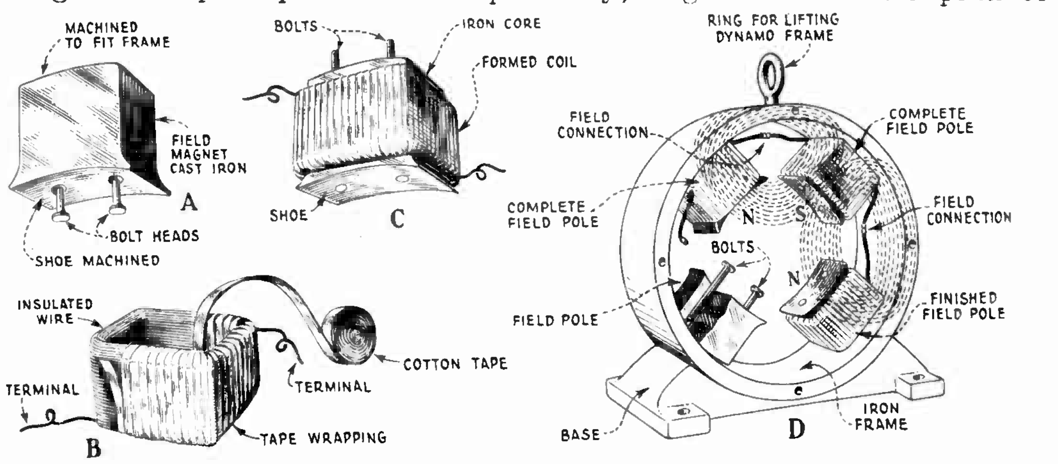


Fig.10-Details of the field magnets in a direct current generator

the magnetic field through the frame, is also shown at "D", Figure 10. This figure shows a four pole generator. Bipolar (two pole generators) are also used.

The field coils are connected in different ways according to the design of the machine. In most commercial direct current generators the fields are self excited; that is, they are energized from the current generated in the armature. In alternating current generators the field is generally excited separately by a small D.C. generator connected directly to the armature shaft of the alternator, or from the D.C. supply mains.

The soft iron used in the field magnet retains a small amount of magnetism, called residual magnetism, after the generator is shut down. On starting the generator this residual field makes it possible for the armature coils, as they cut this weak field, to generate an induced E.M.F. thereby starting an induced current. As soon as current begins to flow in the armature it strengthens the field winding, gradually building up the magnetic field strength until it becomes normal.

There are times when this residual magnetism fails; that is, the pole pieces lose their magnetism to such an extent that the E.M.F. will not build up. In this case it is necessary to separately excite the field magnet winding by connecting several dry cells in series with the field coils to produce a field strong enough for the armature to develop an E.M.F. As soon as the E.M.F. starts to build up the dry cells are disconnected and with the field circuit restored, the machine will operate normally.

Let us observe some of the ways the generator field coils are connected with the armature, which designates the type of D.C. generator. To make this as easy as possible we will use three drawings; all three slightly different in appearance but, nevertheless, the circuits are the same.

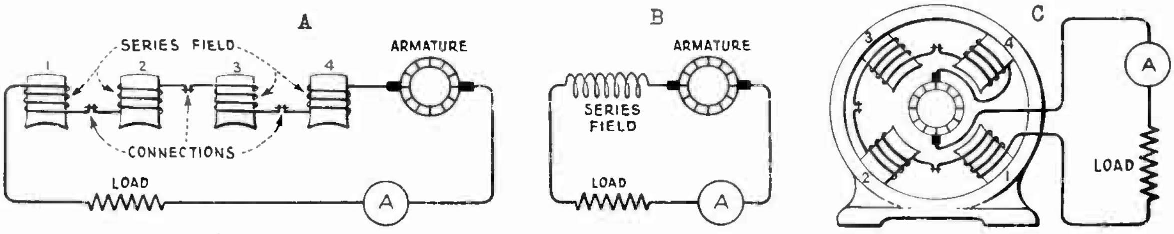


Fig.11-Diagrams illustrating series wound field coil connections

Figures 11A, 11B, and 11C show the connections for a series generator in which the field coils are connected in series with the armature; <u>all</u> the current passing through the armature windings must pass through the field windings as well.

Suppose first we lay four field magnets out in a row as shown in Figure 11A. Connect them all in series and then connect No. 4 to the armature brush; the other field winding terminal, No. 1, goes to the load and meter. The other armature terminal goes to the meter. This is a series connection. Figure 11B is a schematic drawing of the same thing, while in Figure 11C we have placed the coils and armature in a frame. By tracing the circuits you will find "A" and "B" the same.

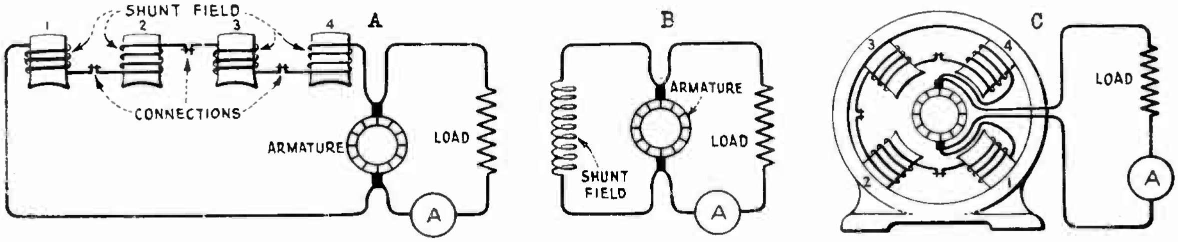


Fig.12-Diagrams illustrating shunt wound field coil connections

The shunt type of D.C. generator is shown in Figures 12A, 12B and 12C. Notice that the field coils are wound in series with each other and connected across, or in parallel with, the armature coils and <u>NOT IN SERIES.</u> The coils are wound with a large number of turns of fine wire as only a small portion of the armature current flows through the field. Figure 12A shows the field coils in a row. Figure 12B is the schematic drawing, and in Figure 12C the field coils are shown placed in the generator frame.

The compound wound generator is a combination of both the series and shunt generators, having both a series and shunt field. The characteristics of both the series and shunt machines are thus combined in one machine and much better regulation of the voltage is secured under all conditions of varying loads.

The series winding is connected in series with the armature and the load as shown in Figure 13A,B and C, while the shunt field is connected in parallel or in shunt, with the armature.

The action of the windings is as follows: When a load is thrown on the generator the shunt field is weakened and at this point the series field helps out by strengthening the shunt field thereby automatically maintaining a constant voltage under a varying load.

The current in the compound wound windings must flow through both the series and shunt windings in the same direction in order that the resultant field will be strengthened.

The electromotive force or voltage generated depends upon the following factors:

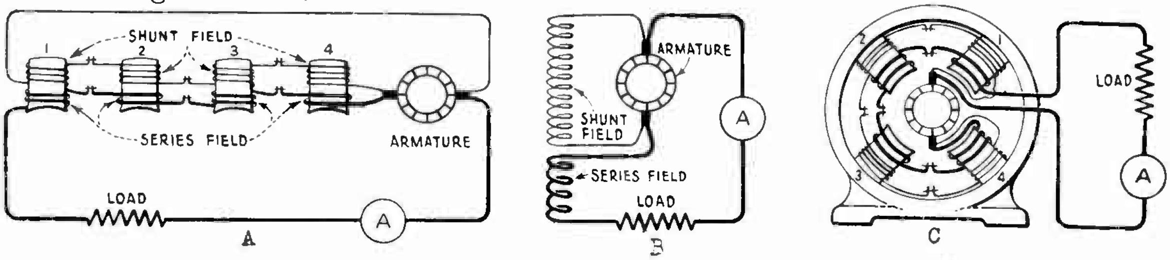


Fig.13-Diagrams illustrating compound wound field coil connections

1st. The number of loops or conductors on the armature revolving in the magnetic field.

2nd. The strength of the magnetic field or lines of force.

3rd. The rate at which the armature carrying the loops or conductors move through this magnetic field.

It is necessary therefore that these factors be given careful consideration to obtain maximum voltage from a generator.

For a detailed explanation of the commutator refer to Figure 9 and the text associated therewith on D.C. motors. Both the assembly and discussion of the commutator is presented.

The brushes used in nearly all types of generators are made of carbon. The hardness and softness depends upon the copper segments of the commutator. A soft copper segment requires a soft carbon brush while on hard copper a hard brush can be used. The degree of hardness of the copper is not changed intentionally; this variation occurs during manufacture and different grades of carbon brushes are made to meet this condition. The size of the brushes primarily depends upon the amount of current being taken from the armature of the generator. If the current is high in value then brushes large enough to easily pass such current must be used. Conversely, if the current is low in value then proportionately smaller brushes are used.

The device holding the brush in the proper place and bearing on the commutator is called the brush holder, a diagram and explanation of which is shown in Figure 14.

This brush holding device is secured to a brush frame from which it is insulated, fitted with a handle, and so arranged as to allow the brushes to be shifted around the commutator. This is called the rocker arm and allows the brushes to be moved at times in order to compensate for distortion of the magnetic field. This is explained under the subject of "armature reaction".

ARMATURE REACTION

Armature reaction is caused by the effect of the magnetic field about the rapidly revolving iron armature and its coils upon the main magnetic field set up by the field coils and this reaction distorts or draws the main magnetic field out of its natural position. The neutral point is thereby changed and the brushes must be shifted to compensate for this reaction. This change in the setting of the brushes is shown in Figure 15.

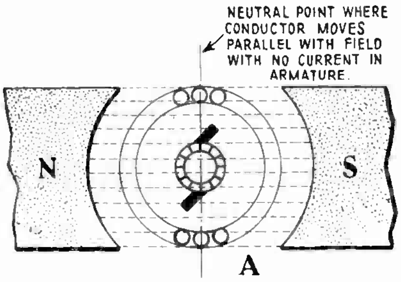


Fig.14-Diagram showing the use of the brush holder

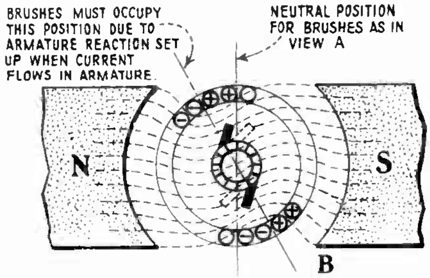


Fig.15-Diagram illustrating required adjustment of brushes to compensate for armature reaction

By referring to the cycle of events in the loop as shown in Figure 6 and the neutral point mentioned there, armature reaction may be more readily understood with the following explanation. The neutral point or plane, you remember, is that point where the armature loop or coil moves parallel with the magnetic lines of force and is the point of zero voltage or where no induction occurs. The current changes direction in the loop at either side of zero position. Armature reaction changes this neutral point, or point of commutation, as it is most generally termed.

Suppose that an armature revolves in a magnetic field with the external circuit open or not connected to the brushes on the commutator. The main field will in this instance remain normal, that is, the lines of force will extend from N to S, or from north to south magnetic poles as shown by the dotted lines in Figure 14. When a load is thrown on the generator the circuit through the armature coil is closed and reaction between the field proper and the field of the armature results. This reaction between the armature field and the magnetic field of the pole pieces causes the normal neutral plane to shift, and it is readily seen that the coils, which are passing the point where the neutral plane formerly existed without any load on the armature, are not moving parallel with the magnetic field but are cutting the lines of force at an angle; see Figure 15. Therefore the brushes must be moved to that new position of the neutral point which results from such distortion of the magnetic field, for at this new point the coils on the armature will be travelling parallel with the distorted magnetic field. The proper adjustment for the brushes is at the "point of commutation". The brushes must be shifted on both generators and motors.

FIELD CHARACTERISTICS

Each of the aforementioned types of field winding produces a generator with different output voltage characteristics.

A voltage characteristic curve for a series wound machine is shown in Figure 16. It will be seen that the voltage output increases with load until a certain load current is reached; at this point the voltage starts to fall off rather rapidly. The reason for this is that the field windings have reached a condition of magnetic saturation so that further increase in current gives no further increase in excitation. In addition the armature reaction is increasing causing a reduction in effective excitation flux. The armature IR drop is also increasing.

The output voltage characteristics of a shunt wound machine are shown in Figure 17. Here it will be noticed that a comparatively high value of E.M.F. is produced even at no load, but the curve falls off gradually until a certain value of current is reached at which point it falls off abruptly. This curve can be kept relatively flat by the use of a rheostat in series with the field which could be used to adjust the amount of excitation for each change in load.

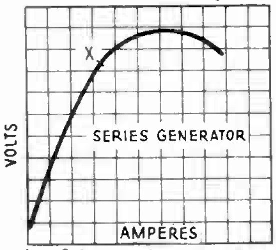


Fig.16-Series wound generator voltage curve

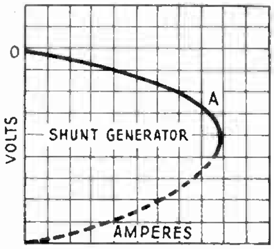


Fig.17-Shunt wound generator voltage curve

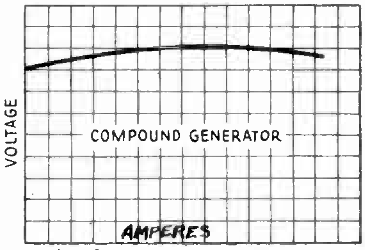


Fig.18-Compound wound generator voltage curve

As the load through the armature increases there is an increase in armature reaction as well as an increase in IR drop through the armature. This causes considerable voltage drop at the armature terminals or brushes reducing the impressed voltage on the field resulting in rather a large decrease in field excitation. The sharp dip in the curve shows where this excessive excitation drop takes place.

By reference to the two curves it will be seen that Figure 16 shows a rising voltage characteristic and Figure 17 a falling voltage characteristic. The compound wound generator which is a combination of the two windings produces a voltage characteristic which is a combination of those shown in Figures 16 and 17. This characteristic is shown in Figure 18 and it will be readily seen that this approaches the ideal characteristic where the generator is to be operated under varying load conditions.

TYPES OF COMPOUNDING

There are in use three types of compound windings:

1. Flat compound; a winding so designed as to keep the voltage constant under wide variations in load.
2. Over-compound; a winding designed to permit the voltage to increase slightly as the load increases.
3. Under-compound; voltage drops slightly as load increases.

THE EFFICIENCY OF D.C. GENERATORS varies from 77% in the smaller sizes to as high as 94% in the larger size units. Efficiency of a generator may be stated as an equation as follows:

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}}$$

or since it is sometimes difficult to measure the input to a generator the equation may be stated:

$$\text{Efficiency} = \frac{\text{Output}}{\text{Output} + \text{Losses}}$$

It is desirable at times to express the voltage regulation of a d.c. generator in terms of percentage. This is stated as a formula as follows:

$$\text{Voltage regulation} = \frac{\text{No load voltage} - \text{full load voltage}}{\text{Full load voltage}}$$

The losses in a generator are three in number, namely:

1. Iron losses (hysteresis and eddy currents)
2. Copper losses (I^2R in armature and field)
3. Mechanical losses (bearing friction and windage)

The watts lost in the iron of the armature are caused by hysteresis and eddy currents.

Hysteresis losses it will be remembered are losses incurred by the reversal of the molecules of iron each time the direction of magnetic flux is reversed. The amplitude of these losses in a generator are dependent upon the number of reversals made per second of the magnetism in the armature core, the amount of iron in the core, the quality of the iron and the density of the magnetism in the iron. Generally the softer the iron the lower the losses due to hysteresis.

Whenever a conductor cuts lines of force an E.M.F. is induced in it. This applies to the armature core as it does to the conductors. These currents tend to flow from one end of the armature to the other under one magnetic pole and return under an opposite magnetic pole. These currents require power to establish and maintain them. This power is expended in the form of heat which tends to heat up the armature and might reach a point where it would prove damaging to the insulation. However by making up the armature of laminations of thin discs and insulating each disc from its neighbor this trouble can be largely eliminated.

The copper losses are the watts lost in the excitation of the field and the losses due to resistance of the armature coils.

The mechanical losses are made up of the friction of the brushes rubbing on the commutator, friction of the bearings and the friction of the air which is called windage.

POSSIBLE TROUBLES

Generators should be watched carefully to correct troubles which may appear unimportant at first but which may later become serious. The most important possible troubles follow:

The bearings of a generator and motor should be kept in good condition; the oil should not be allowed to become gummy. The oil rings should be watched at all times to see that they are carrying oil to the shaft and bearing.

Figure 19 illustrates a bearing and oil rings. "A" is the bearings with the oil rings in the slots fitted loosely on the shaft. The dotted lines show the shaft which carries the rings; as the shaft turns in the bearing the oil rings which rest on the revolving shaft also turn, picking up oil as they rotate and thus splashing the oil onto the shaft. "B" shows the pillow block, the lower half containing the oil well (the rings are shown in dotted lines) the upper half of which is held in place by bolts and is called the "housing" which covers the bearing.

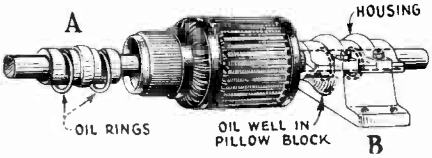


Fig.19-Armature bearings and oil rings

The brushes must be given special care. They should fit into the brush holders in such a manner as to prevent "chattering" and still be free to move up and down.

The spring holding the brushes in contact against the commutator should be examined and adjusted for proper tension to avoid scoring of the commutator by the brush.

Keep the brushes and brush holder free from dust and see that the face of the brush resting on the commutator is fitted properly to the commutator in order that the brush bears evenly at all points against the segments. Should it become necessary to refit the brush to the commutator do so as shown in Figure 20. Lift the brush and place a piece of double 0 (00) sand paper with the smooth side against the commutator. Allow the brush to drop back against the rough or sanded part of the paper, then allow the sand paper to follow the curvature of the commutator and with a back and forth movement the sand paper will cut away the carbon brush, insuring a close fit. The tension of the spring will keep the brush against the sand paper while you are moving it back and forth. This is the only abrasive that should be used for the purpose. DO NOT USE EMERY PAPER. The machine should be so left that it cannot be accidently started during the process of fitting the brushes.

Keep all abrasives, especially those of a metallic nature, away from the commutator and bearings; emery paper will cause short circuits between the segments of the commutator and will cut the bearings if allowed to come in contact with them.

Sparking at the brushes can be caused by high spots on the commutator which should be remedied. Rough or pitted commutators should be turned down on a lathe. Excessive loads at times cannot be avoided, but after such instances the brushes and commutator should be examined and cleaned and given as good care as possible. The mica insulation between the copper segments is often higher than the segments themselves; the mica should then be cut down on a lathe. If the brushes are out of the neutral plane, i.e., point of commutation, they may be correctly adjusted by shifting the

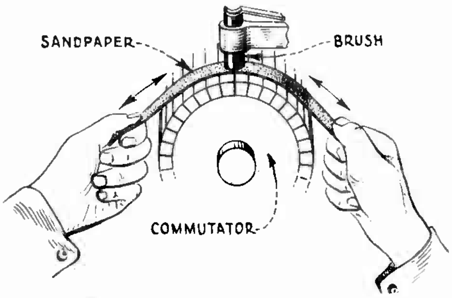


Fig.20-Illustrating method of cleaning and shaping brushes

rocker arm. If a brush becomes wedged in its holder it should be removed and be given a thorough cleaning.

An armature coil which is partially short circuited will cause sparking; this must be located and repaired.

The commutator may at times become extremely hot due to excessive current being drawn from the generator. There is, in this case, only one remedy; reduce the load on the generator to normal.

The armature loops or conductor terminals may become loose in the segments; this raises the resistance of the contact and produces heat.

At times metallic particles become lodged between the segments of the commutator due to gummy oil which has been splashed there from the bearings. The particles come under the brushes and being deposited between the segments, they cause sparking. The commutator and brushes should be cleaned, using clean gasoline on the commutator and polishing with a piece of heavy canvas.

A burned out, or shorted, or grounded armature coil will cause sparking. Tests for locating such trouble will be given you later, together with tests for locating short circuits, grounds and broken connections.

EXAMINATION QUESTIONS

1. Is there any major difference between an electrical motor and an electrical generator?

2. What is the purpose of an electric generator?

3. What grade of emery paper should be used to clean a commutator?

4. What is the purpose of field poles?

5. What is meant by the term "residual magnetism"?

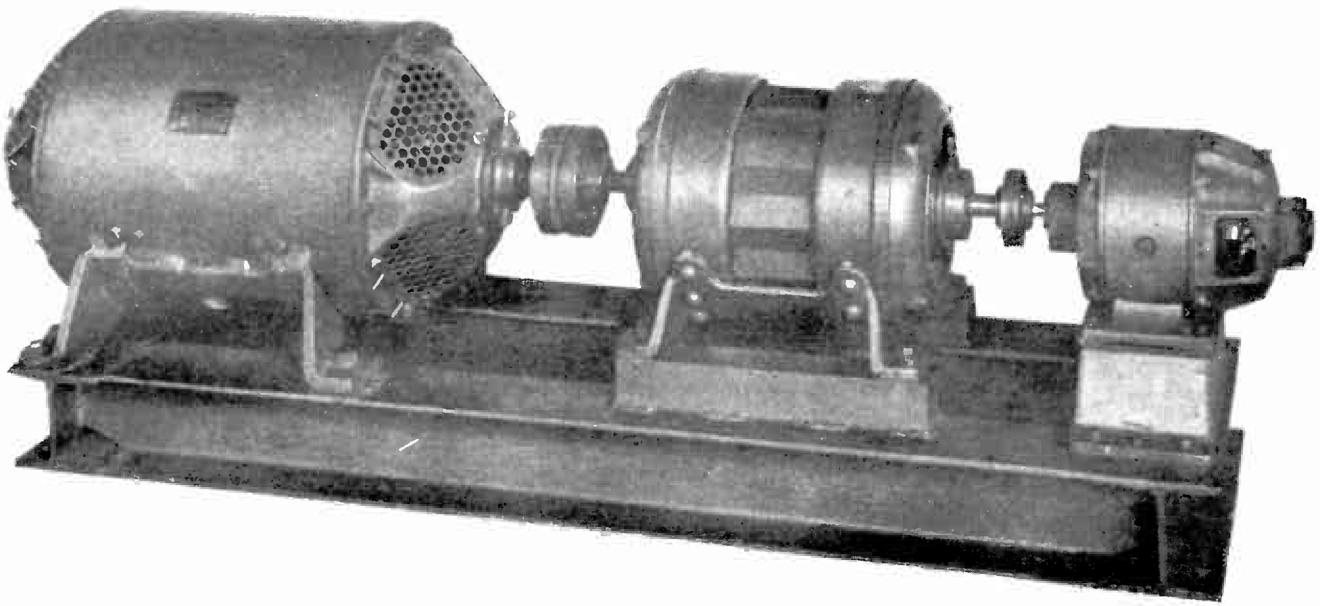
6. Draw a diagram of a shunt generator.

7. (a) What are brushes used for? (b) What care should they receive?

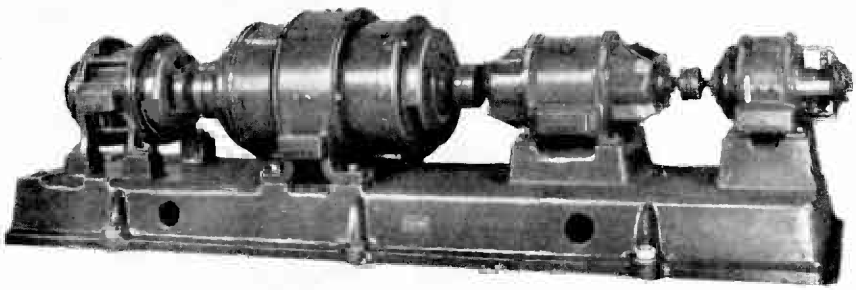
8. Are the bearings of a generator considered important?

9. Suppose the field poles lose their residual magnetism, how would you proceed to overcome this difficulty in order that the generator might be used?

10. What is the purpose of collector rings?



Bias Motor Generator Set
Unit consists of driving induction motor, exciter and two generators on one frame. Each generator has individual fields and controls



Motor generator set consisting of driving motor, high voltage generator, grid bias generator and exciting generator

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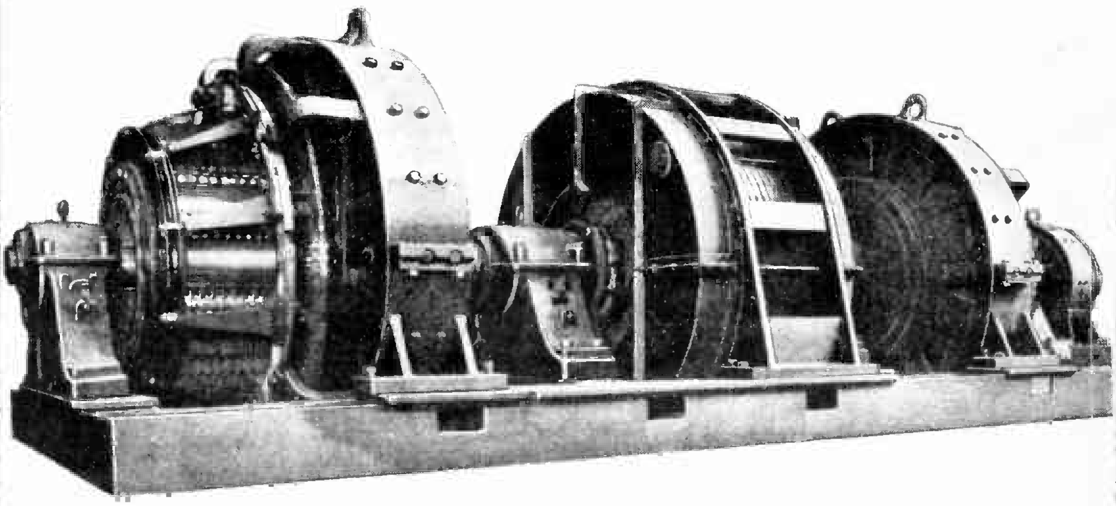

Westinghouse 12,000 Ampere, 3-Unit Synchronous Motor Generator

ALTERNATING CURRENT

Vol.10#10

Dewey Classification R100

ALTERNATING CURRENT

Generators may be classified as follows; alternating current generators and direct current generators. More specifically A.C. generators are often called "alternators", and D.C. generators are called either "generators" or "dynamos".

The electrical energy produced by a coil revolving in a magnetic field is primarily alternating current. When it is desired to obtain D.C. in an external circuit, i.e., current which is steady in value and which moves continuously in the same direction, it becomes necessary to equip the generator with a commutator. The commutator, as you know, allows the current to flow through the external circuit in one direction only.

In radio telegraphy and telephony it is often necessary to utilize alternating current therefore we do not equip the machine with a commutator, but employ slip rings which permits the induced current to flow from the coils of the armature into the external circuit just as it is generated, or as alternating current.

In your lesson on direct current generators you learned that the armature, revolving in a magnetic field, produced alternating currents in the coils of the armature. When one side of the closed coil moved through the magnetic flux of the north pole there was induced in it an E.M.F. which caused current to flow through the armature coil in one direction. The other half of the coil begins to cut the magnetic flux of the south pole of the magnet at the same time which also causes a current to move in this half of the coil for the same reason as caused current flow in the first half.

If the terminals of this revolving coil are connected to a pair of brass rings, or slip rings, and a pair of brushes rest against and make contact with these rings, (to which is connected the external circuit), the induced current can be made to follow the conducting wires forming the external electrical circuit.

In order to better explain the fundamental action going on in the alternating current generator, or alternator, we will consider a single coil instead of an armature containing many coils, and study each effect as it takes place during the revolution of a closed coil, or conductor, through the magnetic field or flux.

Now refer to Figure 1. Here we have arranged a single armature coil; the terminals, as shown, are connected to the slip rings. The rings themselves are held in place by an insulated shaft. The brushes and external circuit are clearly shown and marked.

As the coil is forced to revolve in the magnetic field the slip rings must move with the armature coils, all being mounted on a common shaft. The brushes are stationary and merely serve to provide a sliding contact on the rings.

Side "A" has induced in it an electromotive force as it cuts through the magnetic field, causing the induced current to flow in a definite

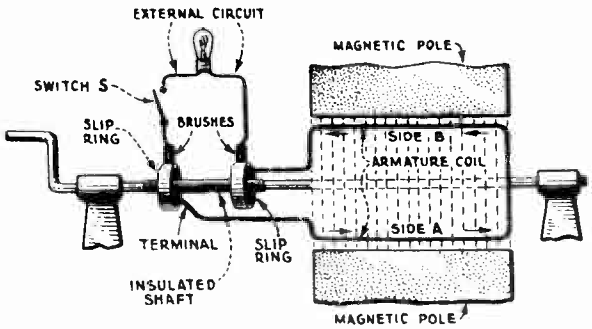

Figure 1

direction as shown by the arrow, if the circuit is closed by closing the switch "S". Likewise side "B" also has induced in it an E.M.F. with current flowing as shown by the arrow.

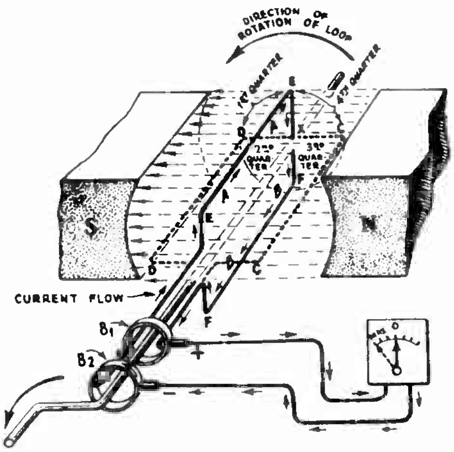

Figure 2

Remember this,-- any wire cutting a magnetic field will have induced in it an induced electromotive force and the current flow is a direct result of this induced E.M.F. but it will not flow until the coil forms a closed loop. Since we know the parts of this simple alternator we can go further and trace the current as it alternates or reverses its direction through the circuit.

Let us study Figure 2 where we have the same piece of apparatus as shown in Figure 1 but drawn in a different position allowing us to see the full circular path of the loop or armature coil through the magnetic field. The side of the coil marked "AA", you will notice, is at the top of the magnetic flux or field at position "EE" while the side "BB" is at the bottom of the field, position "FF".

The meter needle is pointing to zero indicating that while the loop is in this position relative to the magnetic field there is no induced E.M.F. and consequently no induced current will flow because the sides of the loop "AA" and "BB" are parallel with the lines of force and are not cutting the flux.

Before we consider the flow of current suppose we first cause the loop to revolve to show the positions the side "AA" will assume during a complete revolution of the coil. "AA" side of the loop is shown at the position "EE". The loop begins to revolve in a counter clockwise direction, shown by arrows, on its shaft "X", and immediately begins to cut the lines of force or flux of the "S" pole of the magnet.

When it arrives at position "DD", the end of the first quarter revolution, it will be cutting the maximum number of lines of force, leaving position "DD" it cuts less lines of force until at position "FF", the end of the second quarter of revolution, it is again parallel with the lines of force, cutting no flux.

Continuing into the third quarter of revolution it again cuts the magnetic flux, upward this time, gradually cutting the lines of force at a greater angle each fraction of upward movement until at position "CC", or end of the third quarter of revolution, it will be cutting the greatest number of lines of force under the "N" pole or magnetic field of north polarity.

Leaving position "CC", and continuing into the fourth and last quarter of revolution, less and less lines of force are cut per unit of time and, upon arriving at position "EE", the end of the fourth quarter of revolution, it is again parallel to the magnetic field and no lines of force are being cut.

This completes one revolution of the coil through the magnetic field. The loop can be rotated another full revolution and the same cycle of events would be repeated over again.

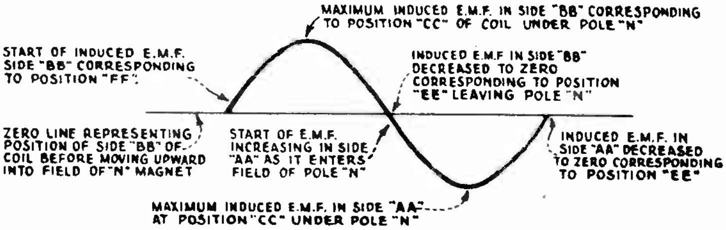

Figure 3

On the second journey of the loop we are going to study how the induced E.M.F. is affected by the cutting of the lines of force,- how it rises from zero strength to maximum strength, and then falls again to zero value.

On the second revolution we will concentrate upon side "BB". The armature starts, "BB" moves upward into the north magnetic field and, because of the cutting of the lines of force, it has induced in it an electromotive force, the strength depending upon the speed it moves and upon the strength of the magnetic field through which it travels.

The induced electromotive force will cause current to flow in this side of the loop in the direction shown by the arrows, making brush "B1" positive. The current increases in strength due to the increased electromotive force induced by the greater number of lines of force cut per unit of time, until the coil reaches position "CC". Here the maximum number of lines of force are cut and the maximum electromotive force is induced. Therefore the maximum current strength possible is obtained at this position, assuming the field to be uniform and the speed constant.

While side "BB" has moved to position "CC", side "AA" has moved into position "DD". An E.M.F. and current is induced in "AA" exactly as in side "BB", but opposite in direction, as shown, making the brush "B2" negative. The resulting induced current has moved through the circuit causing the meter needle to move to the left, pointing to maximum.

Side "BB" now moves out of the maximum field position "CC", cutting less lines of force per unit of time as it moves toward position "EE", therefore less E.M.F. is induced and consequently the induced current decreases in strength, until it reaches "EE" where no lines of force are cut and the E.M.F. drops to zero as indicated by the needle of the meter when it returns to zero position.

We may plot this rise and fall of current taking place in side "BB" of the coil as it passed under the north pole of the magnetic field, as shown in Figure 3, by a curved line which moves upward from zero to a maximum height and then as gradually decreases again to zero.

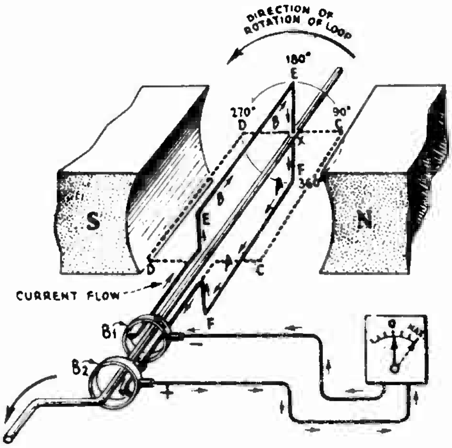

Figure 4

The position of the loop now indicates side "BB" at position "EE" and side "AA" at position "FF". "BB" now moves downward, under the influence of the south magnetic field, and the current induced flows through "BB" and the external circuit opposite to the direction of flow when "BB" was under the north magnetic field. See Figure 4.

The induced E.M.F. rises from zero to maximum and falls again to zero as the coil was moving under the "N" pole, and as shown by the meter needle which has moved across the scale, this time to the right, returning to zero when side "BB" has reached position "FF"; this reversal of current flow will cause the needle to move in the opposite direction.

In Figure 3 we have shown a sine curve which graphically illustrates the continuously varying values of E.M.F. induced in the conductor as it moves through the magnetic field.

VALUE OF E.M.F.

The value of the induced E.M.F. depends upon the following factors:

1st. The number of conductors revolving in the field.
2nd. The strength of the magnetic field.
3rd. The rate at which these lines of force constituting the magnetic field are cut.

In our simple alternator only one conductor was used and we assumed the field strength to be constant.

TIME A DETERMINING FACTOR OF INDUCED E.M.F.

We may now consider the rate at which the lines of force are cut and why the value of the induced E.M.F. varies as the armature coil completes a revolution through the field.

In Figure 5 we have a diagram intended to show how time, or the rate of cutting the field, and the field strength, determines the value of the E.M.F. It is obvious, after studying Figure 5, that a conductor moving through the magnetic field, either from "A" directly to "C" or along the path "A", "B", "C", will cut exactly the same number of lines of force, both having moved through the entire field, and both having cut every line of force in the field. The distance, however, from "A" to "C" is shorter by approximately two thirds the distance than along the path A, B, C.

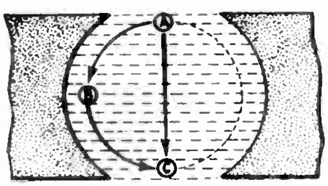

Figure 5

Now assume that the conductor is moving at a speed requiring one second of time to travel from "A" to "C" thereby cutting through all the lines of force with a definite value of E.M.F. being induced. At the same speed it now follows the path A, B, C, and, this path being fifty percent longer than path A, C, it requires 1 1/2 seconds of time to complete the distance. All the lines of force are cut, but at a slower rate, therefore less lines of force are cut in one second in this path than the path "A", "C", and less induced E.M.F. will be the result.

The rate at which the lines of force are cut then in a given time is also going to depend upon the angle at which the conductor moves through the field. When the conductor moves from "A" to "C" every line of force is cut at right angles and, at the given speed of one second , the induced E.M.F. is maximum.

Now revolve the conductor through path A, B, C; it is obvious that as the conductor leaves "A" it is moving nearly parallel with the magnetic field. As it progresses towards "B" its path becomes more nearly at right angles to the field and an increasingly greater E.M.F. is induced, until at "B" the conductor is moving directly at right angles to the field and, at this point, the induced E.M.F. is at its highest value.

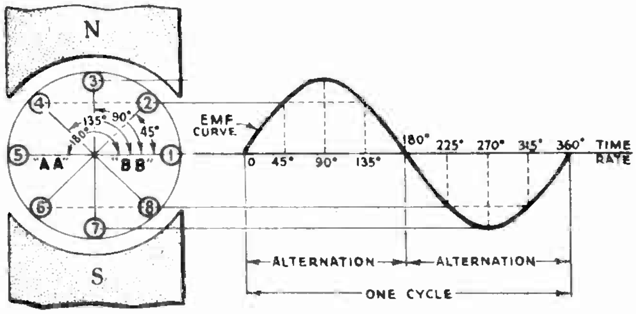

Figure 6

On leaving "B" the conductor ceases to cut the lines of force at right angles and, as it progresses from point "B" to "C", it cuts the lines of force less and less at right angles, consequently the induced E.M.F. gradually decreases until at "C" the conductor is again parallel to the field and induction ceases, with a consequent cessation of induced E.M.F. and current flow.

TIME RATE EXPRESSED IN DEGREES

The armature coil is so arranged on the armature core that it must describe a complete circle in the magnetic field. In the construction of a sine curve indicating alternating current this is expressed as the time rate in degrees.

In any complete circle there are 360 degrees and, if we wish to show the increase and decrease of induced E.M.F. in an armature coil in successive steps, we may do so by dividing the circle so described by the armature coil through the magnetic field into degrees of time. This will be explained with the assistance of Figure 6.

When the side of the coil "BB" is in position 1 Figure 6, in the magnetic field, no flux is being cut, hence no E.M.F. is induced in the coil. At this point of the base line representing time rate in degrees, we start our E.M.F. curve. The coil now moves from position 1 to 2, or 45 degrees, and cuts the flux and, the induced E.M.F., being of positive polarity, is plotted above the base line.

Now draw a vertical line from the base line until it intersects the horizontal line extending from position 2 of coil "BB" to the right and parallel to the base line. The point of intersection will indicate the rise of the induced E.M.F. of coil "BB" and by connecting this point and "45 degrees" on the base line we show graphically the rise in the induced E.M.F.

The coil now reaches position 3, or 90 degrees from position 1. A vertical line is erected from 90 degrees on the base line and the horizontal line drawn from position 3. From the point where these lines intersect another line is drawn to the 45 degree position indicating the amount of increase that has taken place.

As the coil proceeds we plot position 4, or 135 degrees, and from your study of Figure 2 you know that the induced E.M.F. is now decreasing. When position 5 is reached (180 degrees) no E.M.F. has been induced in the coil. This completes the first alternation of E.M.F. Side "BB" now continues to rotate and, upon passing through points 6, 7, 8 and back to 1, (the starting point), it completes one revolution. During the last half of this revolution exactly the same inductive action takes place as in the first half revolution but with this difference; the current induced in the side "BB" now flows in the opposite direction, for the side "BB" is now under the influence of the south pole and not the north pole as in the first half revolution. This reversal of the current flow is clearly shown in Figure 6. As already mentioned, the inductive action is the same and, therefore the procedure of plotting the value of the induced current upon the curve is the same as for the first half revolution of this coil.

ALTERNATIONS, FREQUENCY AND CYCLES

The induced E.M.F. in side "BB" rises from zero to maximum value between 0 degrees and 90 degrees then falls in value from 90 degrees until zero is again reached at 180 degrees; this is termed an alternation. From position 5 to position 1 side "AA" has induced in it an E.M.F. which changes in value similar to that in side "BB".

This rise and fall in the value of the induced E.M.F. takes place twice during each complete revolution of the armature coil. In every cycle, then, there are two alternations of E.M.F., i.e., one positive and one negative alternation. The frequency of an alternating current generator is expressed in cycles per second.

When the coil "AA", "BB", rotates 60 complete revolutions per second 120 separate reversals of current per second are induced therein and since one cycle consists of two alternations, or reversals, the FREQUENCY of the current is said to be 60 cycles per second.

This is only true in the case of our simple alternator which employed two field poles. In most commercial alternators, however, you will find more than two field poles and, as the speed and the number of field poles determine the frequency, we are going to give you a simple formula whereby you can easily determine the frequency of any alternating current generator.

The frequency will equal the number of poles in the alternator multiplied by the speed at which the armature revolves and divided by the alternations per cycle - which is always two. We must not overlook the fact that if we wish to know the frequency in cycles per second, the speed of the generator must be given in revolutions per second. In working out this formula for cycles per second it is necessary, therefore, to change the speed of the generator to revolutions per second and this is easily done by simply dividing the speed (as stated in RPM) by 60.

Assume that our simple two-pole alternator of Figure 2 revolves at the speed of 3600 RPM, what will be the frequency of the generated alternating current?

Write down your formula in this fashion; $F = \frac{N \times S}{2}$, where F = frequency, N = number of poles and S = the speed of the machine in revolutions per second.

If the speed of the alternator is 3600 RPM then its speed in revolutions per second will equal $\frac{3600}{60}$, or 60 revolutions per second.

Substituting these values in the formula we have $F = \frac{2 \times 60}{2} = \frac{120}{2} = 60$.

Therefore, F (frequency) is 60 cycles per second.

The majority of commercial alternators have more than two poles and it is just as easy to find the frequency of a multi-pole machine as it was to find the frequency of our simple two-pole alternator. Simply substitute the known number of poles for N and also the other known values in the formula and solve as shown above.

PHASE

The phase of an alternating current wave can be any point on that wave.

You learned in plotting the sine curve of Figure 6 that degrees were used to denote time as regards the values of the E.M.F. and current as they rise and fall during each alternation. Hence, the term "phase" may also refer to time. More specifically, phase may also be said to be the time instant when some maximum, zero, or any intermediate value is reached by the wave.

In Figure 6 we used 45 degree intervals so in further describing phase we will also use 45 degree intervals of time and illustrate it in Figure 7. The phase, "A" "A'", unless otherwise specified in such a curve, is regarded as a 360 degree phase; that is, the phase begins at 0 degrees and ends at 360 degrees.

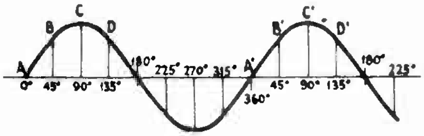

Figure 7

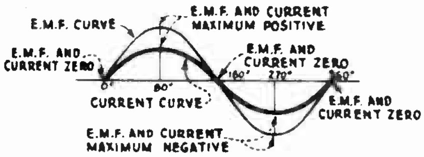

Figure 8

Any other point may constitute the phase of the curve, such as "B" and "B'" which is a 45 degree phase, "C" and "C'" a 90 degree phase, "D" and "D'" a 135-degree phase, and so on.

PHASE RELATIONS, CURRENT AND VOLTAGE

The current of the alternator alternates as well as the E.M.F. and will have the same general form as to frequency etc., and both current and E.M.F. can be plotted from the same base line. The circuit through which the alternating current flows will have, however. an influence on the current and will either cause the current to lag or lead the electromotive force. Capacity and inductance are the determining factors in regards to the lag or lead of the current. This will be taken up in detail in a later lesson.

In this lesson we will show you three curves having different phases. The first, shown in Figure 8, is one which would be obtained in an alternating current circuit where resistance only is present in the circuit. Notice the E.M.F. and current curves. Both start to rise at the same instant and continue to rise and fall keeping in step with each other throughout the cycle. In other words, they are in phase with each other. This condition, as stated, results only when pure ohmic resistance is present in the circuit.

Figure 9 illustrates the resulting effect on the current when pure inductance only is in the alternating current circuit, and in this case causes the current to lag behind the voltage or E.M.F. by 90 degrees. In other words the retarding effect of inductance prevents the current from starting through the circuit until after the E.M.F. has increased in value corresponding to 90 degrees.

Figure 10 illustrates the phase relationship between the current and the E.M.F. when pure capacity only is present in the circuit. In this instance the action is quite the opposite of that when the alternating current was flowing through pure inductance, i.e., the current now leads the voltage by 90 degrees.

These curves simply show graphically how, first, a current and E.M.F. which is in phase is depicted and, second, how the current is out of phase with the E.M.F. by 90 degrees with the current lagging the E.M.F. and, third, the current leading the E.M.F. by 90 degrees.

The reasons why this phenomena is apparent will be taken up in detail later on.

EFFECTIVE CURRENT AND VOLTAGE

The ampere is the unit of electrical current flow and we told you that it was the rate of unit flow that would pass through a resistance of one ohm at a pressure of one volt. More correctly it is stated as follows: "The ampere is that unvarying current which, when passed through a solution of nitrate of silver in water, will deposit silver at the rate of 0.001118 grams per second." From this standard method we may determine exactly the amperes flowing in a D.C. circuit.

We are, however, dealing with alternating current and you know alternating current varies, changing its value every instant of the cycle and reversing its direction every 180 degrees, or each alternation. This standard of measurement cannot, therefore, be used in determining the amperes in an A.C. circuit. The first alternation would deposit a certain amount of silver, true enough, but the next alternation would be opposite in direction to the first and it would take away the silver just deposited. For that reason some other means of finding the current in amperes in an A.C. circuit must be used.

This may be determined by the heat produced. We know the effect of heat is entirely independent of the direction of the current producing it and as alternating current has no special unit of its own we will use the direct current ampere as a unit for comparison purposes.

With that in mind we can say than an alternating current is equivalent to a direct current when it produces the same average heat effects, contingent upon exactly similar conditions. This is called the effective value of alternating current, measured in amperes, and is the value which is measured by alternating current measuring instruments. Heat is present in a current carrying wire regardless of the amount of the current flowing. Heat is produced even though you may not be able to physically detect it. It is known that the heating

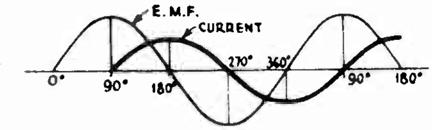

Figure 9

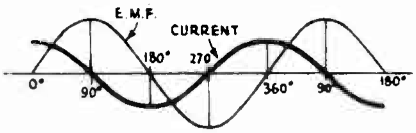

Figure 10

effect of an unvarying current in a circuit of fixed resistance varies as the current squared. For example, Figure 11, we have shown a current curve and heat curve; at any instant the heat effect is equal to the current squared.

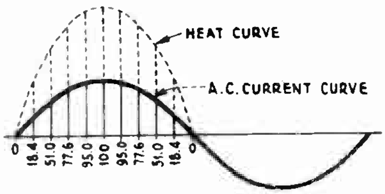

Figure 11

Since the heating effects of an electric circuit is equal to the current squared (I^2), then to find the heat effects of our curve, Figure 11, we must find the square of each individual current value over the alternation. This we do and then extend dotted lines above the verticals proportional to each squared current value. Connecting the ends of these extensions by a line we have a second curve which is the heat curve. It is necessary now to obtain the average of these heat squares which is done by dividing the sum of the squares by 9, since we have 9 instantaneous values of current.

The square root is now found of this average which gives us the final result,- the effective current. It is this result which is read by all electrical meters and is the current useful in calculating the power of the circuit.

It is not likely you will, in your practical work, have occasion to do work of this kind. It is done here simply to show you how it is calculated because this forms the basis from which all alternating current and voltage values are found. The step by step solution follows: Taking the values of instantaneous current values from the curve we write:

1st	instant	of	value	18.4
2nd	"	"	"	51.0
3rd	"	"	"	77.6
4th	"	"	"	95.0
5th	"	"	"	100.0
6th	"	"	"	95.0
7th	"	"	"	77.6
8th	"	"	"	51.0
9th	"	"	"	18.4

and squaring the above current values we have:

18.4	=	338.56
51.0	=	2601.
77.6	=	6021.76
95.0	=	9025.
100.0	=	10000.
95.0	=	9025.
77.6	=	6021.76
51.0	=	2601.
18.4	=	338.56

The sum of these squares equals:

```
   338.56
  2601.00
  6021.75
  9025.00
 10000.00
  9025.00
  6021.76
  2601.00
   338.56
 --------
 45972.64
```

Dividing the sum of the squares by 9 to obtain the average of these squares:

```
9)45972.64(5108.071
  45
  --
   9
   9
   --
   72
   72
   --
    64
    63
    --
     1
     9
```

Extracting the square root of the average squares:

```
   71.47
 √5108.0710
  49
  ---
   208
   141
   ----
    6707
    5696
    ------
    101110
    100009
```

which equals 71.47 the effective current.

The effective voltage has the same relation to the maximum voltage that the effective current has to the maximum current and is found in the same manner. You will note that the effective current is less than the maximum current.

In dealing with voltage the effective voltage is also less than the maximum voltage, because the maximum voltage reaches a higher potential than the effective voltage. This accounts for the insulation requirements of an A.C. circuit being higher than in a direct current circuit.

POWER

The power of an alternating current circuit is expressed in watts just as in direct current circuits and is found by multiplying the current by the voltage. Thus, W = I x E.

This only holds good in a circuit where resistance only is present; in other words, the current must be in phase, or in step, with the voltage, as illustrated in Figure 8. When the current lags or leads the E.M.F. due to the presence in the circuit of inductance or capacity, or both, a power factor is used which is the ratio of the true watts to the apparent watts (the watts you would obtain by multiplying the volts by the amperes). In other words it is the ratio between the useful current and total current.

The formula for finding the POWER FACTOR follows: $\text{POWER FACTOR} = \frac{\text{RESISTANCE}}{\text{IMPEDANCE}}$

EXAMINATION QUESTIONS

1. Is alternating current necessary for the operation of a radio transmitter?

2. What are "slip rings" and why are they used instead of a commutator?

3. Explain the fundamental action of an A.C. Generator.

4. Upon what factors does the value of E.M.F. of a generator depend?

5. (a) What is an alternation? (b) A cycle?

6. (a) What is frequency? How is frequency determined?

7. What is the meaning of "Phase"?

8. What is meant by "effective value" of A.C.?

9. What is meant by the term "power factor"?

10. What is the relation of voltage and current when only actual (ohmic) resistance is present in an A.C. circuit?

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Motor-Generators and Other Machine Converters

VOL. 10, No. 11

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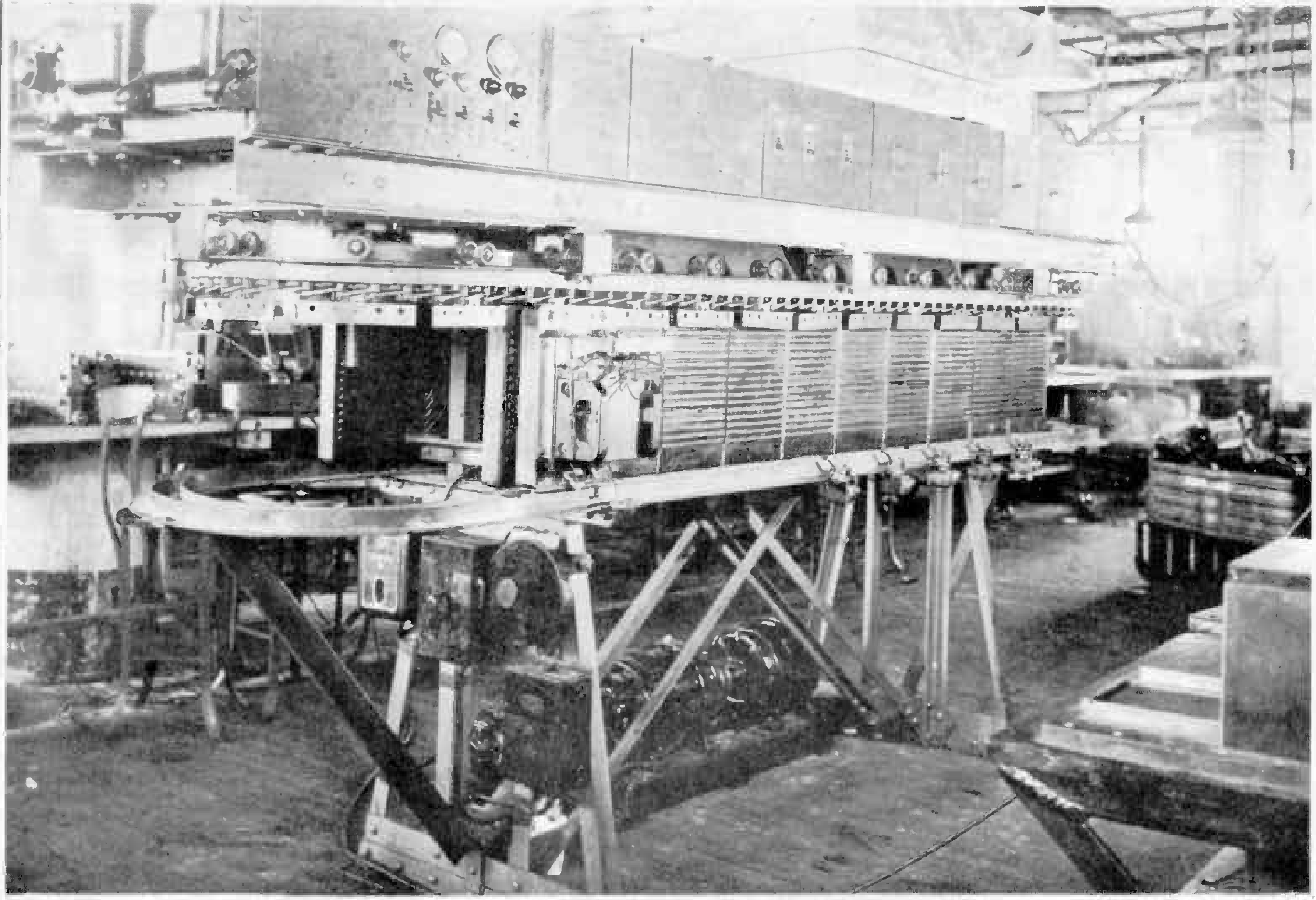


THE MOTOR-GENERATOR USED WITH THIS EQUIPMENT PROVIDES UNUSUAL VOLTAGES FOR TESTING THE POWER TRANSFORMERS CONVEYED ALONG THIS AUTOMATIC TESTING MACHINE

MOTOR-GENERATORS AND OTHER MACHINE CONVERTERS

Along with the many varieties of electrical circuits which require either a-c or d-c for their operating power we frequently encounter different types of rotating machines used for the conversion of electrical energy from a-c or d-c sources into the a-c or d-c form at different voltages and frequencies according to requirements. In this lesson we deal with three principal types of converting machines which are named and defined as follows:

I. MOTOR-GENERATOR, consisting of a motor and one or more generators which have their shafts coupled together for a mechanical transfer of power, but which have no magnetic fields in common. This means that each machine is complete in itself as far as armatures, armature conductors, and field structures are concerned.

II. ROTARY CONVERTER, which is a single machine with one armature, one magnetic field, and only one set of armature conductors, which serve for both the driving and the generating functions of the machine.

III. DYNAMOTOR, which is a single machine with one armature and one magnetic field, but whose armature bears two sets of conductors, insulated from each other. One set acts with the common magnetic field to provide the driving action; the other set acts with the common field to generate the desired voltage.

The usual forms of conversion may be classed according to their purpose as follows:

A. Direct current to direct current of a different voltage.

B. Direct current to alternating current of a desired frequency and voltage.

C. Alternating current of an available frequency and voltage to a direct current of a desired voltage.

D. Alternating current of one frequency to alternating current of another frequency.

It is to be understood that alternating current at a certain voltage and frequency may be converted to a.c. at another voltage but of the same frequency by means of a machine, and such a conversion may be accomplished without rotating parts by employing a power transformer. The theory of power transformers is outside the scope of our present lesson, which will be limited to the three machine types listed above.

MOTOR-GENERATORS

When the shaft of a motor is coupled to the shaft of a generator, there is no difference in the fundamental design of either the motor or the generator. For purposes of mechanical rigidity they are mounted on a common base.

Fig. 1 shows a common form of motor-generator, the motor being at the left of the illustration. The method of coupling the two machines together is clearly shown, together with the housing for the bearings used to support the shafts of the motor and the generator. In this case the motor and generator have independent bearings.

In some machines the coupling plate used is a specially prepared disc of flexible material which will withstand the twisting strain of the motor shaft turning the generator armature. This allows for small irregularities in the alignment of the shafts. Where a solid mechanical connection is made the tightening of the bolts in the coupling device might easily throw the shaft out of alignment causing it to bind on one or more of the bearings. In Fig. 2 is illustrated the general outline of the motor-generator, all bearings and bearing housings being omitted for the sake of clearness.

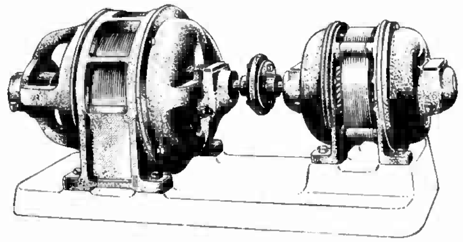


Fig. 1 - A MOTOR AND GENERATOR COUPLED TOGETHER

The general features of a machine employed for the conversion of direct current to alternating current can be grasped from the sketch in Fig. 2. Note the names and purpose of various parts which go to make up a machine of this kind as outlined in the legend given below

1. The switch controlling the direct-current supply.
2. The leads connecting the main line current supply with the motor armature.
3. The direct-current motor.
4. The armature of the motor.
5. The commutator of the motor.
6. The motor brushes.
7. The motor shaft.
8. The leads running from brushes supplying current to the motor field windings.
9. The motor field coils.
10. Motor coupling plate secured to motor shaft.
11. Flexible material used between metal coupling plates.
12. Leads from direct-current source supplying the field coils of the alternator.

13. Alternating-current generator.

14. A-C generator field coils.

15. A-C generator armature.

16. Generator coupling plate secured to generator shaft.

17. Collector rings of generator.

18. Generator shaft to which collector rings are secured.

19. Collector ring brushes which lead current from collector rings into external circuit.

20. Alternating-current leads to external circuit.

The motor shown is of the shunt wound type and receives its power from the available d-c power mains, usually at 110 volts. Note, at

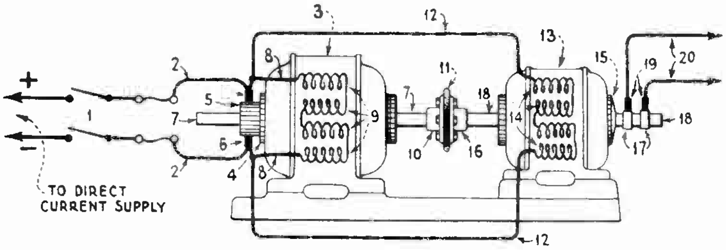


Fig. 2 - SHUNT-WOUND MOTOR COUPLED TO AN ALTERNATOR WITH ITS FIELD IN SHUNT TO THE D-C SUPPLY

this point, that the a-c generator field coils are connected with the same d-c supply which is driving the motor, direct current being necessary to excite the field coils of the alternator. In some installations, however, a small exciting generator is used which is driven from the motor shaft by a belt or directly coupled thereto. In practical work we find machines rated at different frequencies and voltages according to the design and purpose for which they are intended. The few examples which follow will serve to illustrate this point: Motors designed for 110-120 volt, 60 cycle a-c operation are extensively used; d-c generators which supply voltages from about 15 volts to 1000 volts are used to operate certain types of vacuum tube circuits; generators supplying 500 cycle a-c to power transformers have limited use in certain older types of radio telegraph (spark) transmitters; in certain sections of the country 25 cycles is the standard frequency used for industrial electrical equipment and so on. In sound picture practice the load on the alternator is practically constant and, therefore, the simple shunt-wound units in the above assembly will be satisfactory.

The requirements for a motor-generator used in radio telegraph communication are constant frequency and steady voltage under varying load conditions. The load on the generator is caused by the closing of the telegraph key which allows current to flow to the alternating-current transformer of the transmitting set. The load, therefore, is intermittent in character and when the key is closed the full amount of current is drawn from the generator immediately. There is no gradual increase of load; it is thrown on suddenly and discontinued just as abruptly.

Hence, it can be readily appreciated that some means must be provided to maintain a constant frequency output and constant voltage and, where possible, both conditions should be met. This calls for a self regulation which is secured by the manner in which the field coils of the motor generator are designed.

It now becomes necessary to divide the motor-generator equipment into three separate classes according to the field coil connections.

The first type, shown in Fig. 2, is a shunt wound motor coupled to an alternator with its field in shunt to the d-c supply; second, the same type of motor coupled to an alternator having compound field windings; third, the simple a-c generator of the first type driven by a motor having compound field windings. Let us consider these three divisions by studying the simple schematic drawings of Figs. 3, 4 and 5.

Before proceeding further, let us advise that if you are not already familiar with the electrical symbols, place the sheet bearing these symbols before you when studying the motor-generator diagrams.

Fig. 3 is the diagram of a simple shunt wound motor-generator set; it has the same field and generator connections as shown in Fig. 2. The parts are all clearly labeled. You will notice two field current regulating rheostats — one in the motor field circuit and one in the generator field circuit. We will explain the operation of these two rheostats.

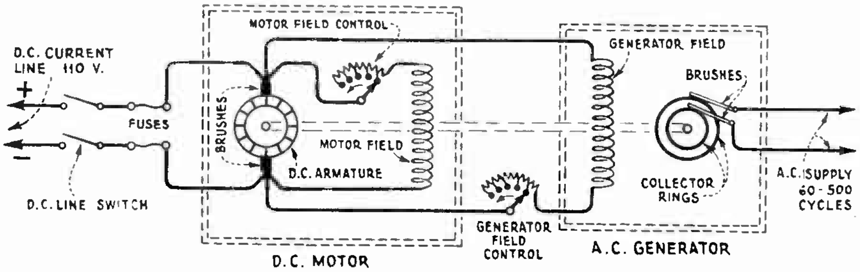


Fig. 3 - SIMPLE SHUNT WOUND MOTOR-GENERATOR SET

Beginning first with the motor field, if we turn the rheostat to the left as indicated by the arrow more resistance will be added to the field circuit, and this will reduce the current flowing in the motor field windings. This weakens the magnetic field which results in the motor speeding up, and since the generator is coupled to the motor the generator speed will also increase. It is very evident that the frequency output of the generator will be increased because its frequency depends upon its speed. By reversing this procedure, that is, decreasing the motor field resistance by turning the rheostat arm again to the right, the opposite effect is produced. In this case the motor and generator both slow down and, therefore, the frequency of the generator is reduced.

Now go through the same procedure with the generator field rheostat; turn it to the left as shown by the arrow thereby cutting in more resistance. Naturally, the result is a decrease in the current intensity in the generator field which reduces the generator output voltage. Reversing this process, that is, decreasing the generator field circuit resistance, will increase the field strength and consequently raise the output voltage.

Keep in mind the results just explained when introducing resistance in a generator field circuit and in a motor field circuit. Be sure that you fully comprehend the two actions and do not confuse them.

In Fig. 4 we have a shunt wound motor and compound wound generator; the motor and generator shunt fields have adjustable rheostats connected in their circuits enabling the speed of the motor to be regulated and the voltage of the generator to be controlled. When the desired speed of the motor is secured and the proper voltage output of the generator is obtained, these rheostats are left in that position.

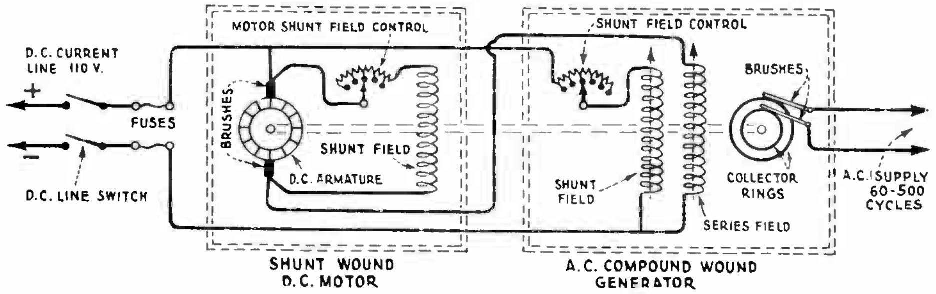


Fig. 4 - SHUNT WOUND MOTOR AND COMPOUND WOUND GENERATOR

The shunt and series field windings of the generator are connected in such manner that the field of the series winding and that of the shunt winding are in the same direction, i.e., of the same polarity. The motor-generator is subject to sudden loads when the telegraph key is closed and when this happens there is a tendency toward a decrease in speed. A decrease in speed causes an increase of current flow through the series winding, because the series winding is in series with the armature of the motor. This increased current flow through the series winding strengthens the field of the generator at once and it tends to restore the voltage to normal. Thus, in this type of motor-generator the speed of the motor and voltage output of the generator are maintained fairly constant under sudden variations of the load.

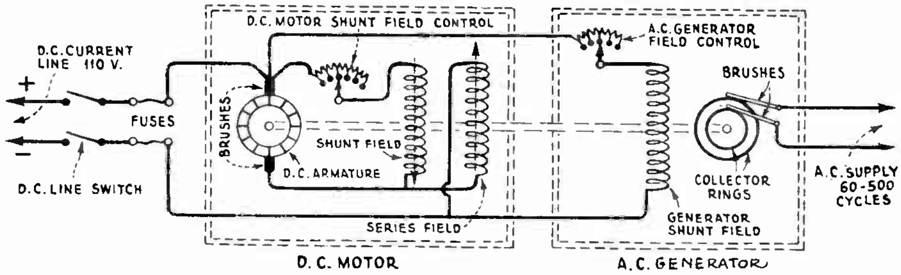


Fig. 5 - A DIFFERENTIALLY COMPOUND WOUND MOTOR COUPLED TO AN A-C GENERATOR

Now let us look at Fig. 5. The motor in this case is differentially compound wound. In other words, the magnetic field due to the shunt winding is opposed by the field due to the series winding, as determined by the relative directions of their turns about the field poles and the direction of current flow through the windings. Let us analyze the effect when the field of the series winding opposes the field of the shunt winding of this motor.

when a load is thrown on the generator in Fig. 5 the speed of the motor is reduced, thereby decreasing the counter e.m.f. As the shunt field winding is connected across the line, its current tends to remain normal, and the field flux due to the shunt winding, therefore, does not change. However, as the series winding is connected in series with the armature, the series winding will receive the increase in current caused by the lowered counter e.m.f. of the armature. The field flux due to the series winding will, therefore, increase. Since this flux opposes the main field flux which is due to the shunt winding, we find that the motor field as a whole will be weakened. This allows the motor to gain speed at once, building up the counter e.m.f. until a steady state has been reached with the motor running at its normal speed.

There is even a condition under which the generator will produce a higher frequency under load than when the load is removed. This occurs when the motor is "over-compounded". This term describes the effect of having the series winding wound with so many ampere-turns that the field flux created by it offers a considerable opposition

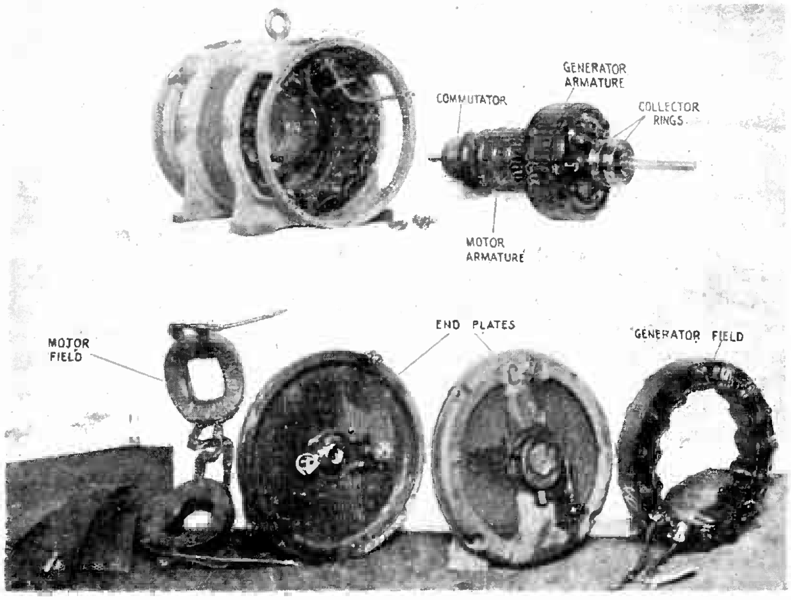


Fig. 6 - A DISASSEMBLED VIEW OF A CROCKER-WHEELER MOTOR-GENERATOR SET

to the field flux due to the shunt winding. Under this condition, when the load is applied, the motor field as a whole is so weakened that the machine comes up to a steady speed in excess of its no-load speed. This causes the generator frequency to increase as the load is applied; for a radio transmitter this is as objectionable as for the frequency to shift lower, under load.

In Fig. 6 is shown a disassembled d-c to a-c motor-generator of the 2 kw. Crocker-Wheeler type as used in some shipboard installations. It will be noted that the shaft is in one piece and carries both the motor armature and the generator armature. Their magnetic fields are effectively separated by suitable spacing along the shaft, which maintains the distinguishing quality of a motor-generator as compared to rotary converters and dynamotors. These latter have a common armature and common field structure for the motor and generator functions.

It is often difficult to tell the three types apart from a casual inspection of their exteriors.

D-C TO D-C MOTOR-GENERATOR SETS

When a d-c generator is driven by a d-c motor the generator field may be supplied by the d-c power mains (as in the case of the alternator previously described) or the generator may be self-excited. When several generators are coupled to the same motor a further variation in practice may occur. One d-c generator of the group may provide the field excitation for another generator, whether the latter is d-c or a-c as to its output. The use of such a connection is dictated by common sense in the designing by the manufacturer.

This might occur especially in the case of a high-voltage d-c generator, whose field is designed for separate excitation at a much lower voltage as a measure of safety and economy in the use of wire and insulation. If the voltage of the supply mains is lower than the normal voltage required for that field, the latter may be excited by another d-c generator. This may have been added for that purpose alone, or it may have been required for some other electrical purpose concerned with the equipment.

An example of this practice is shown in Fig. 7, which shows the four-unit motor-generator set used with early sound-picture installations of the type PG-1 and PG-2. The 15 volt d-c generator is

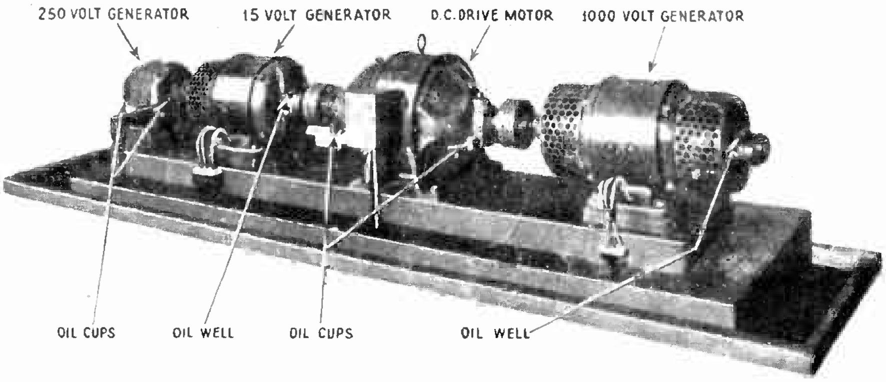


Fig. 7 - A FOUR-UNIT MOTOR-GENERATOR SET DESIGNED FOR SOUND PICTURE EQUIPMENT

required for filament voltages, the 1000 volt d-c generator supplies plate voltage for the last several stages of the amplifier, and the 250 volt d-c generator provides grid bias voltage for the output stage. This 250 volt machine is self-excited, and in addition provides the field excitation voltage for both the 15 volt and the 1000 volt generators.

One of the main reasons for having a d-c generator separately excited has to do with a difficulty encountered in getting a self-excited generator to build up its terminal voltage, starting out with only the residual field magnetism in its poles. If the normal load for which it is installed happens to be connected to the generator terminals when the motor-generator is started up, the terminal voltage might not build up. In the set described above, the current load on the 250 volt generator is small, and its terminal voltage easily rises to normal. However, the filament load on the 15 volt machine is very heavy, so its field is separately excited to insure operation, even with the load on, when starting up.

The 1000 volt generator has two commutators, one on each end of the armature, and each delivers 500 volts. These commutators are connected in series to give a total of 1000 volts. This construction not only reduces the insulation requirements and the sparking at

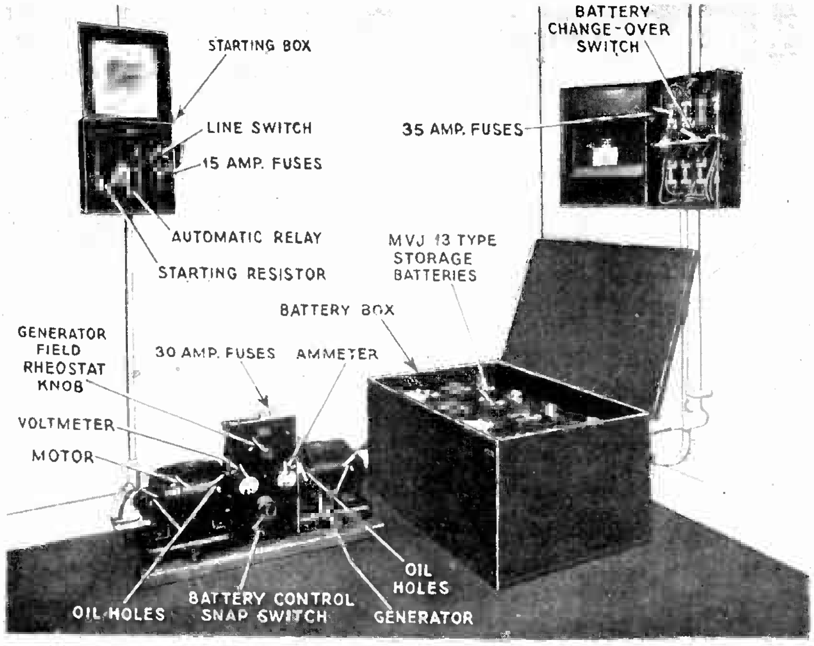


Fig. 8 - ARRANGEMENT OF BATTERY CHARGING EQUIPMENT USED WITH A SOUND-PICTURE INSTALLATION

the commutators, but provides economically the intermediate voltages of 500 and lower which would otherwise have to be secured through series resistances or voltage dividers applied to the total 1000 volts generated.

Even when the power mains provide direct current for the charging of storage batteries, it is found more economical to reduce the vol-

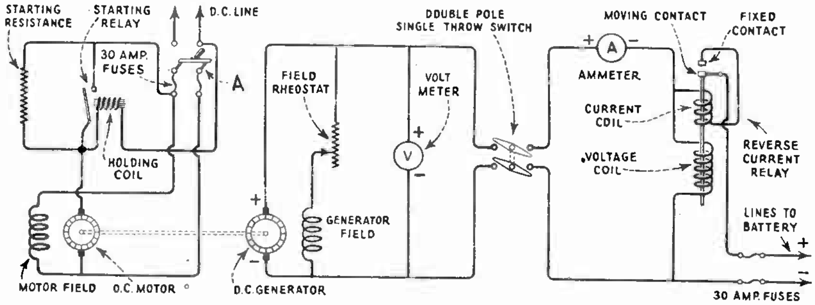


Fig. 9 - SCHEMATIC DIAGRAM OF A D-C MOTOR-GENERATOR CHARGING UNIT

tage by the motor-generator method than by the use of series resistance in the circuit. This is particularly true when the battery terminal voltage is small compared to the line voltage. This is demonstrated in the case of a battery-charging arrangement used for certain sound-picture installations, as illustrated in Fig. 8. A schematic drawing of the connections is shown in Fig. 9, including the starting equipment and a reverse current relay for the charging circuit, designed to prevent the battery from discharging into the generator circuit when the e.m.f. generated by the machine becomes less than the internal e.m.f. of the battery, due to slowing down or other causes.

A-C TO D-C MOTOR-GENERATOR SETS

It is easier to understand the many variations that come under the head of motor-generators if we bear in mind these fundamentals:

1. The electrical characteristics of the motor are determined by the available electric supply.

2. The power rating of the motor is determined by the shaft power required to drive the generator or generators under their normal loads.

3. The electrical characteristics of each generator coupled thereto are determined by a specific load requirement of the device or apparatus to be operated.

Manufacturing economy has long since dictated that standard parts be used for as many purposes as possible. This has resulted in identical frames being used for motors produced for a variety of voltages, and including both a-c and d-c types. Only the field and armature structures may differ. With the frame mounting holes and shaft heights identical for motors of widely different electrical characteristics, we see that the motor-generator becomes a very handy and convenient device for matching load requirements to an available electric power supply.

We find, therefore, that motor-generator sets for use with certain installations will vary in different localities mainly in the motor equipment and the necessary starting and control accessories. A further difference enters in the case of a-c mains, in that the generator fields will not be excited from the power mains.

The photograph on the back cover page shows a three-unit motor-generator set of which one generator develops 600 volts d.c. and the other 12 volts d.c. The field of the low-voltage machine is excited by the terminal voltage of the high-voltage machine. With such an arrangement, when the set is started up, the field rheostat of the 600 volt machine is always adjusted first for its normal voltage, because the voltage of the second generator will depend on its 600 volt field excitation. Then the field rheostat of this 12 volt machine is adjusted to its normal voltage as shown by the panel voltmeter. A novel construction enters here, in that the two field rheostats are mounted on the same center line, and a single control knob serves for both, being shifted in or out a short distance to engage the contact arm of the rheostat which is to be moved.

A-C TO A-C CONVERSION

The conversion of alternating current of one frequency into alternating current of another frequency is met with less often than the other forms of conversion. This change may be made with or without an accompanying change in the number of phases and the voltage. This might occur where the power mains were 25 cycle single-phase alternating current, and it is desired to operate standard radio transmitting equipment of the 60 cycle three-phase type.

THE ROTARY CONVERTER

Rotary converters have several uses. In commercial practice they are generally used to convert alternating current into direct current for use on traction lines, in the charging of storage batteries, and in electro-plating plants. In the communication fields, such a conversion is usually accomplished by electronic or gas discharge devices.

For a-c to d-c operation, the machine may be designed, as a motor, for single-phase, two-phase or three-phase alternating current. There are no new principles with which you are not familiar in the fundamentals of this machine other than its physical construction. Just remember when you think or hear of a rotary converter that it is simply two machines in one. There is one armature and on this is placed a simple winding which serves to revolve it and from which generated current is collected. This generated current is the result of what was, in the independent motor or generator, the counter

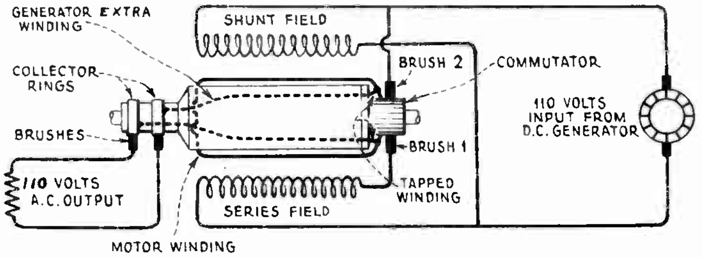


Fig. 10 - FUNDAMENTAL CIRCUIT OF A ROTARY CONVERTER

e.m.f. Furthermore, only one set of field windings is used to supply the magnetic field for both the motor and generator functions of the machine.

The use of a commutator, properly connected to the individual sections of the armature winding, makes available the counter e.m.f. developed in these sections, as a direct current.

If arrangements are made to revolve the armature by mechanical means, such as a gasoline motor, both alternating and direct current will be delivered. In this case the field windings of the machine would, of course, be excited from the d-c brushes of the commutator end.

By applying direct current to the windings and field from an external source, alternating current can be obtained from the collector rings. When used in this way, the machine is referred to as an inverted rotary converter and sometimes more briefly as a rotary inverter.

The distinguishing feature, as just stated, is the use of a single armature for both alternating and direct current. There are only two bearings needed, and it requires less space for installation. Therefore, the construction and installation of the machine as a whole is simplified.

There is the disadvantage, however, of not obtaining full control of voltage. For this reason it is often better to use the motor-generator than the rotary converter, even though the cost of the motor-generator is higher. When 110 volts is used as the supply, the alternating voltage delivered (which is really the counter e.m.f. of the armature) will reach a maximum of approximately 78 volts. When higher voltages are desired a step-up transformer may be used on the a-c side. It is possible to secure a greater voltage output than that stated, by means of an auxiliary winding. This is used especially when it is desired to have about the same a-c voltage as the d-c voltage supply.

This is shown by the fundamental circuit of Fig. 10. The current flows from the power mains, indicated as a 110 volt d-c generator, through the series field winding into the armature at brush 1, through the armature coils and out at brush 2. The shunt field is connected across the line as in any compound wound machine. As current is applied to the armature coils rotation results, and a counter e.m.f. is generated. If single-phase alternating current is desired, two

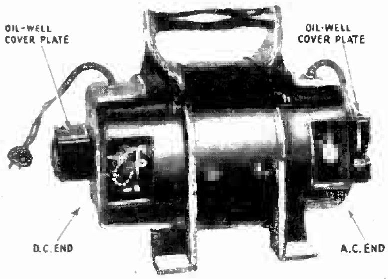


Fig. 11 - A D-C TO A-C ROTARY CONVERTER, RATED AT 3/4 KVA, USING THE AUXILIARY WINDING PRINCIPLE

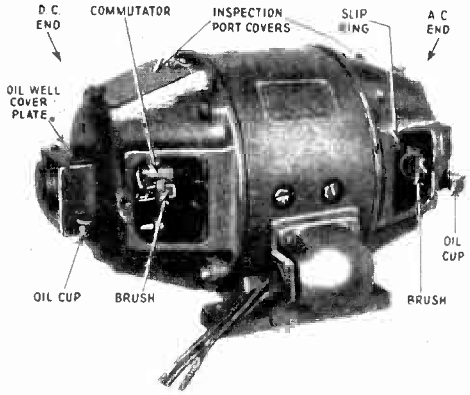


Fig. 12 - THIS MACHINE IS DESIGNED TO FURNISH TWICE THE POWER OF THE ONE SHOWN IN FIG. 11

taps are taken from the armature windings at points 180 degrees different in phase. These taps are connected to the slip rings through additional turns of wire on the armature which are not in the direct current circuit.

The extra conductors are so placed on the armature that the voltage generated in them adds to the voltage secured from the taps on the main armature winding. By proper selection of the number of turns in the extra winding, the desired voltage output can be secured. This construction is used on machines operating from 110-120 volt d-c mains to supply 60 cycle alternating current at 110-120 volts for radio sets of the latter kind. It might be considered that the combination of armature windings on this machine makes it a cross between a rotary converter and a dynamotor. The principles of the latter type of machine are described on the following page.

In Figs. 11 and 12 are shown two rotary converters using the auxiliary winding principle. The chief difference in the two machines is that one is designed for twice the power of the other. Otherwise there are no important differences.

THE DYNAMOTOR

The circuit of the dynamotor is shown in Fig. 13. The armature carries two separate windings wound in separate slots on the core, one to revolve the armature as a motor and the other for the production of e.m.f.

In the sketch shown the direct current used to drive the armature is obtained from a 30 volt storage battery outfit. (Commercial machines can be run on 110 v. d.c.and other voltages.) Voltages ranging from 350 to 2000 volts d.c.may be secured from the generator end, depending upon the design and type of dynamotor. The field is compound wound and is used as both the motor and generator field windings. The speed of this type of machine is 2000 r.p.m. and, to reduce vibration, the entire unit is suspended in a spring suspension saddle shown in Fig. 14.

The dynamotor is practically free from trouble due to armature reaction, and has an appreciably higher efficiency than the motor-generator. It suffers under the same handicap as the rotary converter, i.e., the output voltage can be controlled only by changing the input voltage to the motor side.

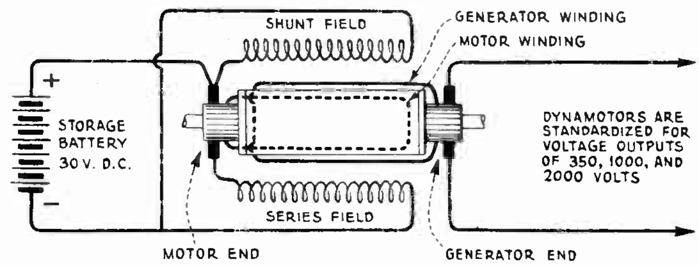


Fig. 13 - FUNDAMENTAL CIRCUIT OF A DYNAMOTOR

This type of converting machine is particularly useful in securing high d-c voltages for operation of airplane transmitters and receivers, when only a storage battery is available as a main power supply; the same holds good for automobile radio receivers when dry batteries for plate supply are to be avoided. Another important use is in sound picture work, where a 110 volt d-c supply is converted to a lower voltage for supplying exciter lamps, field supplies, and filaments of vacuum tubes, through a filter circuit designed to eliminate the commutation ripple.

In such uses, it will be seen that the dynamotor performs the same voltage step-up or step-down function for direct current that is performed for alternating current by a power transformer. In fact, we can truthfully carry this comparison still further. When a direct current is applied to the dynamotor armature and it rotates, the individual motor coils of the armature receive a current which continually changes direction, that is, it alternates, due to the commutator action. The motor coils, therefore, serve as the primary winding of a transformer whose iron core is the armature structure itself. The generator winding acts as the secondary of this transformer action, having induced in it an alternating e.m.f., the voltage of which depends on the relative number of turns in the primary and secondary windings (the motor and generator armature conductors). The second commutator then serves to rectify the alternating current, producing a direct current output at the generator terminals.

In the electrical entertainment industries, a dynamotor is used for a particular function, but we must remember that the principles of its operation are such that its function can be reversed in direction. By that is meant the conversion of voltages can be made in the

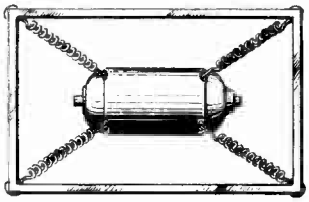


Fig.14 - DYNAMOTOR MOUNTED IN A SPRING SUSPENSION SADDLE TO REDUCE VIBRATION

opposite direction. If the input voltage to the motor side is 30 volts, with an output of 350 volts at the generator side, it would be possible to have the same machine supplied from an outside source with a potential of 350 volts or greater applied to what was the generator side of the first case. Then we would secure a voltage of about 30 generated by what was previously the motor side of the machine. In the technical subjects we are studying there is very seldom an occasion for doing this.

EXAMINATION QUESTIONS

1. What is a motor-generator?

2. What are the electrical requirements of a motor-generator set?

3. Draw a diagram of a shunt wound motor generator.

4. What are the three types of motor generators?

5. Draw a diagram of a compound wound generator set.

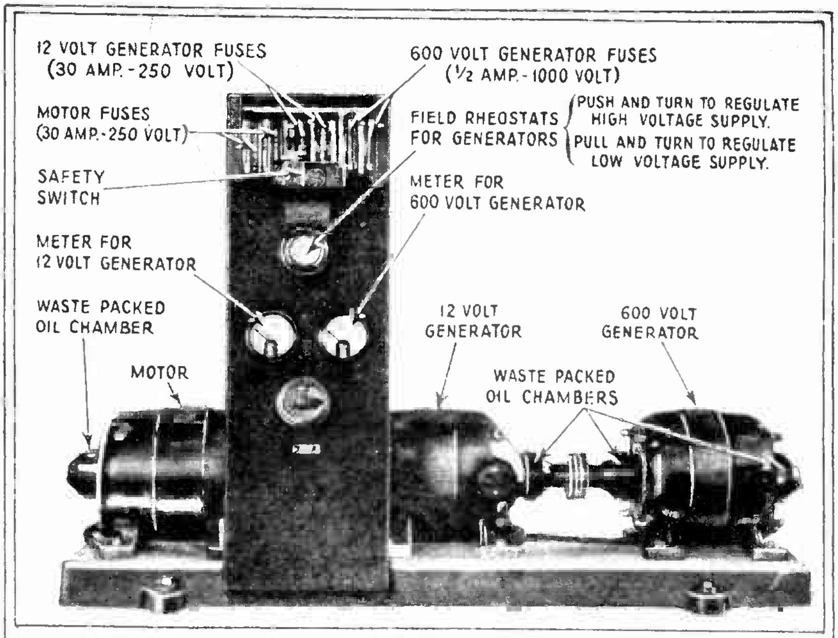
6. How would you regulate the speed of a shunt wound motor-generator?

7. Explain how the voltage output of the generator is controlled in a motor-generator set.

8. What is a dynamotor? Explain fully.

9. What is a rotary converter? Explain fully.

10. What advantage has the motor-generator over the rotary converter and the dynamotor?



PANEL BOARD AND MOTOR-GENERATOR SET USED WITH CERTAIN SOUND-PICTURE EQUIPMENTS. THE MOTOR IS A-C OPERATED AND THE GENERATORS SUPPLY D.C.

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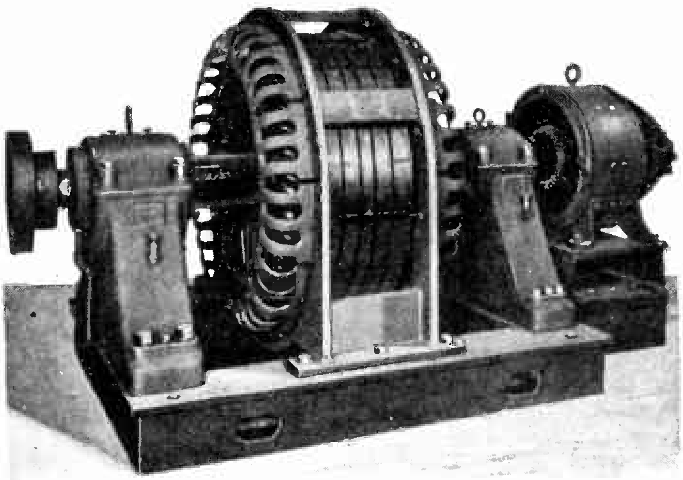

Westinghouse Synchronous Motor

A. C. MOTORS

Vol. 10#12

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A.C. MOTORS

In the operation of Sound Motion Picture projectors and in Sound Picture recording work A.C. motors are used to a great extent. In recording they are used almost exclusively due to the fact that if a number of A.C. motors of the type known as "synchronous" are connected to the same source of alternating current they will all run at exactly the same speed due to the fact that the speed of each motor is controlled by the frequency of the power supply, or in other words the number of times the supply current alternates per second. In most cases the supply line furnishes 60 cycle current so that every synchronous motor designed to run at a certain speed on 60 cycle current will absolutely keep in step with every other motor of the same type connected to the same power supply. This enables the picture camera to run through the same number of feet of film per minute as is being run through the sound-on-film recording machine, for if the motor which drives the camera and the motor which drives the recorder are connected to the same power supply they will run at identical speeds. This makes it possible to take the motion pictures on one film and record the sound on a different film.

Later on in the process the pictures and sound track are photographically printed side by side on one positive film. It can easily be seen that if the speed of the film as it runs through the camera is not the same as the speed of the film that passes through the recorder then it would be impossible to reproduce the sound in correct relation or "synchronism" as it is called, with the picture. By synchronism is meant the timing of the sound and picture so that when a subject on the projection screen speaks, for instance, the words will be heard coming from the stage speaker directly behind the screen at the exact moment the lips of the speaker move.

The A.C. synchronous motor has thus made it possible for the motor driving the camera to be at one place on the "set" while the recorder is being driven by another motor in the recording booth which is placed out of the way at some distance from the action.

The very term "synchronous" means "in unison" or "in step" so that in general a synchronous motor is said to be one that operates in step with the phase of the alternating current which operates it. Any A.C. generator will run as a synchronous motor when it is supplied with current at the same voltage and frequency as it produces when run as a generator. It must be borne in mind that a single-phase machine must be brought up to so-called synchronous speed before being put "in circuit".

A standard synchronous motor consists primarily of an armature and a field. The field is "excited", that is, its magnetic field is established, by a separate source of direct current which produces a magnetic flux of unchanging polarity. This field flux is shown in Figure 1, which is a sketch of an elementary alternator which generates single phase current (shown at the left) and of an elementary single phase synchronous motor (at the right). The

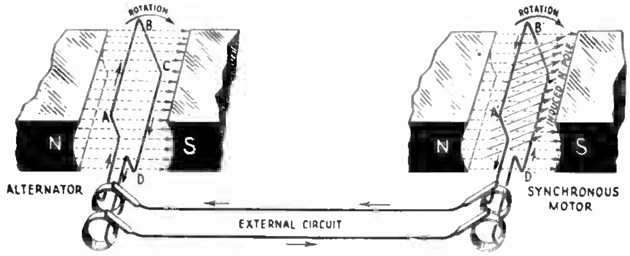

Figure 1

armature circuit of each is connected through slip rings to that of the other forming an external circuit. Assuming both armatures are at rest, if the armature of the alternator be turned slowly, in a clockwise direction as shown, a current will be generated which will flow through the external circuit and through the motor armature in the direction indicated by the arrows. The current flowing through the motor armature will produce a magnetic flux or induced N pole as shown by the line of arrows pointing upward to the right. As like poles repel and unlike poles attract, the S pole of the field will pull the induced N pole of the armature toward it while the rotation of the armature will be aided in this

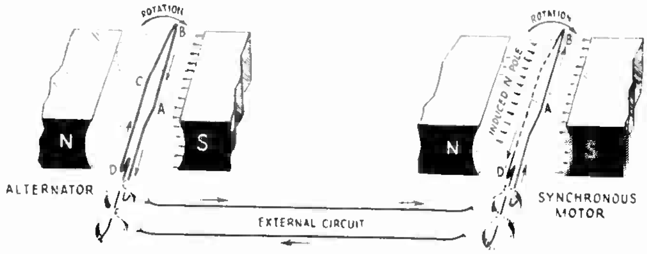

Figure 2

direction by the attraction of the N field pole pulling on the induced S pole of the armature. The conditions just stated hold true while the side A-B of the alternator armature is nearest the N pole during the upward journey of side A-B and the downward journey of side C-D. As the alternator armature continues to revolve the side A-B cuts the field flux near the S pole in a downward direction while side C-D sweeps upward through the field flux near the N pole. This we know results in a reversal of the current through the alternator armature and as it is connected to the motor armature through the external circuit the induced armature N pole becomes reversed in direction. The armature of the motor having passed through its vertical position the direction of the induced magnetic flux is such as to cause the N pole of the field magnet to repel the nearby induced N pole of the armature and the S pole of the field to repel or push away the nearby S armature pole. This condition is as shown in Figure 2.

By referring to Figures 3 and 4 and remembering what we have just learned, it is easy to see why a single phase motor is not self-starting when connected to an A.C. power main without first having been "brought up to speed". In this case the alternator itself is not at rest to start with because it is required to be in continuous operation for the general public using that power line. The alternator is therefore always "up to speed" as far as the line supply is concerned.

Due to the fact that an armature possesses "inertia" it cannot be moved instantly, and the speed of 60 cycles per second is too great

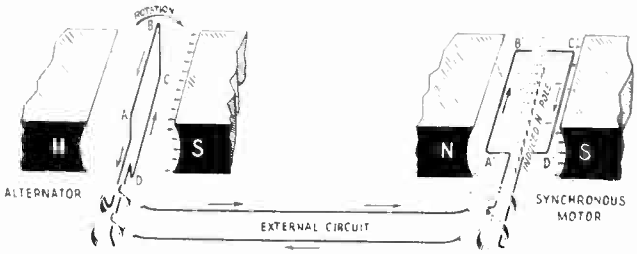

Figure 3

to allow the motor armature to get into motion before the polarity of the induced pole of the armature reverses and produces a torque, or tendency to rotate, in the opposite direction. This is demonstrated by Figure 3 which shows the alternator armature at one position and by Figure 4 in which the armature is shown in a reversed position. During one-half the cycle or revolution of the alternator armature the current flows through the motor armature producing armature poles as shown in Figure 3. This tends to rotate the armature in a counter-clockwise direction as shown by the motor arrow 1/120th of a second later (the next half cycle) and before the armature has had a chance to move, the current through the generator and the motor armature reverses and an induced armature polarity is set up in the motor as shown in Figure 4, changing from its direction in Figure 3 to that in Figure 4 and back again

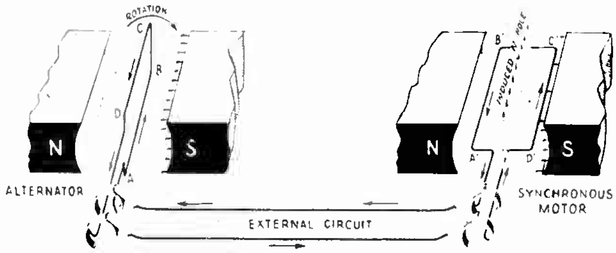

Figure 4

at the rate of 60 times per second. It can be seen that the torque or tendency toward rotation of the motor armature is opposed in the two figures. The only movement that results is a vibration as the armature is shaken back and forth 60 times per second with no chance to get into continuous rotation due to its inertia. If some means were provided, however, by which the armature of the motor could be brought at least nearly up to speed so that its inertia would not be a large factor in pulling it into synchronism, then it would have its armature in the correct position to produce torque or turning effort continuously in one direction as shown in Figures 1 and 2.

If a motor could operate in exact synchronism with the A.C. supply the armature of the alternator and the motor would always make equal angles with their respective fields as shown in Figure 5. This condition could only be realized if there were no mechanical load on the motor which is impossible because even the friction of the armature shaft in the bearings constitutes a form of load. If the ideal condition of no mechanical load were possible, however, the alternator and motor armatures would revolve at exactly equal angles with their fields and the counter E.M.F. generated by the motor armature as it cut the field flux would exactly equal the impressed E.M.F. that is furnished to the motor armature by the

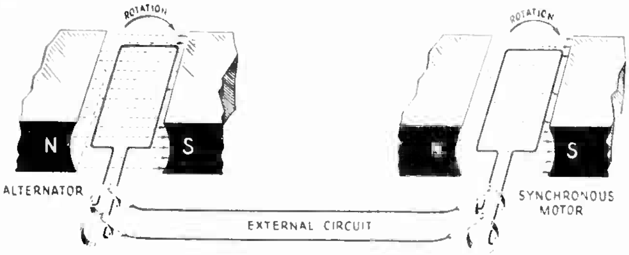

Figure 5

alternator; the two E.M.F's. impressed in opposite directions across the same armature would cancel each other and no current would flow.

Now what actually happens when a load is thrown on the motor is that the mechanical resistance holds back the motor armature so that instead of rotating in the same plane as the alternator armature it lags a certain number of degrees so that it takes a position as shown in Figure 6. In this condition the counter E.M.F. generated by the motor armature will lag the impressed E.M.F. by the same angular amount the motor armature lags the alternator armature. We found that, in Figure 5, when the counter E.M.F. from the motor equalled the impressed E.M.F. from the alternator and they were in phase opposition, no current flowed; but now that the

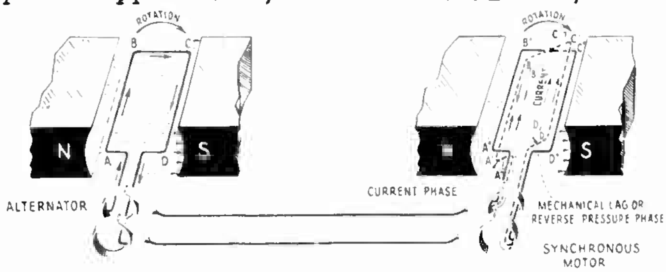

Figure 6

phase of the counter E.M.F. lags behind that of the impressed E.M.F. there is a resultant difference in potential, and current from the alternator flows through the motor armature inducing poles in it and producing torque. It will be seen from Figure 6, that the impressed E.M.F. is the alternator terminal voltage, the current lags just behind it, and the counter E.M.F. of the motor lags behind the current. The greater the mechanical load put on the motor, the more will it lag behind the alternator armature, and the greater will be the current which flows through the motor armature. The motor will continue to run under a load increasing up to the point where the lag of the motor armature is 90 degrees (one-quarter revolution) behind the alternator armature.

When the load on the motor becomes greater, so that the lag becomes greater than 90 degrees, the motor will "pull out of step" with the current supply and quickly come to a stop. Figures 7 and 8 show why this is so, Figure 7 showing a condition of motor load that causes a lag slightly less than 90 degrees. The motor will still continue to rotate and pull strongly due to the fact that the field poles and the induced poles of the armature are in the correct relation to produce rotation by repulsion of like poles and attrac-

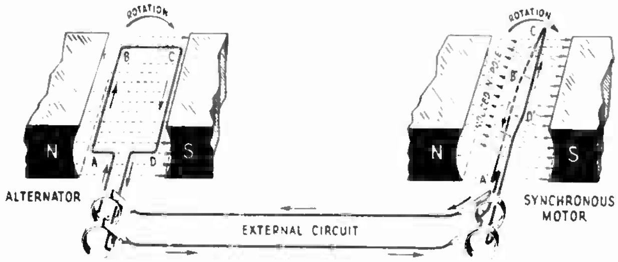

Figure 7

tion of unlike poles. Figure 8 shows the condition which prevails when additional load on the motor has caused it to lag more than 90 degrees behind the current supply phase. The induced poles will be as shown but now, due to the fact that their positions have been changed in relation to the field poles, the repulsion effect of like magnetic poles produces a torque or turning effort in a direction opposite to that of its former rotation. In actual operation this brings the motor to rest very quickly acting in a manner similar to a brake.

The synchronous motor is usually brought up to synchronous speed without load and a starting compensator is used to limit the starting current. If the motor is provided with a self-starting device,

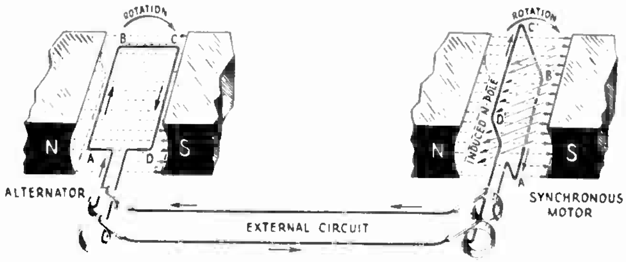

Figure 8

the device must be cut out of circuit at the proper time. A three-phase synchronous motor as used in certain Photophone equipments to drive projector motors is seen in Figure 9. This type of synchronous motor differs from the above in several respects. Two of the most important differences are: first, it requires no D.C. field excitation and, second, the rotating part serves as the field. These motors are sometimes called "hysteresis" motors because they depend on the hysteresis or molecular inertia of the iron for their operation. This type of motor will be studied later in this lesson.

INDUCTION MOTORS

An induction motor is quite different from other forms of motors especially in that, while D.C. motors and some synchronous A.C. motors have some kind of electrical connection between the rotor (which corresponds to the armature in a D.C. motor) and the source of current supply, the induction motor will operate with no electrical connection between the rotor and the power source. The currents which flow in the rotor winding are caused by the voltage induced by the action of the field magnetic flux as the rotor sweeps past the field poles in a rotating path. According to the kind of current that an induction motor is designed to operate on, it may be classified as a single phase or as a polyphase motor. A single phase motor is, as the name implies, one that will run on single phase current while a polyphase motor may be designed to run on two phase current or it may be designed to operate on three phase supply. The magnetic field produced in a motor by a single phase current is said to be oscillating in character while the field resulting from two or three phase current is said to be rotating. The principles of polyphase motors can be best understood by means of elementary diagrams showing how polyphase currents produce a rotating magnetic field.

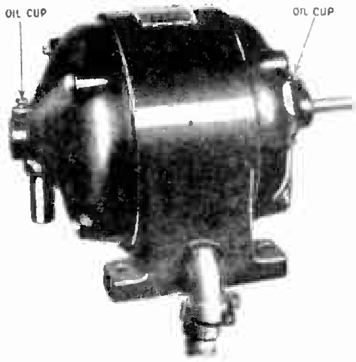

Figure 9

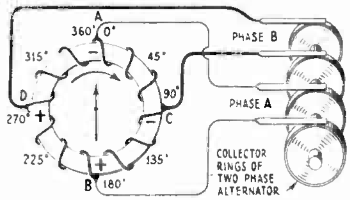

Figure 10

PRODUCTION OF A ROTATING MAGNETIC FIELD BY TWO PHASE CURRENT

Figure 10 represents an iron ring wound with coils of insulated wire, connected to a source of two phase current at the points, A, B, C and D. It will be remembered that two phase current requires four leads or line wires to conduct the phases separately to the point where current is to be used, and so four leads, two coming from phase A and two from phase B, are connected as shown in Figure 10. Remembering also that current B differs in phase 90 degrees from phase A, we find that if only one current (a) entered the ring at A with a return at B, a negative pole (-) will be produced at A and a positive pole (+) at B causing a magnetic needle pivoted in the center of the ring to point vertically upward towards A. If at this instant, corresponding to the beginning of an A.C. cycle in phase B, this second phase is connected to the ring at C and D the needle will still point upward toward A because the current in phase A is at maximum while that in phase B is passing through its zero value. As the cycle continues, however, the current strength of phase A will grow less while that of phase B increases thus moving the induced pole toward C until phase B reaches its maximum current strength and phase A falls to its zero value, which will be at 90 degrees as seen in Figure 11 or at the end of the first quarter of the cycle. At this time phase A reverses in direction and produces a negative pole at B and as its strength increases from 90 degrees to 180 degrees and that of phase B diminishes the negative pole is moved past C toward B until phase A reaches its maximum and phase B falls to its minimum at 180 degrees.

When this condition is reached the needle points toward B. At the 180 degree part of the cycle phase B reverses in direction and produces a negative pole at D and as the variations in the amplitudes of the currents of the two phases in the second half of the cycle bear the same relation to each other as during the first half, the resulting poles of the rotating magnetic field thus produced carry the needle around in continuous rotation so long as the two phase current passes through the windings of the ring.

By referring to Figure 11 the direction of the rotating field for each of eight different phase relations may be seen. Thus the

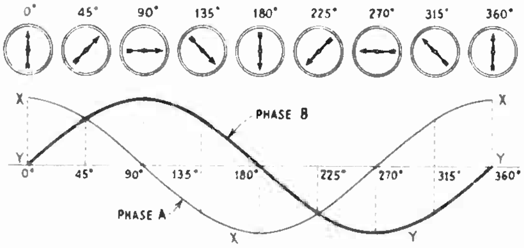

Figure 11

rotating field of a polyphase motor is not something that can be seen as for instance the rotation of an armature, but merely a constant shifting of polarity around a circular path within the motor field. A mechanically rotated magnetic field would be one produced by, say a horseshoe magnet turned by hand or other means, which would drag a needle around in much the same manner as the electrically rotated field just studied. The mechanically rotated fields, of course, are not used in motor practice; it is mentioned only to show that the magnetic field would in both cases have a similar

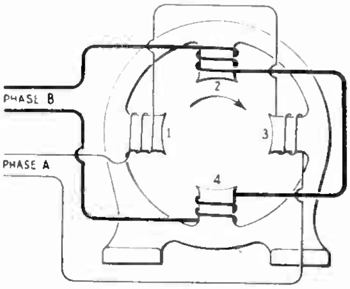

Figure 12

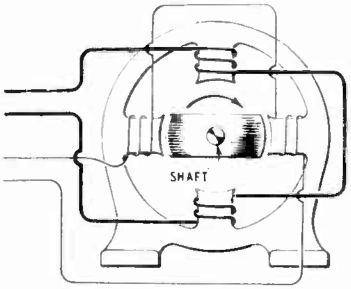

Figure 13

effect on a needle. Figure 12 shows how a 2-pole 2-phase motor is connected to a supply line to obtain a rotating field. Its action will be evident from its similarity to the ring type field which type, however, is not used in motor practice.

During one cycle of current the polarity will be as follows 0 to 90 degrees pole 1 will be a N pole while pole 3 will be S; 90 to 180 degrees Pole 2 will be N and pole 4 will be S; 180 to 270 degrees Pole 3 will be N and pole 1 S and during the remaining quarter of the cycle from 270 to 360 degrees pole 4 will be N and pole 2, S. The change in polarity is not accomplished in jumps, however, but proceeds smoothly as the current strengths of phase A and phase B vary from 0 to maximum. This results in a smooth movement of the needle around the circle. If now the needle were replaced with a solid iron bar fastened to a shaft as shown in Figure 13, and this bar were so centered that it furnished the shortest path possible for the magnetic flux from N to S then, from what we previously learned about the tendency of an iron bar to place itself lengthwise in the path of the magnetic flux we know that it would move around as the induced pole rotated. This kind of a motor amounts practically to a synchronous machine for the speed of its armature depends upon the speed of rotation of its revolving field. Figure 14 is a graphic method for visualizing the resultant magnetic field of two-pole, two-phase motor field at different phases of the currents during a complete cycle showing how an armature, represented by the arrow, is dragged around as the field rotates. A two-pole motor is easier to study when learning rotating field principles, but of course,most

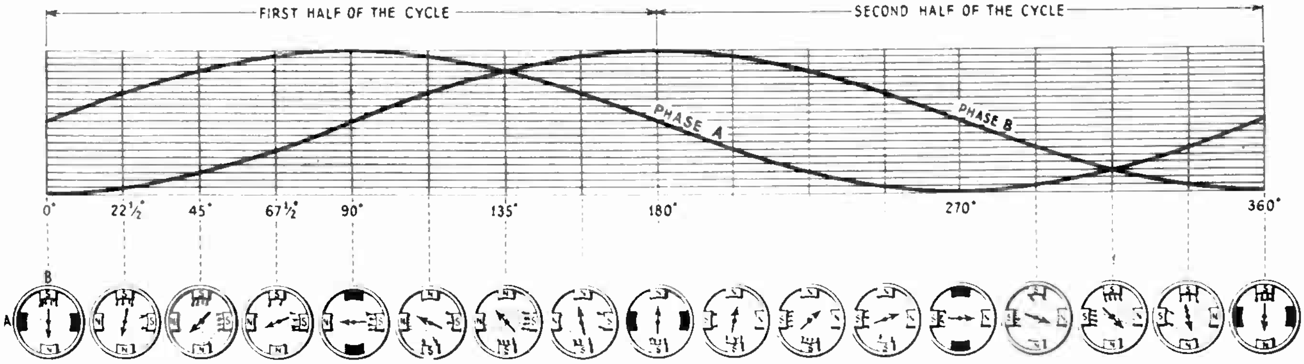

Figure 14

motors are constructed so as to have more than two poles in order that they may operate at lower speeds in producing mechanical power. Figure 15 shows a two-phase, six-pole field winding and it can be seen that the operating principles have not changed, the field poles in phase A being wound oppositely so as to produce alternate N and S

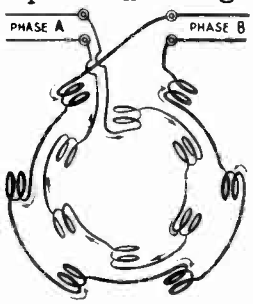

Figure 15

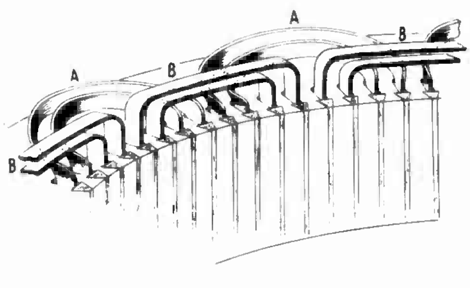

Figure 16

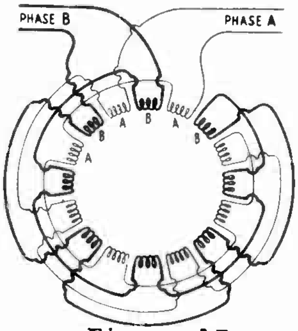

Figure 17

poles in that phase, while the phase B windings are also connected in like manner. Figure 16 is a pictorial representation of the two windings of Figure 15 placed in a motor field showing how the slots are closed with wooden wedges to keep the coils in place. In Figure 17 an eight-pole, two-phase winding is shown and although the circuit is slightly different if the wires are traced through it will be found that each alternate pole in phase A is wound in such a direction as to make each phase A pole opposite in polarity to the following pole in the same phase. The same arrangement is followed in the wiring of phase B.

Now that we have studied the action of two-phase current in producing a rotating field we may pass on to the subject of how a rotating field is produced by three-phase current. The action is quite similar to that of a two-phase current and can be better visualized if we first consider an iron ring wound as shown in Figure 18 with the winding supplied with three-phase current at the points A, B. and C, which are 120 degrees apart. When current is flowing into the winding at A, two currents, each of which is 120 degrees out of phase with it and with each other, will flow out at B and C, producing a negative pole at A and a negative pole at E. The needle will thus point toward A, but as the cycle advances the relationship of each current to the other as regards strength and the time each reverses in direction will be such that when current is flowing in at one of the points A, B, or

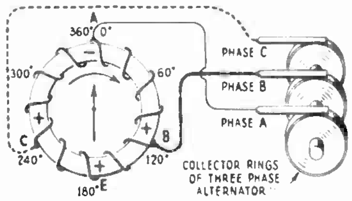

Figure 18

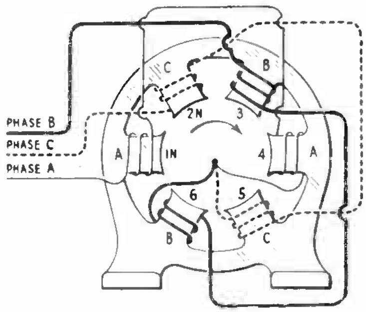

Figure 19

C, two currents 120 degrees out of phase with the first mentioned current and with each other, will flow in or out at the other two points. This action will result in a complete rotation of the magnetic field at each cycle of the current. The action is analogous to that of three cranks set at 120 degrees with respect to each other on a crank shaft. Figure 19 shows a three-phase, two-pole motor field winding, and by referring to Figure 20 the magnetic field flux condition of the field may be visualized at various periods. In Figure 21 a Y-connected winding is seen on the four-pole field.

In order to understand the action of an induction motor it is necessary to know why the rotating field has a tendency to revolve the armature with it. This is best demonstrated by using a copper cylinder for the armature and considering the magnetic field to be produced

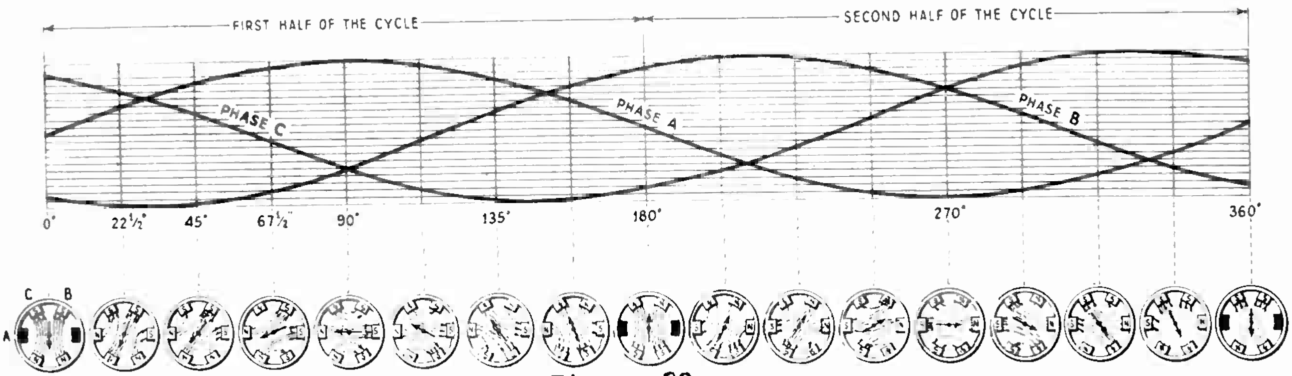

Figure 20

by the poles of a permanent magnet, the N pole of which is on one side of the cylinder, the S pole being directlyopposite on the other side, shown in Figure 22. If the whole magnet is now rotated mechanically the magnetic field will move across the face of the copper cylinder and as we learned previously, whenever a magnetic flux is cut by a conductor a current is generated according to well-defined laws. In the case of Figure 22 currents are generated on the surface of the cylinder in a direction shown by the arrows which produces magnetic poles in the areas marked by N and S. As the N pole of the field magnet rotates it pushes the N pole of the armature by the repulsion

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effect of like poles while at the same time it pulls the S pole by the attraction effect of unlike poles. This results in the rotation of the cylinder. It is easily seen that the greatest driving effect or torque is produced while the cylinder is at rest and decreases as the cylinder more nearly attains the speed of the field even up to the point where there is no driving effect or torque at all, at which time the cylinder revolves at the same speed as the field.

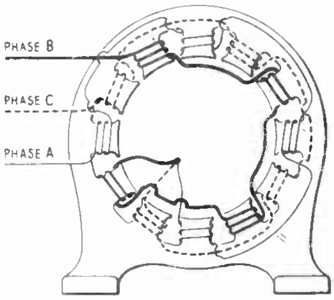


Figure 21

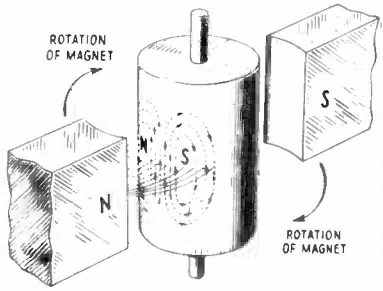


Figure 22

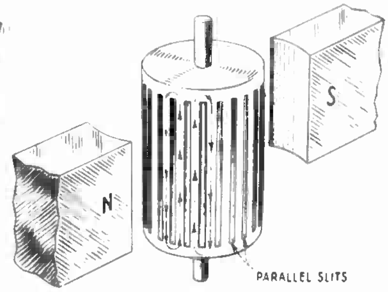


Figure 23

This follows from the fact that in the first place the currents generated in the cylinder are due to the action of the magnetic field in sweeping past the cylinder, in other words, the current generated varies as the difference in speed between the rotating field magnetism and the cylinder. When the cylinder is at rest the field flux sweeps rapidly over its surface, but when the cylinder is revolving at the same speed as the field then the field flux does not pass over the surface of the cylinder, and with the cylinder cutting no lines of force no current can be generated. This latter condition can hardly exist because the force that drives the cylinder results from the difference in speed between the field and cylinder and when that difference in speed is no longer present the driving force is removed, the cylinder begins to slow down and this immediately re-establishes a driving force. If a mechanical load is put on the cylinder shaft

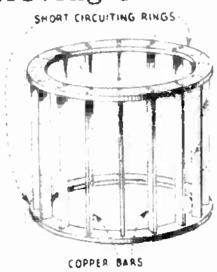


Figure 24

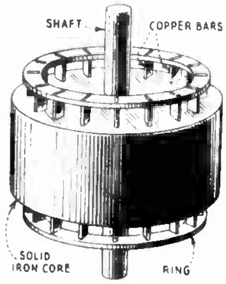


Figure 25

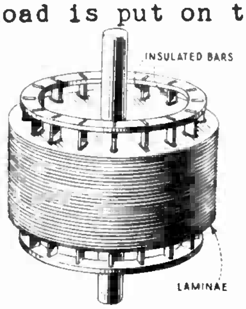


Figure 26

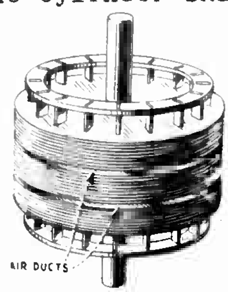


Figure 27

then it will be slowed and as it decreases its speed the increased sweep of the field past it generates more current in it and greater torque results. This establishes a rule of the action of induction motors which says that the more "slip" (difference of speed between rotating field and armature) there is, the greater will be the torque.

The copper cylinder armature used in the early experiments with this type of motor failed to provide a restricted path in which the induced currents could flow because the surface of the copper was continuous and thus the currents spread out considerably. Another defect was that there was no iron present to furnish a path of low reluctance to the magnetic flux produced by the induced current. The first attempt to get over the former difficulty was the cutting of the slots in the cylinder as shown in Figure 23 which confined the induced currents to the path shown, the effect of which was to produce stronger magnetic poles in the armature. Then an iron core was added to a cage-like contrivance made of copper bars and connecting end rings, the"squirrel cage" appearing as in Figure 24 and the core and cage assembled as in Figure 25. Further stages were the insulation of the copper squirrel cage from the iron core and the building of the iron core out of laminated sheets of iron which reduced loss from eddy currents as seen in Figure 26, then the provision for ventilation to cool the armature as seen in Figure

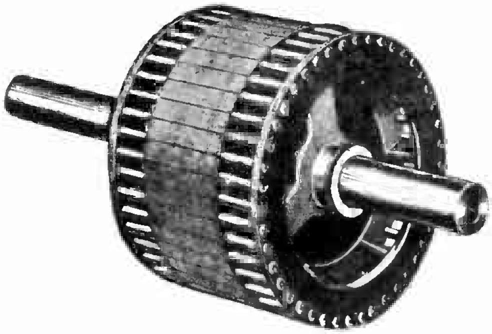


Figure 28A

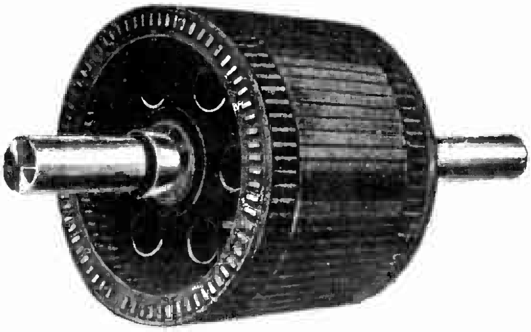


Figure 28B

27 and finally the modern "squirrel cage" armature was developed, the designs used by several leading motor manufacturers appearing as in Figure 28-A and B.

In Figure 29 is seen the field construction of a three-phase induction motor, each of the tube-like squares shown in close-up view in Figure 30, being a coil of wire taped into a bundle and set into place in the proper slots.

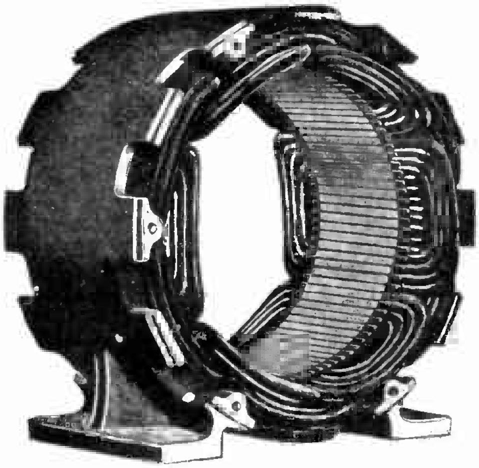


Figure 29

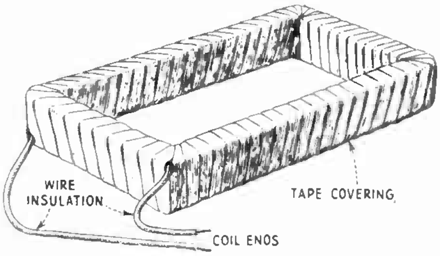


Figure 30

Now that we understand how a rotating magnetic field is produced by a polyphase current and also how that rotating field acts upon a squirrel-cage armature to cause it to follow the magnetic field we have only to place an armature such as the one shown in Figure 28-B into the field shown in Figure 29 and when the shaft is properly supported by bearings a commercial motor is the result which appears as shown in Figure 9. This motor is generally called a synchronous motor because the iron core is so shaped that after the motor is brought up to speed by action of the revolving field on the squirrel cage armature, the core finds itself in such relation to the lines of force in the rotating fieldthat it furnishes the path of least reluctance to the magnetic field and therefore is dragged around in synchronism with the rotation of the field. When it is operating in this fashion, at synchronous speed there is no inductive action between them and therefore it runs purely as a synchronous motor. If however, such a load should be put on the motor as to cause it to fall out of synchronism with the revolving field, then the field, sweeping past the squirrel-cage inductors, will induce a current in the armature and this will cause the motor to run as an induction

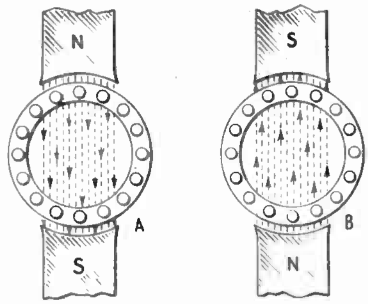


Figure 31

motor only until it gets to synchronous speed once more. Thus we see that a motor of this type has many desirable characteristics, for it is self-starting due to its squirrel-cage inductors which will bring the motor up to synchronous speed and in addition will take up the load should the armature lose synchronism with the field, besides which it will run as a synchronous motor under normal load, producing the constant speed desired for Sound Picture projection.

Single phase A.C. motors are used extensively in this field and they are run on the induction principle, various methods being used

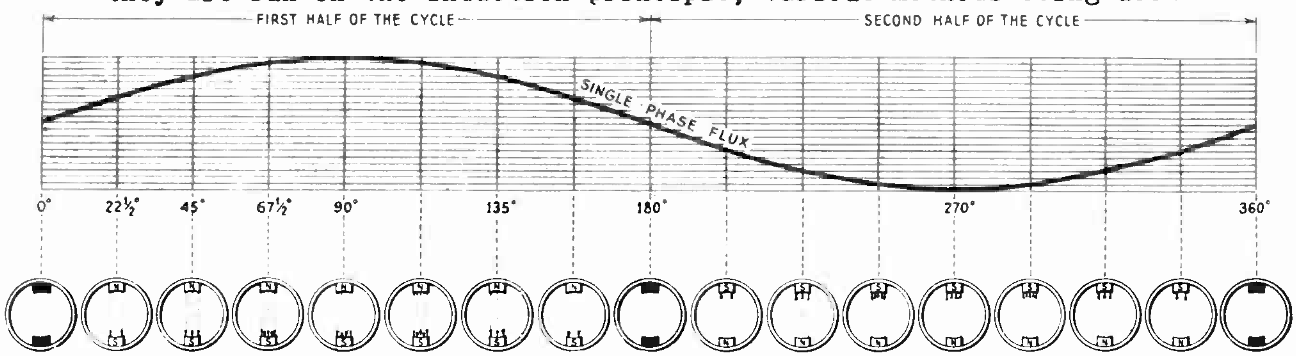


Figure 32

for starting and bringing the armature up to speed. The problem of starting a single-phase motor is different than in the case of a three-phase motor due the fact that a single phase current is not able to produce a rotating magnetic field without some special form of winding of the field or a method of starting the rotor to revolve by means of a commutator. Before we go into an explanation of the operation of each type of starting arrangement it will be well to understand why a single-phase current cannot produce a rotating field without some special arrangement of wiring. In Figure 31 is shown a diagram illustrating how a single phase current produces a vibrating or alternating magnetic field rather than a rotating field as is the case with two or three phase current. Sketch A in Figure 32 shows the condition of the magnetic field during the first half cycle, a N pole being produced at the top and an S pole at the bottom.

In the second half of the cycle the polarity of the magnetic field is reversed and the top becomes an S pole while the bottom becomes an N pole. It can be seen by the arrows denoting the magnetic flux that the inductors of the squirrel cage (shown by the small circles in the rim of the large circle) are cut by the field lines of force equally on each side of the center which means that whatever pull or torque is developed is equal on each side of the armature and therefore no rotation can result.

Figure 32 shows the condition of the magnetic field at various times during a complete cycle of single phase current. Although the strength of the magnetic field changes as shown by the number of arrows there is no production of a rotating field. The figure shows only two poles, but even if there were six poles as shown in Figure 20 and they were wound in pairs, due to the fact that the current is only single phase the magnetic field would not rotate, but would simply oscillate back and forth directly through the center of the armature gap and no turning effect or torque would be produced. At the beginning of this lesson we explained why a single phase current is unable to start an armature revolving and how, after the armature is speeded up to synchronism it has power to keep it revolving in synchronism with the power supply.

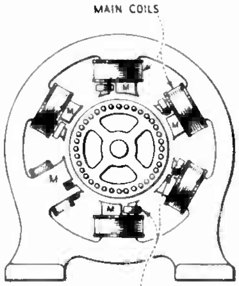


Figure 33

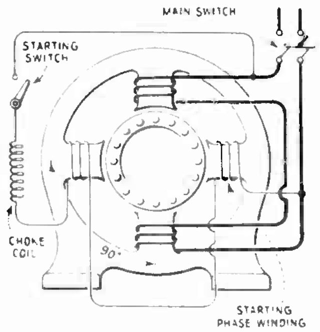


Figure 34

We will now consider the most widely known methods for producing the rotating field effect from a source of single phase current. We know that when magnetic poles are near each other in which the strength of the current in one phase to that in the other phase is used to produce in progression magnetic fluxes varying in intensity in separate sets of coils this will produce an effect of a rotating field. With single phase current we are not able to take advantage of the variation of two distinct currents from a source of supply, therefore we must produce the effect of a double source of supply from a single source. One method is known as the shading coil method of "splitting the phase", a diagram of which is shown in Figure 33. The main coils, which are the six large ones shown, are wound with copper wire and produce magnetism, the strength of which rises and falls and reverses as the strength of the single phase current rises and falls and reverses. This action in itself produces a reciprocating or pulsating field, in the main or large pole pieces M. An auxiliary pole-piece A is provided beside each main pole piece, however, and this has a "shading coil", which may be either short-circuited coils of wire or a solid copper cylinder placed over the auxiliary pole piece. Now, the effect of this shading coil is to keep the strength of the magnetic flux from dying out of the auxiliary pole pieces as rapidly as it leaves the main pole pieces.

It follows then, that the desired effect of adjacent poles having magnetic flux of different strength, which varies as the strength of the current varies, has been attained by this method. The rotating field thus produced is not as smooth nor as symmetrical as that produced by two-phase current and two sets of field windings, but it is sufficient to start the motor and bring it up to synchronous speed where it will remain due to the fact that its rotation is correctly timed with that of the field to produce efficient torque. Another method of "splitting the phase" is by the use of two separate windings in which a phase difference of current is produced by introducing either inductance or capacitance in one of the windings.

Figure 34 shows in simple form a split phase motor in which the current in the running or main winding is considerably ahead of the current in the starting winding due to the choking or retarding effect of the choke coil shown. A choke coil opposes both the rise of current and the fall of current in its circuit due to generation of counter E.M.F. and this property of a choke coil is taken advantage of in this instance to produce a current in the starting winding which is out of phase with the current in the main winding. With the starting poles and running poles placed as shown in Figure 34 this produces the effect of a rotating field somewhat like that produced by two phase current. After the motor has been brought up to speed the starting

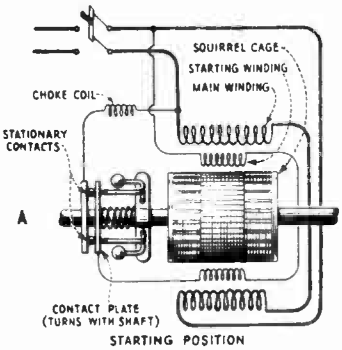


Figure 35A

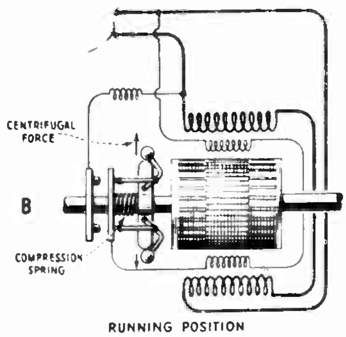


Figure 35B

windings are cut out of the circuit by opening the starting switch shown in Figure 34. In actual practice, however, the starting windings are cut in and out of service by an automatic device, the principle of operation of which is shown in Figure 35, A and B. In A the centrifugally operated switch is shown closed with the governor balls near the shaft. As the combination of the starting and running windings start the motor and bring it up to synchronous speed the balls fly apart against the force of the compression spring and pull the contacts open, cutting the starting windings out of circuit and allowing the motor to operate on its main windings. Figure 36 shows a split phase motor as used in certain Photophone Sound equipment.

Another starting device for a single phase motor is known as "the repulsion type", and when combined with a motor that runs on the induction principle after being brought up to speed the motor is called a repulsion start, induction-run motor. This type of motor consists of an armature, commutator and field magnets, the armature being wound exactly like a direct current motor armature the windings being connected to a commutator similar to that used in a D.C. motor.

The starting device consists of two brushes mounted so as to make contact with the commutator; a resistor to limit the current by-passed through the brushes; and a centrifugal mechanism for shorting out the entire commutator after the motor has attained sufficient speed to run as a single-phase induction motor. In Figure 31 we saw that the pull or torque exerted on the squirrel cage windings was equal on each side of the center or shaft of the armature, thus producing vibration,but no rotary motion of the armature. The brushes here used effectively by-pass a large portion of the current induced in part of the armature winding. This unbalance of the actual armature currents unbalances the torque set up by the rotor currents. The current in the rotor is due to the transformer action between the stator and rotor windings.

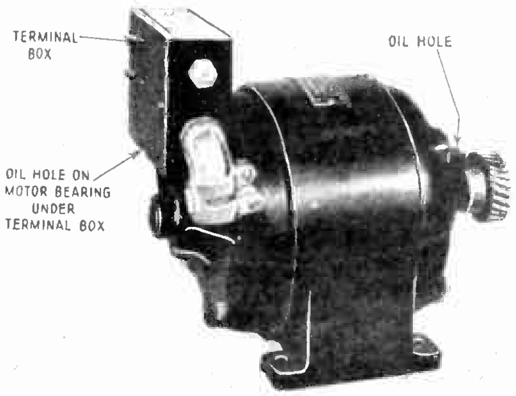


Figure 36

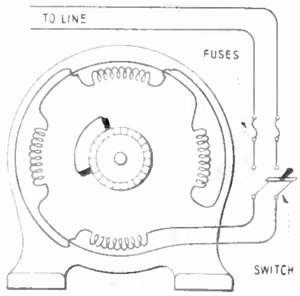


Figure 37

The unbalancing action gives a predominance of torque in a direction which depends upon the position in which the brushes are mounted. The running winding will keep the motor running in either direction once it is up to speed. If the brushes were short-circuited through a very low resistance, such as a copper wire, the starting torque might be too great for the particular load to which the motor was connected. In this case a resistor of several ohms is used to connect the two brushes together. As the armature rotates, succeeding armature coils are short-circuited while the armature is in continuous rotation in one direction. Figure 37 shows the field winding and the position of the short-circuiting brushes on the commutator.

After the armature is brought up to synchronous speed it operates as an induction motor, but in order that it shall be able to do this it is necessary to short circuit all the armature coils so that large currents may be induced in them by the field flux. To do this all the segments of the commutator must be connected together electrically and this is done usually by means of a copper plate that automatically presses up against all the segments of the commutator when the armature has attained a certain speed. The device for connecting electrically all the segments of the commutator as used in a Photophone projector drive motor is shown in Figure 38. In the top view the various parts of the device are shown assembled on the motor while the view at the bottom left shows how the commutator short-circuiting plate is pushed up against the commutator when the fly weights move outward causing the separator balls to thrust outward. The view at the bottom right is an enlarged view of the centrifugal

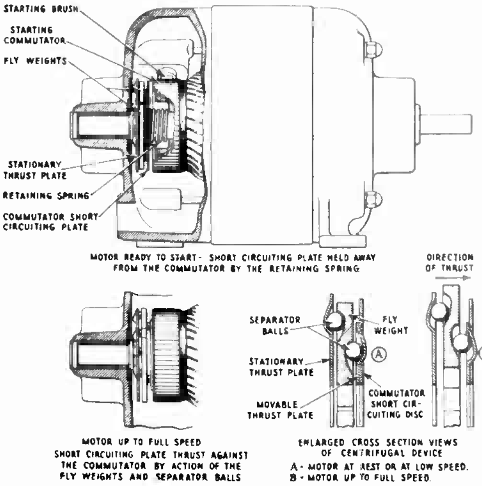


Figure 38

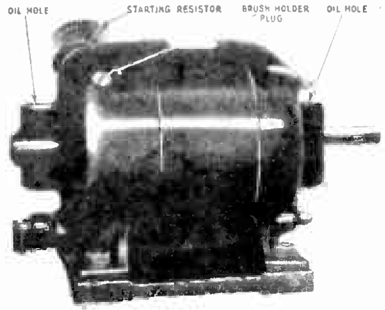


Figure 39

device with motor at rest and with motor up to full speed. A photograph of this motor is seen in Figure 39.

In order to reverse the direction of rotation of a two-phase, four-wire motor interchange the connections of the leads of either phase; of a three-phase motor interchange the connections of any two leads. The direction of rotation of a motor with "shading coils" cannot be reversed by any change in the leads, but single phase, split phase motors can be reversed by reversing either winding with respect to the other winding.

With the completion of this lesson the subject of motors as used in Sound Picture equipment is well covered and if the principles discussed are learned by the student it will be easy to "shoot trouble" in any motor he may be called upon to service.

EXAMINATION QUESTIONS

1. What is meant by the term "rotating field"?

2. What is the principle of operation of a squirrel-cage motor?

3. What is meant by "slip"?

4. Why does a single phase motor need some sort of starting device?

5. Name three methods for starting single phase motors and bringing them up to synchronous speed.

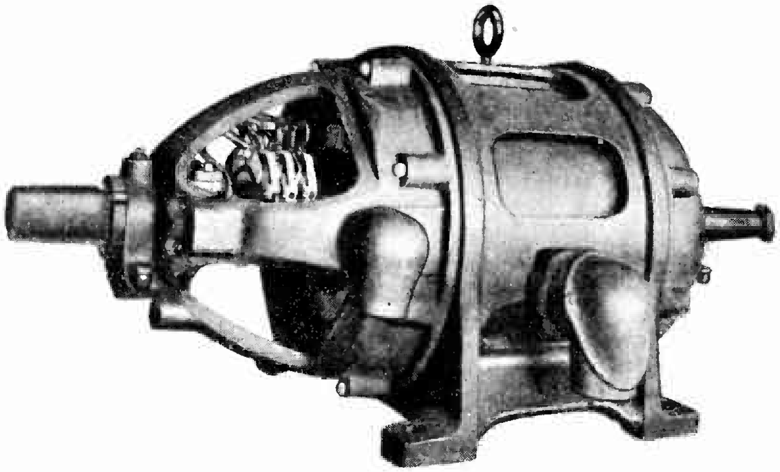
6. When has a squirrel cage motor the greatest slip, with or without mechanical load?

7. Why are A-C Motors especially adaptable to recording work?

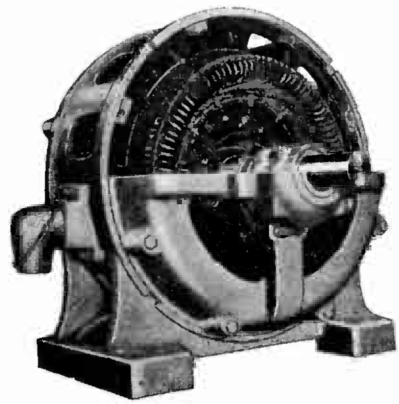
8. What will happen to a synchronous motor if too great a mechanical load is put upon it?

9. Explain the shading-coil method of producing a rotating field effect.

10. How is the current in the starting coils made to flow "out of phase" with that in the running coils in a split-phase motor?



Polyphase Wound-Rotor Induction Motor



Polyphase Induction Motor With Top
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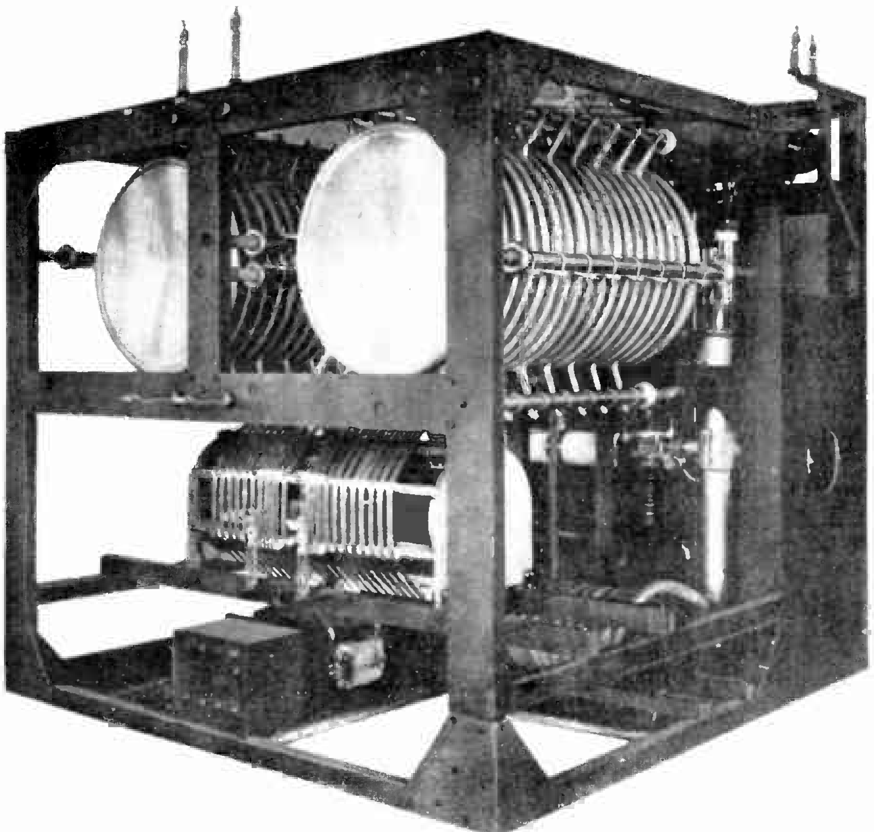

Rear View, 50-Kw. Amplifier showing tank-circuit inductance and air dielectric tuning condensers above

CAPACITANCE AND CONDENSERS

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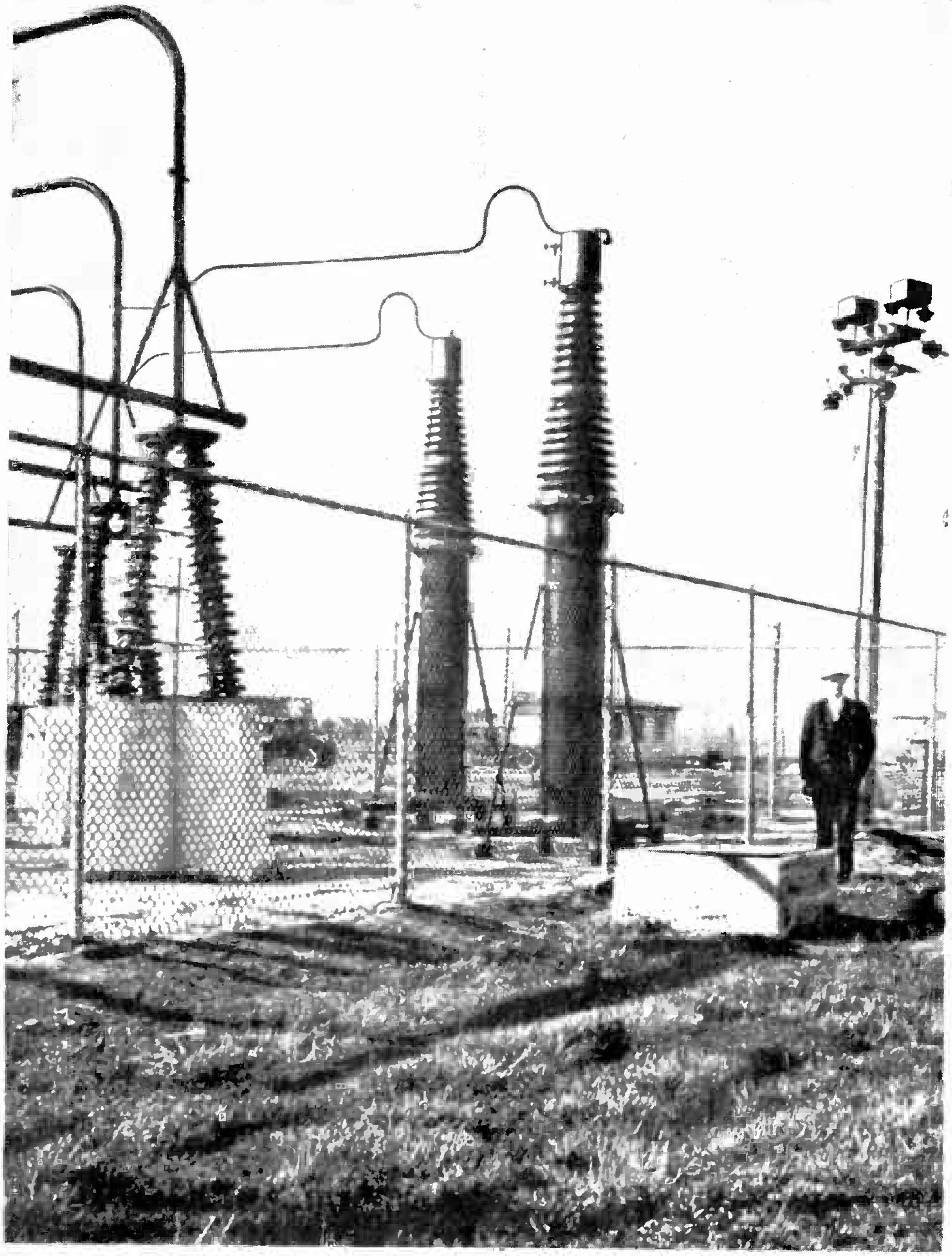

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CAPACITANCE AND CONDENSERS

What is capacity? Under what other names does it appear and where and why is it used? Capacity is the ability to receive, contain and store up energy. For example, a tank has the ability of storing water, oil and other forms of liquid. A condenser, in the electrical sense, stores electricity. It is used in power line transmission as well as in radio.

Fig. 1--Component unit of a condenser

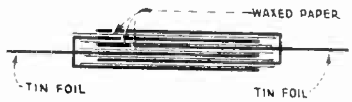


Fig. 3--Paraffined paper condenser

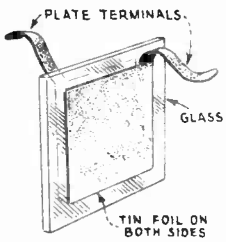


Fig. 2--Construction Details

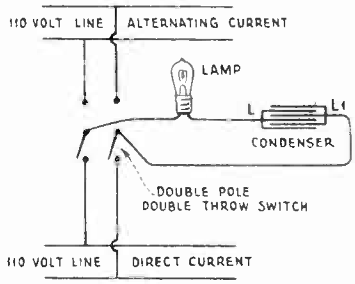


Fig. 4--Circuit used to illustrate condenser action

Capacitance is the term applied to the quality a device may have of being able to receive and store an electrostatic charge. As capacitance plays a large part in many ways and in various phases of the radio industry it may be well for you to know how simple it is to construct a device possessing capacity or capacitance. If you secure a piece of glass and two sheets of tinfoil you have the elements of a very simple condenser. Figures 1 and 2 indicate how this condenser is assembled. A large number of commercial condensers used with spark coils are made of tinfoil and paraffined paper, the tinfoil being the conductors and the paper being the insulator or dielectric, as it is called. Alternate layers of tinfoil and paper make up the condenser. A paraffined paper condenser with leads is shown in Figure 3.

Suppose we conduct an experiment, the purpose of which will assist us to visualize the effect taking place when a condenser of large capacitance is placed in a direct current circuit and then in a circuit carrying alternating current. We will use a hook-up as shown in Figure 4. Throw the double-pole double-throw switch down, thus connecting the circuit containing the condenser and lamp to the source of direct current. It is noticed that the lamp does not light. In a direct current the condenser acts as an open circuit exactly as though you had opened the circuit by cutting the wire with a pair of pliers, and this experiment proves it, for otherwise the lamp would have given off light. In tracing the circuit through the lamp you will find a connecting path for current as far as, and including, the plates marked "L", but the intervening dielectric, which is an insulator, prevents current from flowing to "L1". A potential difference does exist, however, and is available between the condenser terminals. This potential rose from zero (line disconnected) to a maximum value equal to the potential difference of the line wires, when the switch was closed. Before this value was reached, the coulombs of electricity entering the condenser per unit of time gradually decreased to zero. The lamp, if the capacitance of the condenser and resistance of the lamp were correct, might become incandescent for a fraction of a second giving a flash of light, but it would not remain illuminated. This would indicate that there was a momentary current flow after which the lamp ceased to glow.

Let us apply an alternating E.M.F. to the same circuit by throwing the switch up. The lamp at once burns at moderate incandescence and remains in this state giving off light until the circuit is opened. While we could obtain a single flash of the lamp when a direct E.M.F. was applied, we find that by applying alternating current a continuous illumination results, proving without question that a condenser, when of the correct capacity, does not produce in an a-c circuit the effect of an open circuit as it did in the direct current circuit. There is an electrical phenomenon taking place in the space between the plates of the condenser. This space together with the condenser plates constitutes capacitance. This space has the ability to receive and hold an electrical charge and is called the Dielectric. The plates of the condenser serve only the purpose of distributing the electromotive force over the dielectric.

The most common form of dielectric material is found in the shape of insulators. Air as a dielectric is frequently used, and it is from air that we base our standard for the "Specific Inductive Capacity" of the dielectric. Air, mica, glass, rubber, paper, and oil all may be utilized to form a dielectric for the condenser. As air is taken as a standard it is given the value of unity, or 1. To explain this value of Specific Inductive Capacity, suppose we determine by measurement the amount of charge a condenser using air as the dielectric will accumulate with a definite E.M.F. Then under the same conditions we will measure the amount of charge in the same condenser using glass as the dielectric. It will be found that when glass is the dielectric medium the condenser will take a charge from 5.4 to 10 times as great as the condenser having air as the dielectric, this specific inductive capacity depending upon the grade of glass used.

SPECIFIC INDUCTIVE CAPACITY

The following table indicates the Specific Inductive Capacity of some of the most commonly used dielectrics:

Air	has a dielectric constant	of	1.00		
Castor Oil	" " " "	"	4.67		
Hard rubber	" " " "	"	2.5	to	3.50
Glass	" " " "	"	5.4	"	10.00
Mica	" " " "	"	4.0	"	8.00
Paper	" " " "	"	1.5	"	3.00

We find that when different insulating material is placed between the plates of a condenser the capacity of the condenser will be changed.

To explain the charging action of the condenser it will be well for us to review briefly the subject of conductance, insulation, and a phase of the electron theory dealing with the atomic structure. The condenser circuit is composed of the conductor plates which are usually aluminum, tinfoil or copper.

The material selected as a conductor must have a low resistance, in other words, it should offer very little opposition to the movement of electrons which, as you know, produces what is termed an electric current.

Insulation is so named because of the opposition which it offers to the electronic movement and resulting electric current. Insulation in a direct current circuit produces the effect of an open circuit, but when the same insulation is used as a dielectric of a condenser and placed in an alternating current circuit it may have the effect of being a conductor, as you learned by the lamp and condenser experiment. The condenser does not permit an actual continuous passage of electrons in one direction; it has the effect of permitting a shifting back and forth of the electrons in an otherwise conductive path. This statement may, at first appear contradictory and somewhat confusing, but the effect of the conduction of alternating current through a condenser can be readily explained and made clear if we will but consider the nature of electric current flow as set forth in the electron theory.

According to the electron theory all bodies are considered to be made up of infinitesimally small particles of matter called Atoms and, revolving about the atom, much as the earth and other planets revolve about the sun, are much smaller particles called Electrons. The atom is considered to be made up of one or more charges of positive electricity. All bodies are made up of atoms and, since the atom is considered to constitute a positive charge of electricity and the electron negative electricity, all substances possess large quantities of electricity. We found in previous lessons that like charges repel and unlike charges attract. In nearly all cases, however, the positive electrical charge equals the negative electrical charge thereby neutralizing each other and from all outward effects no electrical charges are evident. This complete balance of positive and negative electricity may be upset and we then observe electrical effects.

Negative electricity, or the electron, is considered to be the only form of motional electricity. Therefore, if we can succeed in forcing an electron to leave an atom there will be less negative charge than positive, the system becomes unbalanced, and the atom predominates in positive charge. By returning the negative electron to the atom we again produce a balance and the atom is again neutral or uncharged. Now force an electron to the balanced atom; the atom now will have an excess of negative charge thus making it negative.

In a substance which is a good conductor of electricity, such as copper and some of the other metals, the electron can be moved easily from atom to atom and this is what takes place when an electromotive force is produced by either mechanical or chemical means.

As all electrons are negative charges of electricity any electron caused to move from one atom to the next will cause an electron adjacent to it to be repelled with great force, and as long as the electromotive force is applied this repelling of electrons continues. It is this movement of electrons which results in what is called current flow.

In insulators, such as we employ as dielectric mediums of a condenser, the atom has a far more stable structure and greater electromotive force is required to drive an electron from the atom.

Now suppose we have a condenser and a source of E.M.F., the value of which is not great enough to completely dislodge or drive the electrons from the atom, but sufficiently great to strain the electron from its normal orbit without completely dislodging it from the atom, that is, to a position just short of the complete breaking away point, as the E.M.F. forces the electrons from the circuit into one condenser plate, piling them in by the millions, the electrons in the atoms of the dielectric are repelled and displaced from their normal position. The second plate, being positive, attracts the electrons in the atoms of the dielectric. It is this moving away of the electrons from their normal position in the atom that is called the displacement current, and the condenser is said to be charging; that is, charging in the sense that electrons continue, as a result of the E.M.F., to pile up in the negative plate. The displacement of the electrons has produced a strain on the whole structure of the atoms. When the holding forces of all the dielectric atoms to their electrons is equalled by the repelling force of these electrons against the electrons moved into the negative condenser plate, the potential difference between the two plates has become equal to the electromotive force applied from the external source. Then the movement of electrons out of one plate and into the other through the external circuit will cease.

This action, so far, can be illustrated by imagining a tank of proper design used to store air. Let an air pump represent an electric generator and the particles of air the electrons. On starting, the pump air at once is set in motion and is forced into the tank; the tank is under pressure and becomes strained. This strain caused by the piling up of air particles begins to exert a back pressure on the air being forced into the tank. This continues to increase with every stroke of the pump until the stored up air reaches a pressure equal to the driving pressure of the pump, when the flow of air will cease.

A similar action takes place in the electric circuit. As the applied E.M.F. decreases in the alternating current circuit the strained dielectric is relieved, allowing the electrons to again assume their normal positions about the atoms. This reverse movement of the electrons produces a displacement current in the opposite direction and the condenser is discharging. As the applied E.M.F. passes through zero value and reverses, the charging movement of electrons is toward the plate which was positive during the first half-cycle; the electrons in the dielectric atoms are displaced in the opposite direction. As the alternating E.M.F. is constantly varying in strength and direction, electrons are continually moving back and forth through the circuit tending to keep the condenser plates at the same potential difference and polarity.

It is this movement of the electrons into and out of the condenser plates which results in the current causing the lamp to glow in the experiment of Figure 4. It is therefore clear that the electrons do not actually pass through the dielectric from one plate to the other, but simply move into and out of the plates, swinging through the circuit from one plate through the generator to the opposite plate. With this knowledge of the behavior of the condenser we are enabled to make an efficient test as to the worthiness of a condenser by using direct current for the test.

From a source of direct E.M.F., such as a 45 volt "B" battery, bring out two leads as suggested in Figure 5, one lead having a suitable voltmeter in series. Touch the terminals of the condenser and at the same time observe the voltmeter. The needle will be deflected once and then return to zero. Remove the test tips and at once bring them in contact with the condenser a second time; on the second contact there will be no deflection of the voltmeter needle. This proves, first, that the condenser is charged and, second, that it will not accept a further charge with the E.M.F. of 45 volts. Third, the current will not flow entirely through the dielectric.

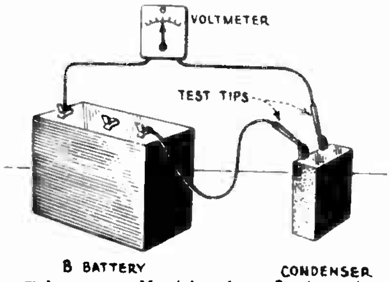


Fig. 5--Method of test-charging a condenser

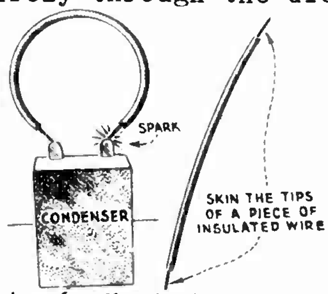


Fig. 6--Method of test-discharging a condenser

Take a piece of insulated wire, skin the ends and short circuit the condenser as shown in Figure 6. When testing certain condensers in this manner a bright spark will result, proving that the condenser held the charge until a path was offered to the charge to flow out, which it immediately did through the wire forming the circuit to the opposite plate, thus equalizing the charge until there was no difference of potential between the condenser plates.

Now secure a punctured condenser and follow the same procedure as before. The indicating needle of the meter will be deflected at every contact of the test tips indicating that the dielectric is broken down allowing current to flow directly through from one plate of the condenser to the other. A broken down condenser will not hold a charge.

A water analogy of the action of a condenser follows to illustrate displacement current. Refer to Figure 7. Here is a system of pipes "E" and "C", and a tank divided into two divisions, "A" and "B", by a rubber partition "R". A reservoir is shown at "D" (the use of which will be explained later). On filling this system with water it is clearly seen that the water will be divided and prevented from moving by the rubber partition "R". There will be the same pressure in the half of the system B-C-D as in the half A-E-D, therefore there is no distortion of the rubber partition "R" and no movement of the water through the system. The conflicting arrangement of the arrows is intended to picture the water as idle; that is, no particular direction of motion would be evident.

Figure 8 is the same arrangement but, in the reservoir "D", we have installed a centrifugal pump so designed that a continuous pressure is exerted on the water forcing it continually in one direction as long as the pump revolves. Revolving the pump in a clockwise direction the water will be forced into motion and will flow, as shown in Figure 8, from the reservoir "D" through pipe "E" and into the "A" section of the tank. Now what happens? The water cannot move beyond the rubber partition but, due to the nature of the rubber, it will stretch and become strained by the pressure of the water as shown. A displacement of water into section "A" takes place, resulting in a like displacement out of section "B".

We will assume that the pump has sufficient force to extend the partition to the limit, but not enough to rupture it. The water in "B" section of the tank will be displaced along the B-C-D half of the system by the forced distortion of the rubber partition, and will move toward reservoir "D". Now retain this: There has been a

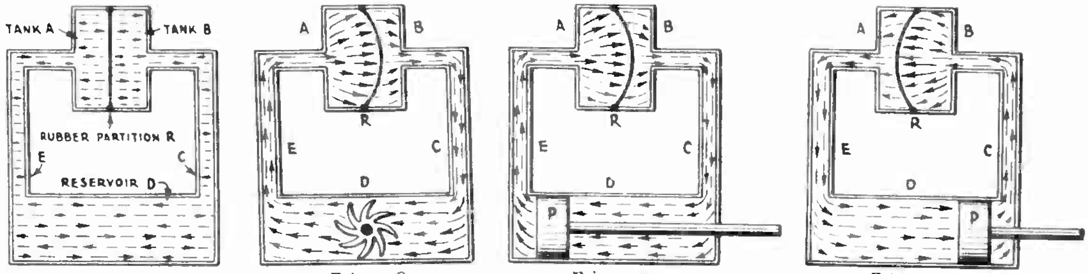


Fig. 7 Fig. 8 Fig. 9 Fig. 10

Various Water Analogies of Condenser Action

displacement of water out of "B" through "C" to "D". Do not forget the word displacement because you will have to associate it with electronic movement later. Remember also that a stress has been placed against the rubber partition and, under this stress, it has been strained and because of this strain movement results in the rubber, causing a displacement of the water in "B" section of the tank.

As the pump continues to revolve continuously in the same direction it maintains a stress upon the rubber partition and the rubber remains in a fixed strained position. As it cannot be strained further there is no further displacement of the water in "B" section when the partition has reached its limit of strain and therefore only one surge of water takes place in the B-C-D half of the system as long as the water is forced to move in the same direction.

This action is similar to the action of a condenser in a direct current circuit. There is actually one surge of displacement current through a condenser in a direct current circuit just as there was one surge of displaced water in Figure 8, but that completes it because the condenser dielectric is strained by the E.M.F. displacing electrons sufficiently to cause one surge of current.

Explaining the water analogy for the alternating current we will use Figure 9 which is the same type of arrangement as shown in Figures 7 and 8 but, instead of the centrifugal pump, we have a piston "P" which fits closely to the walls of the reservoir. Water fills the system as it did in Figure 7. It is clearly seen that if the piston "P" is moved to the left, Figure 9, it will exert a pressure on the water in the "EA" half of the system thus placing a stress on the rubber partition "R", causing it to stretch and a displacement of the water in "B" follows, which moves all the water in B-C-D. The elastic rubber partition is exerting a back pressure against the water forced against it by the piston.

When the piston is returned toward the center of "D" the strain on the partition is relieved, and its back pressure is effective in aiding such a movement of the piston because of the tendency of the partition to straighten out. Therefore the suction effect of the returning piston and the back pressure effect of the partition combine to give back into section "ED" the energy stored up in "A". At the same time the movement of the piston has forced water back up through the pipe "C" into "B" until the partition is completely straightened out and at rest. As the piston continues its movement past the center of "D" and on to the extreme right position as shown in Figure 10 the extra quantity of water moved into "B" section bulges the partition to the left, being opposed by a back pressure due to the strain in the rubber. The water in the "A" section becomes displaced into the "ED" section as shown by the arrows. With this arrangement and by a rapid forward and backward movement of the piston water will move first in one direction and then in the other.

It must be apparent that we may insert in either the "E" pipe or the "C" pipe some device operated by water flow and have work done in this device, the energy used being provided originally by the pump plunger. In like fashion we may insert an electric device, such as a lamp, in one of the electron-conducting wires between a condenser and a source of alternating E.M.F., and energy in the form of heat and light may become available at the inserted device.

CAPACITANCE

The capacitance of a condenser is a measure of the relation between the amount of a charge in the condenser and the potential difference in volts required to produce that charge. We may say that: $C = Q/V$, where Q is the quantity of electricity measured in coulombs, V the potential difference, and C is the capacitance, the unit of which is the FARAD.

In Figure 9 the volume of water displaced varied directly with the pressure, the cross-sectional area of section AB, and the elasticity of the rubber partition, but inversely with the thickness of the partition. We might write this relation as follows:

$$\text{Water Volume Displaced varies as } \frac{\text{Pressure x Area x Elasticity}}{\text{Thickness of Partition}}$$

$$\text{or } \frac{\text{Water Volume Displaced}}{\text{Pressure}} \text{ varies as } \frac{\text{Area x Elasticity}}{\text{Partition Thickness}}$$

which latter term may be considered the "capacity" of the section. In the electrical case we find a closely similar relation:

$$\frac{\text{Quantity of Charge}}{\text{Potential Difference}} \text{ varies as } \frac{\text{Area x Dielectric Constant}}{\text{Dielectric Thickness}}$$

From the preceding paragraph we know that Q/V is the capacitance of the condenser, and the exact formula for it may be written:

$$C = \frac{8.85 \times K \times A}{t \times 10^8}$$

where C = Capacitance in microfarads
K = Specific Inductive Capacity
A = Area in square centimeters of one plate of a two-plate condenser as in Figure 2.
t = thickness of dielectric in centimeters.

If, instead of a single pair of metal plates, there are N similar plates with dielectric between (Figure 3) with alternate plates connected together into two groups, we find that:

$$C = \frac{8.85 \times K \times A \times (N-1)}{t \times 10^8}$$

It will be seen that the capacitance is expressed in MICROFARADS. A condenser having a capacitance of one farad is beyond construction, it would have to be so large. Condensers in actual use have capacitances of only a very small fraction of a farad. In engineering practice, decimal parts are expressed as microfarads and micro-microfarads. Micro means "one millionth of" and micro-micro means "one million-millionth of". Hence a condenser of one microfarad has a capacitance of one-millionth of a farad, etc.

The capacity of a condenser is sometimes expressed in centimeters, one centimeter of capacity being equal to 1.1124 micro-microfarads. This unit, however, is not so frequently used as the one explained in the foregoing paragraph.

When the physical dimensions of a condenser are measured in square inches and inches instead of sq. cms. and cms. the following formula holds good:

$$C = \frac{22.4 \times K \times A \times (N-1)}{t \times 10^8}$$

The area of the plates, the number of plates and distance between the plates can easily be found. The specific inductive capacity, or "K", however, must be determined by actual test and measurement when absolute accuracy is desired. When an approximation is desired a value of "K" may be used as given in specific inductive capacity tables. For example, suppose a condenser has a total plate area of 800 square inches. The dielectric is mica, one one-hundreth (1/100) of an inch in thickness. We now have all the necessary data from which to calculate the capacity of the condenser except the specific inductive capacity (dielectric constant "K").* This can be obtained from tables giving the dielectric constant of different materials. Referring to the table given previously we find the dielectric constant for mica varies from 4.0 to 8.0, depending upon the grade of mica.

*(Note: specific inductive capacity (K) is more often termed the "dielectric constant").

Let us assume that the mica being used in this condenser has a dielectric constant of 5. Substituting these known values in the formula for capacity, the formula becomes:

$$C = \frac{22.4 \times 5 \times 800}{.01 \times 100{,}000{,}000}$$

$$C = \frac{89{,}600}{1{,}000{,}000}$$

$$C = .0896 \text{ mfd.}$$

Capacity effects exist between any two conductors with a dielectric between them. As you learned, air or any insulating substance is a dielectric, and there is always a capacity effect between two electrical conductors. If they are bare wires, air is the dielectric; if covered with insulation the insulation acts as a dielectric.

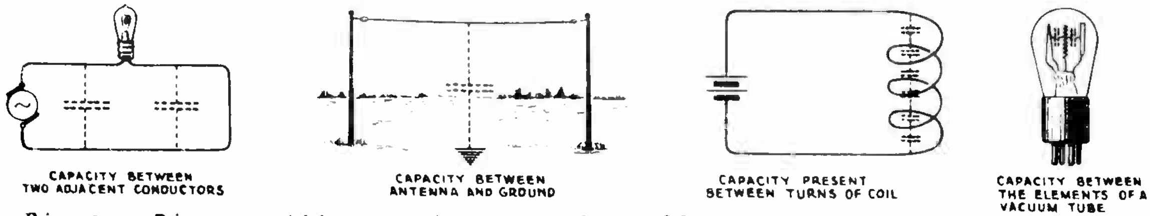


Fig.11--Diagrams illustrating capacity effects in familiar circuits

In bare wires running from pole to pole or, on a ship, from mast to mast, the air around the wires acts as a dielectric, the ground acting as one side, or plate, of a condenser while the wire is the other plate, and capacity exists there exactly as between two conductors running close to each other, or as in a condenser. Figure 11 gives an idea of capacity in circuits familiar to you.

In determining capacity it is seen that formulae for all conditions under which capacity exists would be rather a complicated work.

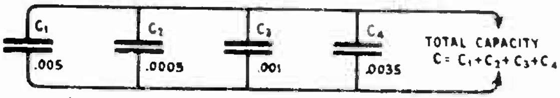


Fig.12--Parallel connection of condensers

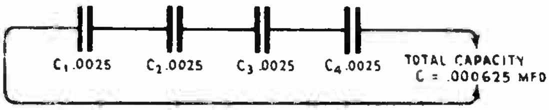


Fig.13--Series connection of condensers

CONDENSER GROUPING

Condensers are grouped to obtain various capacities and to perform certain functions. Certain circuits may call for condensers in series and others in parallel.

When condensers are connected in parallel, as shown in Figure 12, the total capacity resulting from such a connection is the sum of the individual capacities. In this instance, the different condensers in the group are shown as having capacity of .005 mf, .0005 mf, .001 mf and .0035 mf. The total capacity of such a parallel arrangement is, as stated, the sum of the individual capacities, or .01 mf.

Assume that the four condensers of Figure 13, C1, C2, C3, C4, have a capacity of .0025 each. What would be the total capacity when connected in series as shown in Figure 13? To obtain the total capacity of a number of condensers of equal value connected in series simply divide the capacity of one of the condensers by the total number of condensers in the circuit. Applying this rule to Figure 13 we obtain the answer, .000625 mfd., the total capacity of these four condensers when connected in series.

It becomes necessary under certain conditions, to employ condensers of different values in series. When this is the case the formula of reciprocals is required to solve for total capacity.

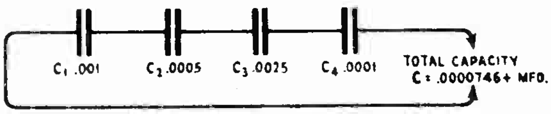


Fig. 14--Series connection of condensers having unequal values

In Figure 14 we have four condensers C1, C2, C3, C4 connected in series. What is the total capacity? The formula for condensers connected in series is as follows:

$$C = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \frac{1}{C_4}}$$

Substituting our known values as stated in Figure 14, the formula becomes:

$$C = \frac{1}{\frac{1}{.001} + \frac{1}{.0005} + \frac{1}{.0025} + \frac{1}{.0001}}$$

$$C = \frac{1}{1000. + 2000. + 400. + 10000.} \qquad C = \frac{1}{13,400}$$

```
C = 13,400)1.0000000(.0000746
             93800
              62000
              53600
               84000
               80400
                3600
```

$C = .0000746$ mfd. (microfarads), or $C = 74.6$ mmfd. (micro-microfarads).

CAPACITIVE REACTANCE

The effect of capacitance in an alternating current circuit, termed capacitive reactance, will now be considered. When inductance is introduced in an alternating current circuit, the effect produced is to retard or cause the current to lag the electromotive force.

Capacitance produces exactly the opposite effect, that is, the current leads the electromotive force.

Capacitive reactance is expressed in ohms, as is inductive reactance, and is written X_c (X sub c) while inductive reactance is expressed X_l (X sub l).

The capacitive reactance in any circuit changes with a change in frequency and the greater the frequency the less effect will capacity have on the circuit. An increase in frequency, when inductance is being considered, produces a greater reactive effect.

The formula is as follows: $X_c = \frac{1}{6.28fC}$

X_c = capacity reactance
f = frequency
C = Capacity in farads

In a 110-v., A.C. 60-cycle circuit, we have a .0025 farad condenser connected in series with the line. What is the capacity reactance?

By formula given: $X_c = \frac{1}{6.28 \times f \times C}$

Substituting: $X_c = \frac{1}{6.28 \times 60 \times .0025}$

Multiplying the denominator then $X_c = \frac{1}{.942000}$

```
   6.28
     60
 376.80
  .0025
 188400
 75360
.942000
```

Dividing

```
.942000)1.0000000000(1.0615
         942000
          5800000
          5652000
           1480000
            942000
            5380000
            4710000
```

We find that the capacitive reactance in the circuit as given above amounts to 1.0615 ohms.

Now let us increase the frequency to 500,000 cycles using the same condenser of .0025 farads. This will show us that, with an increase of frequency, the reactance is lowered.

Again by formula $X_c = \frac{1}{6.28 \times f \times C}$

Substitute $X_c = \frac{1}{6.28 \times 500,000 \times .0025}$

Multiplying the denominator

```
  6.28
     500000
 3140000.00
      .00 25
 1570000000
 628000000
 7850.000000
```

```
7850)1.000000000(.00012738
      7850
      21500
      15700
       58000
       54950
        30500
        23550
         69500
         62800
          67000
```

or X_c = .00012738 ohms.

The purpose in working out this problem has been to show how according to the formula, capacitive reactance decreases with an increase in frequency. You found that, with a frequency of 60 cycles, a capacitive reactance of a little over one ohm reactance was present. When the frequency was increased to 500,000 cycles, however, the reactance was reduced to a fractional part of an ohm.

The table below gives the capacitive reactances of condensers of various capacitances, at frequencies commonly met with in radio practice. For other frequencies it will be easy to determine the reactance of a condenser by proportion. For instance, the reactance of a .001 mfd. condenser at 50 cycles is 3,180,000 ohms. Then the reactance at 5,000 cycles $= 3{,}180{,}000 \times \frac{50}{5000} = 31{,}800$ ohms.

CAPACITIVE REACTANCE IN OHMS

CAP. IN MFDS.	FREQUENCIES					
	POWER SUPPLY		AUDIO		BROADCAST	
	60	120	50	8,000	700,000	1,500,000
.0001	26,500,000	13,300,000	31,800,000	199,000	2,270	1,060
.00025	10,600,000	5,300,000	12,700,000	79,600	910	425
.0005	5,310,000	2,650,000	6,370,000	39,800	455	212
.001	2,650,000	1,330,000	3,180,000	19,900	227	106
.002	1,330,000	664,000	1,590,000	9,950	114	53.1
.005	531,000	265,000	637,000	3,980	45.5	21.2
.01	265,000	133,300	318,000	1,990	22.7	10.6
.02	133,000	66,400	159,000	995	11.4	5.3
.05	53,100	26,500	63,700	398	4.55	2.12
.1	26,500	13,300	31,800	199	2.27	1.06
.25	10,600	5,300	12,700	79.6	.92	.42
.5	5,310	2,650	6,370	39.8	.46	.21
1.0	2,650	1,330	3,180	19.9	.23	.11
2.0	1,330	664	1,590	9.9	.11	.05
3.0	885	443	1,060	6.6		
4.0	664	332	796	5.0	.06	.03
8.0	332	166	398	2.5		
10.0	265	133	318	2.0	.02	.01

GENERAL TYPES OF CONDENSERS

Condensers may be divided into four or five general types according to the dielectric used in their construction. The "Leyden jar" type was, at one time, a very common form of condenser used in transmitting equipment. It consists of a glass jar with walls about 1/8" thick coated inside and out to within two inches of the top with a tinfoil, copper or silver coating. This type is shown in Figure 15. The "Leyden jar" was one of the first types of electro-static condensers developed and, although it is quite efficient it has been rendered almost obsolete by more modern condensers incorporating higher efficiency and greater capacity in units of smaller physical dimensions.

The Glass Plate Condenser for use with high potentials is constructed as follows: Plate glass is used as the dielectric to which is glued tinfoil plates and, after being thoroughly dried, they are coated with shellac or hot paraffine. A single plate is shown in Figure 2.

A number of plates, depending upon the capacity desired, are connected together and immersed in an oil container as shown in Figure 16. This type of condenser is not used to any great extent due to the inconvenience of assembly and the time and work required in replacing broken plates in case of break-down.

The Compressed Air condenser is a type that will be found in use in very few radio installations because expense in construction and upkeep does not warrant its general use. Briefly, the compressed air type is constructed as follows: A metal tank contains steel plates in which half of the plates are insulated from the tank and the other half connected to the tank. The tank is pumped to a pressure of 250 pounds providing a dielectric capable of withstanding a potential of 25,000 volts. Should a break-down potential be applied to this type of condenser no damage is done because the air simply fills in again making the dielectric perfect. This type of condenser is heavy, hard to handle and, in nearly all cases, trouble is experienced in maintaining the tank air tight.

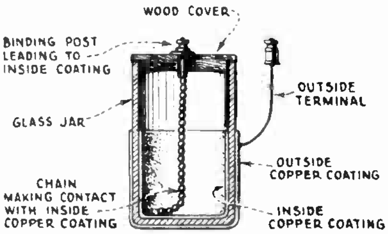


Fig.15--"Leyden Jar" Condenser

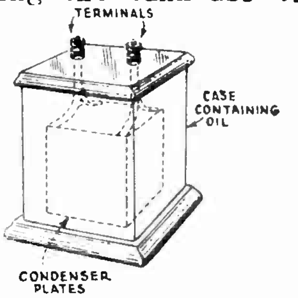


Fig.16--Glass Plate Oil Condenser

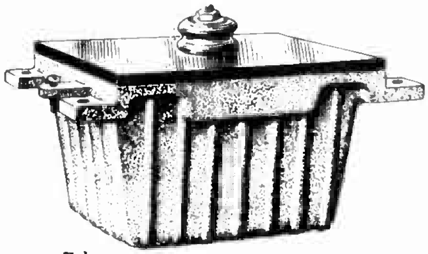


Fig.17--Mica Transmitting Condenser

The foregoing types of condensers were rendered obsolete, as far as modern radio practice is concerned, by the mica condenser. They have been mentioned because, at the period of their development, they each represented an advancement in good practice in radio condenser construction.

The mica condenser uses sheet mica as the dielectric and the plates are made of tinfoil, or copper foil. Properly designed and constructed, this condenser will withstand the high potentials encountered in radio transmitters; —its electrical efficiency is very good and large capacities may be secured within comparatively small physical dimensions. Furthermore, it is very sturdy as compared to the fragility of condensers employing glass as the dielectric —such as the Leyden jar and the glass plate condensers.

A modern mica transmitting condenser is shown in Figure 17. The condenser is enclosed in an aluminum case, the space between the condenser and the case being filled with an insulating compound to render the condenser moisture proof and to reduce brush discharges. The metal case is used as one terminal of the condenser while the other terminal is brought out to the binding post on the bakelite cover of the case.

THE WET ELECTROLYTIC CONDENSER

(The following information on the wet type of electrolytic condenser consists chiefly of an extract of an article by Mr. H. O. Siegmund printed in the Bell System Technical Journal. The material is reprinted here with permission.)

Since the discovery about 75 years ago of the unusual polarizing effect of aluminum it has become well known that certain metals, notably aluminum and tantalum, as anodes in a suitable electrolyte become coated with a film having remarkable electrical properties. Films formed in this manner are characterized by the influence of impressed potential on their electrical resistance.

This resistance characteristic imparts to the film the capability of conducting current more freely in one direction than in the other; of breaking down as an insulation between the metallic electrode and the solution when voltages above a critical value are applied; and, in combination with the thinness of the film, of holding a substantial charge of electricity at potentials below the break-down voltage.

Each of these characteristics provides the principle around which a distinctive class of electrical apparatus has been developed. The electrolytic rectifier, widely used in small direct-current supply sets for battery charging and radio purposes, employs the uni-directional conducting characteristic. The aluminum electrolytic lightning arrester, used extensively for protection of direct-current railway equipment, depends for its operation upon the break-down characteristic of the film. And finally the aluminum electrolytic condenser, now being used in direct-current telephone and radio power plant equipment, utilizes the dielectric property of the film to provide electrostatic capacity.

There are a number of electrolytes, including various concentrations of phosphates, borates, tartrates and carbonates in which films can be formed on aluminum to withstand potentials upwards of 300 volts,at least for limited periods. If a film is formed on a piece of aluminum to this maximum voltage and the metal is then made the anode (positive electrode) in an electrolytic cell across which variable potential can be applied, a current corresponding to a density of less than one microampere per square centimeter of filmed surface will flow when a potential of one tenth of the maximum voltage is impressed.

As the potential is increased this "leakage" current will increase at a rate somewhat greater than proportionate to the voltage. As the maximum or breakdown potential is approached it will be noticed, if the room is darkened, that the anode begins to glow uniformly over the surface with a pale light and with further increases in voltage sparks begin to scintillate over the entire electrode, being noticed first at the surface of the electrolyte. The current through the cell becomes appreciable under this condition and increases more rapidly until at voltages slightly above the sparking potential the cell acts virtually as a short circuit.

Upon reduction of the voltage, however, the insulating properties of the film are restored and the current decreases with decreasing potential in substantially the same relation to voltage as before. The sparking over the surface will be observed to cease at about the same potential at which it began, the glow will disappear and the low leakage-current values will be obtained when the voltage is reduced sufficiently.

Upon reversal of potential on the aluminum electrode there is a much larger flow of current, the value of which is limited by a counter voltage of several volts, and by the low internal resistance of the cell with negative potential applied.

CAPACITY OF ALUMINUM FILMS

Like the ordinary paper or mica static condenser, the electrolytic condenser consists of two conducting surfaces separated by an insulator. The high-resistance film constitutes the insulator in the electrolytic cell, and the electrolyte on one side of the film and the metal of the film-bearing electrode on the other provide the two conducting surfaces. The cathode in this type of cell merely provides a means for making electrical contact with the electrolyte.

When a film is formed upon a smooth polished aluminum surface the coating is transparent. If observed under favorable illuminating conditions the "filmed" surface is seen to be colored and may be either green, yellow, red or blue, depending upon the thickness of the film. The actual thicknesses of films on aluminum have been determined to be from 0.001 to 0.00001 mm., depending upon conditions of formation.

Because of this extreme thinness of the dielectric and its high insulation resistance when positive potential is applied, unusually large capacities per unit area of surface can be obtained. The capacity of a film formed to 30 volts on aluminum is about 0.18 microfarad per square centimeter of dielectric surface, or about 1,000 times that of paper condensers. The capacity per unit area is approximately inversely proportional to the potential at which the film is formed, indicating that the thickness of the dielectric is proportional to the voltage of formation.

EFFECT OF IMPRESSED VOLTAGE ON CAPACITY

When an electrolytic cell with a "formed" anode has impressed on its terminals a voltage greater than the formation voltage, the film must build up to the new potential before the electrical characteristics of the cell become stable. At this higher voltage the capacity of the cell will be reduced to correspond to the increased potential. Where large plate areas are involved the direct application of a potential above the formation voltage results in a heavy flow of current, which may overheat and damage the cell if not properly limited.

If a voltage is impressed on a condenser lower than the potential applied during the formation of the film, the cell will operate satisfactorily, but the capacity will not be immediately affected and will correspond to the potential at which the film was originally formed. However, if a condenser operates for a long time at a reduced voltage the excess film will be removed slowly by the chemical action of the electrolyte, and the capacity will increase gradually to a value depending upon the operating voltage.

When the second electrode of an aluminum cell is made of a non-film forming metal, current will be conducted freely when the aluminum electrode is made the cathode (negative line terminal connected to it). Accordingly this type of cell (called "asymmetrical") is capable of holding a charge of electricity and serving as a condenser only while the aluminum is at a higher positive potential than the electrolyte.

REQUIREMENTS FOR ALTERNATING CURRENT SERVICE

A cell with a non-film forming cathode makes a suitable condenser to operate on direct-current or pulsating-current circuits, in which the aluminum always remains positively charged. On alternating-current circuits, however, such a cell will operate as a rectifier rather than as a condenser, unless two similar units are connected in a series-opposed relationship. In this case, while one cell is acting as a condenser the other cell merely acts as a series resistance; when the current reverses the functions of the two cells are interchanged.

A suitable condenser for operation on alternating current service can also be made by having two electrodes of film-forming metal in the same solution, the electrical relations between the "formed" electrodes being the same in this case as in the series-opposed arrangement of two asymmetrical cells. In either case one or other of the film-forming electrodes opposes the flow of current during each half cycle and its film therefore serves as a condenser dielectric. As the alternating potential varies between maximum values in each direction, the charge is transferred from the capacity provided by one film-forming electrode to the other, the sum of the charges on these two electrodes at every instant remaining constant.

LOSSES IN ALUMINUM CELLS

In the matter of electrical impedance characteristics, the electrolytic condenser does not approach a perfect capacitance as nearly as the more familiar forms of static condensers. Three sources of energy loss in the electrolytic condenser impart to it an equivalent series resistance, as a result of which the condenser current leads the impressed voltage by a phase angle somewhat less than 90 degrees.

The first of these losses is the dielectric hysteresis loss, which, as in the case of the paper condenser, is approximately proportional to the frequency. The second loss is the heat dissipation in the electrolyte due to its resistance and, in the case of aluminum condensers, this may be of appreciable magnitude because of the low electrical conductivity of most suitable electrolytes. This electrolyte resistance remains practically constant over a wide range of frequencies. The third possible loss is heat dissipation in the film due to its leakage-resistance, which in its effect is similar to a high resistance in parallel with the condenser. Ordinarily this loss is negligible because the leakage current is of very low magnitude.

CONDITIONS AFFECTING THE LIFE OF CONDENSERS

To be successful from a commercial point of view an electrolytic condenser must have long life and must not require frequent attention. Otherwise the advantage in the matter of mounting space and the cost per unit capacity is offset by the depreciation and maintenance costs involved. There are two common conditions affecting the life of aluminum condensers that must be controlled if the cells are to operate satisfactorily.

The first concerns the chemical action of the electrolyte on the electrodes and the film. This action, which is merely a matter of the film dissolving and forming aluminum hydroxide in the solution, takes place when the cell is off circuit as well as when potential is impressed. With impressed potential, new film forms under the influence of the leakage current to replace that which is dissolved, but in time the fluid becomes saturated with aluminum hydroxide, which may precipitate as a white jelly and adversely affect the life of the condenser.

The second consideration involves corrosion of the positive electrodes. The susceptibility of aluminum to corrosion is well known, and in the use of electrolytic condensers corrosion of the anode is the most damaging irregularity that can occur.

Obviously then an electrolyte must be chosen that does not rapidly dissolve the film, and the material for the electrodes as well as for the electrolyte must be selected and prepared to prevent serious corrosion of the "formed" aluminum plates.

A COMMERCIAL APPLICATION AND DESIGN OF ELECTROLYTIC CONDENSER

In telephone systems and radio transmitters the principal application of this device involves its use in electric wave-filters. These filters are placed in the supply circuits associated with storage batteries at central telephone offices and at radio stations (used for vacuum tube filaments) and their purpose is to eliminate noise-producing ripples and pulsations introduced by battery-charging apparatus and signalling equipment

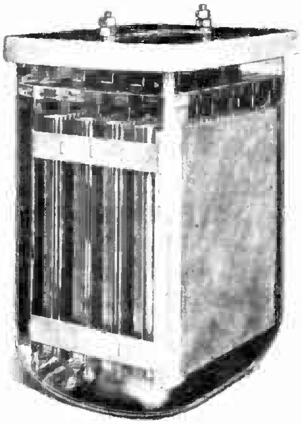


Fig. 18--Aluminum electrolytic condenser, designed for d.c. filter service

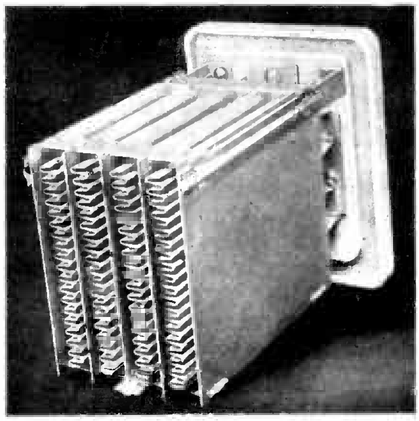


Fig. 19--Aluminum electrolytic condenser showing construction of electrodes

In Figure 18 is shown an electrolytic condenser of the type designed for direct-current filter service. When prepared for operation on 24-volt d-c circuits, the capacitance of this cell is nominally 1,000 microfarads at 1,000 cycles, and for 48 volts is about 600 mfd. at the same frequency. (The frequency of the ripple is stated because the capacity of a condenser of this type decreases with increasing frequency. This is due principally to the corrugated shape of the plates on which the film is formed).

The container for the condenser is made of heat-resisting glass which reduces possible breakage due to temperature variations. The electrodes, both of aluminum, are rigid and are bolted to a porcelain cover to keep them in proper space relation. Two supporting bolts, one from each electrode properly marked with respect to polarity, extend through the cover to provide the terminals for the condenser. A thin layer of high grade paraffine oil is used on top of the condenser fluid to prevent evaporation and to keep the inside of the cell from sweating under varying room temperature conditions. The cover is sealed to the glass jar with paraffine to provide additional protection against evaporation and to prevent dirt from getting into the cell.

ANODE CONSTRUCTION AND MATERIAL

The construction of the electrodes is shown in Figure 19. The positive electrode on which the dielectric film is formed is made of four corrugated aluminum plates, each supported by four integral ears. In an assembled condenser the positive plate surfaces are entirely immersed in the electrolyte, the ears extending up through the oil and providing contact with the positive terminal. The material for the positive plates is aluminum of special composition, selected on a basis of properties which influence the formation of the film, the leakage current, and the life of the metal. In general, the higher the purity of the aluminum the more rapid is the formation of the film and the lower is the resultant leakage current. In the matter of life, however, the purer metal seems to be more readily attacked by agencies capable of causing electrolytic corrosion.

THE NEGATIVE ELECTRODE

This consists of five rectangular flat plates, having a combined useful surface area about 35% of the total positive surface. They are also of aluminum, but they do not have a film formed on them because their sole function is to provide contact with the condenser fluid. In an ammonium borate electrolyte, such as is used in these condensers, there are a number of other materials, including tin and carbon, which can be used for the negative electrodes.

In normal operation with aluminum negatives there is a tendency for a film to occur, even though the condenser is operated on direct-current circuits, because the negative electrode becomes an anode during the interval that the condenser discharges. This disadvantage in the use of aluminum is overcome by making this negative electrode of an aluminum alloy containing other substances such as silicon which impedes the formation of a film on its surface.

WET ELECTROLYTIC CONDENSERS IN RADIO RECEIVERS

The lack of space in a radio receiver dictates that any electrolytic condenser used shall be small in volume even when there is an advantage of increased capacitance over those of the paper type. There are special construction features concerned, but the preceding information on the wet type holds good for these smaller units used in receivers. Since their external appearance is quite similar to a number of other condensers of the dry electrolytic type shown in Figures 23 to 30 inclusive, no particular illustrations will be presented here. It must be remembered that the wet type of condenser requires a safety valve, usually in the form of a live rubber disc with a number of pin hole vents, permitting the escape of gas, but not of liquid.

THE DRY ELECTROLYTIC CONDENSER

In our everyday experience we have become more or less acquainted with the use of the words "wet" and "dry" to distinguish between the storage battery as used for automobiles (also radio tube filament supply) and the ordinary No. 6 primary cell used for door-bell and amateur telephone systems. We can realize that both are in fact wet, since each depends for its operation on the presence of a chemical solution.

In the field of electrolytic condensers we find the same general misuse of the words "wet" and "dry" as applied to two different mechanical forms of the same electric principle. We may say that both wet batteries and wet electrolytic condensers are wet because they employ a mass of liquid as the electrolyte, whereas in dry batteries and dry electrolytic condensers the liquid electrolyte is absorbed in a chemically inactive medium. They may be considered "dry" for all practical purposes since the electrolyte will not splash around or spill.

The comparison of course does not hold in the sense of the electrical work performed. It will be remembered that in a battery electrical energy is taken from the cell as the result of a chemical or voltaic action in the cell. In a condenser the only energy given up by the condenser on discharge is the energy put into the condenser when it is charged.

In order to inform you more completely on this subject we continue with a summary of various technical articles prepared by the Aerovox Wireless Corporation on their particular make known as the Hi-Farad Dry Electrolytic Condenser. The illustrations included here as Figures 20 to 30 inclusive are reprinted by their permission. Certain technical features are found only in that particular make, but are included here for their general interest.

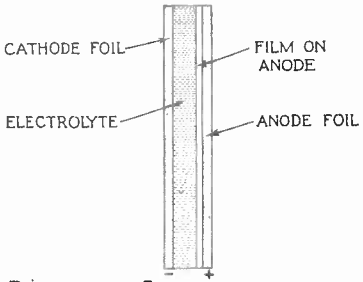


Fig. 20--Constructional detail of the Hi-Farad Dry Electrolytic Condenser

GENERAL

Essentially the Hi-Farad electrolytic condenser consists of:

1. The anode, an aluminum foil,
2. The film, formed electrochemically on the surface of the anode.
3. The electrolyte, which is the cathode proper,
4. Several layers of gauze saturated with the electrolyte, and
5. The second metallic electrode which forms the cathode terminal.

The relative disposition of these various parts is shown in Figure 20.

The foil used for anode and cathode is a particular alloy of aluminum which, in combination with a special electrolyte that does not attack aluminum, precludes any tendency for corrosion and facilitates the formation of a durable film on the anode.

The gauze must also be devoid of any impurities which may affect the forming or the operation of the condenser. Two layers of gauze are placed between the foils. Not only do the two layers of gauze absorb the necessary amount of electrolyte, but the double layer minimizes the danger of breakdown in the case of severe overloads.

A stagger arrangement of the two foils is used for several reasons. In the first place the electrostatic field is most intense along the edges of the foil. Also the film cannot be formed on a sharp edge as effectively as it is formed on a smooth surface. The tendency for increased leakage currents and breakdown in the case of overloads is greatest along the edges, and these conditions are therefore taken care of by separating the edges by about $\frac{1}{4}$ inch.

The electrolyte ingredients are boric acid, glycerine and ammonia, either gaseous or as ammonia water. For producing the electrolyte the ingredients may be combined in the proportion of 1,000 grams of glycerine, 620 grams of boric acid and about 50 cubic centimeters of 26% ammonia water. With the use of this electrolyte, a condenser is formed in a relatively short time and it will, in use, withstand a voltage considerably in excess of 500 volts without breakdown.

WINDING THE CONDENSER

The condenser is made ready for winding by placing the gauze around the end of the cathode foil. The anode foil is then placed in position and the condenser wound up. The outer layer of foil which is the cathode affords quite complete effective electrostatic shielding and also aids in the dissipation of any heat generated within the unit.

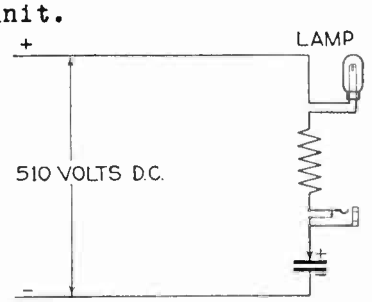
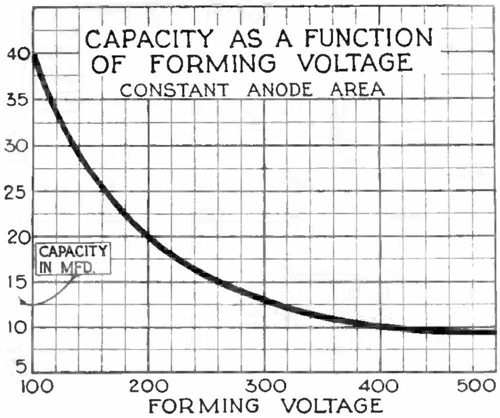


Fig. 21--Film Forming Circuit

Fig. 22--(Right) Capacity Graph



IMPREGNATION

After the condenser has been wound it is ready for impregnation in the electrolyte. As this is a liquid we can thoroughly and uniformly impregnate the sections by immersing them for a period of time in the hot electrolyte. The electrolyte has a relatively high specific resistance, but this does not appear as a disadvantage to the same extent as it would in a wet electrolytic condenser. The dry condenser has such a thin portion of electrolyte between the cathode and the film that the total series resistance is held to a comparatively low value.

FORMING

Before forming we have a unit consisting of two foils separated by two layers of gauze which is completely saturated with electrolyte. The next operation is the forming of the film on the anode. The condensers are formed at a d-c voltage somewhat in excess of that for which they will be rated to operate. Across the d-c supply there is placed in series a resistor, a small incandescent lamp and the condenser to be formed, as shown in Figure 21. Initially, that is before any film is formed, the current is limited almost entirely by the resistance of the resistor and the lamp. The lamp serves to visually indicate that the forming process is proceeding satisfactorily; it also indicates open circuits and high resistance contacts. Leakage currents are checked by means of a milliammeter inserted in series with the circuit. After removal from the forming bath the sections are individually tested for d-c leakage and capacity. They are then ready for final assembly.

The average capacity as a function of the forming voltage is shown in Figure 22.

ASSEMBLY

These condensers can be mounted in containers without any additional dipping or impregnating. Since there is no unabsorbed electrolyte they can be operated in any position and can be placed in either cardboard or metal containers.

Condensers to be mounted in cardboard containers are constructed in the same manner as for metal containers. The cardboard containers are thoroughly impregnated with wax of high melting point and the condensers with the contact tabs riveted to a fiber terminal are placed in the box. The unit is then sealed with an application of pitch over the end of the box.

When the condenser is to be mounted in a metal can the anode contact tab is secured to an aluminum stud projecting from a hard rubber cover. After the unit is mounted on the cover in this manner the section is wrapped in heavy waxed paper and assembled in the can. The grounding of the cathode tab to the can is then accomplished.

Fig. 23
Single Anode Unit
Large Size

Fig. 24
Double Anode Unit

Fig. 25
Triple Anode Unit

Fig. 26
Quadruple Anode Unit

TYPES OF CANNED CONDENSERS

In commercial practice from one to four condensers are included in a single protective can, and (in all cases of the Aerovox manufacture at least) every negative plate is connected to the can. The positive terminals are brought out to terminals on the insulating cover. Figures 23 to 26 inclusive show the external appearance of various types and sizes.

There are various methods of securing such condensers to the chassis of a radio set or other piece of apparatus where it is to be used. In Figures 27, 28 and 29 are shown several ways of mounting such condensers by means of a clamping ring. Figure 30 shows an ingenious method of securing a single-anode type condenser directly to the chassis. Through the chassis there is drilled a hole just large enough to provide clearance for the threaded section of the insulating cover. When the unit is mounted the edge of the can makes contact with the chassis, providing a negative contact thereto. The addition of a lock washer and nut to the threaded section projecting beyond the chassis makes a firm support for the condenser with the least trouble.

PAPER CONDENSERS

Practically every telephone in this country makes use of at least one condenser in which one or more thin sheets of paper act as the dielectric between two or more sheets of metallic foil. The same general type has also had a widespread use in radio receivers, particularly where low voltages are used, but an appreciable capacitance is required, as in by-passing radio frequency currents to prevent their wandering around into other circuits.

If a condenser were built up solely of tin foil and paper, the actual insulating material would be partly paper and partly air, since the paper itself includes air and in addition there are interstices between the layers of paper and foil which also contain air. The effective dielectric constant of the insulating medium of a wound paper condenser is small due to the large effect of air present. To raise this constant it has been customary to impregnate the condenser unit with a substance having a higher dielectric constant than air. Until recently paraffine has been used for this purpose.

How the mounting ring is used to mount a condenser upright above a subpanel.

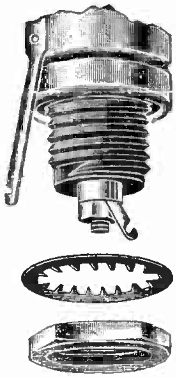
Fig. 27

In this method of inverted mounting, the cover and terminals project through the bottom of the subpanel.

Fig. 28

Showing inverted mounting with terminals on bottom of subpanel with unit partly above and partly below the subpanel.

Fig. 29



Mounting Method

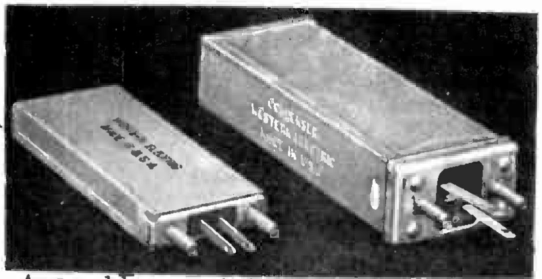
Fig. 30

Manufacturing methods in the past ten years have improved, and laboratory research has developed thin papers of high breakdown voltage, also improved impregnating compounds, particularly one called "halowax". We therefore find that very efficient and economical condensers using paper and foil are still in very good use in many of the radio and audio frequency communication systems. In Figure 31 is shown a comparison between the 1924 and 1932 models of a one mfd. condenser as used in the Bell Telephone System. The saving in space is obvious.

The actual winding process consists in rolling two sheets of tin foil and four sheets of paper so that the completed unit will have two layers of paper between adjacent layers of tin foil. After the winding operation the unit is pressed into compact shape, thoroughly dried in vacuum ovens, and then — while still in a high vacuum — is impregnated with the "halowax." Following this the unit is further pressed to the required size, which forces out all the excess wax, and soldering lugs are fastened to the metal contact strips that, at the beginning of the winding, were laid in contact with the sheets of tin foil. The unit is then ready for potting in the rectangular tin plate containers. Some manufacturers use small cardboard boxes instead of the metal. The containers are partially filled with a sealing compound which, when the condenser units are inserted, completely fills the container and seals the condenser against all entrance of moisture.

In Figure 32 is shown a view of the paper and foil sheets. Aluminum foil has come to replace the tin foil used in earlier condensers.

1932 Model



1924 Model

(Courtesy Bell Telephone Laboratories)

Fig.31--A smaller and better telephone condenser as a result of much research

AIR DIELECTRIC CONDENSERS

These are the simplest to understand, since they are merely a particular application of the fundamental principle that there exists a capacitance between any two conducting areas in air. A familiar type is the rotary variable condenser with which every one is fami-

Fig.32--Two sheets of paper between adjacent layers of aluminum foil form the elements of a telephone condenser

liar in the modern radio receivers and low-powered transmitters, an example of it being shown in Figure 33, the variation being by change in area.

An interesting example of condenser construction is that shown on the front cover, being a pair of tuning condensers for the tank circuit of a 50 k.w. radio transmitter. They are adjustable somewhat

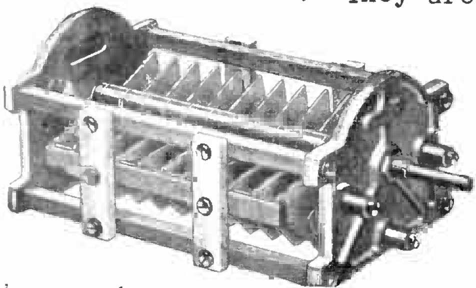


Fig.33--A rotary variable condenser (Courtesy Hammarlund Mfg. Co.)

roughly by loosening the clamps which hold the several plates fixed in position, and moving the individual plates toward or away from each other. In contrast with the preceding paragraph, this variation of capacitance is by change in the thickness of the dielectric. It is obvious that a variation of capacitance by area change could also be accomplished, by merely removing one or more plates from their supporting frame.

EXAMINATION QUESTIONS

1. What is a dielectric material?

2. Explain what happens when a condenser is placed in an A.C. circuit.

3. Describe a simple condenser.

4. What is capacitive reactance?

5. (a) Show by diagram how you would connect three condensers in series. (b) In parallel.

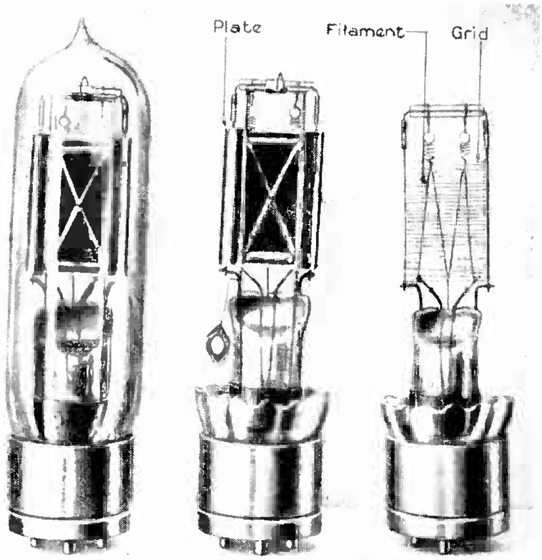
6. What is your understanding of the term "capacitance"?

7. When three condensers, each having a capacitance of .001 microfarads are connected in series what is the total capacitance?

8. Describe three types of condensers.

9. What is the action of a condenser when placed in D.C. circuit?

10. When four condensers, each having a capacitance of .002 microfarads are connected in parallel what is the total capacitance?



The closely-spaced metal elements of a vacuum tube provide capacitances which are of importance in amplifier design

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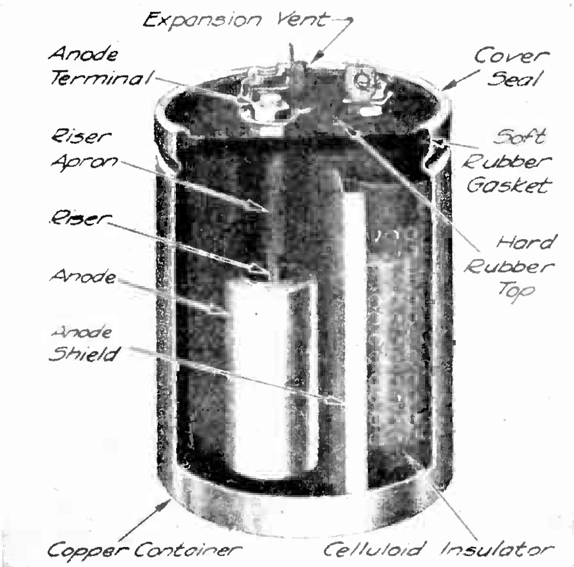

Interior Construction of Amrad condenser

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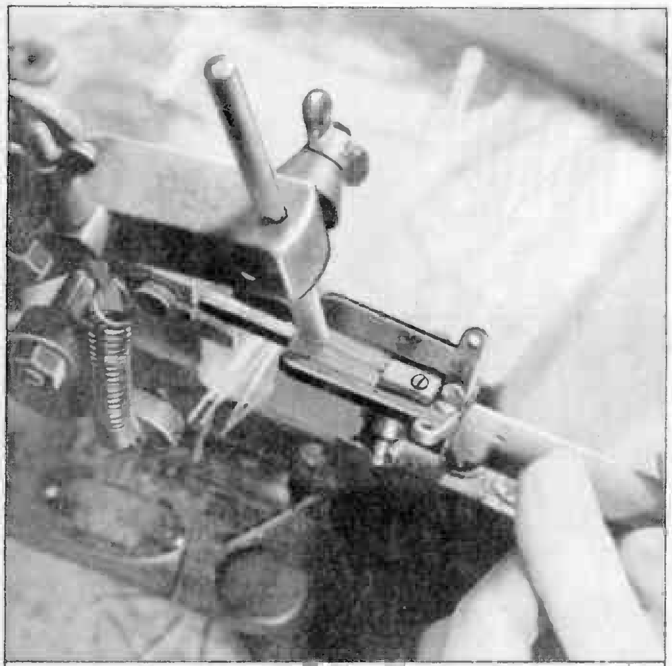
UNIVERSAL RACK FOR TESTING ALL TYPE RECEIVING TUBES UNDER VARIOUS VOLTAGE CONDITIONS

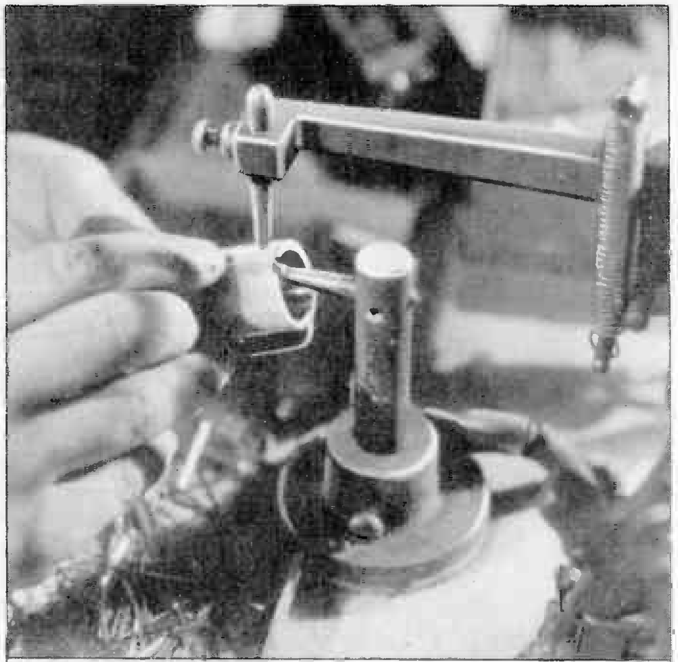
RECEIVING VACUUM TUBES

VOL. 13 # 1

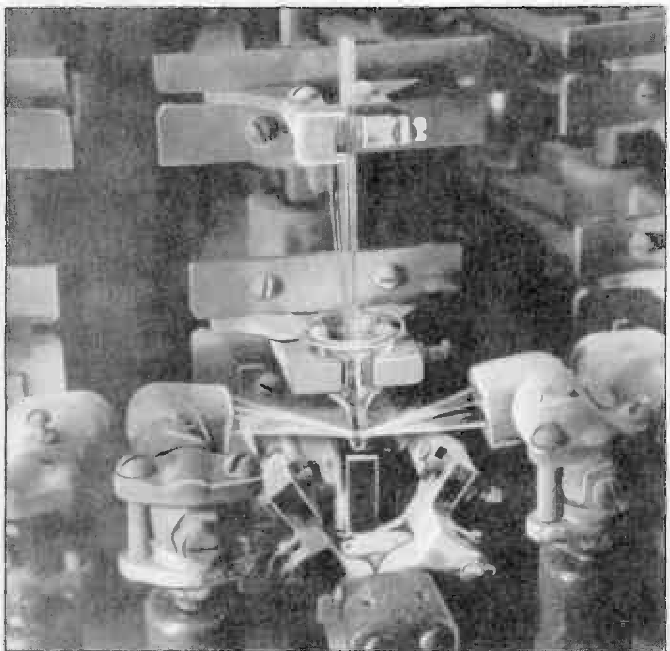
DEWEY DECIMAL CLASSIFICATION R130



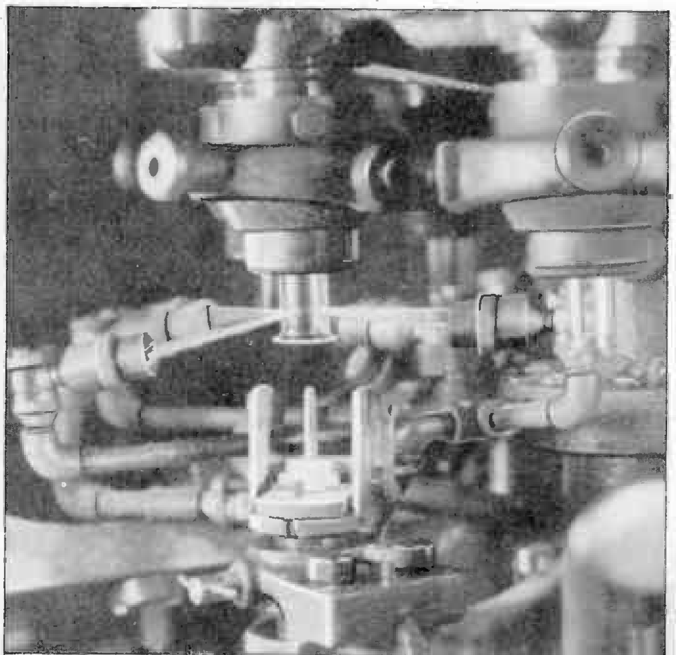
FORMING THE SCREEN BY ELECTRICAL WELD



IN SOME TUBES THERE ARE AS MANY AS 52 SPOT WELDS



THE STEM JUST AFTER THE MOLTEN GLASS HAS BEEN PINCHED TOGETHER, ENCASING THE LEAD-IN WIRES



AUTOMATIC, PRESSURE MEASURED GAS FLAMES HELP SHAPE THE FLARE OF THE GLASS STEM OF THE TUBE

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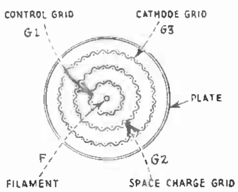
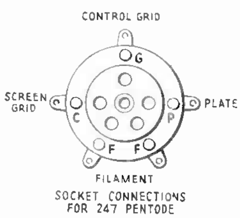
RECEIVING VACUUM TUBES

POWER OUTPUT PENTODE.....TYPE 247 FOR A-C SETS

Considerable interest exists at present in the pentode tube. The pentode, as its name implies, is a five-electrode tube. The outstanding characteristics of the tube are its high amplification factor, high internal resistance and high mutual conductance. These properties are obtained by the use of two electrodes or grids which are arranged in the tube as shown in Figure 1. In the illustration, the electrodes are identified as follows: F represents the filament; G1 is a conventional control grid; G2 is a grid or screen which is maintained at a high positive potential and serves to reduce the effects of "space charge" around the filament and to flatten out the plate current-plate voltage characteristics; and G3 is a grid or screen which is usually connected internally to the filament or cathode of the tube and is therefore maintained at essentially ground potential.

A very important function of grid G3 is to suppress or prevent the flow of electrons (liberated by secondary emission effects) from the plate P. The secondary emission is caused by the tremendous impact of electrons on the plate which liberates other electrons from the plate. These new secondary electrons would tend to move toward the screen grid because of its high positive potential were it not for the presence of the extra grid which is operated at the same potential as the filament and therefore does not exert an attraction for electrons. Hence, the secondary electrons return to the plate and together with the regular electrons that collect on the plate increase the flow of electrons in the plate circuit.





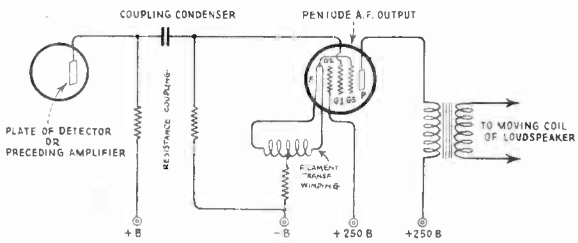


Figure 1 Figure 1-A Figure 2

A schematic connection for the pentode tube is shown in Figure 2. A pentode is thus essentially a power amplifier tube having high mutual conductance and high "power sensitivity," that is, relatively small input voltage is required to control rather high power in its plate circuit. This tube employs a coated filament designed primarily for a-c operation. The filament should be operated at its normal rated voltage of 2.5 volts at the normal design line voltage. The socket required by the pentode is of the standard UY type and should be mounted to hold the tube in a vertical position. Grid bias for the 247 may be obtained either from a fixed voltage source or by automatic self-biasing from a resistor in the cathode circuit.

POWER OUTPUT PENTODE - TYPE 247

Tentative Rating and Characteristics

Filament Voltage	2.5	volts
Filament Current	1.5	amperes
Plate Voltage, Recommended	250	volts
Screen Voltage, Recommended and Maximum	250	volts
Grid Voltage	-16.5	volts
Plate Current	32	milliamperes
Screen Current	7.5	milliamperes
Plate Resistance	38,000	ohms
Mutual Conductance	2,500	micromhos
Load Resistance, Approximate	7,000	ohms
Power Output	2.5	watts
Base and Socket		UY

The pentode has possible applications (with different designs) in both the audio-frequency and radio-frequency amplifier circuits of broadcast receivers. When used as a radio-frequency amplifier the tube has the form of a screen-grid tube in which an additional grid is placed between the filament (cathode) and usual control grid. This additional grid serves to reduce the effects of "space charge" around the filament (cathode) and results in a tube having higher mutual conductance than screen-grid tubes now available. The theoretical advantage sought in tubes of this kind in the r-f stage of a receiver is that, because of their greater amplification factor, the total number of tubes used might be reduced. However, present broadcast conditions and selectivity requirements are such that a reduction in the number of tuned r-f stages is not permissible and therefore, if one tube is used per stage, as other practical considerations require be done, the total number of radio-frequency tubes cannot be reduced. Also, if too much amplification per stage is attempted it will likely result in a circuit whose operation is critical and unstable. The new 247 pentode has been developed for use as an audio-frequency output or last stage amplifier tube in a-c receivers designed for it. Due to its higher undistorted output (U.P.O.) this tube takes the place of the 245 in the latest model sets.

PENTODE FOR BATTERY-OPERATED RECEIVERS - TYPE 233

The power amplifier pentode, type 233, has been developed for use in the power output stage of battery-operated receivers designed especially for it. The filament employed in this new tube is of the coated type and its low filament current drain makes this tube particularly applicable for use in combination with the 230 and 232 when one or both of these types are incorporated in sets where economy of filament current is an important factor.

As in the case of other pentode tubes the large audio output of the 233 with relatively small input signal voltages on the grid is made possible by the addition of a "suppressor" grid between the screen and the plate.

POWER OUTPUT PENTODE - TYPE 233

Preliminary Ratings and Characteristics

Filament Voltage	2.0	volts
Filament Current	0.260	ampere
Plate Voltage	135	volts
Screen Voltage	135	volts
Grid Voltage	-13.5	volts
Plate Current	14	milliamperes
Screen Current	3	milliamperes
Plate Resistance	45,000	ohms
Mutual Conductance	1,400	micromhos
Amplification Factor	63	
Load Resistance	7,500	ohms
Undistorted Power Output	650	milliwatts
Base and Socket		UY

As we have already explained the suppressor is connected inside the tube to one end of the filament, and is effective in practically eliminating the secondary emission effects which limit the power output from four-electrode screen-grid type tubes.

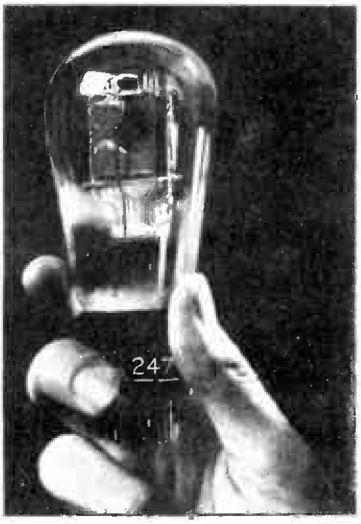


Figure 3

Figure 4

The tube illustrated in Figure 3 is the new 247 pentode which has been developed for use in the audio output stage of a-c receivers designed for it. The three tubes in the photograph in Figure 4 are the new series of indirectly heated cathode tubes designed especially for automobile receivers.

POWER AMPLIFIER TUBE - TYPE 171-A

The 171-A type vacuum tube is a power amplifier for supplying large undistorted power output to a loudspeaker. It is intended for use in the last stage of an audio-frequency amplifier. This tube is designed for use with the standard UX socket, which should be mounted so as to hold the tube in a vertical position. The socket should make firm contact on the filament prongs to minimize contact resistance. The socket connections are given in Figure 5.

The filament of the 171-A type may be operated from a storage battery or from the a-c line through a step-down transformer. In either case the voltage applied to the filament terminals should be the rated value of 5.0 volts. When operated at this voltage, the coated filament will glow at only a dull red color. If alternating current is used to operate the filament, the leads should be of twisted pair and should be kept away from other parts of the circuit where possible. It is recommended that the power be turned off before any tube is removed from the receiver so that excessive voltage will not be applied to the filaments, or heaters, of the remaining tubes.

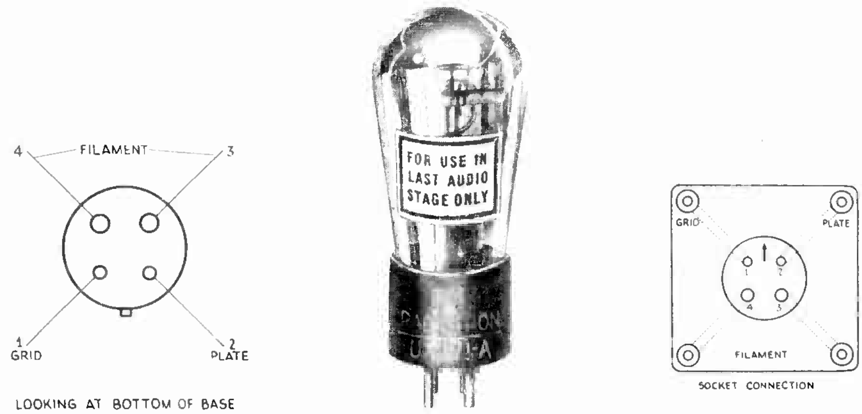


Figure 5

A-C LINE VOLTAGE. If the source of e.m.f. for operating the filament of the 171-A type is the a-c power line, precautions should be exercised to insure that the line voltage is the same as that for which the primary of the filament transformer is designed. To be sure that such is the case, the supply line voltage should be determined with a high grade a-c voltmeter having a range of 0 to 150 volts. If the line voltage measures in excess of that for which the transformer is designed, a series resistor should be inserted in the supply line to reduce the line voltage to the rated value of the transformer primary. Unless this is done, the excess input voltage will cause proportionately excessive voltage to be applied to the filament. Remember that any radio vacuum tube may be damaged or made inoperative by excessive operating voltage.

If the line voltage is consistently so much below that for which the primary of the transformer is designed as to make it impossible to ever obtain a filament voltage of 5.0 volts, it may be necessary to install a booster transformer between the a-c outlet and the transformer primary. Before such a transformer is installed, the a-c line fluctuations should be carefully measured. Many radio sets are equipped with a line voltage switch which permits adjustment of the power transformer primary to the line voltage. When this switch is properly adjusted, the series resistor or booster transformer mentioned above is seldom required.

CIRCUIT REQUIREMENTS. When the filament is operated from a d-c source, the grid and plate returns should be made to the negative filament terminal. When a-c is used on the filament, the plate and grid returns should be brought either to a mid-tapped resistor of from 20 to 40 ohms across the filament windings, or to the mid-tap of the filament winding itself.

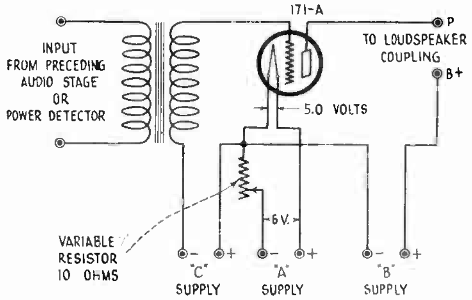


Figure 6

A negative grid bias, as shown in the table of "OPERATING VOLTAGES" on the following page, should always be used with this tube to prevent distortion and overloading. This bias may be obtained by means of a "C" battery or by means of the voltage drop through a resistor in the plate return lead, as shown in Figures 6 and 7 respectively. These diagrams show typical audio power amplifier circuits. The proper value of the resistor is 2150 ohms when 180 volts are used on the plate; 1700 ohms when 135 volts are used; and 1600 ohms when 90 volts are applied to the plate.

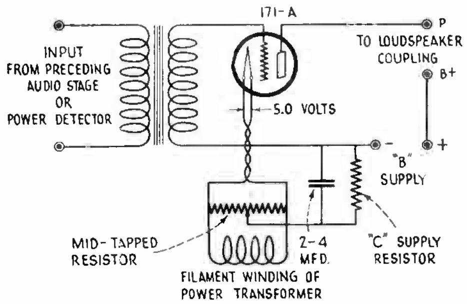


Figure 7

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Either an output transformer or a choke coil and condenser should be used, as shown in Figure 8, to keep the high plate current of the 171-A from the windings of the loudspeaker driving unit.

Figure 8

In regard to the operating voltages and characteristics of this tube it can be said that the value of 180 volts with its corresponding grid voltage need be used only in cases where there is a sufficient signal to secure the full grid swing and where the maximum power of the tube is desired. Where maximum output is not essential, the use of either of the lower values of plate voltage with their respective grid bias voltages, is recommended. It should be noted that high plate voltage does not of itself produce appreciably greater volume. What it does is to allow the use of a larger negative grid bias and this in turn permits the application of a larger signal voltage to the grid. The combined result gives higher volume without distortion when the volume control of the receiver is advanced.

POWER AMPLIFIER TUBE - TYPE 171-A

Rating and Data

Filament Voltage			5.0	volts a-c or d-c
Filament Current			.25	amperes
Plate Voltage	90	135	180	volts maximum
Grid Voltage (C-Bias)*	19	29.5	43	volts
Peak Grid Swing	16.5	27	40.5	volts
Plate Current	12	17.5	20	milliamperes
Plate Resistance	2250	1960	1850	ohms
Amplification Factor	3	3	3	
Mutual Conductance	1350	1520	1620	micromhos
Undistorted Power Output	125	370	700	milliwatts
Approximate Direct Inter-Electrode Capacitances				
Grid to Plate			8.2	mmf.
Grid to Filament			4.5	mmf.
Plate to Filament			2.5	mmf.

*Values of grid voltage are given with respect to the mid-point of the filament operated on a-c. If the filament is d-c operated, each given value of grid voltage should be decreased by 2.5 volts and be referred to the negative end of the filament.

If it is desired to obtain, without an increase in plate voltage, more power output than one tube of this type will deliver then two tubes may be operated in parallel or in push-pull. The parallel connection permits increased power output without any increase in the signal applied to the power stage, while the push-pull connection for maximum power output requires that the input signal to the power stage be doubled, but it provides more freedom from distortion.

POWER AMPLIFIER - TYPE 245

The 245 vacuum tube is a power amplifier for supplying large undistorted output to a loudspeaker. It is intended for use in the last stage of an audio-frequency amplifier, in a socket whose filament voltage is 2.5 volts. It should be borne in mind that a 245 tube is not interchangeable with a 171-A tube or any other power amplifier tube.

The socket connections for this tube are like the standard UY socket. It is important to locate a tube of this kind in a set to allow sufficient natural circulation to prevent overheating. The filament may be operated from a storage battery or from the a-c line through a step-down transformer. In either case the voltage to the filament terminals should be the rated value of 2.5 volts. Concerning low resistance connections in the filament circuit splices and about turning the power off before any tube is removed to prevent excessive voltage from being applied to the filaments or heaters of the remaining tubes, the same conditions hold for the 245 as for the 226.

CIRCUIT REQUIREMENTS. To prevent distortion and overloading, negative grid bias as shown in the table of "OPERATING VOLTAGES," should always be used with this tube. It is strongly recommended that this bias be obtained by means of the voltage drop through a resistor in the plate return lead. See Figures 9 and 10 for the general arrangement of circuits utilizing a-c or d-c filament voltage supply.

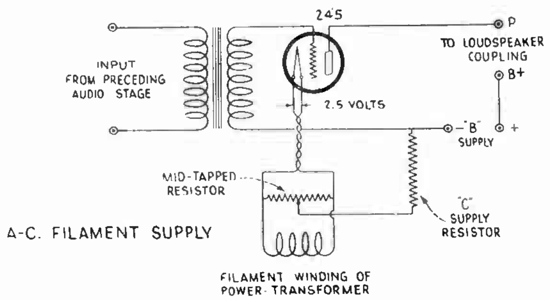

Figure 9

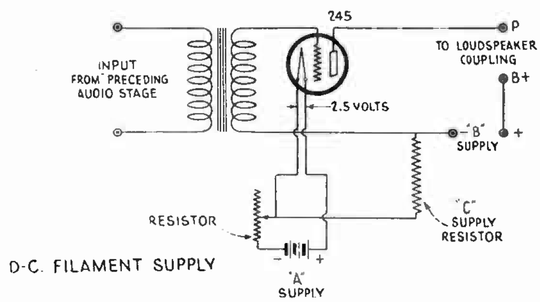

Figure 10

The proper value of a resistor in the plate return lead should be 1550 ohms when 250 volts are used on the plate, or 1350 ohms when 180 volts are used. This method of obtaining the bias must be used in any amplifier circuit where grid leaks are used. In such a circuit a grid leak having a resistance of greater than 1.0 megohm should not be used. When the filament is operated from a d-c source, the grid and plate returns should be made to the negative filament terminals. When a-c is used on the filament, the plate and grid returns should be brought to (1) a mid-tapped resistor of from 20 to 40 ohms across the filament windings, or (2) the mid-tap of the filament winding itself.

Either an output transformer or a choke coil and condenser should be used to keep the high plate current of the 245 from the windings of the loudspeaker driving unit. This was previously referred to in Figure 8.

POWER AMPLIFIER - TYPE 245

Rating and Data

Filament Voltage		2.5	volts a-c or d-c
Filament Current		1.5	amperes
Plate Voltage	180	250	volts (maximum)
Grid Voltage (C-Bias)	-33	-50	volts
Peak Grid Swing	33	50	volts
Plate Current	26	32	milliamperes
Plate Resistance	1950	1900	ohms
Amplification Constant	3.5	3.5	
Mutual Conductance	1800	1850	micromhos
Undistorted Power Output	780	1600	milliwatts

If it is desired to obtain more power output than one 245 tube will deliver then two 245 tubes may be operated in parallel or push-pull. The parallel connection permits increased power output without any increase in the signal applied to the power stage, while the push-pull connection for maximum power output requires that the input signal to the power stage be doubled, as previously explained.

The value of 250 volts with its negative grid bias of 50 volts need be used only in those cases where there is a sufficient signal to secure the full grid swing and where the maximum power output of a 245 tube is desired. Where maximum output is not essential, the lower value of 180 volts with a negative grid bias of 33 volts, is recommended. As stated before, high plate voltage does not of itself produce appreciably greater volume but it allows the use of a larger negative grid bias and this in turn permits the application of a larger signal to the grid. Consequently, the combined result gives higher volume without distortion when the volume control of a given receiver is advanced.

SCREEN GRID R-F AMPLIFIER - TYPE 222

The 222 vacuum tube is a screen-grid amplifier recommended for use primarily as a radio-frequency amplifier in carefully shielded circuits especially designed for it. It may also be effectively used as a space-charge grid tube or as a double-grid tube in special circuits. This tube is designed for use with the standard UX socket, the socket connections being given in Figure 11. The connection for the control grid is made to the metal cap at the top of the tube.

The voltage applied to the filament terminals of the 222 should not exceed the rated value of 3.3 volts. It may be supplied by either dry-cells so connected as to give 4.5 volts or by a storage battery of 6 volts, depending upon whether 3.3 volt or 5.0 volt filament tubes are used in the other stages of the radio receivers.

When the 222 type is to be used in connection with storage battery tubes, for example tubes such as a 201-A, 112-A, and so on, then each 222 should have a 15 ohm resistor connected in series with its negative filament lead with the resistor tapped at 12 ohms. The resistor and filament may then be connected directly in parallel with the 5 volt filaments of the other tubes and operated from the same common rheostat. This connection is shown in Figure 12.

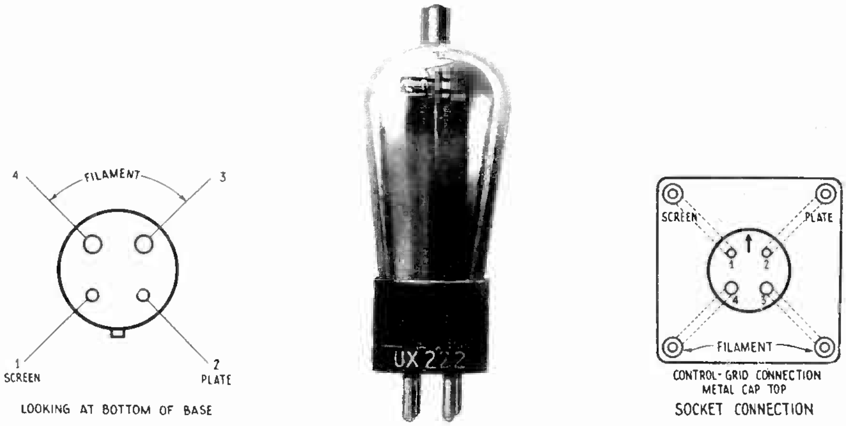

Figure 11

Or, if dry-cell tubes, such as a 199 and 120, are used the filament of the 222 may be connected directly in parallel with the filaments of the other tubes and operated from the same common rheostat. This arrangement is given in Figure 13. It is recommended that both the filament and plate voltage be disconnected before any tube is inserted in or removed from its socket as we suggested before.

HOW TO OBTAIN SCREEN VOLTAGE. The positive voltage for the screen should be obtained from a tap on the plate battery or from a tap so located on the B - supply device, such as a voltage divider for example, as to definitely give the required screen voltage. Never attempt to obtain the screen voltage by connecting the screen through a series resistor to a high plate voltage source, such as that of the power amplifier tube for instance. Such a series resistor connection will not in general be satisfactory for screen voltage supply because of the considerable variation in screen current of different tubes.

The screen voltage obtained from a definite voltage tap on the B - battery or the B - supply device may be made variable between 0 and 45 volts by the use of a potentiometer connected as shown in Figures 12 and 13 which are typical screen grid r-f amplifier circuits. As the voltage applied to the screen is reduced by adjustment of the potentiometer, the mutual conductance of the 222 tube is decreased with consequent reduction in volume. The potentiometer method, therefore, makes a suitable volume control for the receiver in which it is used.

It should be noted that when the potentiometer method of volume control is used with a "B" battery source of screen potential, precautions should be taken to provide for opening the screen grid circuit connection to the "B" battery when the radio set is not in use as indicated at X in Figure 13. If this precaution is not observed, current will continue to flow through the potentiometer and shorten the life of the battery.

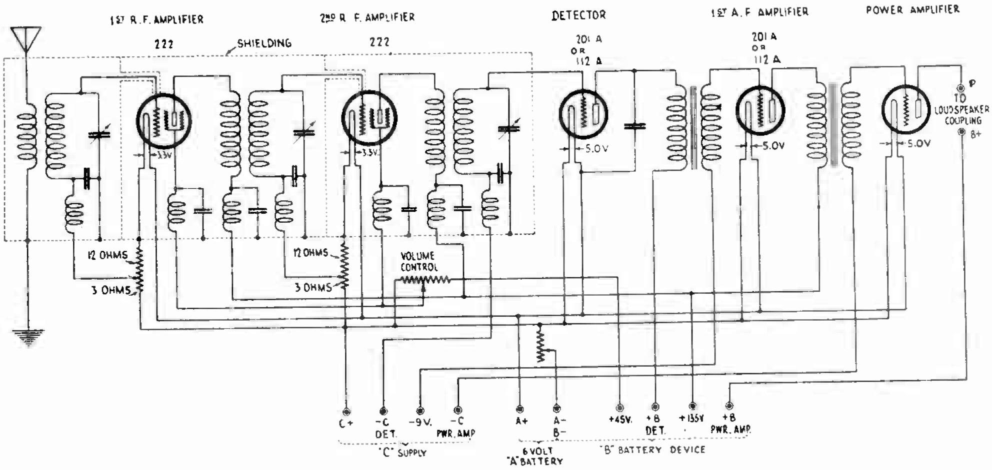

Figure 12

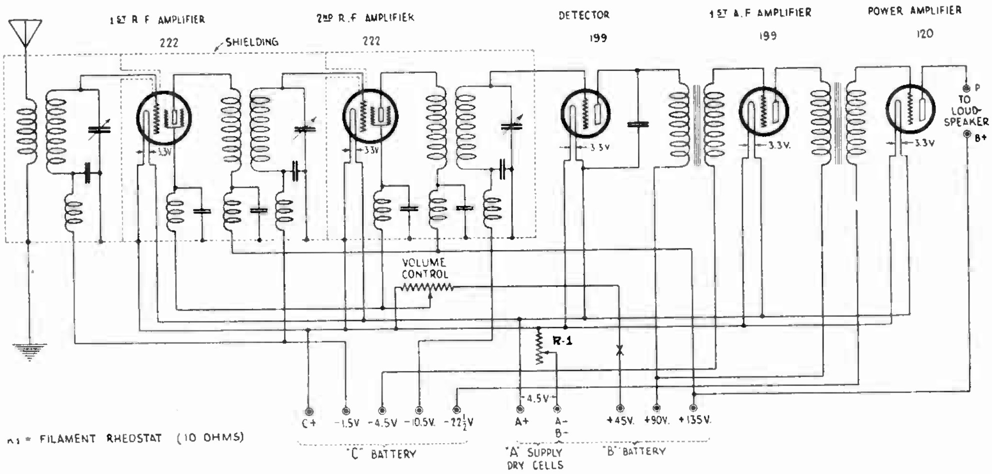

Figure 13

When the 222 type is used as a screen-grid radio-frequency amplifier, neutralization of the inter-electrode capacity between grid and plate to prevent feed-back through the tube is unnecessary because of the internal shielding by the screen. It is necessary, however, to take every precaution to avoid external coupling between the grid and plate circuit elements if stable operation of the 222 is to be obtained in circuits designed to give maximum gain per stage.

In multi-stage amplifier circuits, it is necessary to completely and effectively shield each stage, and to include within the stage

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shield all of the component parts of that stage. You can understand this arrangement by referring to Figures 12 and 13. Unless the coils and condensers of the various stages are shielded from each other, the amplification possibilities of the 222 cannot be fully realized.

If only a single 222 radio-frequency stage is used, it may not be necessary to shield this stage completely for reception of broadcast frequencies. Sufficient shielding will usually be obtained by placing the grid coil and condenser within a grounded metallic shield. In some cases it may be necessary to shield the 222 by a metallic jacket fitting closely over the tube and having an insulated opening at the top for the grid cap. The jacket should extend down at least to the base of the 222 and should be connected to either one of the filament terminals of the socket. The control grid lead should be kept as short as possible and should be spaced from other circuit elements.

The grid and plate circuit returns should be made to the negative filament terminal. The grid bias voltage of - 1.5 volts may be obtained from a "C" battery or from the drop in the 12 ohm portion of the tapped 15 ohm resistor which was previously mentioned. It should be noted that the tapped resistor method of obtaining the control-grid bias is usable only when the filament of the 222 is operated from a 6 volt "A" supply.

As a means of reducing coupling in the circuits external to the tube, the use of radio-frequency filters in all of the leads entering the stage shields as shown in Figures 12 and 13, is recommended. When filters are used the impedance of the circuit from screen to ground is kept as low as possible by the use of by-pass condensers.

In general, properly designed radio-frequency transformers are preferable to impedances for inter-stage coupling, and especially so in cases where a high impedance "B" supply device may cause oscillation below radio frequencies. If, however, impedance coupling is used between stages it is best to employ a blocking condenser having a capacitance of 0.00025 mfd. and a grid lead of from 2 to 5 megohms.

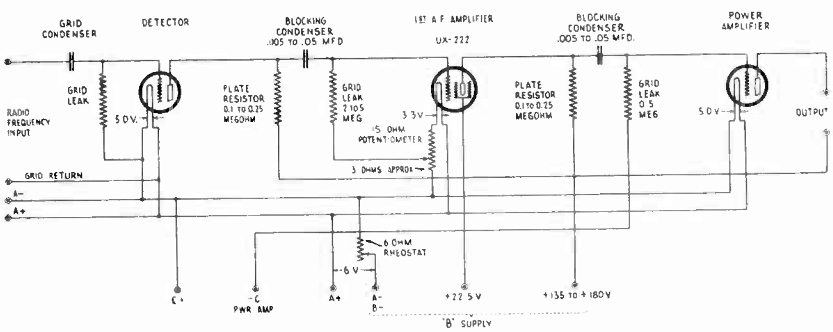

Figure 14

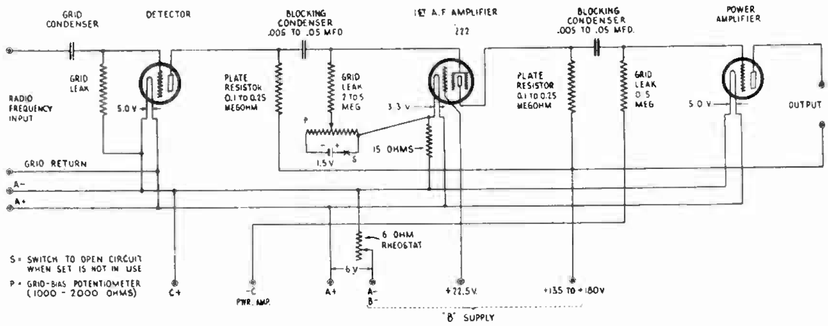

Figure 15

If the 222 type is to be operated as a screen-grid audio-frequency amplifier or as a space charge grid audio-frequency amplifier, resistance coupling should be used in its plate circuit. For either case, the value of the plate coupling resistor should be of the order of from 100,000 to 250,000 ohms. With the value of 250,000 ohms, a voltage amplification of 40 per stage should be obtained from either type of circuit. Suitable values of grid leaks and blocking condensers are shown in Figures 14 and 15. In Figure 14 you see a typical screen grid audio-amplifier circuit while Figure 15 gives a typical space charge grid audio-amplifier circuit.

SCREEN GRID R-F AMPLIFIER - TYPE 222

Rating and Data

Filament Voltage	3.3	volts
Filament Current	.132	ampere
Plate Voltage, Maximum and Recommended	135	volts
Grid Voltage (C-Bias)	-1.5	volts
Screen Voltage, Recommended	+45	volts
Plate Current	1.5	milliamperes
Screen Current	not over 1/3	of plate current
Plate Resistance	850,000	ohms
Amplification Factor	300	
Mutual Conductance	350	micromhos
Direct Inter-Electrode Capacitances		
Effective Grid-Plate	0.0025	mmf. maximum
Input	3.5	mmf. approx.
Output	12	mmf. approx.

In the following paragraphs we discuss about the special considerations concerning operating voltages and characteristics. When the 222 type is employed as a screen-grid radio-frequency amplifier, critical adjustment of the plate or screen voltage is not required. A plate voltage as low as 90 volts may be used but in special cases a screen voltage not exceeding 67.5 volts may be found desirable.

If the 222 is operated as a screen-grid audio-frequency amplifier, a plate supply voltage of from 135 to 180 volts applied through a plate coupling resistor of from 100,000 to 250,000 ohms is recommended. Under these conditions, the screen is operated preferably with + 22.5 volts, and the grid with from − .75 to − 1.5 volts. A

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higher value of screen voltage may be used but because of the greater voltage amplification obtained at the increased voltage, more critical circuit adjustment will be required.

When the 222 is connected as a space charge grid audio-frequency amplifier, the inner or control grid is operated at -22.5 volts to neutralize the electron space charge around the filament. The outer grid then becomes the control-grid and should be biased negatively by from 0 to - 1.5 volts depending upon the conditions of operation. For best results, the use of a variable control-grid bias potentiometer as shown in Figure 15, is recommended.

The screen-grid audio-frequency connection, in comparison with the space charge grid connection, will give somewhat lower maximum amplification but it will permit of better audio-frequency fidelity.

SCREEN GRID R-F AMPLIFIER.....A-C HEATER - TYPE 224

The 224 vacuum tube is a screen-grid amplifier containing a heater element which permits operation from alternating current. It is recommended for use primarily as a radio-frequency amplifier in carefully shielded circuits especially designed for it but it may also be effectively used as a space charge grid tube or as a double grid tube in special circuits as in the case of the 222 type which we just discussed.

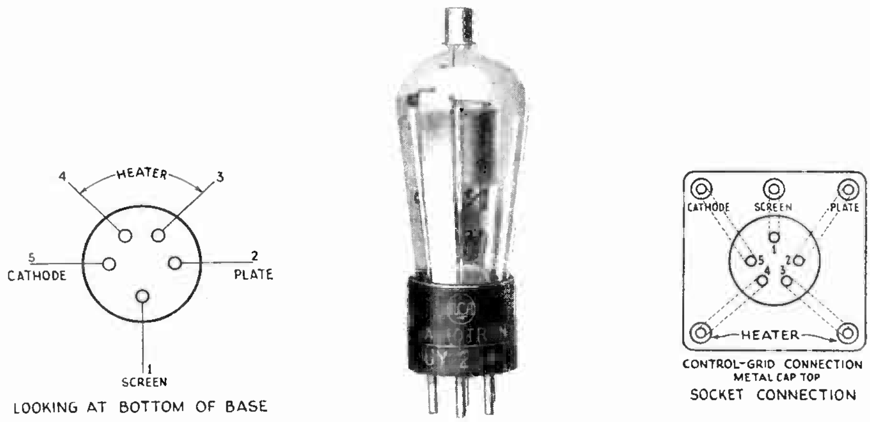

Figure 16

The five-prong base of the 224 type requires the standard UY socket. As with all types of tubes the socket should make firm, large surface contact on the prongs to minimize contact resistance. In Figure 16 we have drawn a sketch showing the socket connections for this tube and keep in mind that the connection for the control grid is made to the metal cap at the top of the tube.

THE HEATER CONNECTION. The heaters of the 224 tube should be connected in parallel, as shown in Figure 17. The transformer winding supplying the heaters should be designed to maintain 2.5 volts across the heaters of the total number of 224 tubes used in the receiver. Due to the high current and low voltage all connections in the heater circuit must be particularly low resistance and all heater circuit leads hould be of high current carrying capacity with all splices well soldered. The heater leads to the different tubes should be as nearly of equal length as is found practicable to make them and all leads carrying alternating current should be of twisted pair.

THE CATHODE CONNECTION. Connection of the cathode to the heater should be made (1) preferably to the movable arm of a potentiometer connected across the heater winding of the power transformer, or (2) to a mid-tapped resistor across the heater winding, or (3) to the mid-point of the heater winding itself. In some circuits, biasing of the heater negative with respect to the cathode by not more than 9 volts may be helpful in reducing hum.

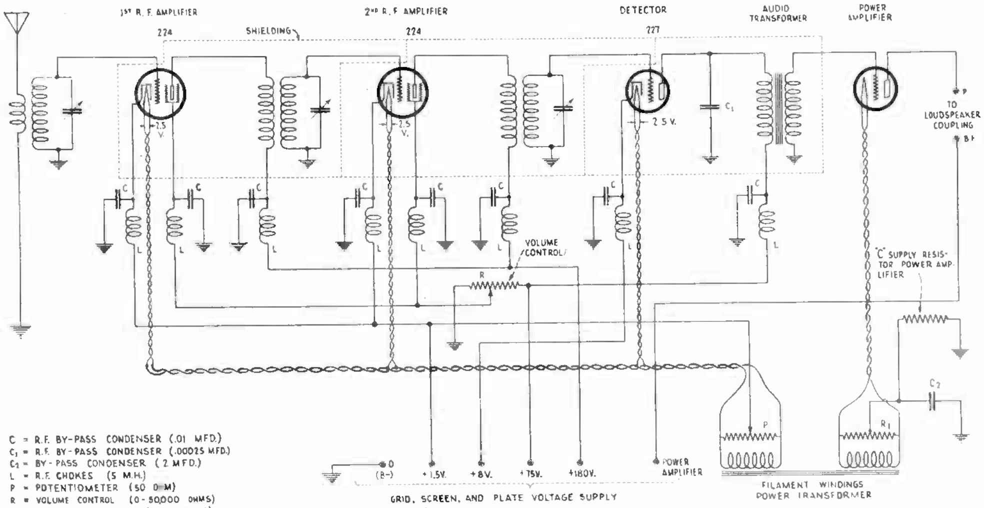

Figure 17

VOLTAGE FOR THE SCREEN GRID. The diagram in Figure 17 illustrates a typical a-c screen grid radio-frequency amplifier circuit. It shows how the screen voltage obtained from the definite voltage tap source may be made variable between 0 and 75 volts by the use of a potentiometer, R, marked "VOLUME CONTROL." Since the voltage applied to the screen is reduced by adjustment of the potentiometer, R, the mutual conductance therefore, of the 224 is decreased with consequent reduction in volume and this action makes a potentiometer a satisfactory volume control for the receiver.

A-C LINE VOLTAGE. The source of power for operating the heaters of the 224 tubes may be one of the secondary windings on the power transformer incorporated in the radio set, or it may be the secondary of a separate transformer. In either case, to obtain from the secondary a heater voltage of 2.5 volts, the transformer primary must be supplied with its rated voltage.

CIRCUIT REQUIREMENTS. When the 224 type is used as a screen-grid amplifier, neutralization of the inter-electrode capacity between grid and plate to prevent feed-back through the tube is unnecessary because of the internal shielding by the screen. It is necessary, however, to take every precaution to avoid external coupling between the grid and plate circuit elements if stable operation of the 224 is to be obtained in circuits designed to give maximum gain per stage.

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SCREEN GRID R-F AMPLIFIER.....A-C HEATER - TYPE 224

Rating and Data

Heater Voltage	2.5	volts a-c or d-c
Heater Current	1.75	amperes
Plate Voltage, Maximum and Recommended	180	volts
Grid Voltage (C-Bias)	-1.5	volts
Screen Voltage, Maximum	+75	volts
Plate Current	4	milliamperes
Screen Current	not over 1/3	of plate current
Plate Resistance	400,000	ohms
Amplification Factor	420	
Mutual Conductance	1050	micromhos
Direct Inter-Electrode Capacitances		
Grid-Plate 0.01 mmf. maximum; Input 5 mmf. approx.;	Output 10 mmf. approx.	

In multi-stage amplifier circuits, it is necessary to completely and effectively shield each stage, and to include within the stage shield all of the component parts of that stage, as you will understand by referring to Figure 17. Unless the coils and condensers of the various stages are shielded from each other, the amplification possibilities of any screen grid tube cannot be realized.

If the 224 type is to be used as a screen-grid detector for either grid leak detection or grid bias detection, the latter being called power detection, resistance coupling should be used in its plate circuit. A value of from 200,000 to 500,000 ohms is best suited for the plate coupling resistor. All of the voltages, except the 1.5 volts for the heater, may be supplied from taps on the same "B" supply device. Neither the plate nor the screen voltage is critical.

The volume of the receiver may be effectively controlled by means of a potentiometer connected as shown in Figure 17, this arrangement being similar to the connections shown in Figures 12 and 13 or by a variable grid resistor inserted in the cathode circuit through which the plate current must flow.

SCREEN GRID POWER DETECTOR. If the 224 type is used as a screen-grid detector, the grid bias method of detection is recommended because of its ability to handle large input voltages without overloading. For this method the following suitable operating values are suggested: a plate supply voltage of 200 volts applied through a plate coupling resistor of 250,000 ohms, a positive screen voltage of 45 volts, and a negative grid bias (approximately 5 volts) so adjusted that a plate current of 0.1 milliampere is obtained with no a-c input signal. Fig. 18 shows the principle of connecting a screen-grid power detector.

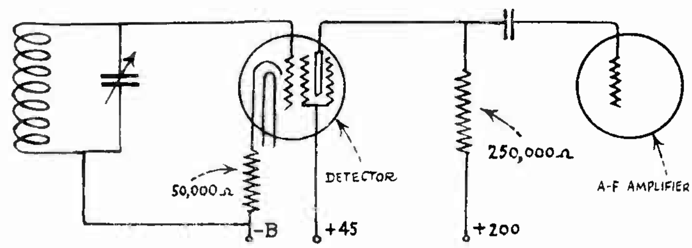

Figure 18

TYPES WD 11 AND WD 12 FOR USE WITH DRY CELLS.

These tubes are among the earliest types of dry cell tube and were designed to be used with one or more #6 dry cells in parallel for filament supply. The -11 type tube has a special arrangement of prongs and so requires a special socket whereas the -12 type was designed to be used in a regular UX type socket. The electrical characteristics of both tubes are the same, hence, in either case the oxide coated filament consumes a quarter of an ampere at 1.1 volts and the plate may be operated with from 40 to 90 volts. Each type is a general purpose tube and can be used either as an r-f or a-f amplifier, or detector.

TYPES WD-11 AND WD-12

Rating and Data

Filament Voltage			1.1	volts
Filament Current			0.25	ampere
Plate Voltage	90	67	45	volts
Grid Voltage (C-Bias)	-4.5	-3	-.5 to 1.5	volts
Amplification Factor			6.6	

For use as a detector the grid return should be connected to the positive side of the filament and for this specific use a 2 megohm grid leak and .00025 mfd. condenser are recommended with 22½ to 45 volts on the plate.

TYPE 199 GENERAL PURPOSE BATTERY-TYPE TUBE.

These tubes are also general purpose battery-type tubes being designed to give more economical battery consumption than the -11 or -12 type. They may be used either as amplifiers or detectors, when used as a detector the grid circuit return should be connected to positive filament and a 3 megohm grid leak and .00025 grid condenser are recommended. Due to the low interelectrode capacity these tubes make good r-f amplifiers and, also, they can be used in the a-f stages to operate small speakers. Care should be taken to use the proper negative bias on the grid of the 199 whenever it is used as an amplifier.

TYPE 199 TUBE

Rating and Data

Filament Voltage	3.3	volts
Filament Current	.063	ampere
Amplification Factor	6.6	
Plate Voltage	90	volts
Grid Voltage (C-Bias)	-4.5	volts

The filament is of the thoriated tungsten type which may be reactivated if desired. Since the normal consumption is .06 ampere at 3.3 volts only three dry cells are necessary to supply the filament current.

TYPE 120 AUDIO OUTPUT AMPLIFIER.

This tube is a power amplifier designed to be used in the last stage of a receiver employing 199 type tubes. It operates with the same filament voltage as the 199 but takes twice as much current to heat the filament.

TYPE 120 AUDIO OUTPUT AMPLIFIER

Rating and Data

Filament Voltage	3.3	volts
Filament Current	0.132	ampere
Amplification Factor	3.3	
Plate Voltage (max.)	135	volts
Grid Voltage (C-Bias)	-22.5	volts

As the characteristic charts indicate, the 120 requires higher plate voltage and greater bias than the 199 and gives more power output without distortion.

TYPE 201-A STORAGE BATTERY TUBE.

For many years the 201-A tube has been the standard general purpose battery type tube. It was at one time the most popular type tube used in radio receivers where the space occupied by the batteries was not of great importance. Although the battery consumption is quite low for a 201-A filament yet a storage battery is recommended instead of dry cells. The plate current is greater than for the 199 and, therefore, higher capacity "B" batteries are recommended.

The filament is of the thoriated tungsten type rated at 5 volts and 0.25 ampere. The UV-type base with short prongs was first used with this tube but now the base has been changed to fit a standard UX socket.

TYPE 201-A TUBE

Rating and Data

Filament Voltage		5	volts
Filament Current		0.25	ampere
Amplification Factor		8	
Plate Voltage	(max.) 135	(recommended) 90	volts
Grid Voltage (C-Bias	-9	-4.5	volts

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Detector operation is not critical and, as in the case of other types of tubes just discussed, a 2 megohm grid leak and 0.00025 mfd. condenser are recommended. The tube also makes a good r-f and a-f amplifier and, as mentioned before for other tubes, care should be taken to use the proper C-bias.

TYPE 240 USED WITH RESISTANCE COUPLING.

This tube is designed primarily to be used as a detector or audio-frequency amplifier where resistance coupling is desired. It is similar in appearance to the 201-A but the grid and plate construction differs to secure higher amplification and the plate impedance is also much higher than that of the 201-A.

TYPE 240 TUBE

Rating and Data

Filament Voltage	5	volts
Filament Current	.25	ampere
Amplification Factor	30	

240 USED AS AMPLIFIER

Plate Voltage	135	volts (recommended)	180	volts (max.)
Grid Voltage (C-Bias)	-1.5	volts	-3.0	volts
Plate Coupling Resistance	250,000	ohms	250,000	ohms

240 USED AS DETECTOR

(Grid Leak Detection)

Plate Voltage	135 to 180	volts
Plate Coupling Resistance	250,000	ohms
Grid Leak	2 - 5	megohms

(Grid Bias Detection)

Plate Voltage	135 volts	180	volts
Plate Coupling Resistance	250,000 ohms	250,000	ohms
Grid Voltage (C-Bias)	-3 volts	-4.5	volts

The above chart gives the various ratings for the 240 when used either as an amplifier, or a grid-leak or grid-bias detector. As just stated, this tube may be used for either grid leak or grid bias detection, the first giving higher sensitivity and the latter freedom from distortion on high signal input voltages. When used in a resistance coupled audio amplifier the 240 gives quite uniform amplification from 30 to 10,000 cycles.

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TYPE 112-A AMPLIFIER.

This is an oxide coated storage battery tube, having a lower plate resistance than the 201-A. It may be used as a detector, r-f amplifier or a-f amplifier. For detector use it is recommended to use 45 volts on the plate, a 0.00025 mfd. grid condenser and a 2 to 3 megohm leak. Due to the difference in interelectrode capacity and plate resistance it may be difficult to control if used in a radio-frequency circuit but the low impedance, however, makes this tube most suitable for use in transformer coupled audio amplifiers. It also makes a good power amplifier having a greater output than the 201-A but less than the 171-A.

TYPE 112-A AMPLIFIER

Rating and Data

Filament Voltage			5	volts
Filament Current			.25	ampere
Amplification Factor			8.5	
Plate Voltage	135	volts (recommended)	180	volts (max.)
Grid Voltage	-9	volts	-13.5	volts

TYPE 250 POWER AMPLIFIER TUBE.

This tube is a heavy duty power amplifier intended for use in installations where more undistorted power output is required than for average home use. The 250 is larger in size than the 210 and requires greater bias for the same plate voltage. For this reason it cannot be used in a set formerly using a 210 unless the set is changed to increase the bias. When this is done it will give a greater power output than the 210. This tube has an oxide coated filament rated at 7.5 volts, 1.25 amperes and draws higher plate current and has lower impedance than the 210.

TYPE 250 AMPLIFIER

Rating and Data

Filament Voltage				7.5	volts
Filament Current				1.25	amperes
Amplification Factor				3.8	
Plate Voltage	250	350	400	450	volts
Grid Voltage (C-Bias)	-45	-63	-70	-84	volts
Power Output (milliwatts)	1000	2400	3400	4600	milliwatts

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TYPES 236, 237 and 238 DESIGNED FOR AUTOMOBILE RADIO RECEIVERS

This group of three tubes consists of a screen-grid tube, a general purpose tube and a power output pentode. All three are of the high vacuum type and employ coated cathodes indirectly heated. The cathodes, which are the same for all three types, have been carefully designed to insure uniform heating over as wide a range of heater voltages as possible in order that the tubes will perform satisfactorily under the normal voltage variation of automobile batteries during charge and discharge. This feature together with that of the general freedom from microphonic and battery circuit disturbances of the heater-cathode type, make these new tubes particularly suited for use in automobile receivers.

The 236 Screen-Grid tube is particularly recommended for operation as a radio-frequency amplifier in circuits especially designed for it. It may be employed also as a screen-grid detector.

The 237 general purpose tube is useful either as detector, amplifier or oscillator.

The 238 power amplifier pentode has been designed to give good output volume consistent with the relatively low voltage and limited capacity of the plate supply battery.

The 236 and 237 will also be found especially adaptable to the design of radio receivers for operation from the d-c power line. In such service the heaters of these two types may be connected in series to operate at 0.3 ampere. This is made possible by the uniform heating of the cathode over a wide voltage range to offset normal line voltage variation.

TYPE 236 FOR AUTOMOBILE SETS

This screen-grid tube may be used as either a radio-frequency amplifier, a detector or an intermediate-frequency amplifier in circuits especially designed for it. The 236 employs a coated cathode of the semi-quick-heater type designed for d-c operation only. Owing to the special cathode design, the heater voltage may range between 5.5 and 8.5 volts during the charge and discharge cycles of the battery without appreciably affecting the performance or serviceability of this tube. No resistor in the heater circuit is required for this type operated from a 6-volt battery.

The socket required by the 236 is of the standard UY type and may be mounted to hold the tube in either a vertical or horizontal position. Socket connections are the same as for a UY-224.

Stable operation of the 236 in radio-frequency circuits designed to give maximum gain per stage requires separation of the input and output circuit elements. In general, with multi-stage amplifier circuits, it is necessary to use complete stage shielding enclosing all the components of each stage. Unless this is done, the amplification possibilities of the 236 will not be realized. The use of radio-frequency filters in all leads entering the stage shields is advised to reduce

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coupling in external parts of the circuit. In regard to heater to cathode bias it should not exceed 45 volts.

Since the screen current of individual tubes is subject to variation, the use of a resistance in series with the plate voltage source for the screen voltage supply will result in poor regulation and uncertain operating screen voltages. It is recommended therefore, that the screen voltage be obtained from either a tap on the plate battery, or from a potentiometer or bleeder circuit which maintains the screen voltage approximately constant at the recommended value. If a bleeder circuit or potentiometer is used, its electrical design should be such as to provide adequate screen voltage regulation; otherwise, the effect will be essentially the same as that of a series resistor with resultant poor regulation. The volume of the receiver should be controlled preferably by varying the grid voltage. The control adjustment should be such as to impress not less than - 1.5 volts on the grid when recommended voltages are applied to the screen. The use of some device for reducing the signal input to the first radio-frequency tube will be necessary where strong local signals will cause high values of peak grid voltage.

TYPE 236 FOR AUTOMOBILE SETS

Rating and Data

Heater Voltage			6.3	volts d-c
Heater Current			0.3	ampere
Plate Voltage	90**	135	135*	volts
Screen Voltage	55**	67.5	75*	volts
Grid Voltage	-1.5**	-1.5	-1.5*	volts
Plate Current	1.8	3	3.5	milliamperes
Screen Current		not over 1/3	of plate	current
Plate Resistance	200,000	300,000	250,000	ohms
Amplification Factor	170	315	275	
Mutual Conductance	850	1050	1100	micromhos

The 236 may be employed as a screen-grid detector of either the grid-bias or grid-leak type. For both of these connections resistance coupling may be used with a plate coupling resistor. An equivalent reactor may be substituted for the plate resistor where greater output from low percentage modulated signals is desired. For most sensitive detection with resistance coupling, it will be necessary to reduce the screen voltage to from 20 to 45 volts. For plate detection the bias may be secured either from a fixed voltage source or by automatic biasing from a resistor in the cathode circuit.

TYPE 237 FOR AUTOMOBILE SETS

This three-electrode tube may be used in circuits of conventional design as either an amplifier, a detector or an oscillator. The tube employs a coated cathode of the semi-quick-heater type designed for d-c operation only. Owing to the special cathode design, the heater voltage may range between 5.5 and 8.5 volts during the charge and discharge cycles of the battery without appreciably affecting the performance of serviceability of this tube.

TYPE 237 FOR AUTOMOBILE SETS

Rating and Data

Heater Voltage		6.3	volts d-c
Heater Current		0.3	ampere
Plate Voltage	90**	135*	volts
Grid Voltage	-6**	-9	volts
Plate Current	2.7	4.5	milliamperes
Plate Resistance	11,500	10,000	ohms
Amplification Factor	9	9	
Mutual Conductance	780	900	micromhos
Load Resistance***	14,000	12,500	ohms
Undistorted Power Output	30	75	milliwatts
Approximate Inter-Electrode Capacitances			
Grid to Plate	2.0 mmf.		
Grid to Cathode	3.3 mmf.		
Plate to Cathode	2.3 mmf.		
Base		small UY	
Socket		UY	

***Optimum load resistance for maximum undistorted power output as given.
*Recommended values for use in automobile receivers.
**Recommended values for use in receivers designed for 110 volt d-c operation.

In detector service, the 237 may be used either with grid lead and grid condenser or with grid bias. If grid leak detection is used, a condenser of 0.00025 mfd. and a grid leak of from 1 to 5 megohms will give excellent sensitivity. However, more stable operation and better quality will be obtained by using a low value of grid leak. For plate detection the bias may be secured either from a fixed voltage source or by automatic biasing from a resistor in the cathode circuit. The heater to cathode bias should not exceed 45 volts as in the case of type 236, and the socket connections are the same as for a UY-227.

TYPE 238 - POWER PENTODE FOR AUTOMOBILE SETS

The 238 is a screen-grid tube designed primarily for giving large audio power output for relatively small signal voltages impressed on the grid. This is made possible by the addition of a "suppressor" grid between the screen and the plate. The suppressor is connected inside the tube to the cathode and is therefore operated at the same potential as the cathode. When connected and operated in this manner, the suppressor is effective in practically eliminating the secondary emission effects which limit the power output from four-electrode screen-grid types.

Other considerations already mentioned in regard to the special types of automobile tubes are that the heater to cathode bias should not exceed 45 volts and the grid bias for the 238 may be obtained either from a fixed voltage source or by automatic self-biasing from a resistor in the cathode circuit. Also, this tube employs a coated cathode of the semi-quick-heater type designed for d-c operation only

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and owing to the special cathode design, the heater voltage may range between 5.5 and 8.5 volts during the charge and discharge cycles or the battery without appreciably affecting the performance or serviceability of this tube.

TYPE 238 - POWER PENTODE FOR AUTOMOBILE SETS

Rating and Data

Heater Voltage	6.3	volts
Heater Current	0.3	ampere
Plate Voltage, Recommended	135	volts
Screen Voltage, Recommended	135	volts
Grid Voltage	-13.5	volts
Plate Current	8	milliamperes
Screen Current	2.5	milliamperes
Plate Resistance	110,000	ohms
Amplification Factor	100	
Mutual Conductance	900	micromhos
Load Resistance	15,000	ohms
Undistorted Power Output	375	milliwatts
Base	small	UY
Socket		UY

THE 2-VOLT TYPE TUBES FOR BATTERY OPERATION

2-VOLT TUBE - DETECTOR AND AMPLIFIER - TYPE 230

The 230 is a new general purpose tube of the three electrode, high vacuum type. It employs a strong metallic filament coated with alkaline earth compounds. The filament has been designed to take as little power as possible consistent with satisfactory operating performance. This new tube, therefore, is particularly suited for use either as a detector or amplifier in radio receivers operating from dry-cells or from a storage battery where economy of filament current drain is important.

This 2 volt tube should be mounted in a vertical position and its socket and connections are the same as for the 199 tube. It should be mentioned that although the 230 is very free from microphonic disturbances, cushioning of its socket may be desirable.

The coated filament of the 230 should be operated at its rated value of 2.0 volts. This voltage may be supplied from dry-cells or from a single cell storage battery, but in either case an adjustable filament rheostat must be used together with a permanently installed indicating instrument to secure the proper filament voltage. This instrument should be either a voltmeter to indicate the terminal e.m.f. or a milliammeter to indicate the current drain. This requirement is applicable to all of the three types of 2 volt tubes, namely, the 230, 231 and 232 tubes. Bear in mind that fixed filament resistors will not give sufficient regulation to permit of satisfactory performance.

When this tube is used as a detector with a grid condenser and leak, the 230 tube should preferably be operated with a plate voltage of not more than 45 volts. The grid condenser and leak may be of usual sizes. However, as an amplifier, the 230 should always be used with a negative grid bias and for a plate voltage of 90 volts, it is best to use a grid bias of 4.5 volts.

2-VOLT TUBE - DETECTOR AND AMPLIFIER - TYPE 230

Rating and Data

Filament Voltage	2.0	volts
Filament Current	0.06	amperes
Plate Voltage (Maximum)	90	volts
Grid Voltage (C-Bias)	-4.5	volts
Plate Current	2.0	milliamperes
Plate Resistance	12,500	ohms
Amplification Factor	8.8	
Mutual Conductance	700	micromhos

Further, let us advise you that the 230 tube cannot be substituted for the 199 tube in radio sets designed for the latter, without circuit modifications. Suitable precautions must be taken to limit the filament voltage to 2.0 volts. In addition, the filament circuit must be altered to conform to the requirements of this new tube. If these tubes are used in tuned radio-frequency receivers not especially designed for them it may be necessary to readjust the neutralizing condensers or grid resistors before stable operation is obtained.

2-VOLT TUBE - POWER AMPLIFIER - TYPE 231

The 231 type tube is a new power amplifier tube of the three electrode, high vacuum type. It employs a strong metallic filament of the coated type which has been designed to take as little power as possible consistent with satisfactory operating performance. This new 231 tube, therefore, is particularly suited for use as the power output tube in radio receivers which operate with 230 or 232 type tubes. Both of the latter type may be used in the same receiver in conjunction with the 231, hence, all three types of the new 2 volt tubes may be employed in a single receiver.

2-VOLT TUBE - POWER AMPLIFIER - TYPE 231

Rating and Data

Filament Voltage	2.0	volts
Filament Current	0.130	ampere
Plate Voltage, Maximum and Recommended	135	volts
Grid Voltage (C-Bias)	-22.5	volts
Plate Current	8	milliamperes
Plate Resistance	4,000	ohms
Amplification Factor	3.5	
Mutual Conductance	875	micromhos
Undistorted Power Output	170	milliwatts

The 231 should be mounted in a vertical position and is to be used with a socket having connections the same as for the 199 or 120. It has been found that provision for cushioned sockets to prevent microphonic disturbances will not usually be necessary when this tube feeds directly into the loudspeaker.

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The recommended and maximum plate voltage for the 231 tube is 135 volts while the corresponding grid bias is - 22.5 volts. Under these operating conditions the plate current, which is 8 ma., is not high enough to require the use of a loudspeaker coupling device.

The 231 tube cannot be substituted for the 120 tube unless the filament circuit is altered to conform to the requirements of this new power output tube since the filament voltage must be limited to 2.0 volts.

2-VOLT TUBE - SCREEN GRID R-F AMPLIFIER - TYPE 232

The 232 type tube is a new screen grid tube recommended for use primarily as a radio-frequency amplifier. It employs a strong metallic filament of the coated type, which has been designed to take as little power as possible consistent with satisfactory operating performance. This new tube, therefore, is particularly useful in the radio-frequency stages of specially designed radio receivers operating from dry cells or from a storage battery where economy of filament current drain is important. The control grid is electrostatically shielded from the plate by means of an extra grid placed between plate and control grid and operated at a suitable positive potential. The resultant reduction in plate to control-grid capacity makes high voltage amplification per stage practical without external capacity neutralization circuits. This isolation of plate and grid results in a small change of plate current with a change of plate potential. The plate resistance, therefore, is high and averages about 800,000 ohms.

2-VOLT TUBE - SCREEN GRID R-F AMPLIFIER - TYPE 232

Rating and Data

Filament Voltage	2.0	volts
Filament Current	0.06	ampere
Plate Voltage, Maximum and Recommended	135	volts
Grid Voltage (C-Bias)	-3	volts
Screen Voltage, Maximum	67.5	volts
Plate Current	1.5	milliamperes
Screen Current	not over 1/3	of plate current
Plate Resistance	800,000	ohms
Amplification Factor	440	
Mutual Conductance	550	micromhos
Effective Grid-Plate Capacitances	0.02	mmf. maximum

The 232 tube should be mounted in a vertical position. The socket connections for the 232 are the same as for the 222 type tube. Although the 232 is very free from microphonic disturbances, cushioning of its socket may be desirable.

The connection for the control grid is made to the metal cap at the top of the glass envelope as is the usual procedure after placing screen-grid type tubes in their sockets.

The positive voltage for the screen should be obtained from a tap on the plate battery and, therefore, never attempt to obtain the screen voltage by connecting the screen through a series resistor to a high

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plate voltage source. Such a series resistor connection will not in general be satisfactory for screen voltage supply because of the uncertain drop produced by the considerable differences in screen currents of individual tubes.

Stable operation of the 232 tube in circuits designed to give maximum gain per stage requires separation of the input and output circuit elements. In general, it is necessary to use complete stage shielding including all the components of each stage. The use of filters in all leads entering the stage shields is advisable to reduce coupling in external parts of the circuit.

It is recommended that the operating voltage be applied to the 232 tube as follows: maximum plate voltage to be 135 volts with all corresponding negative grid bias of 3 volts, and a maximum positive screen voltage of 67.5 volts. You will find when using tubes of this type that neither plate nor screen voltage is critical. The control-grid bias for this tube when working on B-battery operated receivers should be obtained from a C-battery. The 232 tube cannot be substituted for the 222 tube in circuits designed for the latter, without circuit modifications, that is, the filament and grid circuits must be altered to conform to the requirements of this new screen-grid tube.

VARIABLE MU TUBE - TYPE 235

This most recent screen-grid tube has been developed primarily for use in radio-frequency and intermediate-frequency amplifier stages. It is effective in reducing cross-modulation, and modulation distortion over the entire range of received signals. Furthermore, its design is such as to permit easy control of a large range of signal voltages without the use of local-distant switches or antenna potentiometers. This feature makes the tube adaptable to automatic volume control design.

VARIABLE MU TUBE - TYPE 235

Tentative Rating and Normal Characteristics

Filament Voltage	2.5	volts
Filament Current	1.75	amperes
Plate Voltage, Recommended	180	volts
Screen Voltage, Recommended	75	volts
Grid Voltage	— 1.5	volts
Plate Current	9	milliamperes
Screen Current	not over 1/3	of plate current
Plate Resistance	200,000	ohms (approx.)
Mutual Conductance	1,100	micromhos
Approximate Inter-Electrode Capacitances		
Grid to Plate	.010	mmf. maximum
Input	5	mmf.
Output	10	mmf.
Base and Socket		UY

The 235 employs a cathode of the quick-heater type. Its heater should be operated at its normal rated voltage of 2.5 volts at the normal design line voltage. It is interesting to note that a recent survey of normal socket voltage conditions over the United States has established that 113 volts represents average operating conditions.

This tube has a very long characteristic curve that gradually drops off which indicates that very strong grid biases can be applied to the grid before the plate current reaches zero. In effect the signal voltage resulting from the oscillating current in the antenna system picks out the part of the characteristic curve of the tube it chooses to work upon, this being determined by the carrier voltage of this signal. A strong local signal may place a bias on the grid as low as 30 or more volts, whereas the desired signal which is much weaker in intensity may be working around a point which may be only a few volts or even tenths of volts negative. This tube's long characteristic curve is due to the special design of the tube elements which are made in different forms. For instance, the grid may be tilted, or the spacing between the wires may be greater at one part of the grid structure than at another, or the diameter may be non-uniform, that is, wide at one place and narrow at another and so on. Observe that curves A and B in Figure 19 illustrate the idea of how a variable mu tube combines the features of both a low-mu and high-mu tube which permits this tube to work over a wide range of input signal voltages. Curve A is the characteristic for a low-mu tube and curve B is the characteristic for a high-mu tube while the long curve drawn in solid line illustrates the combined characteristics. The various arrangements of tube structure cause a different, or variable mu-factor in operation for electrons emitted from the various elements of the cathode. When the grid bias is low, or near zero, the electron flow is such that current flows from all of these elements but as the grid bias becomes more negative the current from the elements having the higher mu-factors is cut off gradually at a certain rate.

The cathode should be connected directly to the center-point of the heater circuit. If this arrangement is not practical in some receiver designs, the heater may be made negative with respect to the cathode by a potential difference not exceeding 45 volts.

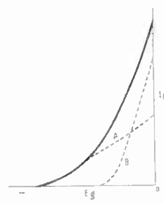

Figure 19

Since the screen current of individual tubes is subject to considerable variation, the use of resistance in series with a high voltage source for the screen voltage supply will result in poor regulation and uncertain operating screen voltages. It is recommended, therefore, that the screen voltage be obtained from a potentiometer or from a bleeder circuit which maintains the screen voltage approximately constant at 75 volts. The electrical design of the potentiometer or bleeder should be such as to draw several times the maximum screen current; otherwise, the effect will be essentially the same as that of a series resistor with resultant poor regulation. Radio-frequency choke filters for screen voltage supply are preferred, due to their low d-c resistance which insures satisfactory screen voltage regulation.

Since the variation in plate current over the operating range of this tube is about 9 milliamperes, the maximum current drain of several tubes may cause a large shift in power pack output voltage. It is, therefore, recommended that the screen voltage be adjusted to average 75 volts between the two extremes of the volume control setting.

Variation of the negative voltage applied to the grid will be found effective in changing the volume of the receiver. In order to utilize the full volume control range of this tube, an available grid bias voltage of approximately 75 volts will be required. This voltage should preferably be obtained from a potentiometer or bleeder circuit. If, however, the receiver is designed so that the required volume control can be obtained without exceeding 45 volts, the cathode resistor method of obtaining the grid bias control voltage is permissible.

The illustration below in Figure 20 shows a diagrammatic circuit for Super-Control R-F Amplifier RCA-235 and Power Amplifier Pentode RCA-247.

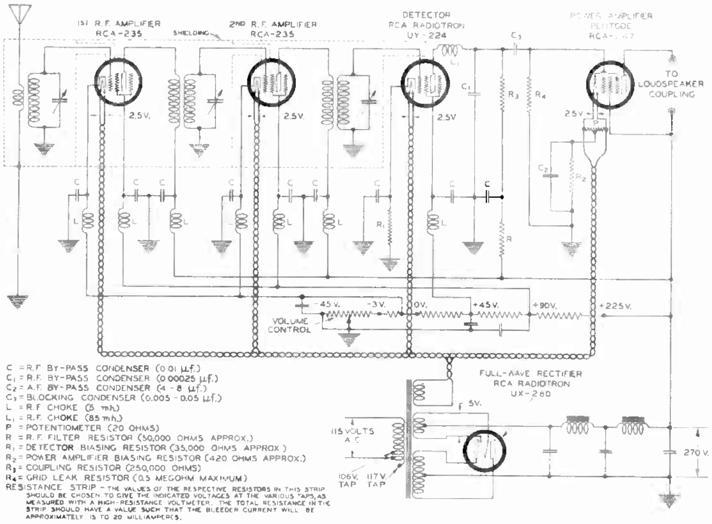

Figure 20

EXAMINATION QUESTIONS (V-13 #1.)

1. Explain the principle on which a pentode tube functions.
2. Calculate the "C" bias resistor for the 245 tube used in Figure 9 with 250 volts plate supply.
3. (a) Under what conditions would you use a 171-A tube with 90 volts applied to the plate and (b) with 180 volts applied?
4. How is screen grid voltage best obtained and how controlled?
5. What is the difference between space charge and screen grid connections?
6. Refer to Question 5. Which makes the better audio amplifier and why?
7. What advantage does the screen-grid type tube have over the 3-element tube as an r-f amplifier?
8. (a) Show by diagram how you would connect a loudspeaker to a 171-A tube, (b) to a 245 tube, and (c) Explain why for each case.
9. A 224 tube used as a detector has 200 volts applied to its plate thru a coupling resistor of 250,000 ohms. Assuming the plate current to be .1 milliampere what voltage is actually impressed on the tube?
10. Give the advantages of the type 235 tube over the type 224 tube.

AVERAGE CHARACTERISTICS CHART

DETECTORS AND AMPLIFIERS

GENERAL								DETECTION			AMPLIFICATION									
Type	Use	Base	Max. Overall Dimensions		Filament Supply	Filament Terminal Volts	Filament Current Amperes	Plate Supply Volts	Plate Current Milliamp.	Grid Return Lead To	Plate Supply Volts	Grid Bias Voltage		Plate Current Milli-amp.	Screen Grid Volts	A. C. Plate Resistance Ohms	Mutual Conductance Micromhos	Voltage Amplification Factor	Ohms Load for Maximum Undistorted Output	Maximum Undistorted Output Milliwatts
			Height	Diam.								D. C. on Fil.	A. C. on Fil.							
WD-11	Detector or Amplifier	WD-11	$4\frac{1}{8}''$	$1\frac{3}{16}''$	D. C.	1.1	0.25	45	1.5	+F	90 135	4.5 10.5	— —	2.5 3.0	— —	15500 15000	425 440	6.6 6.6	15500 18000	7 35
WX-12	Detector or Amplifier	UX	$4\frac{11}{16}''$	$1\frac{7}{16}''$	D.C.	1.1	0.25	45	1.5	+F	90 135	4.5 10.5	— —	2.5 3.5	— —	15500 15000	425 440	6.6 6.6	15500 18000	7 35
UX-112-A	Detector or Amplifier	UX	$4\frac{11}{16}''$	$1\frac{13}{16}''$	D. C.	5.0	0.25	45	4.0	+F	90 135	4.5 9.0	— —	5.2 6.2	— —	5600 5300	1500 1600	8.5 8.5	5600 8700	30 120
UV-199	Detector or Amplifier	UV-199	$3\frac{1}{2}''$	$1\frac{1}{16}''$	D. C.	3.3	0.063	45	1.0	+F	90	4.5	—	2.5	—	15500	425	6.6	15500	7
UX-199	Detector or Amplifier	Small UX	$4\frac{1}{8}''$	$1\frac{3}{16}''$	D. C.	3.3	0.063	45	1.0	+F	90	4.5	—	2.5	—	15500	425	6.6	15500	7
UX-200-A	Detector	UX	$4\frac{11}{16}''$	$1\frac{13}{16}''$	D. C.	5.0	0.25	45	1.5	−F	Following UX-200-A Characteristics Apply Only for Detector Connection					30000	666	20	—	—
UX-201-A	Detector or Amplifier	UX	$4\frac{11}{16}''$	$1\frac{13}{16}''$	D. C.	5.0	0.25	45	1.5	+F	90 135	4.5 9.0	— —	2.5 3.0	— —	11000 10000	725 800	8.0 8.0	11000 20000	15 55
UX-222	Radio Freq. Amplifier	UX	$5\frac{3}{8}''$	$1\frac{13}{16}''$	D. C.	3.3	0.132	—	—	—	135 135	1.5 1.5	— —	1.5 3.3	45 67.5	850000 600000	350 480	300 290	— —	— —
UX-222	Audio Freq. Amplifier	UX	$5\frac{3}{8}''$	$1\frac{13}{16}''$	D. C.	3.3	0.132	—	—	—	180†	1.5	—	0.3	22.5	2000000	175	350	—	—
UY-224	R. F. Amp. or Detector	UY	$5\frac{1}{4}''$	$1\frac{13}{16}''$	A. C. or D. C.	2.5	1.75	Refer to Technical Bulletin		Cath.	180 180	1.5 3.0	1.5 3.0	4.0 4.0	75 90	400000 400000	1050 1000	420 400	— —	— —
UY-224	Audio Freq. Amplifier	UY	$5\frac{1}{4}''$	$1\frac{13}{16}''$	A. C. or D. C.	2.5	1.75	—	—	—	250‡	1.0	1.0	0.5	25	2000000	500	1000	—	—
UX-226	Amplifier	UX	$4\frac{11}{16}''$	$1\frac{13}{16}''$	A. C. or D. C.	1.5	1.05	—	—	—	90 135 180	5.0 8.0 12.5	6.0 9.0 13.5	3.8 6.3 7.4	— — —	8600 7200 7000	955 1135 1170	8.2 8.2 8.2	9800 8800 10500	30 80 180
UY-227	Detector or Amplifier	UY	$4\frac{11}{16}''$	$1\frac{13}{16}''$	A. C. or D. C.	2.5	1.75	45	3.5	Cath.	90 135 180	6.0 9.0 13.5	6.0 9.0 13.5	2.7 4.5 5.0	— — —	11000 9000 9000	820 1000 1000	9.0 9.0 9.0	14000 13000 18700	30 80 165
RCA-230	Detector or Amplifier	Small UX	$4\frac{1}{4}''$	$1\frac{3}{16}''$	D. C.	2.0	0.06	45	1.0	+F	90	4.5	—	2.0	—	12500	700	8.8	—	—
RCA-232	Radio Freq. Amplifier	UX	$5\frac{1}{4}''$	$1\frac{13}{16}''$	D. C.	2.0	0.06	—	—	—	135	3.0	—	1.5	67.5	800000	550	440	—	—
UX-240	Detector or Amplifier	UX	$4\frac{11}{16}''$	$1\frac{13}{16}''$	D. C.	5.0	0.25	135† 180†	0.3 0.4	+F	135† 180†	1.5 3.0	— —	0.2 0.2	— —	150000 150000	200 200	30 30	— —	— —

*For Grid-Bias Detection, refer to Technical Bulletins. †Applied through plate coupling resistor of 250000 ohms. ‡Applied through plate coupling resistor of 200000 ohms.

POWER AMPLIFIERS

Type	Use	Base	Height	Diam.	Filament Supply	Filament Terminal Volts	Filament Current Amperes	Plate Supply Volts (Detection)	Plate Current Milliamp. (Detection)	Grid Return Lead To	Plate Supply Volts	D. C. on Fil.	A. C. on Fil.	Plate Current Milli-amp.	Screen Grid Volts	A. C. Plate Resistance Ohms	Mutual Conductance Micromhos	Voltage Amplification Factor	Ohms Load for Maximum Undistorted Output	Maximum Undistorted Output Milliwatts
UX-112-A	Power Amplifier	UX	$4\frac{11}{16}''$	$1\frac{13}{16}''$	D. C. or A. C.	5.0	0.25	—	—	—	135 180	9.0 13.5	11.5 15.0	6.2 7.6	— —	5300 5000	1600 1700	8.5 8.5	8700 10800	120 260
UX-120	Power Amplifier	Small UX	$4\frac{1}{8}''$	$1\frac{3}{16}''$	D. C.	3.3	0.132	—	—	—	135	22.5	—	6.5	—	6300	525	3.3	6500	110
UX-171-A	Power Amplifier	UX	$4\frac{11}{16}''$	$1\frac{13}{16}''$	A. C. or D. C.	5.0	0.25	—	—	—	90 135 180	16.5 27.0 40.5	19.0 29.5 43.0	12.0 17.5 20.0	— — —	2250 1960 1850	1330 1520 1620	3.0 3.0 3.0	3200 3500 5350	125 370 700
UX-210	Power Amplifier	UX	$5\frac{5}{8}''$	$2\frac{3}{16}''$	A. C. or D. C.	7.5	1.25	—	—	—	250 350 425	18.0 27.0 35.0	22.0 31.0 39.0	10.0 16.0 18.0	— — —	6000 5150 5000	1330 1550 1600	8.0 8.0 8.0	13000 11000 10000	400 900 1600
RCA-231	Power Amplifier	Small UX	$4\frac{1}{4}''$	$1\frac{3}{16}''$	D. C.	2.0	0.130	—	—	—	135	22.5	—	8.0	—	4000	875	3.5	—	170
UX-245	Power Amplifier	UX	$5\frac{5}{8}''$	$2\frac{3}{16}''$	A. C. or D. C.	2.5	1.5	—	—	—	180 250	33.0 48.5	34.5 50.0	25.0 34.0	— —	1900 1750	1850 2000	3.5 3.5	3500 3900	780 1600
UX-250	Power Amplifier	UX	$6\frac{1}{4}''$	$2\frac{11}{16}''$	A. C. or D. C.	7.5	1.25	—	—	—	250 350 400 450	41.0 59.0 66.0 80.0	45.0 63.0 70.0 84.0	28.0 45.0 55.0 55.0	— — — —	2100 1900 1800 1800	1800 2000 2100 2100	3.8 3.8 3.8 3.8	4300 4100 3670 4350	1000 2400 3400 4600

RECTIFIERS

UX-280	Full-Wave Rectifier	UX	$5\frac{5}{8}''$	$2\frac{3}{16}''$	A. C.	5.0	2.0	1 { A. C. Voltage per Plate (Volts RMS) 350; D. C. Output Current (Maximum MA.) 125 2 { A. C. Voltage per Plate (Maximum Volts RMS.) 400; D. C. Output Current (Maximum MA.) 110	For D. C. Output Voltage delivered to filter of typical rectifier circuits, refer to Technical Bulletin.
UX-281	Half-Wave Rectifier	UX	$6\frac{1}{4}''$	$2\frac{7}{16}''$	A. C.	7.5	1.25	A. C. Plate Voltage (Maximum Volts RMS.) 700 D. C. Output Current (Maximum MA.) 85	For D. C. Output Voltage delivered to filter of typical rectifier circuits, refer to Technical Bulletin.

SPECIAL PURPOSE

UX-874	Voltage Regulator	UX	$5\frac{5}{8}''$	$2\frac{3}{16}''$	Designed to keep output voltage of B-Eliminators constant when different values of "B" current are supplied.	Operating Voltage 90 Volts D. C. Starting Voltage 125 Volts D. C. Operating Current 10-50 Milliamperes
UV-876	Current Regulator (Ballast Tube)	Mogul	$8''$	$2\frac{1}{16}''$	Designed to insure constant input to power operated radio receivers despite fluctuations in line voltage.	Operating Current 1.7 Amperes Voltage Range 40-60 Volts
UV-886	Current Regulator (Ballast Tube)	Mogul	$8''$	$2\frac{1}{16}''$	Designed to insure constant input to power operated radio receivers despite fluctuations in line voltage.	Operating Current 2.05 Amperes Voltage Range 40-60 Volts

FOR AMATEUR AND EXPERIMENTAL TRANSMITTING USE

Type	Use	Base	Maximum Overall Dimensions		Filament Terminal Volts	Filament Current Amperes	Voltage Amp. Factor	Normal Plate Volts	Approx. Grid Bias Volts	Approx. Screen Volts	Maximum Plate Current Amperes	Maximum Plate Dissipation Watts	Normal Power Output Watts
			Height	Width									
UX-852	Oscillator or R. F. Amplifier	UX	$8\frac{3}{4}''$	$6\frac{1}{8}''$	10.0	3.25	12	2000	250	—	0.10	100	75
UX-865	Oscillator or R. F. Amplifier	UX	$6\frac{1}{4}''$	$2\frac{3}{16}''$	7.5	2.0	150	500	75	125	0.06	15	7.5
UX-866	Half-Wave Rectifier	UX	$6\frac{3}{8}''$	$2\frac{7}{16}''$	2.5	5.0	Maximum Peak Inverse Voltage 5000 Volts Maximum Peak Plate Current 0.6 Ampere Approximate Tube Voltage Drop 15 Volts						

THE CATHODES ARE CAREFULLY SPRAYED TO GIVE THEM A UNIFORM COATING OF THE ELECTRON EMITTING MATERIAL

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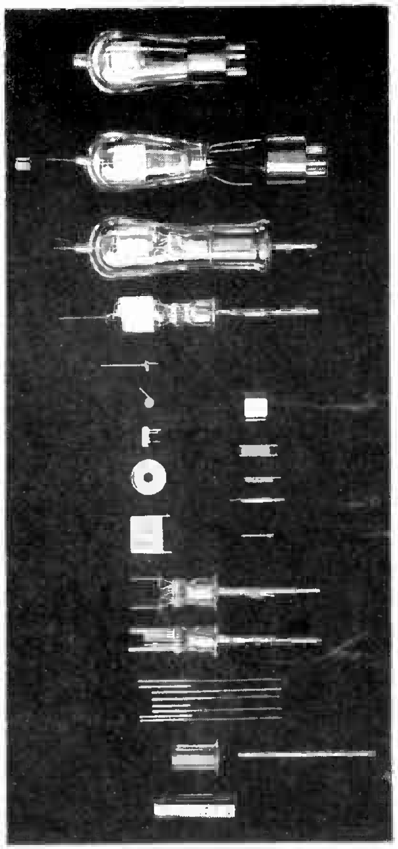
VACUUM TUBE THEORY

VOL.13#3



Parts Assembly of the '24-A Type Tube

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VACUUM TUBE THEORY

We now come to the study of the Vacuum Tube, a device which is the very heart of the radio receiver. The student will, at this point, have to give his undivided attention to that which follows and proceed with an open mind and active imagination. In order to understand the action of the vacuum tube we should review the action of the electron in a vacuum. To imagine an electron is one thing, but to follow the actions of electrons is quite another. The study of the electron theory as applied to the vacuum tube is comparatively easy if the student will concentrate, otherwise it is a difficult study and only results in a state of confusion. It is intensely interesting and, when understood, gives a clear idea of the relation between radio circuits and vacuum tubes.

The vacuum tube is not confined to radio alone; it is used in any number of other scientific fields, especially those in which high frequency rays are involved.

Let us consider for the time being that in the vacuum tube we have a device which will not only rectify an alternating current but will also reproduce, in amplified form, the most feeble variations of E.M.F. applied to it regardless of the frequency.

The tube may be employed as a rectifier of alternating currents of any frequency. The term rectifier is sometimes used to indicate the detector action.

It is termed a radio frequency amplifier when it is used to amplify the high frequency currents induced in the antenna by the incoming signal wave.

Further, the tube is used to amplify the output currents of the detector and when so used it is known as an audio frequency amplifier.

When used as a generator of high frequency undamped oscillations in an oscillatory circuit it is called an oscillator.

Before these various functions can be explained it is necessary to have a knowledge of the characteristics of the vacuum tube and to what extent these characteristics can be controlled. Until recent years no satisfactory explanation was offered concerning many phases of electrical phenomena known to science. As the application of electricity developed, however, there was a great amount of data secured which enabled scientists to formulate some of the laws governing the flow of electricity. For example, the relation between electromotive force, current, and resistance was explained by Dr. Ohm and put into the form of a law, the law being known universally as Ohm's Law.

Discoveries were also made regarding the generation of electrical pressure by chemical action between certain liquids and metals. This led to the development of the battery, and then came the evolution of the dynamo. No satisfactory explanation was offered at the time concerning the electrical phenomena of these discoveries yet they were of great practical value in determining from the results obtained, experimentally, many of the present laws of electricity. It also became necessary to settle upon certain arbitrary standard units by which electrical force and energy could be measured and computed, these being known as Universal Electrical Units which were explained in a previous lesson.

It was also found necessary to assume a certain direction in which electricity flowed through a conductor. Scientists decided to call the copper or carbon plate of a primary cell the positive terminal, and the zinc plate the negative terminal, and considered that electricity flowed in an external circuit from the positive electrode to the negative electrode. It must be understood that this direction given to the current flow was entirely an arbitrary one and was agreed upon only as a matter of convenience in understanding certain phenomena.

For many years the atom was regarded as the smallest unit into which matter could be divided and still retain its chemical and physical properties and the phenomenon was then explained by the atomic theory. In recent years many scientists have accepted the general belief that the atom is itself subdivided into many thousands of particles termed electrons and that these electrons carry with them a charge of electricity. It has been found that under certain conditions these electrons or particles of negative electricity can be made to move. Their movement is from a negative to a positive electrode and when in motion they constitute a current flow. This new theory is known as the "Electron theory of matter".

THERMIONIC CURRENTS

Thermionic current is the name given to electricity which is the result of electrons thrown off or emitted from hot bodies. A discovery made by Thomas A. Edison in 1884, known as "The Edison Effect", gave rise to an investigation of thermionic currents which leads up to the vacuum tube of today. Edison, in his work with the electric lamp, found that after a lamp had been in use some time a dark coating formed on the inside of the lamp, becoming in some instances nearly black with long continual use. He became interested in this effect and further research brought out the fact that when a metal plate was placed inside the lamp and connected to one side of a sensitive galvanometer and the other terminal of the galvanometer then connected to the positive terminal of the battery supplying current to the filament of the lamp, the galvanometer would show a deflection when the filament of the lamp was heated.

The effect at the time seemed to indicate that an electric current flowed from the positive side of the filament through the galvanometer to the plate inside the lamp, through the vacuum of the lamp, returning to the filament. Edison also discovered that, when the galvanometer

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terminal was removed from the positive side of the filament and connected to the negative side, practically no deflection of the galvanometer followed. After the discovery of this phenomenon experiments were carried out by several scientists. J. A Fleming, after considerable experimenting and research on the Edison effect, came to the conclusion that NEGATIVE electricity passed from the filament of the lamp to the plate when the plate was relatively cold with respect to the filament and the plate was charged to a positive potential.

Conclusions of the experiments of J.J. Thompson led to the belief that what is now called the electron existed and that negative electricity consisted of masses of these electrons which were forced away from the filament of an electric lamp when the filament was brought to incandescence. In other words the filament itself consisted of these infinitely small particles called electrons. It has now been generally accepted that it is by means of the electron that electricity is carried through a conductor or through a vacuum.

There are always large numbers of electrons in an atom and normally this quantity amounts to a given number just sufficient to neutralize the effect of the positive nucleus. Generally but one electron can be detached from an atom even though it may have a great many associate electrons. Under normal conditions the atom possesses no electrical charge because a perfect state of neutralization exists between the positive charge and the electrons. When, however, one of the free electrons is forced away by some cause or other this perfect balance is destroyed and the atom predominates in positive charge because it is now deficient in its complement of electrons.

ELECTRON EMISSION

The emission of electrons is dependent upon the temperature of the filament, the size (area) of the filament, the nature of the substance employed as the filament, and the medium in which the filament is heated. The number of electrons emitted will be proportional to the area of the filament. For example, if you have two filament lengths, one twice as long as the other, by heating one filament to a given temperature a certain electron emission occurs. With the same heat applied to the filament of twice the length, double the emission occurs. This happens however only when the same heat is applied to both filaments.

The temperature of the filament is very important in that, with each increase of filament heat, there will be an increase in electron emission. This increase in electron emission increases as the temperature increases until the maximum emission takes place which is just below the melting point of the filament. Heating the filament to excessive temperature is of no advantage as you will later learn.

The composition of the filament, that is, the material employed in its manufacture, will have a bearing upon the electron emission. Some metals, when heated, do not emit as many electrons as others. Carbon, for example will emit a certain quantity of electrons but not nearly in as large quantities as tungsten. Tungsten is materially helped in electronic emission when another metal called thorium is combined with it. It is the Thoriated Tungsten filament that is used in many types of tubes because at low temperatures it has a very high rate of electron emission.

There is still another factor which has a great influence on electron emission and that is the medium in which the emission occurs. In the first place it must be in a vacuum, or at least a partial one. It is quite impossible to obtain a complete vacuum and small traces of gas left in the tube will decrease the electron emission. Most of the gases in the tube, with few exceptions, are inert gases. The presence of gas in the vacuum presents a resistance to the emission of electrons unless ionization takes place. (This particular subject will be taken up later in more detail).

The most important factor in the rate of emission is the temperature of the filament for, upon the rate of emission alone in a certain tube, will depend the number of electrons emitted. It must be understood at this point that the term "Emission" refers only to the emerging of the electrons from the filament and not to the passage of the electron through the vacuum.

Suppose now we attempt to visualize that which takes place in the filament when it is heated. As heat is applied the whole atomic structure is set into a violent agitation and the free electrons about the atoms of the filament are set into rapid vibration. With each increase of heat this vibration increases and the electrons finally gain a velocity in their movements great enough to carry them beyond the positive force of the atom which normally holds them within the filament. As this velocity is attained they emerge from the filament in clouds much as does steam from a pan of boiling water. This happens only after they have acquired a speed which is able to project them beyond the influence of the atom to which they belong.

Once beyond the attractive force of the parent atom they are subject to collisions which are continually occuring as they move about in the filament. Their velocity, on leaving the filament, varies according to the retarding effect these collisions have had upon the electron in its attempt to escape. Once outside the filament they again have difficulty due to the gas molecules which may be present within the vacuum, and with which they continually collide until their energy is exhausted whereupon they are drawn back to the filament.

SPACE CHARGE

The electron constitutes a negative charge of electricity and, on emerging from the filament, leaves the filament positive in respect to the projected electron. The tendency, therefore, is for the electron to be attracted back to the filament. Any gas in the vacuum also presents a resistance to be overcome by the electron. There is also another repelling effect which must be overcome. This is the repelling effect of electrons which are moving at a greater distance from the filament than the newly emitted electrons.

As stated before, the electrons fill the space about the heated filament much as steam fills the space over a pan of boiling water. The electrons, in their countless thousands, may be considered as actual particles of negative electricity, and they constitute in reality an actual negative charge in the space they fill. It is this condition that is called "The Space Charge".

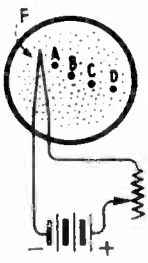

Figure 1

Let us now consider the effect this space charge has upon electrons leaving the filament and, for example, we will consider a single electron. In Figure 1 the filament is shown emitting electrons which are represented by the black dots. The electron A, which is represented by the enlarged dot, is shown a short distance from the filament F and we will assume its velocity carries it to the point shown, first, by overcoming the tendency of the filament to draw it back, second, its velocity carries it against whatever resistance is offered by any gas present and, third, it is carried against the repelling force exercised against it by the electrons which are moving about ahead of it.

At the point shown at "A" the velocity of the electron is spent and it has no further energy to carry it ahead. It is then easily influenced by the repelling action of the electrons beyond it,- also by the attractive force of the filament and it finally returns and is absorbed by the filament.

We will consider Electron "B" as having gained a greater velocity on leaving the filament. It reaches point B before it is drawn back to the filament.

Electron "C" has left the filament at a still greater velocity than either A or B and has reached the point C as shown. This electron has reached a point in the space charge where there is a greater number of electrons behind it than ahead of it and, since like charges repel, electron "C" is actually assisted on its course further away from the filament to point D.

The foregoing will serve to acquaint you with at least a working knowledge of the forces acting upon the electron, this being important because it accounts for certain phenomena which will be encountered later on in our detailed study of the tube.

THE PLATE

In addition to creating a supply of electrons in the vacuum tube it is necessary that we also create some attraction which will cause these electrons to move from their point of origin. This is accomplished by sealing a second element called the plate in the vacuum space. This is shown in Figure 2. It is to be noted that the plate has a connecting lead brought out for a purpose which we will soon explain. For the time being we shall consider the plate as shown in Figure 2 to be sealed in the tube but not connected in any way.

Electrons being emitted will accumulate on the plate and charge it to a negative potential, the negative charge will increase until the plate repels any further electrons moving in its vicinity. Let us now give the plate a positive charge by connecting it to the positive side of a battery, called the "B" battery, as shown in Figure 3. Since this makes the plate positive its natural tendency, in order to restore the state of balance, is to attract any negative charge possible. This it does by drawing to it the electrons being emitted by the filament.

When the plate is connected in the circuit as shown in Figure 3, and is given a positive charge, electro-static lines of force immediately are set up between the plate and terminate at the filament. It is along these lines of force that a positive charge of electricity, as formerly understood, would travel. The electron being a negative charge would move along the same lines of force but from filament to plate which simple means, when expressed differently, that the positive plate will attract to it the negative electrons (unlike charges attract). The attractive force the plate has for the electrons will depend upon the potential of the plate relative to that of the filament

The original tube, known as the Fleming Valve, consisted of only two elements, the filament and plate, as shown in Figure 3.

CHARACTERISTICS OF THE FLEMING VALVE

The phenomenon of a vacuum tube can best be understood by making a preliminary study of the Fleming Valve.

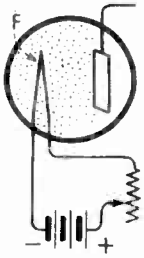

Figure 2

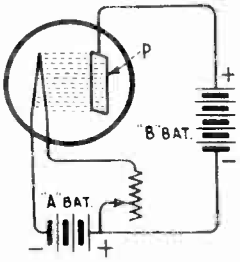

Figure 3

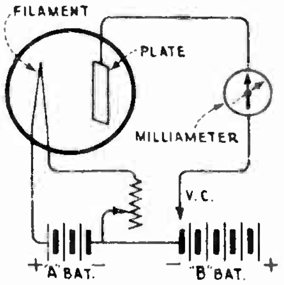

Figure 4

The circuit consists of a source of current, known as the "A" battery to heat the filament. The E.M.F. applied to the filament is made variable. A source of E.M.F., known as the "B" battery, is used to charge the plate and this should also be variable. Such a circuit is shown in Figure 4.

If the plate has a very small positive potential placed on it as shown in Figure 5 a very weak current will flow through the plate circuit, P, M, A, F, because. under these conditions, only a limited number of electrons will reach the plate and the greater majority of them are drawn back into the filament.

It is to be noted here that the plate will have a potential about equal to the filament. Let us, however, connect a battery in the plate circuit as shown in Figure 5A, giving the plate a high positive potential with respect to the filament. Under these conditions nearly all the electrons emitted from the filament will be attracted to the plate resulting in a flow of a comparitively large plate current, as indicated by the milliameter reading. If the B battery is connected as shown in Figure 4 thus placing a negative potential on the plate, the meter will show no deflection because the emitted electrons are negative and they will be repelled by the negative plate. This clearly indicates that electricity cannot flow from the plate to the filament due to the fact that no electrons are passing in the direction of the filament.

As we stated before the rate of emission will depend upon the material of which the filament is made, the size of the filament, and the temperature at which the filament is heated. In the vacuum tube the temperature of the filament is a variable factor. We cannot change the position nor size of any of the elements within the tube, but we can change the filament temperature by a variation of the current passed through it. For a given filament current there will be a corresponding temperature and this temperature will remain constant, providing the current is not varied. At a certain temperature a definite number of electrons will be emitted.

If the circuit as shown in Figure 6 is set up with the filament switch F S open filament current will not flow and no electrons are emitted· hence no plate current will flow, which is indicated by zero reading of the milliameter, M.A. When switch FS is closed current will flow through the filament from battery A. Electrons will then be emitted and as the current increases through the filament its temperature will be increased with a corresponding increase of electron emission.

If the rheostat is set at a point where less than normal filament current flows through the filament and the plate voltage is varied from

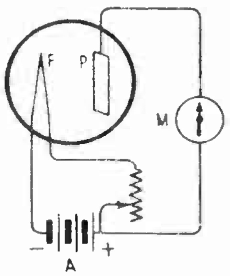

Figure 5

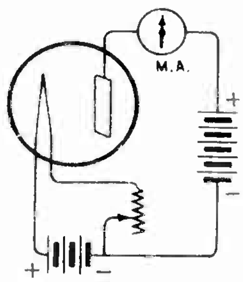

Figure 5A

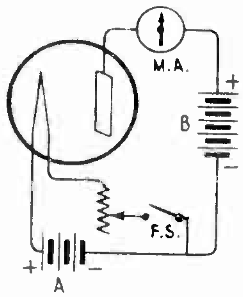

Figure 6

zero upward by changing the taps on the "B" battery a curve as shown in Figure 7, A,B,C,D, is obtained. This shows that plate current increases as the plate voltage is increased. An examination of this curve shows that as the plate voltage is increased at first there is a rapid increase in plate current (A). After a certain value of plate voltage is applied there is no appreciable increase produced in plate current by increasing the plate voltage. This is shown by the horizontal portion D of the curve. If the filament current is now increased and the plate voltage again is varied from zero upward the change in plate current takes place along the curve AEFG. Here the plate current coincides with the lower filament current along part A, but continues to increase above the bend B obtained with the lower filament current. After a certain plate voltage is applied the plate current again fails to increase for further increase in plate potential. This is indicated by the horizontal portion G which however is higher than D, obtained with the lower filament current. If other similar curves are drawn, each corresponding to a definite filament current, the same characteristics would be noted in each, namely a part where the plate current increases as the plate voltage increases and a part were the plate current is constant even though the plate voltage increases.

From these curves it is evident that with a definite filament current there is a definite plate current that cannot be exceeded. Moreover these curves show that as the filament current increases the maximum value of plate current also increases. This shows that a condition exists in the tube itself which limits the amount of current that can be obtained from the filament. Furthermore it seems certain that this limiting factor depends on the filament temperature which in turn depends on the filament current. Thus we can say that the maximum plate current obtainable depends on the filament. But for each filament temperature there is a definite maximum value of plate current.

A further study shows that the proportion of electrons attracted to the plate depends on the magnitude of the plate potential. When the filament temperature is kept constant and the plate voltage gradually increased the number of electrons attracted to the plate, and therefore the current in the plate circuit, will gradually increase as shown at (A) and (B) of Figure 8. This will continue until a condition is reached where all the electrons are drawn over to the plate as shown at (C). A further increase of plate potential will not result in any increase of plate current. This maximum plate current, beyond which there is no increase for increased plate voltage is known as the saturation current of the tube. For each filament temperature there is a different value of saturation current. Saturation for any definite temperature of the filament occurs when the plate attracts the electrons at the same rate as they are being emitted by the filament. In order to increase the plate current beyond this point it is necessary to increase the filament temperature. The modern tube must be so designed that its filament will be able to emit electrons at a high enough rate so that saturation will not occur at the normal filament current and plate voltage. This means an electron emitter having an ample supply of electrons.

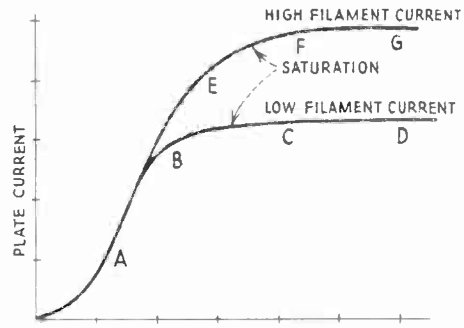

Fig. 7

Characteristic Curves of a Two-Electrode Tube at Two Different Filament Temperatures

GAS EFFECTS

The subject matter just given applies to tubes which are theoretically perfect in vacuum, allowing the electrons to pass in the space between the filament and plate without interference.

When, however, small traces of gas are left in the tube the electron current, which flows when a positive potential is applied to the plate, is increased over that obtained under the same conditions with tubes highly evacuated. The increase in electron current takes place, however, on the condition that ionization takes place.

IONIZATION

Ionization is the effect produced when electrons, on their path from the filament to the plate, collide with the molecules of gas in the tube. The molecule of gas is disrupted by the collision and it frees detachable electrons which then flow with the main body of electrons originating at the filament.

As the "B" voltage is increased the attraction of the plate for the electrons is increased. This, of course, affects the speed of the electrons and when they strike the gas molecules with greater speed the number of electrons freed from the molecules of gas will be increased. It is the liberated electrons from the gas molecules joining the main stream of electrons that increases the plate current.

When the electrons being emitted from the filament have attained a speed great enough they break up the gas molecule into free electrons leaving the gas molecule positively charged. In other words the gas molecule has been ionized and is now what is termed a positive ion. When this takes place in a vacuum tube to any great extent it is made evident by a blue glow which fills the space about the plate because at this point the greatest velocity of the electron occurs. The positive ions thus formed cannot flow to the plate because the plate is positively charged, and like charges repel, and the ions will then move toward the filament. Upon striking the filament they break loose more electrons, which again increases the quantity of electrons available to bombard the plate.

Ionization, therefore, is the splitting or breaking up of gas molecules into free electrons which are always negative and positive charged ions. The freed electrons forming with the main stream of electrons, and the ions shaking more electrons free from the filament which at once start on their journey to the plate, produces increased current in the plate circuit.

THE THREE-ELEMENT VACUUM TUBE

The three-electrode tube differs from the two-element tube only in the introduction of a third element, called the grid.

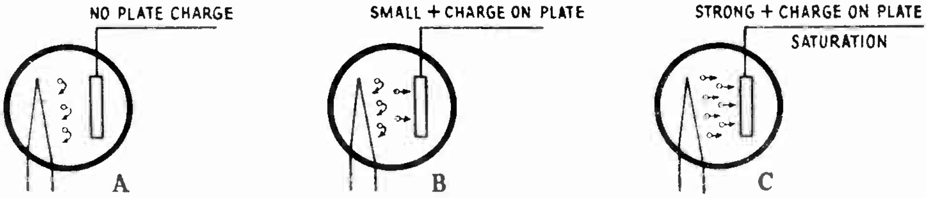

Fig. 8—Action of Electrons in a Two-Element Tube

The introduction of the grid brought about a change in radio that has had a far reaching effect. In fact it was the most important contribution made in the advancement of radio communication since the Fleming Valve was perfected. It greatly increased the sensitiveness of all receiving apparatus used in radio and is directly responsible for all the uses of the modern vacuum tube in transmitting and receiving apparatus.

The grid is capable of controlling the electrons which fill the space between the filament and plate. It exercises a directive power over the cloud of electrons which are racing with tremendous speeds toward the plate. The grid allows certain quantities of the electrons to proceed to the plate or it may prevent them in some cases from striking the plate at all.

By making the grid alternately positive and negative the quantity of electrons flowing from the hot filament to the plate can be increased or decreased. It can thus control large powers of plate current. The amazing feature here is that very small power applied to the grid will exercise this control. How this is accomplished will now be considered

THE USE OF THE GRID

The theory of the two-electrode tube, relative to the electron flow, the space charge, etc., will now be applied while explaining the effects produced by the introduction of the third element, the grid.

The grid is placed in the tube to control the electron flow from filament to plate. For this reason it is often compared to the trigger action of a gun, or the valve control over water, steam lines etc. In the grid, however, we utilize electricity to effect this control. You will remember in our study of the two-electrode tube that the space between the filament and plate was filled with minute negative charges, the electrons. You also know that like charges of electricity will repel and unlike charges will attract.

Now let us refer to the three-electrode tube shown in Figure 9. The grid will then be right in the middle of the cloud of electrons constituting the space charge. If we now connect the negative terminal of a third battery "C" to the grid as shown in Figure 9 we place a negative charge on the grid which will assist the negative space charge.

Since the space charge is already negative an additional negative charge on the grid will repel the greater number of electrons which otherwise would have traveled directly to the plate. As soon as this happens the plate is robbed of electrons and a drop in plate current results. If we have the grid potential battery in Figure 9 arranged so that it is variable, allowing us to gradually increase the negative charge on the grid, a point will finally be reached when the repelling force caused by increasing the negative potential will become great enough to effectually block and turn back all the electrons emitted by the filament.

In this case no current will flow in the plate circuit because electrons are not now reaching the plate. In other words we have made the grid equal in negative force to the positive attraction of the plate and neutralization is the result.

Now let us reverse the battery "C" so the positive terminal is connected to the grid as shown in Figure 10. This will give the grid a positive charge and, since unlike charges attract, the grid will have the effect of attracting the electrons and also conteracting, to a certain extent, the negative space charge. The plate current will be increased because the grid, being made positive, has now added an attractive positive force to that of the plate and consequently assists the plate in attracting electrons to it. By this added positive force in the electron paths the electrons gain a much greater velocity and pass between the fine grid wires striking the plate in greater quantities.

Some of the electrons strike the grid and cause a current to flow therein. This current is usually small and later on methods will be introduced to keep it at a minimum because large grid current is undesirable. If this grid battery C is made variable as in the case of Figure 9, and then gradually changed so that an increasing positive charge is placed on the grid, more and more electrons will be assisted to the plate, but there will be a point reached where further increasing the positive potential of the grid will not draw more electrons from the filament. When the saturation point has been reached further increasing the grid potential will not increase the plate current.

When we consider the repelling effect the space charge has on electrons being emitted it is easily understood how the electron flow is effected when we introduce any element that will either increase or decrease this action of the space charge. The grid has the power to exercise this control as you have observed.

The radio wave is alternating current, rapidly changing from positive to negative. This current is led directly to the grid in the radio receiver and changes the grid rapidly from positive to negative thereby controlling the flow of electrons which, in turn, determine the plate current flow. The plate current flowing through the telephone receivers is made to change in this way. The tube action in the receiving set will bring this explanation out in more detail.

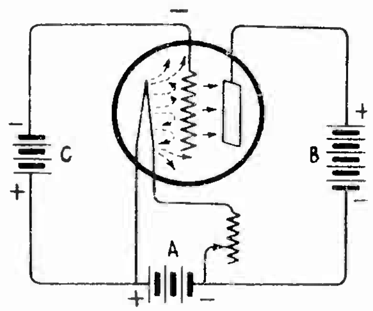

Figure 9

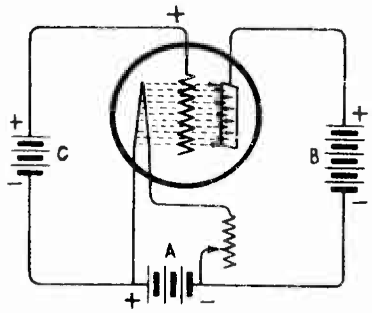

Figure 10

EXAMINATION QUESTIONS

1. What are Thermionic Currents?
2. Of what importance was the discovery of the "Edison Effect"?
3. Does the atom normally possess an electrical charge?
4. Upon what does electron emission depend?
5. Tell what you know about "space charge".
6. (a) In a vacuum tube what is the function of the plate?
   (b) The filament?
7. What is the effect of ionization?
8. How does the three-element tube differ from the Fleming Valve?
9. Of what importance is the grid element?
10. When the heat applied to the filament is increased is there an increase in the electron emission?

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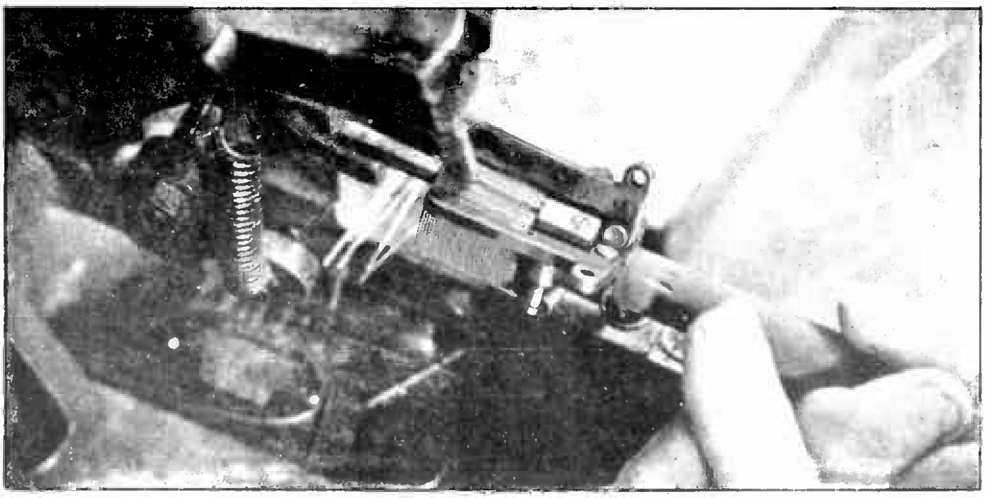

Method of Welding the Screen Grid

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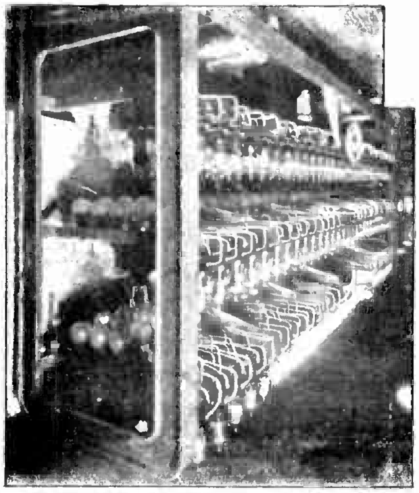

Radiotrons in the
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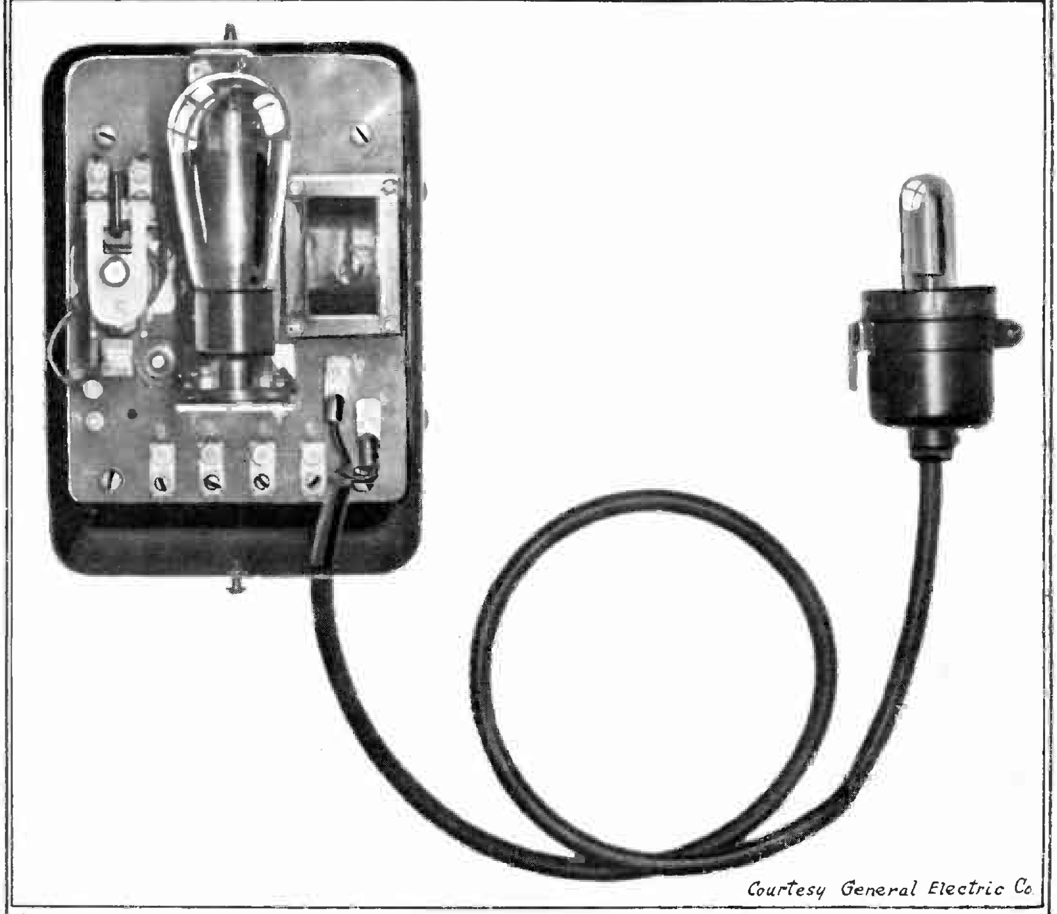

A PHOTOELECTRIC RELAY UNIT SHOWING THE "ELECTRIC EYE" OR PHOTOTUBE AT RIGHT AND AMPLIFIER AND RELAY AT LEFT.

Theory and Uses of Photoelectric Tubes

Dewey Classification 535.3

VOL. 13, No. 5

Courtesy Westinghouse E. & M. Co.

COMMERCIAL MODEL OF A WESTINGHOUSE PHOTOTUBE RELAY UNIT SHOWING THE LIGHT SENSITIVE TUBE (RIGHT) AND VACUUM TUBE AMPLIFIER (LEFT).

THEORY AND USES OF PHOTOELECTRIC TUBES

DEFINITION

In its broadest sense photoelectricity covers two phenomena, namely,

(1) The release of radiant energy when electrons strike particles of matter.

(2) The release of electrons when radiant energy falls on particles of matter.

It concerns, therefore, a transfer from electricity to light, or a transfer from light to electricity.

TYPES OF PHOTOELECTRIC PHENOMENA

Under the first type is the ordinary arc lamp, in which an electric current causes gases to become incandescent, producing radiant energy in the form of visible light waves.

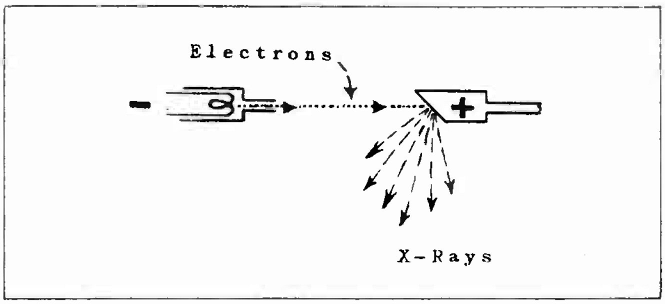

Fig. 1 - PRINCIPLE OF COOLIDGE X-RAY TUBE.

Also under the first type we note the Coolidge X-ray tube, which is simply illustrated in Fig. 1. Here we have a flow of electrons from a filament, the electrons being condensed by a sheath into a fine cathode ray. These electrons attain a tremendous velocity due to the attractive force of the high positive charge on the anode, which is called the "target" for the electron stream. The energy of the electrons in motion is communicated to the molecules of tungsten at the target surface, and these convert the energy into a form of radiation which we call X-rays.

The reverse effect is the emission of electrons from molecules of matter when radiant energy falls on them. This effect was originally discovered by Hallwachs. He found that if a body is negatively charged it will lose that charge when subjected to ultra-violet light. On the other hand, if the body is positively charged it will not be affected by the ultra-violet light. If a negatively charged body loses its charge under the influence of light it follows from the electron theory that we should be able to collect those charges under certain conditions by placing near it a positively charged body. This compares with the ordinary vacuum tube used for radio purposes, in which a positively charged plate is used to collect the electrons given off by the incandescent cathode. In Fig. 2 is shown the energy paths concerned with the Hallwachs effect.

Theoretically at least we could accomplish a double transfer, as shown in Fig. 3. Here we have radiant energy in the form of ultra-violet light directed onto a negatively charged metallic body in a vacuum and which gives up electrons; these would be attracted to the

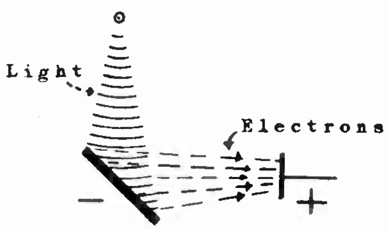

Fig. 2 - PRINCIPLE OF THE HALLWACHS EFFECT.

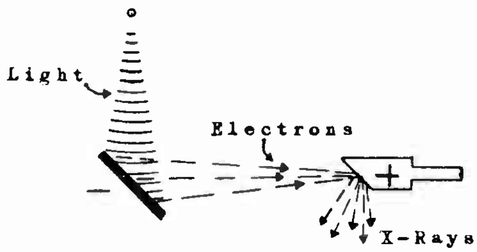

Fig. 3 - THEORETICAL IDEA OF A DOUBLE TRANSFER OF ENERGY.

anode or target. If a sufficient number of electrons could be emitted from the cathode in a given time (not practically possible) X-rays might be radiated from the target due to the energy wrapped up in the bombarding electrons. We observe here a difference in the two forms of radiant energy concerned. Ultra-violet light, while invisible, obeys the well-known optical laws of reflection, refraction and polarization. On the other hand X-rays do not. They do have some properties in common, as we shall see.

IONIZATION OF GASES

In various devices in this branch of science we encounter gases, not only of the non-metallic kind such as oxygen, hydrogen, helium, etc. but also those of the metals themselves, of which the most frequently used is the vapor of mercury, which is normally a fluid. You are familiar with the latter in the wide spread use of mercury vapor lamps, and you find it also in mercury vapor rectifiers.

Gas molecules containing two or more atoms may be dissociated into positive and sometimes negative ions by putting the gas in the line of action of any one of the three paths shown in Fig. 3. In like fashion the single-atom molecules which are electrically neutral are usually made over into positive ions.

Ultra-violet light can ionize mercury vapor by causing the release of one or more electrons from the mercury atom.

Electrons in motion at a sufficient speed may "knock off" other electrons from a gas molecule in their path, leaving positively charged atoms or ions, and sometimes negative ions, depending on the molecular construction.

Furthermore, X-rays also have the ionizing power.

SENSITIVITY TO LIGHT. In a foregoing paragraph we mentioned that Hallwachs, in his experiment, used ultra-violet light. There were natural limitations to this early device on account of the nature of the light. It is easy to see that in a practical way it is much

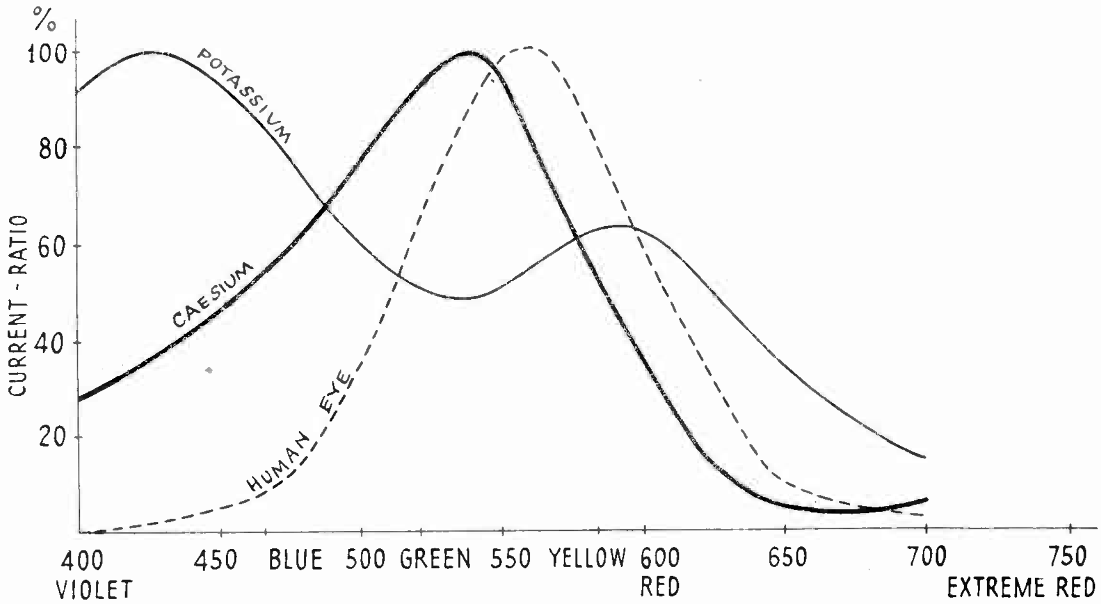

Fig. 4 - CHART SHOWS COMPARATIVE SENSITIVITY OF POTASSIUM, CAESIUM, AND THE HUMAN EYE AT DIFFERENT LIGHT FREQUENCIES.

easier and cheaper to produce and see white or yellow light — which usually contain some ultra-violet, but a much greater percentage of other colors. Thus an ideal material to use would be one that is more sensitive to white light or the same spectrum as the eye.

The discovery that sodium, potassium, caesium and a few other elements were instantly affected by visible light led to intensive development work which brought the photoelectric cell up to its present stage. Although these cells are quite highly developed yet they are not as uniform in performance as the radio tube. Photoelectric cells and radio tubes in general appearance resemble each other and both are classified as "electron discharge devices" although it must be remembered that in the case of the photocell the emission is caused by light while in the thermionic (radio) tube the emission is due to incandescence of the filament or cathode.

An examination of the chart in Fig. 4, which shows the sensitivity of various materials at different light frequencies, indicates that caesium compares favorably with that of the eye. Caesium, however, when used alone is not as sensitive as potassium or copper oxide but it has been found that by coating the caesium on silver oxide its sensitivity is greatly increased and furthermore its frequency characteristic is kept approximately the same as that of the eye.

PRINCIPLES USED IN THE PHOTO-EMISSIVE CELLS

Based on the principles used we have two types of photo-emissive cells or phototubes:

(a) The vacuum type, which consists of a highly evacuated vessel enclosing a positive electrode and a negative electrode, the latter consisting of a surface of such material that it will emit electrons under the influence of radiant energy of the visible or near visible spectrum.

(b) The gas type, which uses the principle of the vacuum type above, with the addition of a certain amount of one or more gases which easily release additional electrons under the forces of collision with electrons emitted from the cathode.

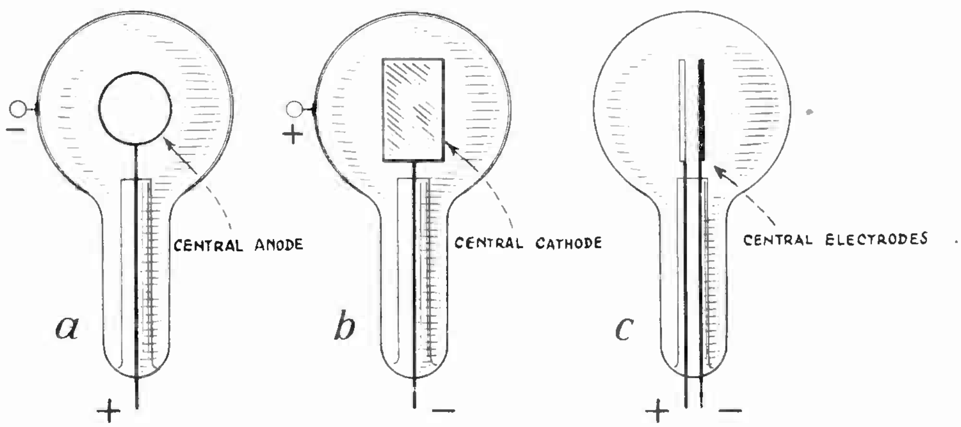

Fig. 5 - PHOTOTUBES ARE CLASSIFIED HERE ACCORDING TO ARRANGEMENT OF THEIR ELECTRODES.

STRUCTURAL FORMS

The three most common forms of phototubes now in use are (a) the central anode, (b) the central cathode, and (c) the central electrodes. In the central anode type the inner surface of the tube is coated with the light sensitive alkali while a rod, used for the anode, is located inside and near the center of the tube. In the central cathode type the inner surface of the tube is coated with a metallic substance and a plate, coated with light sensitive material, is located in the center of the tube. In either case the coating on the inside wall of the tube is connected electrically to a terminal which is brought outside the tube. The third type mentioned or the central electrode tube is now the tube most generally used in sound-on-film movies. It consists of a centrally located rod (anode) with a semi-cylindrical plate (light sensitized cathode) partially surrounding it. Fig. 5 shows the general arrangement of the electrodes.

VACUUM CELL. When the electrodes of a photocell function in a high vacuum it gives them a much different characteristic than when they work in a gas filled medium. When the cathode of a vacuum type cell is subjected to light a certain number of electrons are released and if a high positive potential is applied to the anode all of these electrons will be attracted to and flow toward the anode. On the other hand, if the anode voltage is comparatively low all of the liberated electrons will not be attracted to the anode, but many will continue to remain on the cathode. This characteristic showing the variation in current (electron flow) for a given fixed light intensity, with changes in anode potential is shown in Fig. 6. When the voltage is sufficient to remove all the electrons released by the light, a further increase of voltage should not produce an increase in electron flow. When this condition is reached the current has

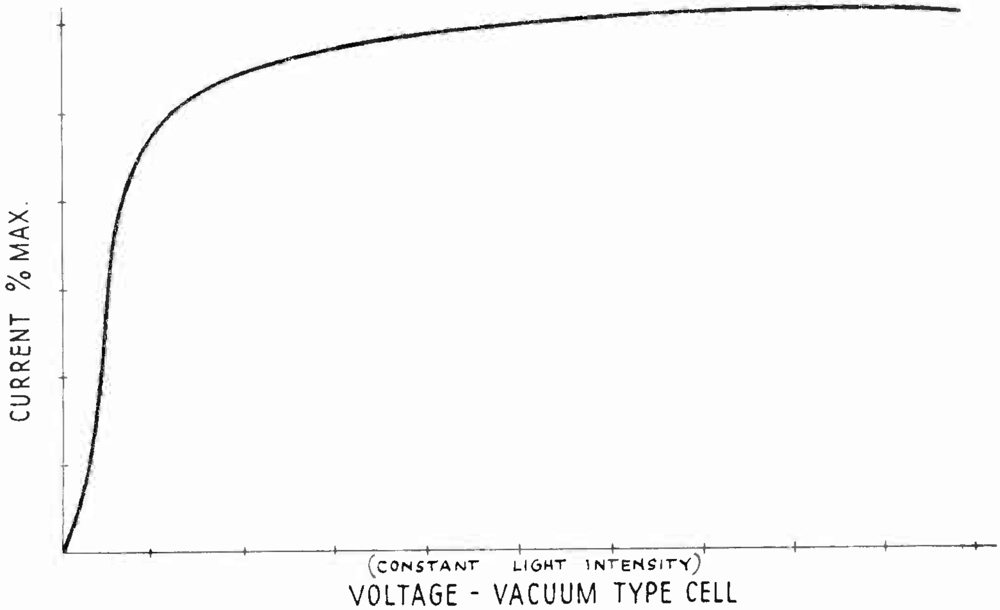

Fig.6 - CHART SHOWS RELATION BETWEEN CURRENT FLOW AND VOLTAGE CHANGES IN A VACUUM TYPE CELL WITH CONSTANT LIGHT INTENSITY.

reached the saturation value. Of course, if the light intensity is changed the voltage-current curve will be different and the saturation current will increase as the light intensity is increased. Due to imperfect vacuum and rough surfaces on the cathode holding back some electrons there will always be some slight increase in current for an increase in voltage, but this increase becomes so slight that it need not be considered.

EFFECT OF GAS ON CELLS. The action of gas filled cells is much more difficult to understand than the explanation just given for the action of the vacuum type cell. In the first place only gases which do not react chemically with photoelectric material can be used.

Argon, neon and helium answer these qualifications. The normal electron stream in motion will have scattered through it gas molecules which are electrically neutral, and therefore not attracted to either the anode or the cathode. The random motion of the gas molecules through the space of the tube will have no special direction. When an electron collides with a molecule the elastic properties of each may cause them to merely bounce off, their directions and velocities being changed but slightly. If the electron velocity is sufficiently great, however, it may give up some of its energy to the task of freeing another electron from the ties that bound it into the structure of a gas atom. The additional electron joins the stream of electrons originating at the cathode, and more electrons reach the anode than were caused by the light falling on the cathode. The gas atom which was robbed of an electron is no longer neutral, having become a positive ion. This ion is repelled from the anode, and attracted to the cathode, whose charge is of the opposite polarity. During its motion in that direction, it may join another electron and become neutral; or it may approach and reach the cathode at such a velocity that the collision causes an extra agitation of the electrons there, with the consequent increase in the number released. Still another effect occurs when a neutral gas atom combines with an electron to become a negative ion, which is attracted toward the anode.

It all gets very complicated when other variations are considered. Increasing the positive potential on the anode serves to increase the whole effect. It is possible to increase this voltage to a point where the emission from the cathode due to the positive ions present, is as great as or greater than the emission due to the light alone. When this condition is reached the emission of electrons will continue even though the light is cut off. The tube then contains a self-sustaining glow discharge which will continue until the anode potential is lowered appreciably, or until the cathode surface is robbed of its available electrons. In the latter case the tube becomes useless, as it cannot be reactivated like an amplifier tube.

It can be seen that while the gas filled cell is much more sensitive than the vacuum type more care is required to keep it from glowing. The same conditions exist in the gas filled cell as in the vacuum cell insofar as that increasing the light intensity changes the best maximum voltage used. Thus, with greater light intensity a lower voltage must be used to prevent glowing. The graphs of Fig. 7 show this. (The "lumen" is the unit of "luminous flux," which may be defined as the radiant power evaluated according to its visibility). The current sensitivities are graphed for three types of cells made by the Westinghouse E. & M. Co.

Type VA is a vacuum cell having a color-response approximating that of the human eye. Type VB is also a vacuum cell, but having about fifteen times the sensitivity of Type VA, but resembles the latter in that it gives constant output for steady light flux, over a wide range of cell voltages. The gas filled Type GB cell gives increased output up to a limit of about 90 volts. The graph at the right of Fig. 7 shows that the unwanted glow discharge occurs at a voltage which depends on the light flux.

Fig. 8 gives the response per unit energy of the three cells mentioned, with a comparison with the human eye. It will be noted that the GB cell has about five times the response of the VB cell, at the voltages used in taking the data, but that the color response of the two cells is identical.

Referring again to Fig. 7 we see the reason for the greater sensitivity of the gas filled cell. At about 30 volts on the horizontal scale, the VB cell has reached the saturation point for the steady

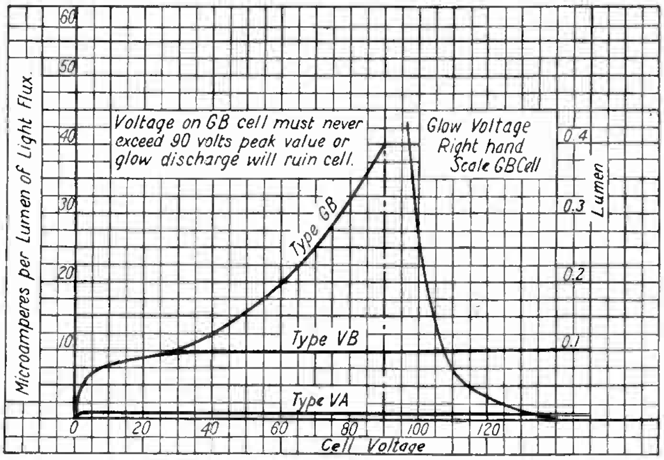

Fig. 7 - TYPICAL CURVES OF AVERAGE CELL OUT-PUT AS A FUNCTION OF APPLIED VOLTAGE AT A LIGHT FLUX OF ONE LUMEN.

light flux condition which determines the electron emission. In the GB cell, however, this voltage is about the point where ionization begins to take effect for that steady light flux, and the current per lumen increases rapidly as the voltage is increased.

In order to limit the cell voltage to a value below that at which glow discharge starts, it is customary to insert a resistor in series with the voltage supply. Its value is such that, as the cell cur-

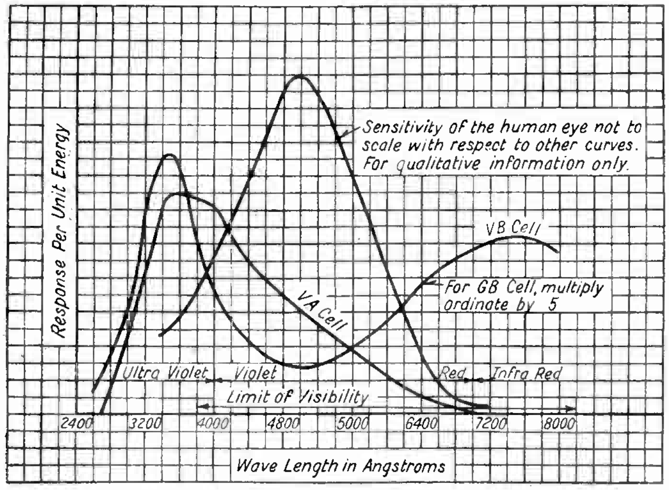

Fig. 8 - COLOR SENSITIVITY OF AVERAGE CELLS OF WESTINGHOUSE TYPES VA, VB AND GB.

rent increases too rapidly near the glow discharge point, the voltage drop across the series resistor will lower the voltage across the cell electrodes. This, of course, reduces the tendency toward a glow discharge. It has a certain disadvantage, in that the average voltage across the electrodes will depend upon the average illumination. What we would like to have is the use of a steady voltage on the electrodes, with the current varying directly as the luminous flux changes. With a resistor in series with the voltage supply, the electrode voltage is no longer constant as the current varies with change in luminous flux. Under this condition there is no longer a nearly linear relation between the illumination and the current, and a slight distortion results.

This disadvantage would not apply to a vacuum type of phototube which is operated above saturation, where a considerable change in electrode voltage makes no appreciable change in current. But then, there is no use in having a protective resistor in the circuit of vacuum phototubes, because the gas in them has been so considerably reduced that no glow discharge could take place except at very extraordinary voltages.

PHOTO-CONDUCTIVE CELLS

The earliest form of photoelectric cell used selenium, but up to very recent times the inherent sluggishness of response limited its usefulness to very few applications. A modern development which is manufactured by the Burgess Battery Company under the name "Radiovisor Bridge" makes use of a unique contact surface and the selenium is carefully treated by a special process. This overcomes much of the slow action of the selenium, and it is claimed to be responsive to variations in light up to a frequency of 10,000 cycles per second. The cell or bridge as it is called consists of two gold electrodes fused into glass. Each electrode is in the shape of a comb, and they are placed with their teeth interlocking, but not touching. The molten selenium is poured over these electrodes in a thin layer and then given a heat treatment to convert it into the chemical form in which it is most sensitive to light. The electrode assembly is then placed in a glass envelope from which air is removed.

The action of this type of cell must not be confused with the photo-emissive cell in which an electronic emission is proportionately caused by light. The property of selenium is such that its resistance to the flow of current is changed by light. The cell resistance decreases when exposed to light, causing more current to flow if the cell is connected across a sufficient voltage. The bridge may be used over a wide range of voltages (10 to 500), the principal difference being that more current flows as the voltage is increased. When dark the resistance is from 1 to 10 megohms. The "bridge" passes appreciably more current than the photo-emissive tubes previously described.

PHOTO-VOLTAIC CELLS

Several oxides of silver and of copper when immersed in solutions of sodium hydroxide become more electropositive when exposed to light. When an electrode having a crystalline cupric oxide surface is associated with an inert electrode of lead, the additional electrochemical potential caused by light makes itself evident as an internal electromotive force which is available for causing current to flow through some external circuit connected across the two electrodes.

The voltage developed in this cell is proportional to the luminous flux to which it is exposed. No external battery is required, which differentiates it from the photo-emissive and the photo-conductive types of cell.

APPLICATION OF PHOTOTUBES IN CIRCUITS

Potassium and caesium cells are very sensitive, but pass such small amount of current that they cannot be used for most commercial purposes unless their output is increased. Since the resistance from

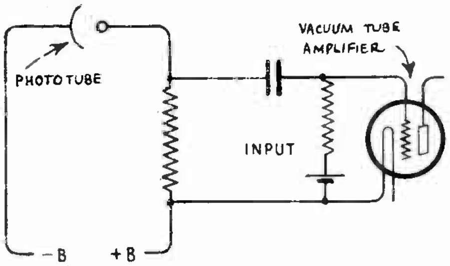

Fig. 9 - ONE METHOD OF COUPLING A PHOTOTUBE TO AN AMPLIFIER TUBE CIRCUIT.

anode to cathode is quite high they are known as high impedance cells. This brings about two requirements. If they are to be used for the production of alternating current of a wide range of frequencies, such as in Sound Pictures and Television, the input impedance of the following amplifier must match that of the phototube. As with any other high impedance circuit, it must be adequately protected by shielding from responding to stray electrostatic and electromagnetic fields which would otherwise introduce random voltages in the signal. These would appear as noise in Sound Pictures, and as flecks of light and shadow in the picture-effect reproduced at a remote Television receiver.

One method of coupling a phototube to an amplifier tube is shown in Fig. 9, where a high resistance is inserted in series with the volt-

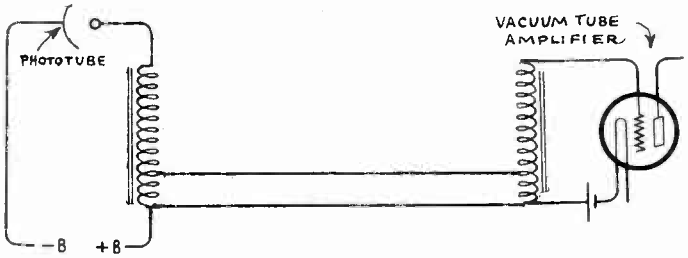

Fig. 10 - AUTOTRANSFORMERS ARE USED HERE TO STEP-DOWN AND STEP-UP THE VOLTAGE.

age supply. As the current changes through this resistor due to light variations on the phototube, the varying voltage-drop is applied to the input of the amplifier tube. This system makes it advisable that the first amplifier tube be placed close to the phototube, not only for noise prevention, but also to prevent the capacity of a long cable acting as a shunt at high frequencies.

These troubles are prevented, and convenience of construction improved, by the circuit of Fig. 10, using an autotransformer close to the phototube to step down the voltage. At the desired location of the first amplifier tube a similar autotransformer steps up the voltage which is applied to the grid of the tube. You will note that this satisfies our requirements because (1) the load on the phototube is a high impedance, (2) the input to the amplifier tube is a high impedance, and (3) the connecting circuit has a low impedance not subject to capacity or magnetic effects to any appreciable degree.

INDUSTRIAL USES OF PHOTOTUBES. The articles entitled "Illumination Control" and "Smoke Density" which follow were written by Messrs. W. R. G. Baker, A. S. FitzGerald and J. I. Cornell of the RCA Victor Company and Mr. C. F. Whitney of the General Electric Company, and are given here with illustrations through the courtesy of the publishers of "ELECTRONICS" in which they originally appeared.

Applications of the photocell in the industrial field are for the control of power through the medium of amplifying systems, thyratrons and relays of the light and heavy duty types and, for indicating smoke density, matching colors, counting articles and so on. These topics will be dealt with in the following pages. Thus many devices that were formerly controlled by hand or by clock-work are now controlled by the photocell. For generations light has been considered

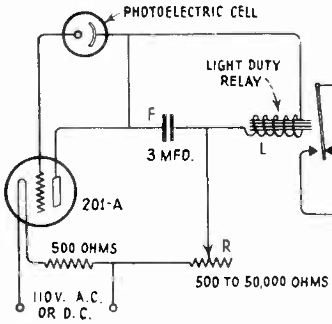

Fig. 11 - A RELAY CIRCUIT WITH PHOTOTUBE AND VACUUM TUBE AMPLIFIER.

only as "something to read by"; of late, however, engineers have begun to realize that beams of light can be put to work. The medium through which light serves for these uses is the surface of an electrode in the phototube which emits electrons under the stimulation of visible or invisible light, as previously explained. These electrons can be used to operate relays and thereby control power of any amount.

A photoelectric cell has the advantage over other devices of being able to operate in periods of unusual darkness during daylight hours which may be caused by a storm for example. Ordinarily during storms apparatus controlled by clock-work would not function. When photocells are used for the switching of incandescent lights used for lighting or for beacons, they are placed in a "window" which faces towards the north so that the direct rays of the sun will not damage the cell. Relays working in conjunction with the light sensitive device make contact when the light shining in the window is less than a certain amount. A typical light-duty relay circuit with photocell and vacuum tube amplifier is shown in Figure 11.

The general scheme for combining several light-duty relays to control many different circuits operated from one light sensitive cell is illustrated in Figure 12. Each relay operates at its own critical current and controls its own heavy duty relay and circuit, although the whole is energized by the same photoelectric cell.

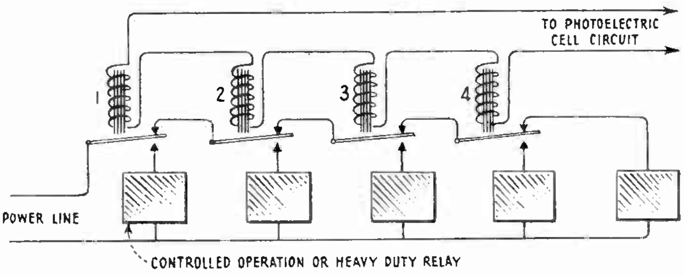

Fig. 12 - AN ARRANGEMENT FOR COMBINING SEVERAL LIGHT-DUTY RELAYS.

A magnetic counting device operated by a photocell is used in many factories at the present time to count the number of articles, such as packages, which pass through a conveyer at a certain point. Any object that is large enough to interrupt a beam of light will operate a photocell, and as a photocell is practically instantaneous in operation, almost any speed may be obtained.

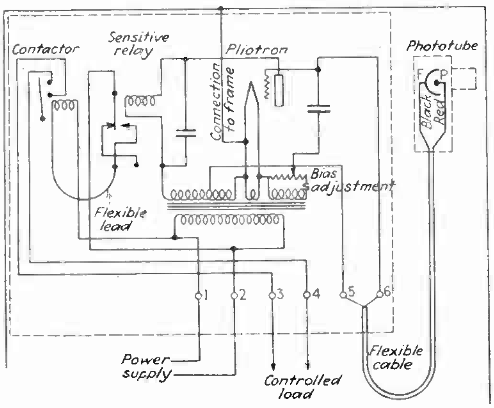

Fig. 13 - CIRCUIT CONNECTIONS OF A LIGHT-OPERATED RELAY.

ILLUMINATION CONTROL. For example, the circuit shown in Figure 13 combines a phototube and triode to form a light-operated relay. The pliotron grid is "biased" negatively by means of a potentiometer across the winding of a transformer and serves to keep the plate current at a low value insufficient to energize a small relay in the plate circuit. A phototube also connects to the grid and a winding of the transformer in such a manner that when light strikes the phototube the grid is made less negative increasing the plate current so that the plate relay is energized. Thus the relay is energized when light strikes the phototube and de-energized when the light is cut off. A contactor capable of controlling usual circuits is operated by the plate relay contacts. By means of normally closed and normally open contacts on the plate relay the contactor may be either energized or de-energized when the light strikes the phototube. The photograph of a commercial unit of this type, illustrated on the front cover, shows the phototube connected to an amplifier and relay unit by means of a flexible cable, thus allowing the phototube to be

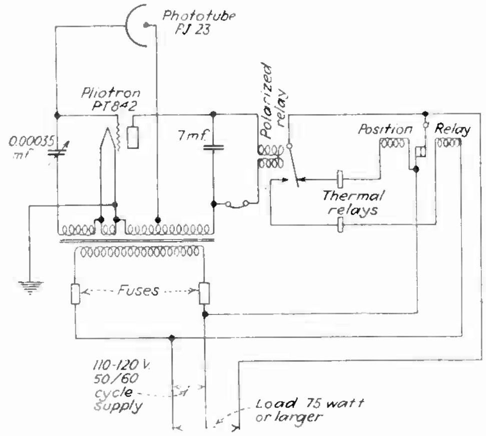

Fig. 14 - THIS CIRCUIT IS ESPECIALLY ADAPTED FOR CONTROL OF ARTIFICIAL ILLUMINATION IN ACCORDANCE WITH DAYLIGHT.

mounted in a variety of positions as required by the application. A modification of the circuit in Figure 13 is shown in Figure 14. Here a phototube and triode are similarly combined, but with special features. The negative bias of the triode is adjusted by means of a variable capacitor which facilitates the setting of the device for operation at a given light intensity. Small thermally operated time-delay relays are interposed between the plate relay and the position

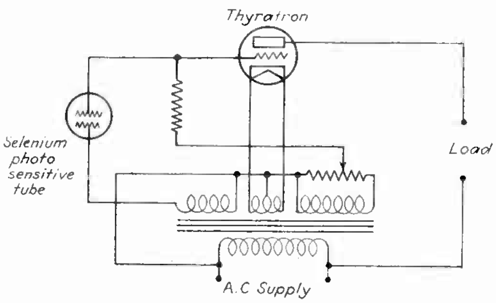

Fig. 15 - A MECHANICAL RELAY IS NOT REQUIRED IN THIS ILLUMINATION CONTROL CIRCUIT.

relay making it necessary for a given change of light to be maintained for several seconds before the position relay is operated. This circuit is particularly adapted for the control of artificial illumination in accordance with daylight. It has been used for street light and sign control. Such apparatus will automatically turn lights "on" and "off."

The circuit in Figure 15 combines a thyratron and a selenium photosensitive tube. It provides for illumination control by means of an "on" and "off" relay which is sensitive to light and capable of controlling a large contactor or load directly without the use of a sensitive mechanical relay. When no light falls on the selenium tube the thyratron has positive bias, but when the selenium tube is exposed to sufficient light, this bias is overcome and the thyratron ceases to pass current.

The practicability of the photoelectric cell for regulating traffic lights is being given serious consideration. The Westinghouse Elec-

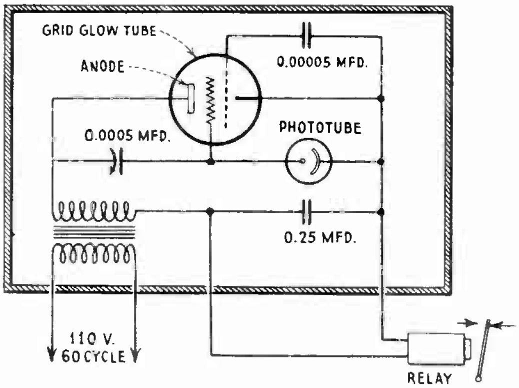

Fig. 16 - PHOTOTUBE SECTION OF A DEVICE WHICH CONTROLS TRAFFIC LIGHTS.

tric and Manufacturing Company has installed traffic lights operated by neon tubes on certain street corners for this purpose. It has long been felt that the stopping of traffic at regular time intervals

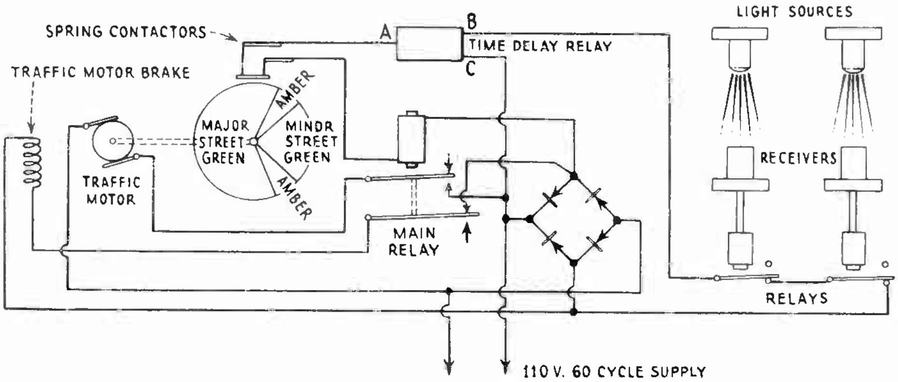

Fig. 17 - THE LIGHT AND RELAY MECHANISM OF A DEVICE USED FOR CONTROLLING TRAFFIC LIGHTS.

on main highways is wasteful of time as very often there are no cars waiting on the intersecting minor street to cross when the main thoroughfare light turns red. The ideal method would be to have a green light on the main thoroughfare at all times giving the right of way to the minor street only when it is needed.

The general arrangement of the phototube circuit and light and relay mechanism are shown respectively in Figures 16 and 17. The function depends primarily upon the interruption of a beam of light by an automobile or any vehicle which comes between the photocell and the light source. In order not to stop traffic on the main highway when cars make a right turn from the highway to the minor street a time delay relay is used which makes it necessary for a car to stop in front of the light beam for a few seconds before the traffic light will change color.

SMOKE DENSITY. Figure 18 shows a schematic diagram of a smoke density recorder which has been built in two units. One box contains a source of light giving a nearly parallel beam, a rectifier-filter system, a photoelectric tube measuring circuit, and a motor-rotated glass dust shield with a wiper to keep the lens system clean. A second box contains a pair of adjustable mirrors set to right angles together with another rotating glass shield with wiper. The shields with cleaning mechanism are important as the smoke to which the whole apparatus is

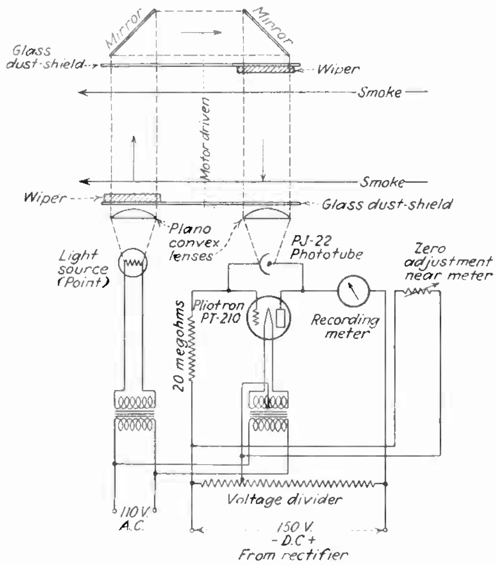

Fig. 18 - SCHEMATIC DIAGRAM OF A SMOKE DENSITY RECORDER.

exposed is heavily laden with carbon, oil, and gasoline fumes. In some cases the units were set about 80 feet apart giving a total beam length of 160 feet.

The system operates as follows: With no smoke interposed between the lens system and mirror system, a fixed amount of light reaches the photoelectric tube which keeps the grid positive with respect to the cathode allowing the plate current to assume a high value. When smoke is carried by the forced draft through the light beam the light is diffused depending upon the density of the smoke. The decreased light on the phototube causes the potential of the grid to become more negative and thus cause a decrease in plate current. This current is brought to the main supervisory control room and a graph is made on a recording milliammeter. A device also made by the Westinghouse Electric and Manufacturing Company for indicating the density of smoke makes use of a combination photocell and amplifier.

The unit is placed in a metal box and is mounted at the end of a small pipe, the end of which opens into one side of a chimney. On the other side of the chimney a lamp is placed so that its rays are directed toward the photocell at the end of the pipe. Thus the rays from the lamp first traverse the smoke in the chimney, then the small pipe, and finally reach the photocell where any change in the smoky medium through which the light rays pass will be recorded and amplified. The output of the amplifier tube is connected to a recorder upon which is kept an accurate record of the smoke density over a period of time. The color of flue gases in a chimney is indicative, to a certain extent, of the quality of combustion in the furnace.

When a chimney emits gases of a dark color it is usually an indication that the fire is poor. A similar device is used in the Holland Automobile Tunnel which connects New York City and Jersey City. The gas fumes given off by automobiles in this tunnel are measured so that the proper ventilation may be maintained to prevent injury to health.

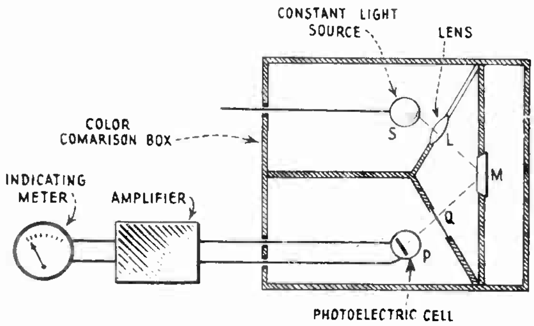

Fig. 19 - ILLUSTRATING THE GENERAL PLAN OF A PHOTOELECTRIC COMPARATOR FOR COLOR MATCHING.

PHOTOELECTRIC CELLS FOR MATCHING COLOR. The photocell may be used in various practical ways for the measurement of different qualities and intensities of light much more accurately than can be accomplished by the eye. This is particularly useful for matching colors.

Figure 19 shows in general how a phototube P, is connected through an amplifier to a meter to indicate any change in color at M. The meter is placed in the plate circuit of the amplifier to provide the indication. A constant source of light S is caused to pass through a lens L and is reflected from any material M whose color is to be compared with that of the standard color glass at Q. If the color of the substance at M is identical with that of the glass at Q no variation will be recorded by the photocell P, and therefore there will be no fluctuation of the indicating meter. The entire unit is made of a light proof material. Color filters may be used to match colors at various points in the spectrum. If, however, the color glass Q is omitted there will be an indication on the meter as the photocell responds to the particular color frequency to which it is sensitive.

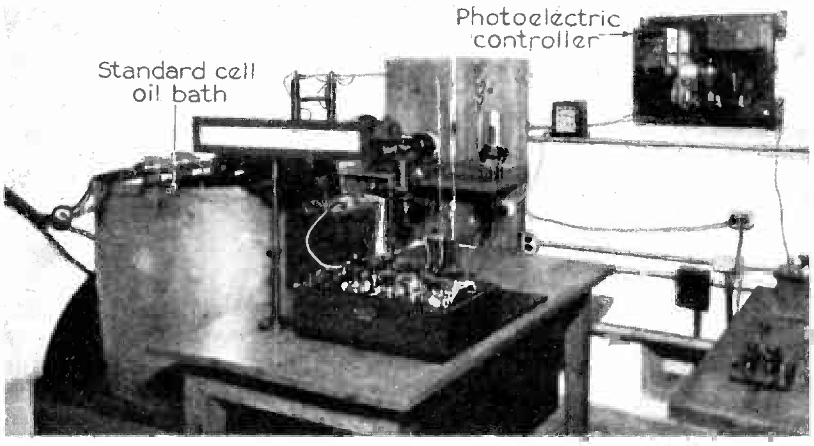

Fig. 20 - VIEW OF INSTALLATION USED FOR MAINTAINING CONSTANT TEMPERATURE.

A PRECISION PHOTOELECTRIC CONTROLLER

The rapid strides made in the design and efficiency of electron tubes in the last few years has produced many ultra-sensitive instruments

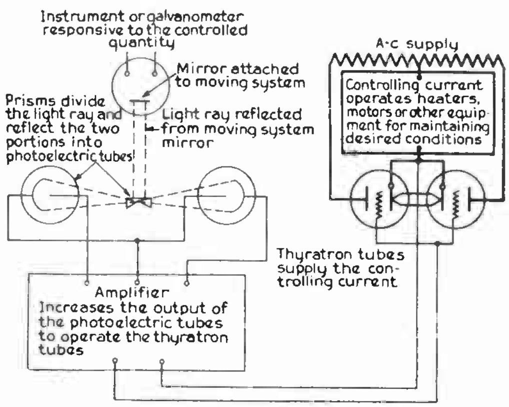

Fig. 21 - DIAGRAM OF CONNECTIONS FOR PHOTOELECTRIC CONTROLLER.

used in the measurement of both electrical and non-electrical quantities. One example is the photoelectric controller, shown in Figure 20, developed by the General Electric Co. for maintaining the standard cell oil bath at constant temperature: the oil bath is in the tank at the left. The schematic diagram of the controller is shown in Figure 21. In brief the equipment operates as follows: The basic instrument is connected across the balance points of a Wheatstone bridge consisting of copper and manganin resistance immersed in the oil bath. The bridge is adjusted to balance at 25° C. and will become unbalanced at other temperatures because of the difference in the temperature coefficient of opposite resistance arms. The illumination on the phototubes will become unbalanced when an unbalance in the bridge deflects the basic instrument. The unbalancing of the illumination on the phototubes sets up a potential which is amplified and applied to the grids of the thyratrons which in turn regulate the value of the heating current passing through resistors placed in the oil bath. The heating effect of the control current is continuously balanced against the cooling effect of water which circulates in the oil bath.

EXAMINATION QUESTIONS

1. What is the principal advantage of the caesium type phototube over the selenium cell?

2. What is the principal disadvantage of any phototube compared to the selenium cell?

3. What is the chief requirement of the load connected to a phototube?

4. What effect on the above is caused by a small capacity in shunt to the load?

5. Describe the structural form of phototubes most used in sound pictures.

6. (a) What is the advantage of a gas filled phototube over the vacuum type?
   (b) What is the disadvantage?

7. How may the gas filled phototube be protected?

8. Why does the photo-voltaic cell not require a battery?

9. Explain simply how a smoke density indicating device works.

10. Name two inventions in which a transfer is accomplished in opposite directions between radiant energy and electrons.

Courtesy General Electric Co.

A PHOTOELECTRIC TUBE OPERATES IN THIS COLOR COMPARATOR USED TO MATCH THE ROAST OF COFFEE BEANS.

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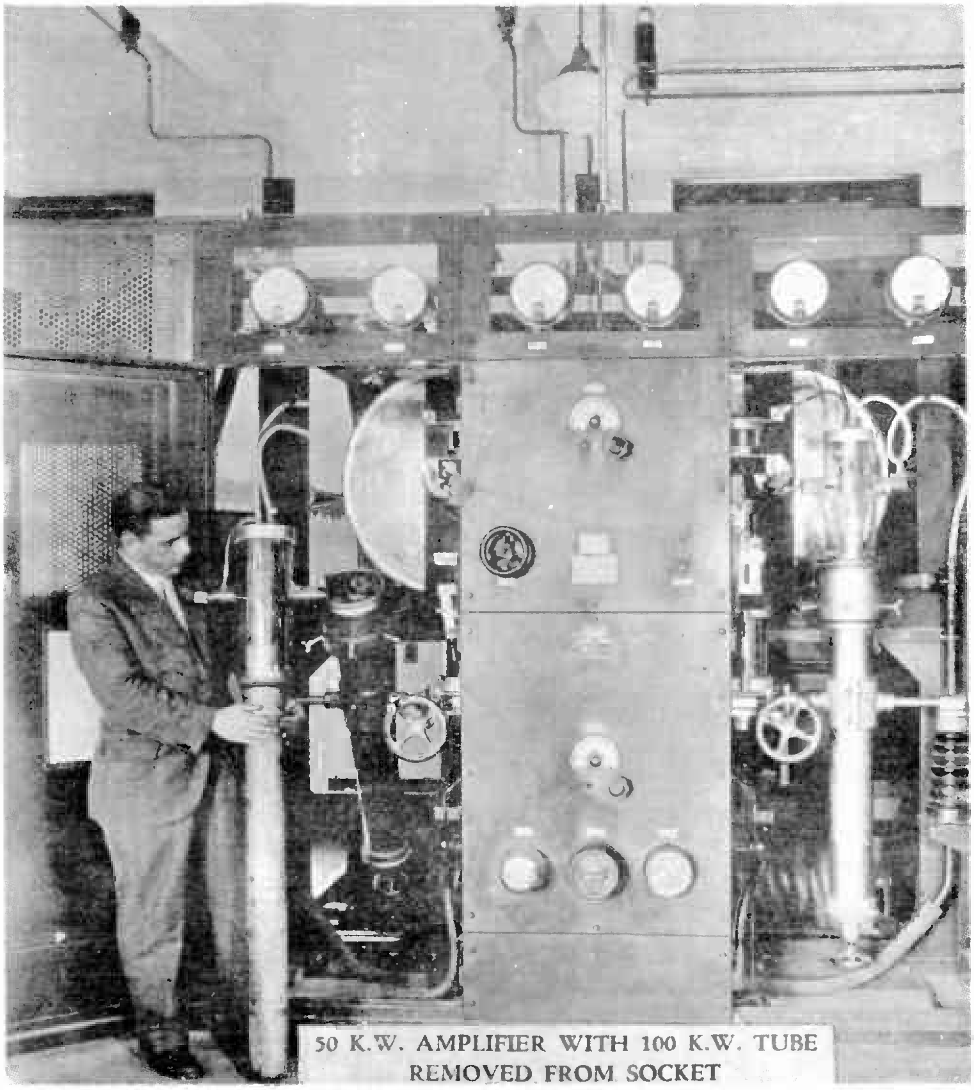

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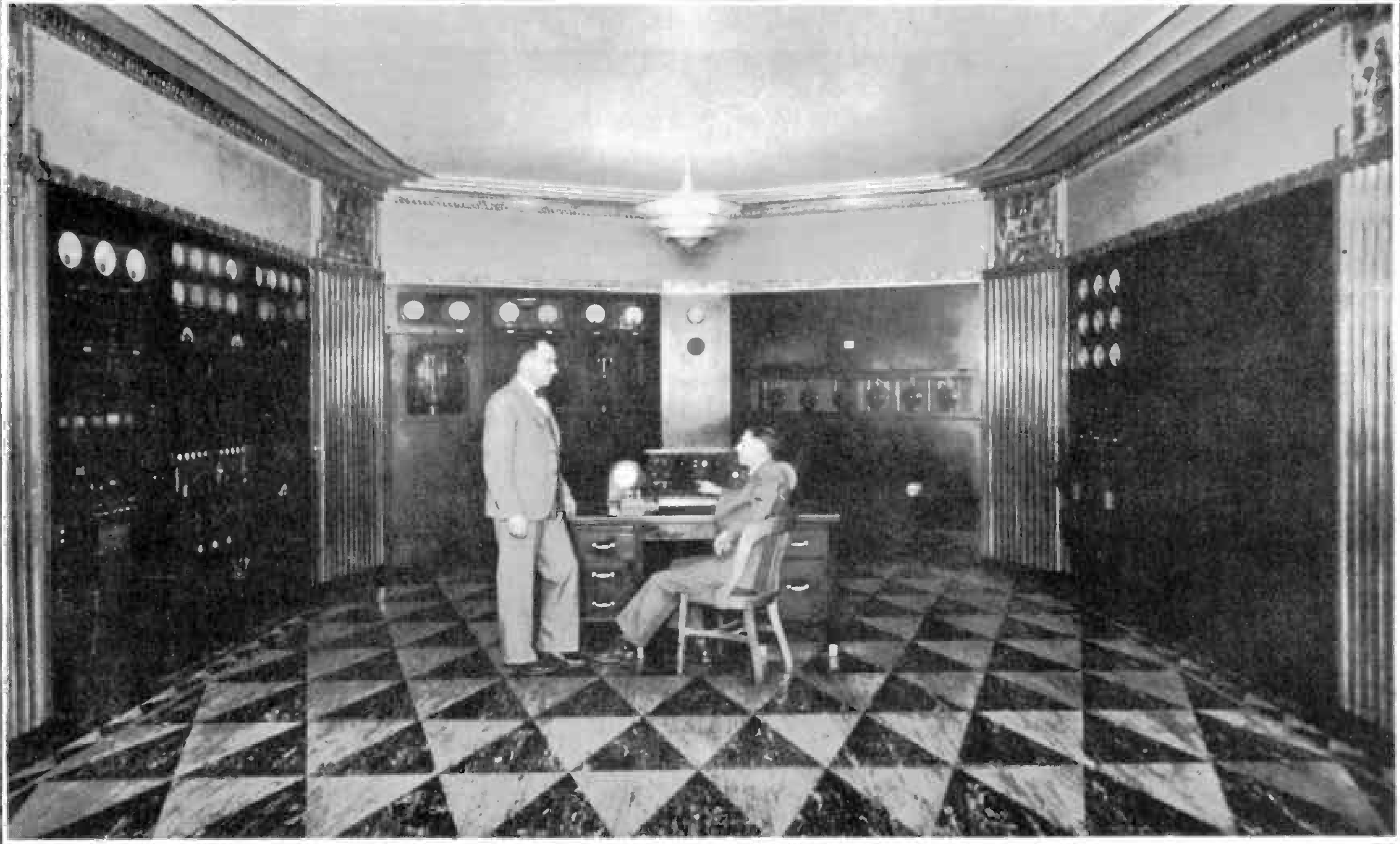
Vacuum Tubes Used in Transmitting

- Class A, B and C Amplifiers -

Dewey Classification R 130

VOL. 13, No. 6.



INTERIOR VIEW OF WEAF'S NEW BROADCASTING STATION LOCATED AT BELLMORE, LONG ISLAND.

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VACUUM TUBES USED IN TRANSMITTING
CLASS A, B AND C AMPLIFIERS

The development of power vacuum tubes has kept pace with the demands for a high percentage of efficiency in the operation of all equipment used in radio communication, both in the field of telegraphy and telephony. All power tubes are rated for their power output. In the following paragraphs we will treat on the various tubes from the smallest one which is accorded a place in the power class, the 7.5 watt type, upward and including the water-cooled type rated at 100 kilowatts.

Before dealing with any specific types we will review some important features regarding vacuum tubes in general and especially about power rating. The three circuits associated with the three-electrode tube are the filament, plate and grid.

During the normal operation of a tube the grid and plate become electrically charged bodies and since they are suspended within the glass envelope in a position surrounding and facing the filament both grid and plate necessarily exert their individual influences upon the electrons given off by the filament. Remember that any electron ejected by the filament is actually in clear free space and being a negative charged particle it is subject to the influence of any body with an electric charge upon it, for such bodies set up electrostatic lines of force between themselves and other bodies. It will be noted that the ends of the grid and plate circuits outside of the tube are always attached to some specified point along the filament circuit. These connections are called the grid and plate return leads, and represent the low voltage or low potential side of the vacuum tube circuit. Thus, in tracing out the complete continuity of either the grid or plate circuits, we would find that they embrace part of the filament. Consequently, the current flowing in either the grid or plate must complete its path through the filament and also through the vacuous space within the tube by virtue of the electrons. Considering the filament circuit alone it is easy to see that it is simply a conductive circuit or we may call it a closed metallic circuit through which the heating current flows.

The filament circuit includes, in general, a rheostat or fixed resistor to regulate the voltage at the filament terminals, and there is also the equipment necessary to provide the electromotive force. In many cases this source of e.m.f. consists of a storage battery or d-c generator, or if the filament is heated with alternating current the battery is replaced and the filament is attached to a low voltage coil on a power transformer. The filament, we may then say, is the electron emitting electrode and it is also known as the "cathode".

The plate circuit includes, in general, a high voltage source of supply which may be a "B" battery, or a d-c generator, or a rectifier device to supply plate voltage. The plate is the positively charged electrode in the tube and it is therefore called the "anode". We have mentioned heretofore that the plate functions to attract the emitted electrons and so, when the grid is excited with a fluctuating voltage, the electron flow is varied and thus the plate in our tube serves to supply a fluctuating or a pulsating direct current to operate any device inserted in the plate circuit. The device we refer to may take the form of an inductance, or transformer, or resistor. Such a device constitutes the "load" on the vacuum tube. Power is required to operate the load device in the plate circuit and hence the plate circuit is known as the "output" circuit.

Next we have the grid circuit which is known as the "input" circuit. The grid circuit is so named because the grid receives its excitation voltage from the currents flowing through this circuit which is always connected between grid and filament. The grid circuit consists of either tuning elements, an inductance and condenser for example, or simply the secondary winding of a transformer. In some circuits fixed condensers are inserted in series with the grid and resistors connect the grid to filament. These condensers should have the correct capacity because the input voltages, that is, excitation voltages, must be carried through them without opposition. Bear in mind that the grid is the controlling electrode, because when supplied with electric potentials (called the input voltages) it will act to regulate the quantity of electrons reaching the plate.

The whole action of any vacuum tube is dependent mainly upon the tiny electrons which are liberated or expelled by the hot filament. These electrons are attracted by the positively charged plate and make up and actually constitute the plate current. Thus, when a plate is maintained at a positive potential it will exert a continuous attraction for the electrons emerging from the hot filament.

The value of plate current necessary to insure the normal operation of a tube is governed by the quantity of electrons pulled to the plate. If we are called upon at any time to summarize briefly the various factors which control the amount of the electron energy reaching the plate we could state these factors as follows:

1. The value of the positive d-c voltage supplied to the plate.

2. The operating temperature of the filament.

3. The value of grid bias used and grid excitation voltage.

4. The degree of vacuum existing in the chamber within the glass envelope.

All three-electrode tubes function on the principle that when an alternating or fluctuating voltage is impressed upon the grid the amount of electrons passing through the vacuous space from filament to plate will be made to vary, thus the plate direct current fluctuates constantly and regularly between certain maximum and minimum limits, depending upon the frequencies and intensities of the voltages impressed upon the grid.

While we are relating facts which are more or less general in regard to our vacuum tubes, it may prove both interesting and instructive to point out the similar effects set up in a circuit by either a pulsating direct current or an alternating current.

Although a fluctuating or alternating voltage on the grid causes the plate current to vary in strength from its normal value to either greater or lesser values, yet it must be understood that this plate current can flow only in one direction. The conduction of electrons within the tube is in the direction only from filament to plate. Thus the plate current flow is unidirectional and it should be easy to understand, then, that it cannot be called a pure alternating current. However, we do call the instantaneous variations of the plate current the "a-c component". It can be shown that these variations do produce all of the effects of an alternating current; as, for instance, they set up a changing magnetic field surrounding a coil inserted in the plate circuit and produce a reactance voltage across or between the opposite ends of the coil. Moreover, by the use of a suitable coil (i.e., inductance) and a condenser the changing plate energy is capable of placing an electrostatic charge in the condenser and the latter then can be used to couple the plate circuit with some neighboring circuit. You will recall from your early studies that reactance voltage is the direct result of a coil's opposition voltage (or, as it is called "reactance voltage") which is set up by changing magnetic lines of force cutting back and forth through the same turns of wire which produced these magnetic lines. That is, the magnetic lines react back upon the turns which set up these lines. This effect produced upon a circuit by a coil when it carries a current which is constantly varying in strength is known as "self-induction". The voltage generated is known as the "induced voltage of self-induction".

Now let us consider some facts concerning the metal which is used in the manufacture of the filament wire. A tremendous amount of study and research has been going on steadily in the laboratories of tube manufacturers to find a metal or combination of metals which would give off an abundant supply of electrons for the least expenditure of heating current.

The three materials used to any great extent are tungsten, oxide coated platinum and X-L, or thoriated tungsten. Tungsten was the metal generally used before Dr. Irving Langmuir discovered that the rare metal, thorium, was especially rich in electronic energy. He showed that a thorium-coated tungsten filament heated to a temperature of 2,300 degrees Centigrade provided an electronic emission more than ten thousand times as great as a pure tungsten filament heated to the same temperature. Filament wire may be either coated with an oxide, or the wire is more often treated throughout with the rare material, thorium. So, with a comparatively low heating current, the modern power tube filament gives off a vastly greater supply of electrons than was formerly thought possible. While the fact that the X-L filament requires a much lower power to insure a proper operating temperature than would be the case if other materials of equal practical value were used, yet another quality that this special wire possesses is that the total electron emission for a given power consumption is comparatively long. Thus the expectance of tube life is prolonged many hours. It is agreed that the operating life of a vacuum tube is one of the most important features. Life expectations show up wide variations with respect to operative conditions and to some extent with individual tubes of similar type. These facts outline in general the essential requirements of the filament wire used in power vacuum tubes.

The manufacturer designs the filament of a tube to have the correct length and thickness using a certain material so that when a specified e.m.f. is impressed across the filament terminals the required current will flow and heat the wire to proper operating temperature.

The life of a thorium treated filament is naturally limited for the electron energy is obtained at the expense of the thorium. It is to be expected, then, that during operation of a transmitting set the filaments of the various tubes are constantly evaporating, or being used up, as it were. Electron energy driven off the surface of the wire is replaced by the diffusion of thorium down inside the wire. The thorium apparently boils out and while the actual amount of thorium lost at any given moment is very small to be sure, yet the filament will eventually lose its emission. That is to say, the useful life of the tube will end when the supply of thorium inside the filament is exhausted. Of course, the disintegration and evaporation of the thorium will be very rapid if the filament is operated at too high a temperature. Any power tube is likely to be subjected to a short overload, and in such events the X-I filament type has proven capable of withstanding three times its normal voltage without a burn-out.

Gases are given off by the plate when the tube is overloaded and under such conditions the tube will show considerable color. To reduce the possibility of a hot plate giving off gases during its normal life, the X-L filament type tubes are constructed with molybdenum plates which during the manufacturing process are heated to extremely high temperatures by means of a high-frequency furnace. That is, the eddy currents set up due to high-frequency induction tend to heat the metal parts. Other internal parts of the tube are also brought to high temperatures when the plate undergoes this treatment and thus all metallic parts are heated to a higher point than they ever reach during normal operation. Electron emission is usually lowered temporarily in the event of a severe plate overload, but this condition can often be rectified by the reactivation or rejuvenation process which is explained in the next paragraph. Reactivation cannot be resorted to if an air leak occurs in the tube. A purplish or pink glow can be taken as an indication that an air leak exists, whereas a distinctly blue glow would suggest gases had been released from the metal parts within the tube.

While the tube with a low emission is of no practical use it may still have its relatively inert tungsten wire intact and in this case the wire is capable of carrying sufficient current to heat and light up to its usual degree of incandescence. It is often possible to restore a tube in this condition to give additional hours of service by a very simple process called "rejuvenation." This process consists of forcing metallic thorium from the inner recesses of the filament wire to its surface by heating the wire to a temperature slightly above normal for about 15 minutes with the plate circuit open. Voltage must not be supplied to the plate during this operation. This re-activation of the filament should be carried on with the voltage about 15% above the normal as specified by the manufacturer, and in many instances we have given the exact limit for many types of power tubes in the discussions which are to follow.

CLASS "A", "B", AND "C" AMPLIFIERS

The power rating of vacuum tubes used in transmitting equipment is dependent upon the manner in which they are used. There are three different ways in which vacuum tubes are used in transmitting circuits. In discussing the operation of tubes in a transmitter, it would be necessary to state how each tube was being used. This would entail rather lengthy explanations were it not for the fact that to each method of using a tube a letter has been assigned. These letters are the first three of the alphabet; viz., Class A amplifier, Class B amplifier and Class C amplifier or oscillator.

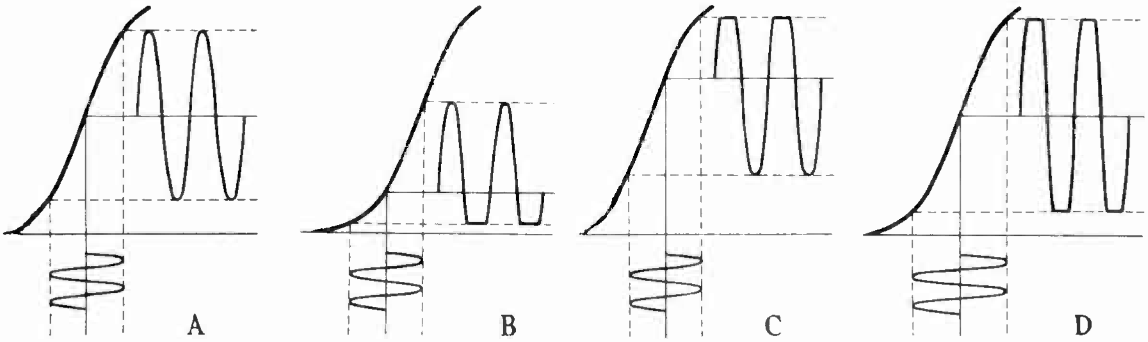


FIG. 1 - (A-B-C-D) CURVES USED TO EXPLAIN CLASS "A" AMPLIFIERS

CLASS "A" AMPLIFIER. The Class A amplifier may be defined as follows: The Class A amplifier is an amplifier which operates in such a manner that the complete output wave form is essentially the same as that of the excited grid voltage. The characteristics of a Class A amplifier are low efficiency and output with a large ratio of power amplification. This type of amplifier is used in most audio-frequency amplifier and modulator circuits.

It is the duty of a Class A amplifier to reproduce in its plate circuit a wave shape which is an exact replica of the wave shape of the impressed grid voltage. In order to accomplish this result it is necessary to operate the tube at that point on the grid voltage-plate current characteristic curve where the change in plate current is directly proportional to the change in grid voltage. In other words, to operate the tube that the entire plate current swing will take place over the straight line portion of the plate current curve. An example of such operation is shown in Figure 1-A. The effect of too high grid bias is shown in Figure 1-B; it will be noticed that in this case the tube operates on the lower curved portion of the characteristic curve introducing distortion.

Another type of distortion is shown in **Figure** 1-C; here the tube is operated with insufficient grid bias resulting in the grid going positive on the positive half of the grid excitation cycle with accompanying distortions.

Too high signal input voltage can also introduce distortion as shown in Figure 1-D. The operation of a tube is the same for a voltage amplifier as for a power amplifier when operating Class A, the only difference being the load in the plate circuit.

CLASS "B" AMPLIFIER. The Class B amplifier is defined as one so adjusted that the power output is proportioned to the square of the grid excitation voltage. This is accomplished by biasing the tube to

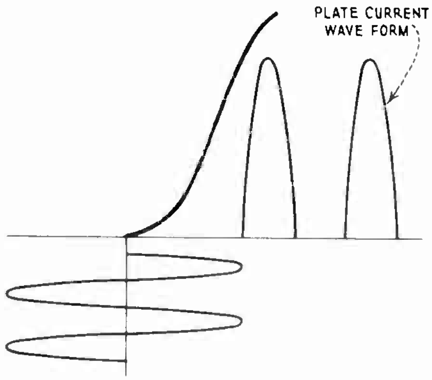


FIG. 2 - CLASS "B" AMPLIFIER CURVES

the cut-off point or nearly so. Plate current then flows only during the most positive half of the grid excitation cycle resulting in half-cycle loops of plate current, each loop representing one-half of the grid excitation cycle, see Fig. 2. During the remaining half of the grid voltage cycle no plate current flows. Since there is no flow of plate current, the plate of the tube is not called upon to dissipate energy. In other words, the tube actually works but one-half the time during the grid voltage cycle.

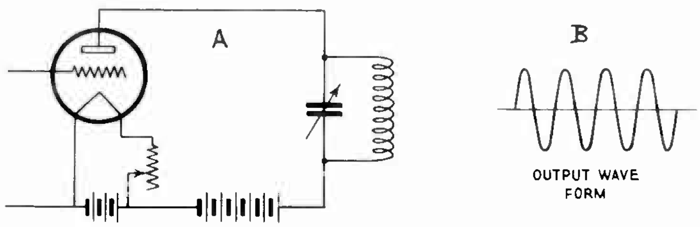


FIG. 3 - ACTION WHEN TUBE OUTPUT IS CONNECTED TO AN OSCILLATORY CIRCUIT

The operation of a tube under these conditions as an audio amplifier would be entirely out of the question as the condition shown in Figure 1-B would be accentuated since as an audio amplifier, the tube would have an aperiodic load in its plate circuit. The wave form of the current through the load would be the same as the tube plate current.

Consider now the circuit shown in Figure 3. The tube is connected in a circuit with an oscillatory circuit as the plate load. The half-wave pulsations of plate current will now be transformed into complete cycles or oscillations through the pendulum effect or fly wheel action of the oscillatory circuits, see Fig. 3-B. The amplitude of these oscillations will depend upon the amplitude of the plate circuit pulsations which in turn depend upon the value of the grid input voltage. It can, therefore, be said that the amplitude of the oscillatory current is proportional to the value of grid input voltage and since doubling the grid voltage would result in twice as much tank current the power output would be quadrupled (I^2R); hence, the definition previously given for the Class B amplifier. The power output of a tube working under Class B conditions is many times that of its Class A rating.

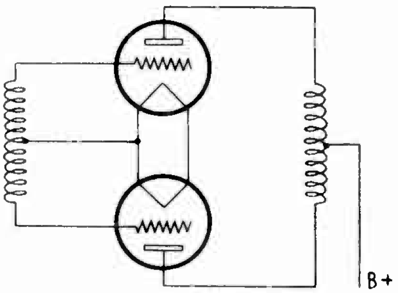


FIG. 4 - TWO TUBES WORKING AS CLASS "B" AMPLIFIERS

Thus far the Class B amplifier has only been considered from the standpoint of a radio-frequency amplifier. It is not restricted to this one use, however, since by special circuits it can also be used as an audio-frequency amplifier.

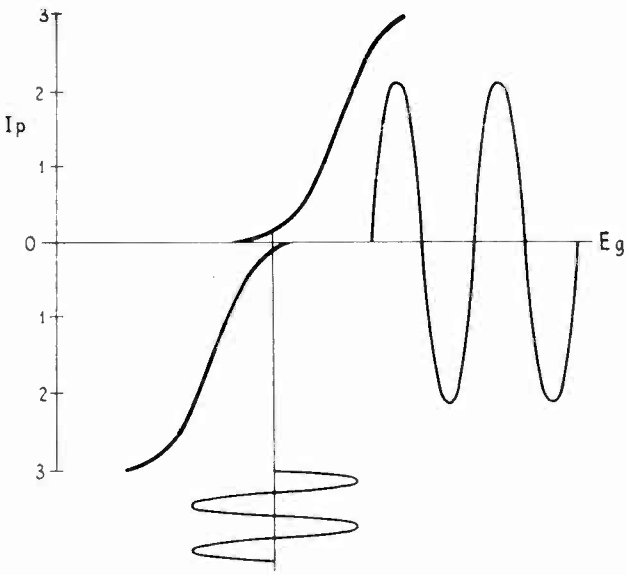


FIG. 5 - CHARACTERISTIC CURVES FOR TWO TUBES IN FIG. 4

Reference to Figure 2 shows that in a Class B amplifier plate current flows during one-half of the grid excitation cycle in the single ended (single tube) amplifier circuit. If a second tube be added and the circuit made as in Fig. 4, the characteristic curves for the two tubes will be as shown in Fig. 5. The curve for tube B is drawn bottom side up since it works on the opposite half of the grid excitation to that of tube A. The double ended Class B amplifier circuit utilizes the complete wave or both halves of the grid excitation cycle; this results in a plate output wave whose shape is a replica of the grid input wave. It should also be noted that the curves at the lower knee bend of the characteristics are opposite to each other and tend to give the effect of a straight line. This fact greatly aids in improving the wave shape in the output circuit. By connecting the two characteristics by a straight line one may think of a double ended Class B amplifier, as a single tube amplifier, Class A, whose characteristic is equal to the combined characteristics of the two tubes working Class B. Such circuits are gaining popularity, as audio output circuits in broadcast receivers, and are in general use to amplify radio-frequency signals after modulation in larger broadcast transmitters. One of the latest types of broadcast transmitters uses a Class B transformer-coupled plate modulator. The double ended Class B amplifier should not be confused with the more common push-pull amplifier. In the latter each tube is biased to work Class A and as the plate current increases in one tube a proportionate decrease takes place in the other and vice-versa; while in the Class B double ended circuit as the plate current increases in one tube no plate current flows in the other. It should also be noted that there is no plate current in either tube when no signal is applied to the grid. This also is contrary to the action of the Class A push-pull amplifier in which an equal amount of plate current flows in each plate circuit when no signal is being received. The efficiency of the Class B amplifier is 30 to 60 percent.

CLASS "C" AMPLIFIER. The Class C amplifier is a vacuum tube amplifier circuit so adjusted that the power output varies as the square of the applied plate voltage.

In order to accomplish this result in practical operation there usually is a biasing voltage applied equal to twice the value required to bring the plate current to the cut-off point.

A sufficient amplitude of grid excitation voltage is then applied to more than drive the plate current to saturation. Such operation gives loops of plate current during the most positive part of the grid excitation cycle.

An efficiency on the order of 60 to 80 percent is obtained under such conditions. Vacuum tubes are operated in this manner when used as oscillators and modulated amplifiers when plate modulation is employed as the output amplifier in radio telegraph equipments.

In Figure 6 is shown an E_gI_p characteristic with a bias equal to twice the cut-off value. From this figure it will be seen that the grid excitation voltage will have reached a certain amplitude on the positive half of the cycle before plate current starts to flow. It is, therefore, evident that this plate current flow exists for less than one-half cycle. The period then during which no plate current exists is greater than one-half cycle. Because of this long period during which the plate is not called upon to dissipate energy it is possible to operate the tube at much higher efficiencies than obtainable with any other type of amplifier.

It is, of course, impossible to utilize such an amplifier for audio-frequency work. When this type of amplifier is used as the modulated amplifier in radio telephone sets, it acts in much the same manner as a pure resistance.

For this use it is customary to vary the plate voltage, the tube responding by increasing or decreasing its plate current in direct proportion to the change in plate voltage. If the plate voltage is doubled the plate current doubles and since, in a resistance the power increases as the square of the current, there will be four

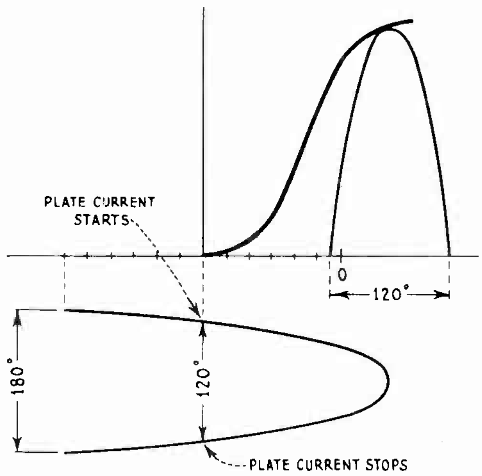


FIG. 6 - CURVES DEPICTING CLASS "C" AMPLIFIERS

times as much power or, in other words, in this type of amplifier the power output varies as the square of the applied plate voltage.

Although the alternating component of plate current may show a comparatively wide departure from sine wave form in such an amplifier, the output voltage will be practically sinusoidal.

HOW VACUUM TUBES USED IN POWER CIRCUITS ARE RATED

The power rating of vacuum tubes used in transmitting equipment is computed by the output energy of the device rather than by the input energy. A considerable part of the power delivered to the plate of a transmitting tube is wasted in heat. Transmitting tubes are used in the capacity of either an oscillator, amplifier, or modulator. A modulator tube is so named because of the specific duty which it is intended to perform, but nevertheless, it is a tube actually working with an amplifier characteristic. Hence, we can consider that transmitting tubes are divided into two general classes according to their function in a circuit; namely, "oscillator" and "amplifier." It should be noted that any type of tube may be used for either of these functions.

The power required to energize the plate of an amplifier or oscillator tube may be furnished by either a "B" battery, a direct-current generator or rectified a.c. depending upon the particular transmitting equipment. To those who study this work it is known that a vacuum tube associated with a circuit containing a suitable amount of inductance and capacity and designed to provide a feed-back of energy from the plate to grid circuits through either magnetic or capacitive coupling will be capable of generating self-sustained oscillations at a predetermined frequency. The tube used in a feed-back circuit is always known as an oscillator. The oscillations are known as continuous oscillations because they are consistent in frequency and their amplitudes are uniform in strength; such energy may be said to have a smooth-topped alternating current wave-form. It is readily seen that a line drawn through all of the amplitude peaks would be a straight line.

From the study of vacuum tube theory we learn how any voltage variation impressed upon the grid of a tube would be reflected in the plate current. Now, in a properly designed oscillator system when a radio-frequency voltage is applied to the grid the plate current continues to rise and fall in strength and, due to the feed-back action, the amplitudes of these plate changes cause further variations in grid voltage which result in corresponding variations in plate current, and so on. A slight change in plate current, as for example when a vacuum tube circuit is first placed in operation, should prove sufficient to set up the initial voltage impulse on the grid to start oscillations. In other words an oscillating current will be maintained so long as the feed-back power supplies grid voltage variations of sufficient amplitude to vary the plate current within limits which will again provide sufficient voltage in the grid circuit for grid excitation. Then in order to generate self-oscillations the amount of plate energy fed back to the grid must be more than that required to supply the losses in the grid circuit.

The point which we desire to set forth is that in any oscillating system there is always a certain amount of plate power dissipated in heat and also loss of power due to the setting up of a current flow in the grid circuit. This means that the actual power which a certain oscillator tube is capable of delivering, called its "output power", must be less than the power input of the plate. We could state this in another way by saying that a certain amount of energy is lost in any oscillatory system through the conversion of direct-current power into alternating-current power.

We must then have some means for determining the efficiency of a vacuum tube oscillator or power amplifier. The measure of the "efficiency" of our power tubes is merely a comparison between the actual power input in watts and the actual power output in watts and the expression of this value in percentage. It is well known that the efficiency of any device in percent is equal to the output divided by the input multiplied by 100. Efficiency expressed in terms of power (watts) may be written in the following way:

$$\frac{\text{WATTS OUTPUT}}{\text{WATTS INPUT}} \times 100 = \text{EFFICIENCY IN \%}$$

In Figure 7 we have the diagram of a vacuum tube radio-frequency oscillator circuit which can be used for transmitting purposes by coupling it to an antenna system in the manner shown. Other methods for keying a circuit of this kind than the one illustrated may be employed for telegraphy; for instance, keying may be accomplished by changing the grid bias from a high- to a low-operating bias. This is done to reduce the key clicks or thumps to a minimum, for when such sounds are reproduced they greatly interfere with the reception of the message. Our aim is merely to show one type of oscillatory circuit in which the plate circuit is directly coupled to the upper end

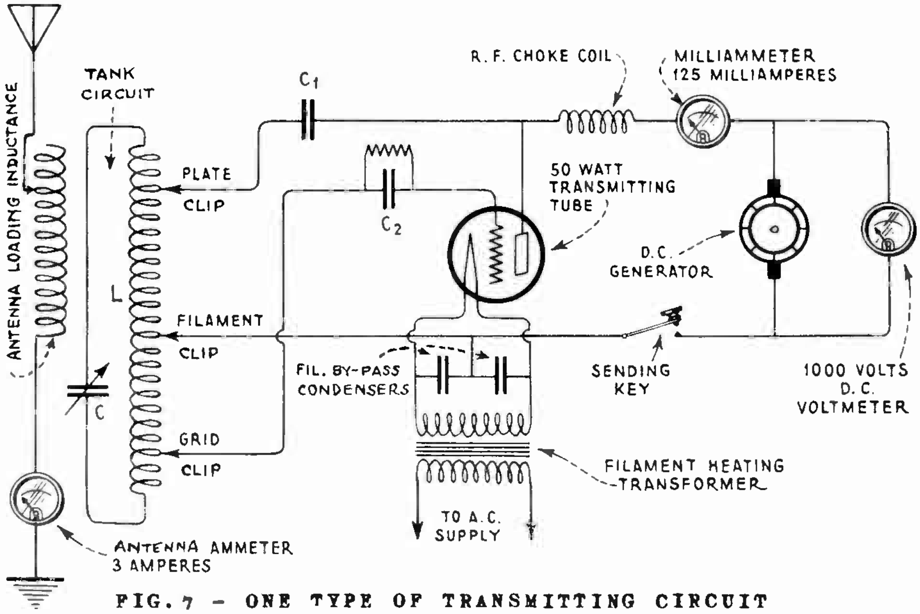


FIG. 7 - ONE TYPE OF TRANSMITTING CIRCUIT

of the oscillatory inductance L by a fixed condenser marked C1, whereas the grid is coupled directly to the lower end of L by the condenser marked C2. Although the frequency of the generated oscillations may be varied by adjusting condenser marked C, the frequency is dependent upon the combined values of L and C. Another

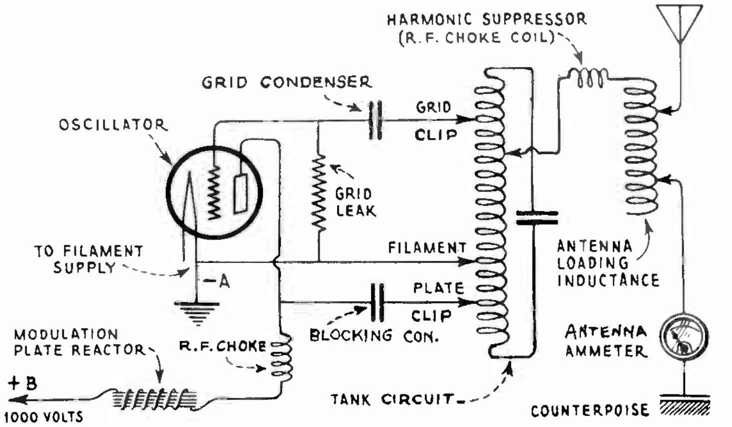


FIG. 8 - ANOTHER METHOD OF COUPLING THE OSCILLATOR OUTPUT TO AN ANTENNA

type of oscillatory circuit and vacuum tube driving an antenna system is shown in Figure 8, this circuit being part of a broadcasting transmitter. These simple circuits are given merely to suggest conventional types to assist in an understanding of the following explanation concerning efficiency and power rating of a power tube. Let us suppose that the power tube in either diagram is rated at

50 watts and, according to the electrical data chart of the manufacturer, the tube draws 125 milliamperes of plate current when the plate is operated with a positive potential of 1000 volts d.c. Then, the power in watts (W) in the plate circuit is equal to the voltage (E) times the current (I), or

$$W = E \times I$$

Note: 125 milliamperes = .125 amperes.

Then W = 1000 x .125; or WATTS INPUT = 125.

It is a simple matter to calculate the watts input. However, to compute the possible power output of this tube working into an antenna system, we find it necessary in our study to assign two arbitrary values; one for the amount of antenna current (I) which would ordinarily be indicated on the antenna ammeter, and the second for the resistance (R) of the antenna circuit. The output power in watts is conveniently expressed as follows:

$$\text{WATTS OUTPUT} = (\text{ANTENNA CURRENT})^2 \times (\text{RESISTANCE OF ANTENNA})$$

or, using the symbols: $\text{WATTS OUTPUT} = I^2 \times R$

Suppose the resistance of the antenna is known to be 10 ohms from previous experimentation, and the current as read on the antenna ammeter is 3 amperes while the 50 watt tube is active and delivering power in the form of an r-f (oscillating) current for antenna excitation. Then substituting these numerical values for the symbols I and E in the formula, we have:

$$\text{WATTS OUTPUT} = (3)^2 \times 10 = 9 \times 10\text{; or WATTS OUTPUT} = 90.$$

Setting down the output and input values in the efficiency formula and solving, we can conclude that the efficiency of this tube is equal to:

$$\frac{\text{WATTS OUTPUT}}{\text{WATTS INPUT}} \times 100 = \frac{90}{125} \times 100 = .72 \times 100 = 72\%$$

It is obvious that the actual power output of the tube itself cannot equal the power input of the plate circuit for reasons already cited. The power lost is equal to the difference between the watts input and the watts output or, in this case, the power lost is equal to 125 minus 90, or 35 watts.

The amount allowed for plate power dissipated in heat, etc., is known as "plate dissipation". This amount should not be exceeded during the normal operation of a tube and a definite limit is set, called the "safe plate dissipation". Since safe plate dissipation is really the power lost it is rated in watts. All power tube characteristics charts list the "safe plate dissipation" in watts for the various types of tubes, and it should now be understood what is meant by this term.

The 50 watt tube in our explanation has a safe plate dissipation of 100 watts. Thus, at 35 watts dissipation, it is being operated within safe limits. Any power tube worked at such a low efficiency as to permit the plate dissipation to exceed the safe limit would be subjected to considerable abuse and in a very short time its ability to supply electronic emission would cease, hence there is only one conclusion or result, the tube's useful life would be shortened.

The interior of the glass envelope of a power tube often takes on a milky white appearance, which condition may be attributed to operating the plate for long periods at an excessively high temperature. This smoky white color indicates that certain gases have been freed from the metal plate. A plate should never be heated to show more than a cherry red.

The heat energy dissipated by the plate of large power tubes, in the one kilowatt class and upward, is normally so high that water cooling is resorted to in order to obtain a satisfactory output of power. Water cooling increases the efficiency of a power tube because it permits the use of a much smaller plate area than would otherwise be possible. A smaller plate reduces the space charge between the electrodes of the tube. It should be noted that although current is required to heat the filament, that is, energy in watts is consumed, yet it is not taken into consideration in the foregoing work on power rating.

GRID CURRENT AND GRID BIAS

Let us now recount a few facts regarding the grid circuit and the current drawn therein. Only a small grid current should be permitted to flow, and let it be remembered that any current in excess of a certain amount cannot serve any useful purpose. In fact, excessive grid current must be subtracted from the current that would otherwise flow in the plate circuit inasmuch as both the grid and plate currents originate from electrons ejected by the hot filament. Thus it is possible for the grid to consume energy which is a total waste by the excessive flow of grid current. Under such conditions the grid acts as a load on the vacuum tube resulting in a reduction of its output power. Furthermore, a large grid current will introduce distortion in any vacuum tube. Distortion is particularly noticeable in tubes used in transmitting and receiving circuits which handle speech and musical frequencies, as in broadcasting. A large grid current would most likely heat the grid causing it to emit electrons, and if this condition were allowed to occur the grid would cease to be an efficient controlling factor in providing the proper variations in plate current. Bear in mind that the electrons absorbed by the grid flow as conduction current; that is, a direct current through the wires, coils, or resistors contained in the outside circuit connected between grid and filament.

From the foregoing it should be clear why a grid must be operated at some definite negative potential maintained upon it at all times. What really happens when a high fixed negative voltage is applied to the grid is that the grid is prevented from actually becoming positive even at such moments as when a positive voltage is applied to it from the currents circulating in the grid circuit. This is readily explained, for the actual voltage upon the grid at any moment is merely the difference between the value of the negative bias and the amplitude values of the fluctuating voltages delivered to the grid from the grid circuit as just mentioned.

Accordingly, the flow of grid current must be controlled and this is easily accomplished by maintaining a permanent negative voltage upon it as already suggested. The value of this negative voltage or grid bias varies for different types of tubes and depends for one thing upon the amount of plate voltage used. The correct grid bias may be supplied by any one of the following methods:

(1) The bias may be obtained from a "C" battery inserted in the grid return lead.
(2) The grid return wire may be attached to some location on a resistor which supplies the necessary drop in potential when the current flows through the resistor.
(3) The voltage drop obtained across a resistor inserted in the negative lead of the high voltage plate supply may be utilized for this purpose.
(4) A small d-c generator especially built for this purpose is often used to give the requisite bias. The majority of transmitters in radio broadcast work employ either one of the first two methods, whereas commercial telegraph transmitters are more likely to employ one of the latter two methods.

With no negative bias on the grid of a power tube the plate current can run up to exceedingly high values, dissipating so much heat that the plate will become whitehot and cause serious damage to the tube.

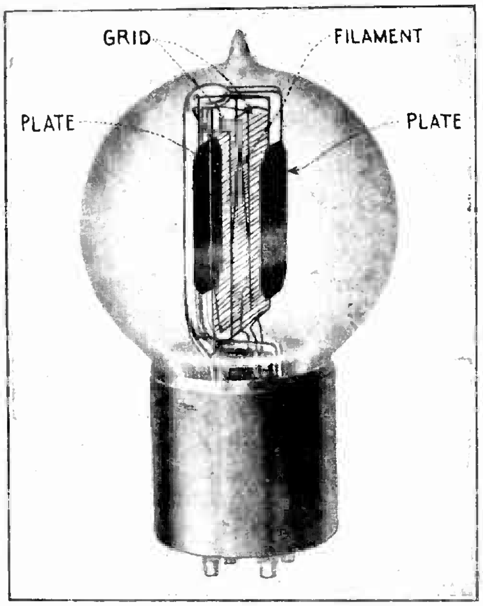


FIG. 9 — WESTERN ELECTRIC TYPE 205-D

7.5 WATT TUBES: { RCA-210, UX-841, UX-842, RCA-843, RCA-844 and RCA-865; WE-205-D and WE-271-A, DeFOREST TYPES 510 and 565.

The 7.5 watt tube is the smallest with a power rating. RCA-210 is particularly suited for transmitting circuits where cost and bulk of the apparatus and power supply are prime considerations. The RCA-210 tube is designed for use as an oscillator, modulator or power amplifier in transmitting equipment. The 7.5 watt tube is used in a large majority of amateur short-wave stations. It is known that under favorable conditions these tubes often supply sufficient antenna excitation to permit messages, carried by the radio waves, to be copied at the opposite ends of the world. These small tubes are also adaptable for use in low powered aeroplane transmitters and for speech amplifiers in broadcasting equipment. When working as a speech amplifier the tube merely functions to step up the necessarily feeble voice and musical frequencies in the output of the microphone to large values before introducing these frequencies into the main modulator-oscillator circuits. The object of amplifying the voice currents is to provide the maximum degree of modulation.

The Western Electric 205-D has similar characteristics except that a lower filament voltage is required. An outline of the 205-D is shown in Figure 9.

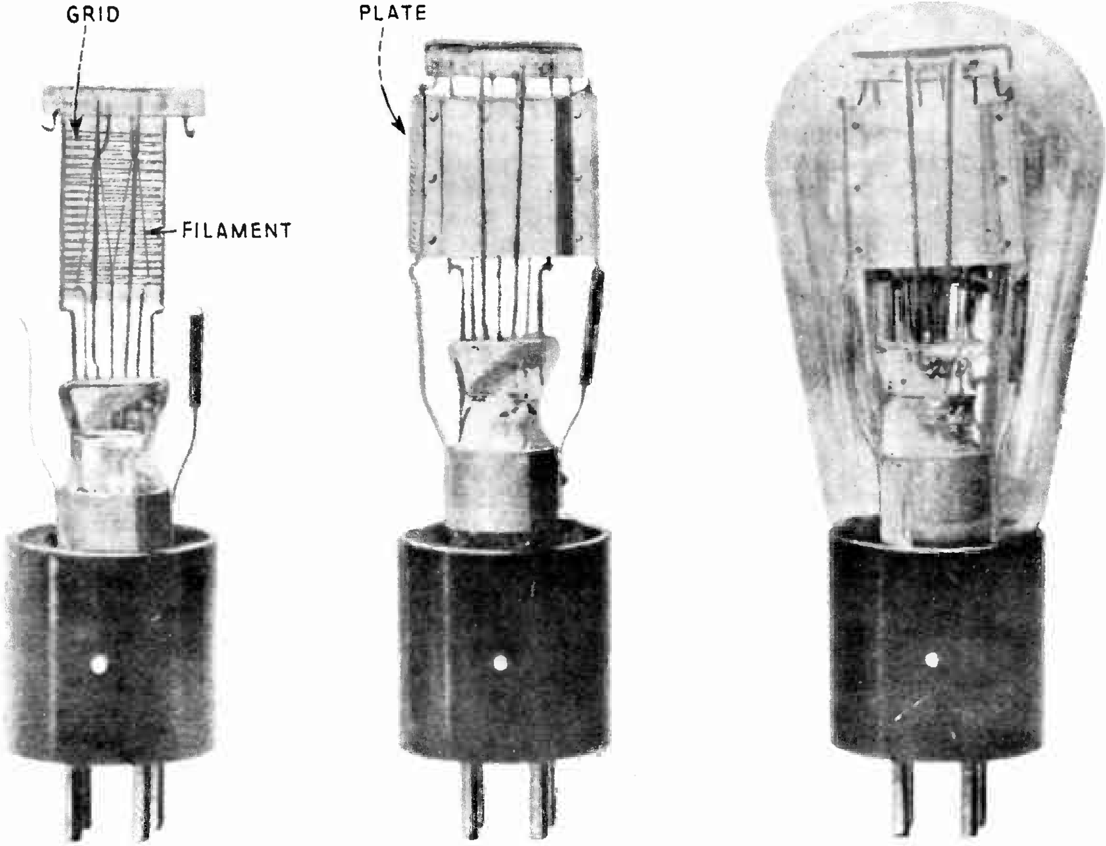


FIG. 10 - SHOWING GRID, PLATE AND FILAMENT OF UX-210 TUBE

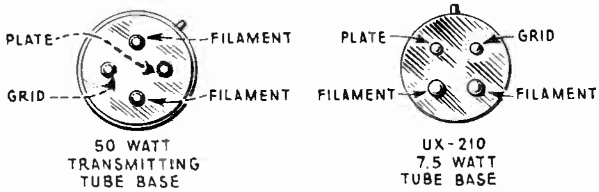


FIG. 11 - IDENTIFICATION OF PRONGS ON TUBE BASES

The views in Figure 10 show the complete tube assembly of the 210, also the grid, filament and plate construction. A sketch in Figure 11, looking at the bottom of the tube base, shows the location of the prongs. The metal shell of the socket must not be connected to ground or any other part of the circuit.

The normal output power of the RCA-210 is rated at 7.5 watts. The filament draws 1.25 amperes when operated at a filament terminal e.m.f. of 7.5 volts. Care should be exercised to operate filaments at constant voltage rather than constant current and always at the rated voltage. A filament voltmeter connected directly to the socket terminals should be used to indicate correct working conditions. It will be noticed that, due to the use of the X-L filament, its brilliancy is much less than that of the older type tungsten filament. A low emission tube caused by a severe overload and consequent overheating may be restored in some cases by operating the filament at its rated voltage with the plate voltage removed. This reactivation process can be accelerated by increasing the filament voltage to 9 volts, but not to exceed this value.

When possible, alternating current should be used to heat the filament, but in certain cases direct current is required, as in radio telephone sets(because of hum)and portable sets for portability of power supply. By using the RCA-843 type of tube, however, a-c filament supply may be used and hum level kept at a very low value. The RCA-843 is the same as a UX-210 except that it has a heater type of cathode requiring 2.5 amperes at 2.5 volts for its operation. The a.c. is, in most all cases, supplied through a step-down transformer and to provide voltage control a rheostat should be included in the primary circuit of the transformer. With a.c. the plate return lead should be connected to the mid-tap of the transformer secondary, whereas with the use of d.c. this plate lead is attached to the positive filament terminal.

Under normal conditions the plate voltage should never be more than 350 volts, the rated value, and with this plate e.m.f. a plate current of 50 or 60 milliamperes may be expected. The plate power dissipation should never be greater than 15 watts. When this tube is used in a non-modulated c.w. telegraph set (usually called straight c.w.) the plate voltage may be raised to 450 volts in order to obtain extreme output.

The amplification constant of the RCA-210 is approximately 7.5 and the mutual conductance value about 2,150 micromhos. Should a tube be required, however, having a higher amplification constant, but retaining the other essential characteristics of the RCA-210, a type UX-841 may be employed which has an amplification constant of 30 and a mutual conductance of 450 to 750 micromhos depending on plate voltage used. This tube is of especial value as a voltage amplifier utilizing resistance coupling and also as a frequency doubler. Let us mention at this time that mutual conductance values are useful for comparison purposes only since the values are computed with the tube operating under zero grid voltage conditions. This does not represent the usual operating condition for we know that in all practical circuits the grid voltage is maintained at some definite negative value and not at zero.

When used as an audio power amplifier or a modulator the value of the negative bias used should be sufficient to limit the plate dissipation, that is, the difference between output and input, to its normal value or 15 watts. For this service, however, it is desirable to use a tube having a lower amplification constant and a higher power output than the RCA-210. It is here that the UX-842 finds a place. This tube has an amplification constant of 3 and an output as a Class A amplifier of 3 watts. While the RCA-210 has an output Class A rating of only 1.6 watts, the UX-842 otherwise has the same operating characteristics as the RCA-210. No less than 15 volts negative should be applied to the grid of the RCA-210 tube with a plate potential of 350 volts. When calibrating a transmitting circuit it will be noticed that with certain adjustments the plate current is greater than the normal amount although the correct grid bias voltage is used. This effect may be traced to an amplifier tube which is oscillating or perhaps a radio-frequency voltage is being picked up from neighboring circuits. This condition is aggravated by the use of a grid leak having an inductive effect in the circuit. A grid leak should be non-inductive, or in other words, its effect should be that of only pure resistance.

It is advisable to insert either a small choke, or a resistance of 10 to 100 ohms, in the grid circuit of each tube when several are operated in multiple in order to prevent the setting up of ultra high-frequency oscillations.

We mentioned previously that the UX-842 is particularly suited for use in conjunction with loudspeakers in receiving circuits. When the 210 is employed in this connection the tube is called a "power audio amplifier" and is capable of delivering a tremendous output without distortion. The characteristic grid voltage-plate current curve of this tube is shown in **Figure 12**. The so-called "straight part" of this curve indicates that the tube is a typical amplifier, for it is easily seen that the slope of the curve follows almost a straight or linear line.

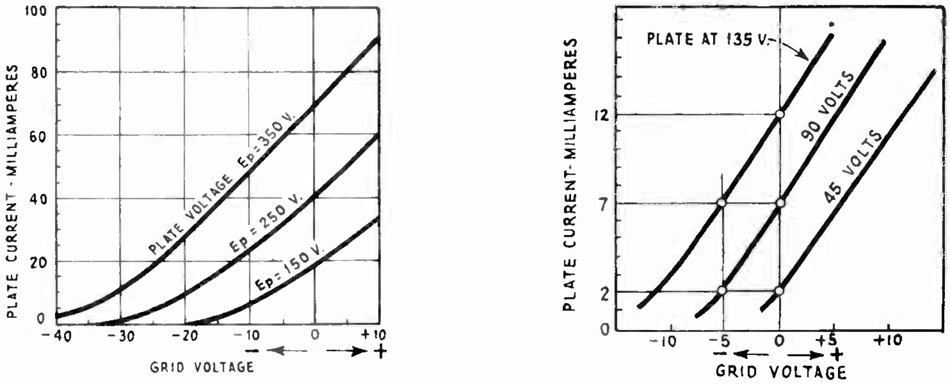


FIG. 12 - CHARACTERISTIC CURVES OF A UX-210

It should be remembered that an efficient amplifier tube provides a greatly enlarged plate current whose pulsations follow in exact accordance and repeat the wave form or modulation frequency of the signal voltages impressed upon the grid. Also, you should fully understand at this part in our course that the only function which the grid is called upon to perform is that of a control member. Any fluctuating voltage, however small, applied to it from any source will cause the electron stream passing from filament to plate (i.e., the plate current) to undergo a corresponding variation. Stated in a few words, this means amplification without distortion. Because of this inherent grid control upon the electron stream we think of the vacuum tube as essentially a voltage operated device.

The straight line variation, as shown by the curves, indicates that the UX-210 can be worked at high or low plate voltages and, with correct grid bias, will deliver the voice and musical frequencies to the loudspeaker with the naturalness of the original rendition in the broadcasting studio. Undistorted amplification is possible in vacuum tubes possessing such characteristics because large grid voltage swings can be delivered to the grid without it actually becoming positive with respect to the filament. A positive grid would attract excessive electron energy causing a large grid current and as we are already aware this undesirable condition would introduce distortion. The grid return lead of the UX-842 when used as an output audio amplifier should be connected to the negative terminal of the "C" battery. The positive terminal post of the "C" battery should be connected to the negative terminal of the filament.

As mentioned heretofore, low power tubes are used extensively in shortwave transmitters. Conservative plate voltages and power inputs should always be maintained in order to be certain that the tube will not be harmed by excessive voltages, currents, or dissipation within the tube. Abnormal conditions are usually experienced at wavelengths less than 50 meters.

The inter-electrode capacity between grid and plate of the tube provides a path of low reactance for currents of high-frequency, or at the short wavelengths. These currents have damaging effects. At long wavelengths, or low frequencies, the capacity reactances are so high that these currents are negligible. For wavelength adjustments below 10 meters great care should be exercised to prevent brush discharges in any part of the tube which are likely to cause breakdown and puncture of the tube. In order to prevent trouble of this kind it is a good rule to reduce plate voltage as the wavelength is reduced. Difficulties in operation of the 3-element 7.5 watt tube on the shorter wavelengths can be easily overcome, however, by the use of 4-element tubes RCA-844 and RCA-865. The difference between these two being that the 844 is provided with a cathode-heater type of filament.

The RCA-865 tube is especially designed for use as a power amplifier in transmitting circuits of the high radio-frequency or short-wave type. The high-frequency transmitters send out continuous wave (c.w.) telegraph signals which cover wavelength ranges as low as 15 to 50 meters, or 20,000 to 6,000 kilocycles. This frequency band may also be expressed as from 20 to 6 megacycles. One megacycle is equal to one million cycles.

This 7.5 watt tube has a plate, filament and two grids, whereas the standard three-element tube has a plate, filament and only one grid. The addition of the extra grid, called the screen or shield grid, minimizes the effects of inter-electrode capacity, that is, it prevents the so-called feed-back from plate to grid. This stabilizes the circuit in which the tube is used. Whistles, howls and other desirable effects are eliminated by the addition of the fourth element.

The theory of operation is that the control grid (the regular grid located adjacent to the filament which is found in all standard tubes) is impressed with the excitation voltages in the manner similar to that for operating any tube, but the screen grid is maintained at a neutral potential with respect to the other electrodes by suitable connection to a source of e.m.f.

The voltage for the screen grid may be obtained either from a potentiometer connected across the plate supply, from the d-c plate supply through a series resistance of approximately 25,000 ohms, or from a separate d-c source. The resistance method, using about 25,000 ohms is the most practical method for maintaining the screen grid voltage at proper value because it provides automatic regulation. When employing the resistance method, the filament supply should not be discontinued for any reason while the plate voltage is on, for this would cause the full plate voltage to be applied to the screen. When the potentiometer method, or separate source method is used the screen grid voltage should not be applied when the plate voltage is off. Under operating conditions the screen grid should never be permitted to reach a temperature which would cause it to show a color more than that of cherry red. When the screen grid is supplied with a suitable positive voltage it acts as an electrostatic screen between the control grid and the plate of the tube. The normal screen grid volts for this tube when operating either as an oscillator or r-f power amplifier is 125 volts. The need for neutralizing the radio-frequency circuits is eliminated by the use of this tube as we have just stated. A photograph of the UX-865 is shown in Figure 13. The UX-865 requires 2 amperes at 7.5 volts for the filament and 500 volts d.c. for the plate. This tube may be employed as a frequency "doubler" and intermediate power amplifier in short-wave commercial transmitters. When used for this purpose the tube's output is fed into a main power amplifier circuit which may also use tubes of the four-element type, but having a greater output power. Tubes especially designed for handling large power at high frequencies are the UV-850, UV-852, UV-860, and UV-861.

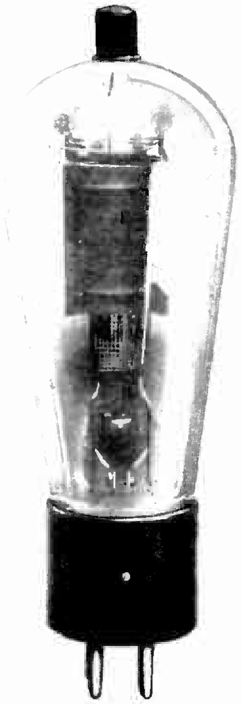


FIG. 13 TYPE UX-865

EXAMINATION QUESTIONS

1. Name as many factors as possible which govern the amount of current drawn in the plate circuit of a vacuum tube.
2. What is meant by "safe plate dissipation"?
3. (a) How is a power tube rated?
   (b) Write the formula for efficiency in terms of watts.
   (c) Suppose the output of a tube is 69 watts and the input 115 watts. Find the efficiency of this tube in percent.
4. What material is generally used for filament wire in power tubes?
5. (a) State as many reasons as you can that make the reactivation of a tube necessary.
   (b) In general, what method of procedure would you conform to in order to reactivate a tube?
6. (a) Why should amount of grid current in a power tube be controlled?
   (b) State several ways how this may be accomplished.
7. (a) How are ultra-high frequencies suppressed in coupled circuits consisting of two or more power tubes?
   (b) Of what practical importance is the four-element tube?
   (c) What is the fourth element and in a general way what is its effect within the tube?
8. Define class A, class B and class C amplifiers.
9. Why cannot single tube class B amplifiers be used in a-f amplification?
10. What is the advantage of screen-grid tubes?

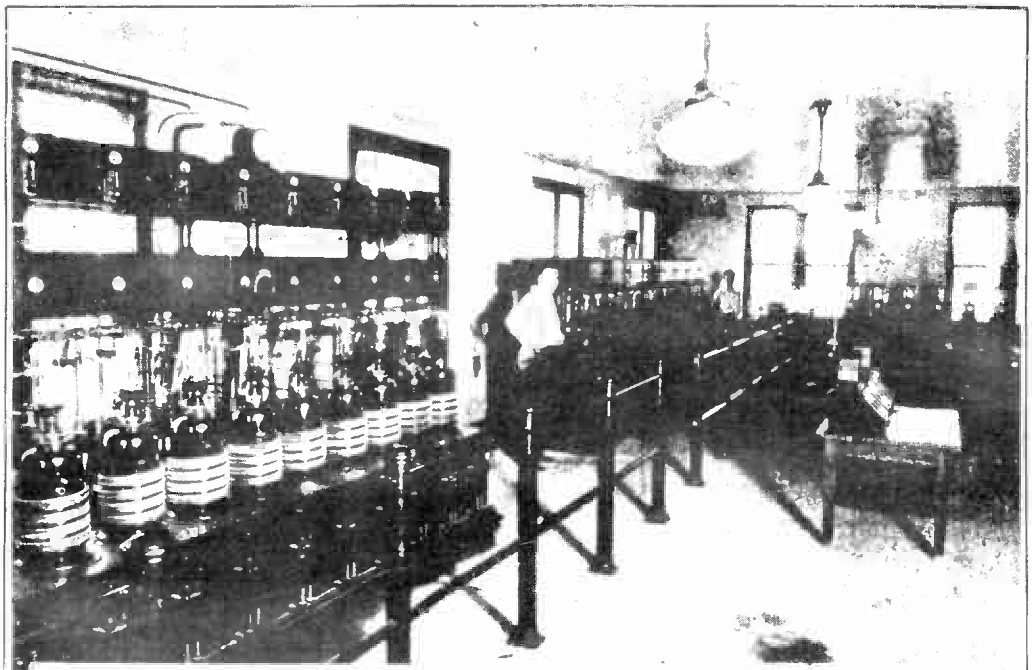
TRANSMITTING VACUUM TUBE CHARACTERISTIC CHART

GENERAL INFORMATION										CLASS "A" AMPLIFIER OR MODULATOR							
Type	Filament Volts	Filament Amperes	No. of Electrodes	Average Voltage Amplification Factor	Average Plate Resistance Ohms	Average Mutual Conductance M. Mhos.	Type of Base	Type of Filament	Type of Cooling	Maximum Plate Volts	Maximum Plate Watt Dissipation	Grid Bias (Eg) Negative Volts	Plate Milliamperes	Oscillator Input Watts per Mod. Tube	Peak Grid Swing - Volts	Power Output 5% 2nd Harmonic	Load Resistance
RCA 210	7.5	1.25	3	8	5150	1550	UX	XL	Air	425	12	35	18.0	4	31	1.6	10200
RCA 841	7.5	1.25	3	30	40000	750	UX	XL	Air	425	12	9	2.2		9	(225 volts)	250000
RCA 842	7.5	1.25	3		2500	1200	UX	XL	Air	425	12	100	28.0	8	96	3.0	8000
RCA 843	2.5	2.5	3		5150	1550	UY	Cathode Heater	Air	425	12	35	18.0	4	31	3.0	10200
RCA 844	2.5	2.5	4	74	125000	600	UY	Cathode Heater	Air								
RCA 865	7.5	2.0	4	150	200000	750		XL	Air								
WE 205D	4 to 5	1.60	3	200 to 300	3000 to 4500		100-M or 115-B		Air	300		10 to 20	15 to 30				
WE 205E	4 to 5	1.60	3	200 to 300	3000 to 4500		100-M or 115-B		Air	350		10 to 30	15 to 30				
WE 271A	5.0	2.0	3	8.5	2850		134-A or 137-A	Cathode Heater	Air	400		25 to 30	39.0				
WE 252A	5.0	2.0	3	5.0	1700		130-B or 131-A		Air	450		65	43.0				
RCA 203A	10.0	3.25	3	25.0	6000	4200		XL	Air								
RCA 211	10.0	3.25	3	12.0	3400	3530		XL	Air	1000	75	52	.072	40	52	10.0	7000
RCA 845	10.0	3.25	3	5.0	1800	3000		XL	Air	1000	75	147	0.075	122	147	23.0	7500
RCA 850	10.0	3.25	4	550	200000	1250		XL	Air								
RCA 852	10.0	3.25	3	12	10000	1200	UX	XL	Air								
RCA 860	10.0	3.25	4	200	180000	1100	UX	XL	Air								
WE 211D	10.0	3.0		11 to 13	3000 to 4000		112-A	Oxide Coated	Air	750 to 1000	100	50 to 60	.005				
WE 242A	10.0	3.25		12.5	3500		112-A	Oxide Coated	Air	1250	100	45	0.150				
WE 276A	10.0	3.0		12	3500		112-A	Oxide Coated	Air	1250	100	50	0.125				
WE 212D	14.0	6.003		15 to 17	2000		113-A	Oxide Coated	Air	2000		30 to 80	.130		55		
RCA 204A	11.0	3.85	3	25	6300	4000		XL									
WE 270A	10.0	9.75		16	1750	9000		Oxide Coated									
RCA 849	11.0	5.0	3	19	3200	6000		XL	Air	3000	300	104	0.110	410	98	81	12000
RCA 861	11.0	10.0	4	300	143000	2100	UX	XL	Air								
WE 251A	10.0	16.0		10.3	2250	4550		Oxide Coated									
RCA 851	11.0	15.5	3	20.0	1400	15000	UV	XL	Air	2000	600	65	0.300	400	60	100	3100
WE 279A	10.0	21.0		10.0	1800	5550	142-A	Oxide Coated	Air								
RCA 1652	14.5	52.0	3	14.0	3000	47000		Tungsten	Water								
RCA 207	22.0	52.0	3	20.0	3500	5700		Tungsten	Water								
RCA 848	22.0	52.0	3	8.0	2400	3300		Tungsten	Water	10000	7500	1040	0.65	7800	1025		
RCA 863	22.0	52.0	3	50.0	7200	7000		Tungsten	Water								
RCA 858	22.0	52.0	3	42.0	8700	4800		Tungsten	Water								
WE 232A	20.0	61.0		40.0	7000	5700	132-A or 133-A	Oxide Coated	Water								
RCA 862	33.0	207.0	3	43.0	2800	17150		Tungsten	Water								

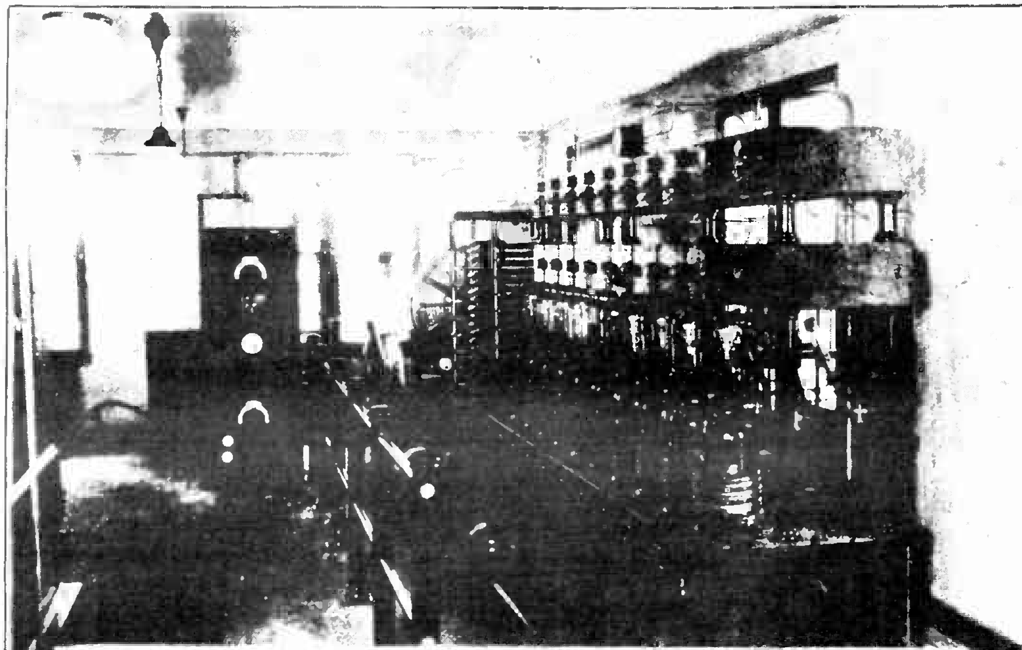
TRANSMITTING VACUUM TUBE CHARACTERISTIC CHART

R-F POWER AMPLIFIER

Type	Max. Screen Dissi-pation	Maximum Operating Plate Voltages: Modulated D-C	Maximum Operating Plate Voltages: Unmodulated D-C	Maximum Operating Plate Voltages: A.C. (rms)	Maximum RF Grid Current (Amperes)	Typical Operation - Class B: E_p	Class B: E_c	Class B: E_d	Class B: Unmodulated DC Pl. Cur. (Amperes)	Class B: (Watts) Peak Output	Class B: (Watts) Carrier Output	Typical Operation Class C: E_p	Class C: E_c	Class C: Output
210		350	450	450	5.0	350	50		0.030	7.5	1.9	350	50	7.5
841		350	450	450	5.0	450	8		0.036	16.0	4.0	450	30	13.0
842		350	450	450	5.0							350	150	7.5
843			450		5.0	350			0.030	7.5	1.9			
844	3	500	500	500	5.0				0.020			500	7	5.0
865	3	500	500	500	5.0	500	40	125	0.030	7.5	1.9	125	80	7.5
205D		350	350	350		350			0.015 to 0.030	20.0		350		5.0
205E		350	350	350		350			0.015 to 0.030	20.0		400	110	5.0
271A		400	400	400		400	55		0.039			450	180	
252A		450	450	450		450	90		0.060					
203A		1000	1250	1000	7.5	1000	35		0.130	160.0	40.0	1000	100	100.0
211		1000	1250	1000	7.5	1000	35		0.130	160.0	40.0	1000	200	100.0
845		1000	1250	1000	7.5	1000						1000	250	75.0
850	10	1250	1000	1000	7.5	1000	8	175	0.100	120.0	30.0	1000	150	100.0
852		2000	3000	3000	10.0	2000	150		0.060	120.0	30.0	2000	250	100.0
860	10	2000	3000	3000	10.0	2000	50	300	0.060	120.0	30.0	2000	200	100.0
211D		1750	1000	1000								750		50.0
242A		1250	1250	1250		1000	80		0.150			1000	160	
276A		1250	1250	1250		100	80		0.125			100	160	
212D		1500	2000	2000		1500			0.130	250.0		1500		2000.0
204A		2000	2500	2000	10.0	2000	70		0.143	340.0	85.0	2000	175	350.0
270A		2500	3000	3000		2500	175		0.350	350.0	83.5	3000		350.0
849		2000	2500	2000	10.0	2000	200		0.260	650.0	165.0	2000	200	450.0
861	35	3000	3500		10.0	3000	60	500	0.250	600.0	150.0	3000	200	540.0
251A		2500	3000	3000		2500	260		0.600	1000.0		3000		1000.0
851		2000	2500	2000	10.0	2000	85		0.750	1200.0	300.0	2000	200	1250.0
279A		2500	3000	2500		3000	325		0.800	2000.0		3000		2000.0
1652		6000	75000		10.0	6000	450		0.600	4000.0	1000.0	6000	1200	4000.0
207		12000	15000			12 kv	600		0.900	14000.0	3500.0	12 kv	2200	15000.0
848												12 kv	2600	15000.0
863		12000	15000		30.0	12 kv	250		0.900	14000.0	3500.0	12 kv	2000	15000.0
858		16000	20000		60.0	18 kv	450		0.900	21600.0	5400.0	18 kv	3500	22000.0
232A			20000							35000.0				35000.0
862			20000		60.0	18 kv	380		4.200	100000.0	25000.0	18 kv	4000	100000.0



THESE 32 WATER-COOLED TUBES WERE FORMERLY USED AT WEAF



R-F POWER AMPLIFIER AND TUNING SYSTEM AT "OLD" WEAF.

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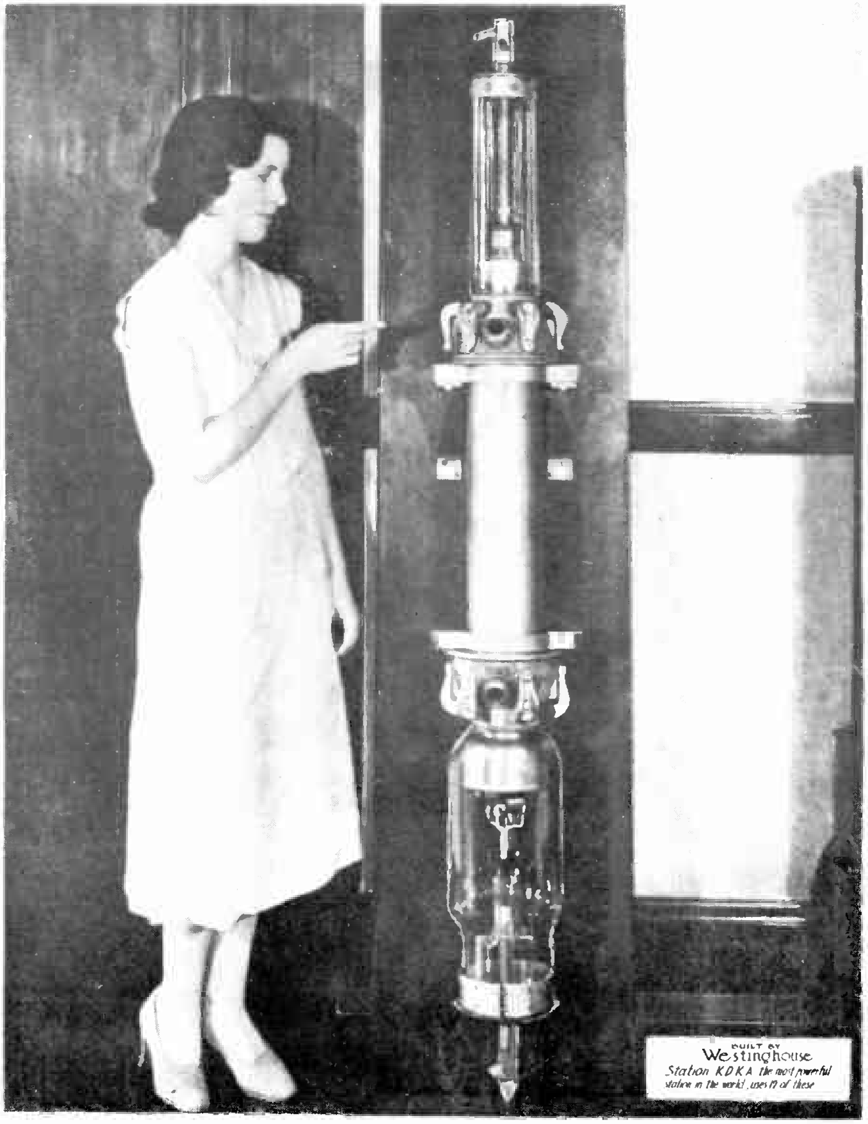
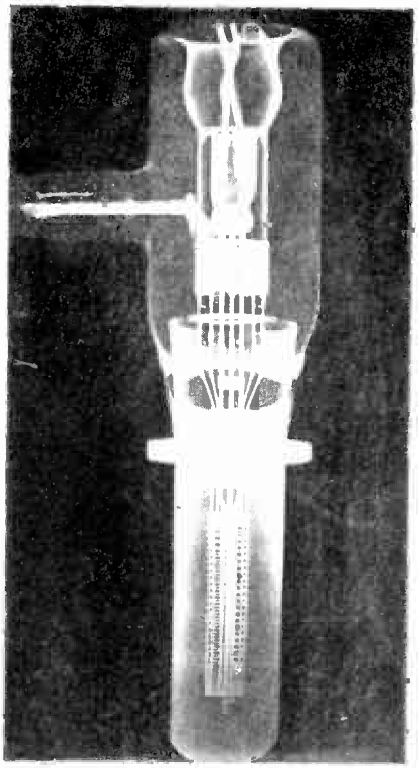


Air-Cooled and Water-Cooled Transmitting Tubes

Measuring Vacuum Tube Characteristics -

Dewey Classification R 130

VOL. 13, No. 7



X-RAY PHOTOGRAPH OF A UV-858
WATER-COOLED TUBE

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AIR-COOLED AND WATER-COOLED TRANSMITTING TUBES
MEASURING VACUUM TUBE CHARACTERISTICS

In this lesson we review standard types of vacuum tubes used in transmitting equipment. Also, we give worked-out examples of the most frequently used constants by which the characteristics of vacuum tubes of the same type may be compared when operating under exactly similar conditions — these are amplification constant, plate impedance and mutual conductance.

100 WATT TUBES: TYPES UV-203-A, UV-211, 845, 850, 852, 860, WE-211-D, 242-A, and 276-A.

The 100 watt tube is manufactured in nine types which differ only in plate impedance and amplification constant or number of electrodes. A photograph of a 100 watt tube is shown in Figure 1 All types are operated at similar filament voltages.

The UV-203-A is intended for amateur and experimental use where voltage amplification is desired. The UV-211 is used extensively in commercial transmitting circuits for oscillators, amplifiers, or modulators. The 845 is better adapted to audio frequency and modulator work than the above mentioned types. An inspection of the characteristic chart shows that the filaments of both tubes normally draw 3.25 amperes at 10 volts, the plate power dissipation being 100 watts when operating either tube as an oscillator at its normal plate potential of 1000 volts.

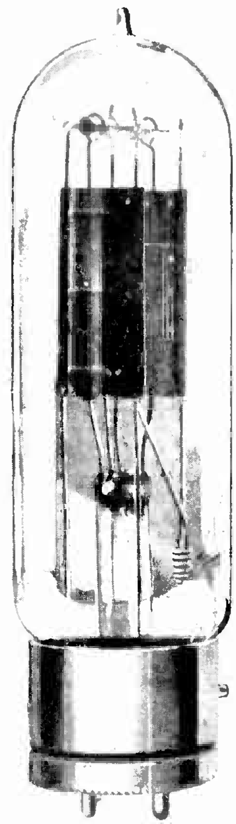


FIG. 1- 100-WATT TUBE

The UV-211 requires a very strong mechanical construction and rigid support of all the electrodes since it is used in many marine tube transmitters.

These transmitters must stand up under severe operating conditions at sea. The plate is mounted on four separate rods imbedded in the glass stem of the tube. Small helical springs attached to the upper end of the supporting rod hold the filament wire and maintain it at the proper tension, thus protecting it from shocks. An elaborate spring suspension for the filaments of small power tubes is unnecessary.

The UV-203-A possesses a very desirable characteristic which protects it from overload. If under any conditions the tube should stop oscillating or lose its negative bias the plate current would not greatly exceed its normal value, as when oscillating. This result is due to the high plate resistance of the tube. On the contrary, however, as in the case of the UV-211 tube, its plate current at zero grid would rise to such excessive values that overheating of the plate would be sure to occur, and in a short time serious damage would result. This inherent plate current characteristic of the UV-211 is due to the low plate resistance of this tube.

Certain types of modern tube transmitters utilize a crystal-controlled master oscillator, several stages of intermediate amplification, and a main power amplifier system. A 50 watt tube is often used with the quartz crystal. The tube supplies power and the crystal controls the frequency at which the continuous oscillations are generated. Experience has proven that for the reliable operation of crystal controlled oscillators, it is essential that low plate voltage be applied to any tube working in conjunction with the crystal. Low voltage permits the transmitter to be operated without fear of subjecting the crystal to excessive voltage which might cause it to crack or shatter. When

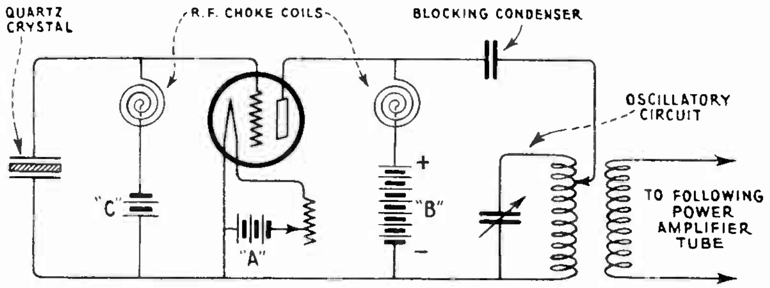


FIG. 2 - 100 WATT TUBE IN A CRYSTAL-CONTROLLED CIRCUIT

used in a crystal circuit the 100 watt tube is usually worked at 500 volts d.c. or at half normal voltage. The schematic diagram in Figure 2 shows a 100 watt tube connected in a crystal-control circuit. It is preferable to use alternating current to heat the filament and in certain commercial sets this a.c. is supplied by means of slip rings on the motor armature connected to a step-down transformer. A center tap on the transformer secondary should be used for plate and grid return leads. Filament voltage is usually controlled through a rheostat placed in the primary side of the heating transformer. When it is necessary to use direct current to energize the filament then it should be remembered to connect the plate return lead to the positive filament terminal. As in the case of all X-L filaments a voltmeter should be provided to check the e.m.f. applied.

If an overload decreases the electron emission in this tube, the activity of the filament may be restored by the reactivation process which simply requires that the filament be heated for a period of ten minutes or longer at the rated filament voltage, but with no plate voltage. If necessary the filament voltage may be raised to 12 volts, but no higher.

A protective fuse which should blow at about .2 to .25 ampere is usually inserted in the plate circuit. Remember that no fuses should ever be placed in a grid circuit since a blown fuse would be equivalent to opening the grid circuit and thus removing the negative bias. A plate voltage rheostat is quite necessary in order that the plate voltage may be lowered so as to protect the tube or other parts in case incorrect adjustments are made, which is likely to happen when first calibrating a new circuit or making regular adjustments in a circuit. The plate voltage may be increased from 1000 volts normal to 1250 volts only when using these tubes in a transmitter circuit in which the tubes are not actually modulating, i.e., when used in a non-modulated c.w. telegraph transmitter.

The UV-203-A and UV-211 are frequently used at wavelengths of less than 100 meters. Precautions should be taken in every case to keep the currents at safe values, but especially is this true in the case of tubes working in short-wave circuits. The 850, 852 and 860 are, however, better adapted to high-frequency work than the 203-A or 211. The RCA-850 is a four-element screen-grid tube, having the same plate voltage and filament characteristics as the 203 or 211 and using the same socket. This makes available a vacuum tube for high-frequency work in the 100 watt class which does not require plate voltages as high as those of the 852 or 860.

100 WATT SPECIAL SHORT-WAVE TRANSMITTING TUBE, TYPE UX-852

The UX-852 tube illustrated in Figure 3 is designed for use as an oscillator or power-amplifier in transmitting circuits operating on 5, 20 and 40 meters. It is also well suited for use as a crystal-controlled oscillator by operating it at less than the rated plate voltage. This tube has a very low inter-electrode capacity made possible by its special construction. Its plate to grid capacity is only 3.3 micromicrofarads as compared to 8.0 mmfd.for the UX-210. Observe in the photograph how the plate and grid electrodes are mounted on separate stems with the connecting leads entering the glass envelope through opposite sides. The filament leads are brought to the prongs on the tube base as in the ordinary tube.

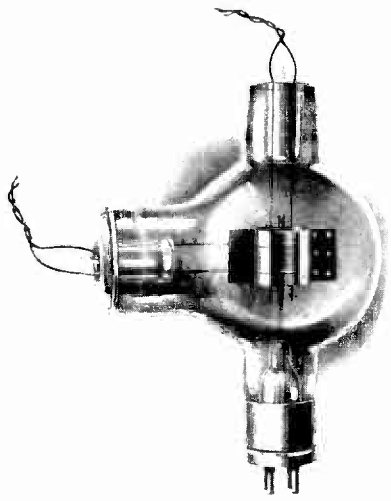


FIG.3 - TYPE UX-852

On 20 meters, the tube will oscillate with stability and under certain conditions will deliver power on 0.7 of a meter.

The double end or T-shaped glass envelope with leads coming out at safe distances from one another prevents damaging base flashes. Connections to each of the grid and plate electrodes is made through two large stranded leads brought out from each stem as we have just mentioned.

These parallel leads permit large circulating currents to be carried safely at the high frequencies and therefore it is imperative that both leads be always used. The X-L filament used in the tube gives a high electron emission. The filament power is rated at 32.5 watts. The tube base should always be mounted so that the filament wire will occupy a vertical position. Alternating current should be supplied to the filament whenever possible. Plate and grid return leads should be connected to the electrical center (center tap) of the filament heating winding of the power transformer.

Although the normal plate voltage for the tube is 2000 volts, this voltage may be raised to 3000 provided the plate dissipation does not exceed 100 watts. Radiating fins on the plate permit a very large heat dissipation at this point. Because of the impracticability of measuring the output of a tube working on short wavelengths its correct operation may be judged sufficiently accurate by observing the plate. Plate temperature should never be permitted to increase above a certain value that would cause it to become more than cherry red in color. If the plate is heated to a cherry red, this color may be taken as an indication that the energy dissipated in heat is equivalent to 100 watts, resulting from electron bombardment of the anode or plate. Remember that whenever a circuit employing this tube is adjusted, the tube loss, that is, the difference between output and input, must always be kept within the safe limits of 100 watts.

The filament of this tube may be reactivated, like the X-L filaments of tubes previously mentioned, by operating at the normal filament voltage for ten minutes or longer with the plate voltage supply disconnected. The activity of the filament may be accelerated by increasing the filament voltage to 12 volts, but no more. In cases where an overload has liberated a large amount of gas this reactivation process will not be successful.

A fuse of the proper size to blow at 10 amperes should be inserted directly in series with the plate supply lead in order to protect the grid, wiring, etc., from overheating when improper adjustments of the circuit have been made. As we have cautioned before a fuse should never be placed in the grid circuit of any tube, because if it should accidently open or blow it would remove the grid bias from the tube with the result that the plate current would immediately run up to a dangerous value.

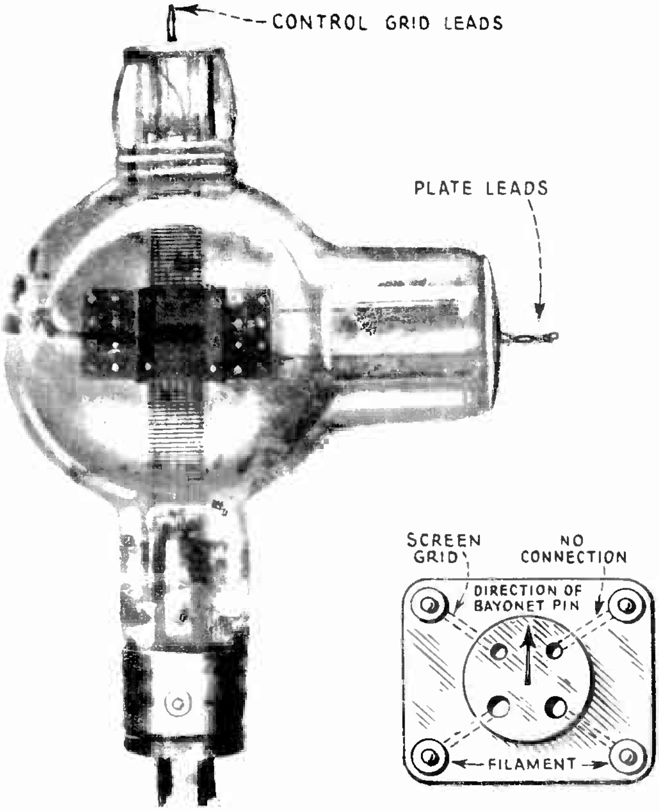
UX-860 FOUR-ELEMENT TUBE, OUTPUT 100 WATTS.

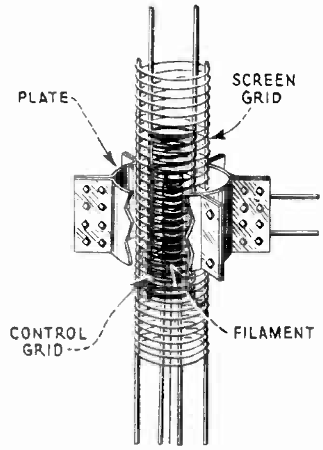
The RCA-860 tube is especially designed for use as a power amplifier in transmitting circuits of the high radio-frequency or short-wave type. The high-frequency transmitters send out continuous wave (c.w.) telegraph signals which cover wavelength ranges as low as 15 to 50 meters, or 20,000 to 6,000 kilocycles. This frequency band may also be expressed as from 20 to 6 megacycles. One megacycle is equal to one million cycles.

This 100 watt tube has a plate, filament and two grids, whereas the standard three-element tube has a plate, filament and only one grid. The addition of the extra grid, called the screen or shield grid, minimizes the effects of inter-electrode capacity, that is, it prevents the so-called feed-back from plate to grid. This stabilizes the circuit in which the tube is used. Whistles, howls and other undesirable effects are eliminated by the addition of the fourth element.

The theory of operation is that the control grid (the regular grid located adjacent to the filament which is found in all standard tubes) is impressed with the excitation voltages in the manner similar to that for operating any tube, but the screen grid is maintained at a neutral potential with respect to the other electrodes by suitable connection to a source of e.m.f.

The voltage for the screen grid may be obtained either from a potentiometer connected across the plate supply, from the d-c plate supply through a series resistance of approximately 70,000 ohms, or from a separate d-c source. The resistance method, using about 70,000 ohms, is the most practical method for maintaining the screen grid voltage at proper value because it provides automatic regulation. When employing the resistance method, the filament supply should not be discontinued for any reason while the plate voltage is on, for





ABOVE: ARRANGEMENT OF UX-860 ELECTRODES

LEFT: SOCKET CONNECTIONS OF UX-860

FIG. 4 - THE 100-WATT UX-860 TRANSMITTING SCREEN-GRID TUBE

this would cause the full plate voltage to be applied to the screen. When the potentiometer method, or separate source method, is used the screen grid voltage should not be applied when the plate voltage is off. Under operating conditions the screen grid should never be permitted to reach a temperature which would cause it to show a color more than that of a cherry red.

When the screen grid is supplied with a suitable positive voltage it acts as an electrostatic screen between the control grid and the plate of the tube. The normal screen grid volts for this tube when operating either as an oscillator or r-f power amplifier is 500 volts. The need for neutralizing the radio-frequency circuits is eliminated by the use of this tube as we have just stated. A photograph of the UX-860 is shown in Figure 4. The UX-860 requires 3.25

amperes at 10 volts for the filament and 2000 volts d.c. for the plate. This tube may be employed as a frequency "doubler" and intermediate power amplifier in short-wave commercial transmitters. When used for this purpose the tube's output is fed into a main power amplifier circuit which may also use tubes of the four-element type, but having a greater output power. Tubes especially designed for handling large power at high frequencies are the UV-861, 858 and WE-251-A.

250 WATT TRANSMITTING TUBE, TYPE UV-204-A.

The large UV-204-A tube illustrated in Figure 5 has an output rating of 250 watts and it also utilizes an X-L filament. The normal plate voltage is 2,000 and the filament is rated at 42.5 watts, drawing 3.85 amperes when supplied with the specified terminal e.m.f. of 11 volts. The maximum safe plate power dissipation is 250 watts. A very high emission is obtained by the use of the thoriated filament; this emission reaches approximately 5 amperes with the filament voltage at 11. The high emission permits the tube to perform very satisfactorily in telephone circuits because the complexities of speech and musical sounds cause large peak values of current.

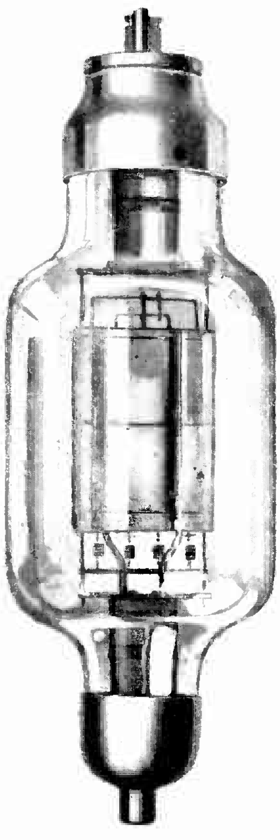


FIG. 5 - TYPE UV-204-A

Two or more 250 watt tubes are sometimes arranged in multiple (parallel) to provide a greater output than that afforded by the use of several smaller tubes. The "Converted P-8" commercial tube transmitter, found on many ships, employs two tubes of this type arranged "back to back" and obtaining their plate excitation from a.c. at 500 cycles supplied from a 500 cycle a-c generator feeding into a step-up power transformer. The note received from a transmitter of this kind whose c.w. is modulated according to the characteristics of a 500 cycle a-c current is somewhat similar to a 500 cycle spark set using a quenched gap. The theory is briefly as follows: The two tubes are connected with their plates to opposite ends of the transformer secondary. Only the positive halves of the alternating current cycles will be utilized. When one plate is positive the other is negative and it is obvious that only that tube which receives a positive half cycle will be active in generating the continuous high-frequency oscillations. Thus each tube alternately generates c.w. energy whose modulation is similar to the wave form of the 500 cycle a.c. This is called "full-wave self-rectification".

Since the positive voltages constantly fluctuate between zero and maximum and zero values according to the wave form of the a-c output of the transformer, then it follows that the resultant modulation produced by rectifying both halves of an alternating current power supply will appear as shown by the curve in Figure 6. There are four completely modulated groups shown in this curve. Each complete modulation produces one click in the receiving head set and since a 500 cycle a.c. is supplied and two tubes are working "back to back", the radiated wave will consist of 1000 completely modulated groups per

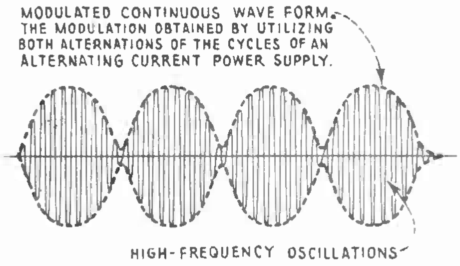


FIG. 6 - MODULATION PRODUCED BY RECTIFYING BOTH HALVES OF AN A-C POWER SUPPLY

second, hence 1000 clicks per second will be heard in the head set. This is known as a 500 cycle note and the tone has somewhat the characteristics of a spark transmitter employing a quenched gap as previously mentioned.

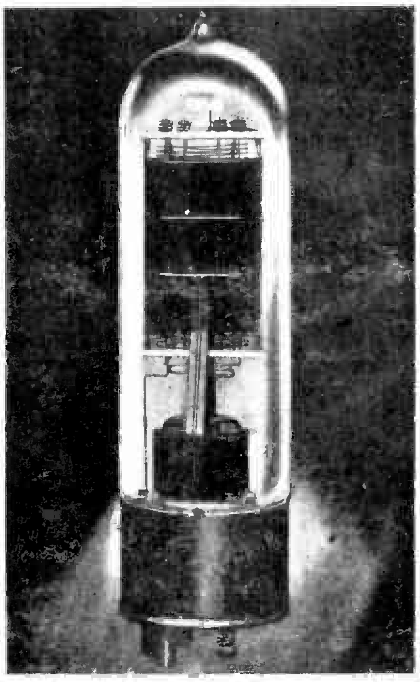


FIG. 7 - WESTERN ELECTRIC 212-D

A tube of similar output rating to the 204-A is manufactured by the Western Electric Company under the number 212-D. In mechanical construction, the tubes are somewhat different in that the 212-D is a single ended tube rather than double ended. The amplification constant of the 212-D is lower and is better adapted to operate as a modulator than the 204-A. A photograph of this tube is shown in Figure 7.

THE UV-849 AND WE-270-A

These two tubes are very similar in their characteristics and both are adapted for use as oscillators, modulators, r-f power amplifiers or audio amplifiers. They are both of the double ended variety, the 849 being shown in Figure 8 and the WE-270-A shown in Figure 9.

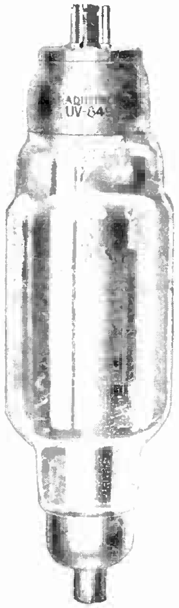


FIG. 8 - TYPE UV-849

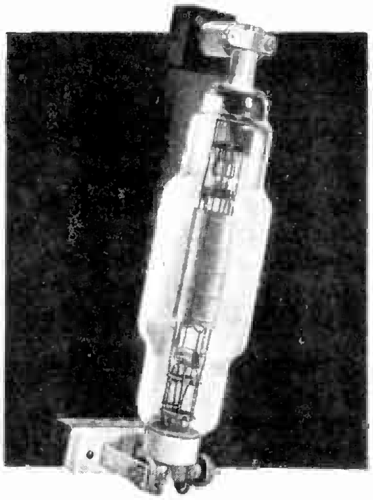


FIG. 9 - WESTERN ELECTRIC 270-A

THE UV-861 FOUR-ELEMENT TUBE, OUTPUT 500 WATTS.

Model UV-861 is a four-element tube of the screen grid type, designed for use as a power amplifier in transmitting circuits. It may also be used as an oscillator and is especially adapted for use in short-wave transmitters. One or more tubes of this type are used in the final power amplifier stage and work directly into the antenna. The

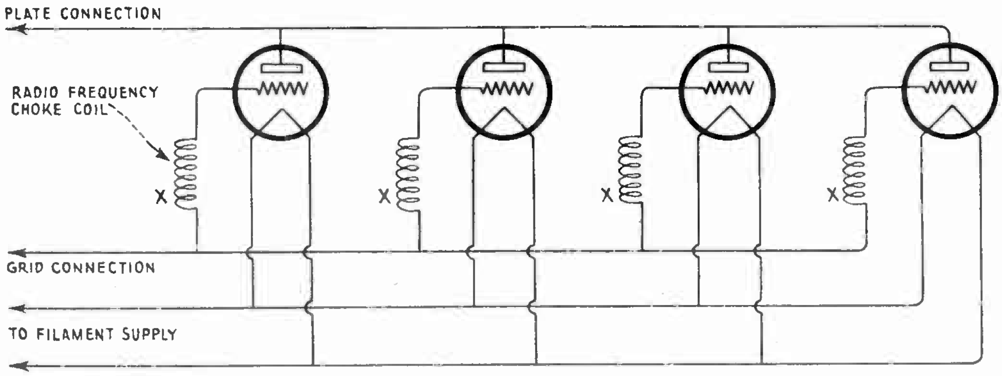


FIG. 10 - WHERE R-F CHOKE COILS MIGHT BE PLACED IN GRID CIRCUITS

input voltages for the UV-861's are supplied by one or more UX-860's located in the intermediate stages. The UV-861 is also constructed with a shield grid, and consequently the use of stabilizing methods in the radio-frequency circuits is likewise unnecessary as in the case of the UX-860. The normal screen-grid volts for this tube is 750 volts. The inter-electrode capacity is reduced to 0.05 mmfd. by the use of the screen grid. In certain types of transmitters the UV-861 plate is energized by a d-c double commutator generator having two 1500 volt windings arranged in series to deliver the normal 3000 volts. A plate current of approximately 0.5 ampere will be drawn at this plate voltage. Power tubes are usually provided with a plate voltage rheostat

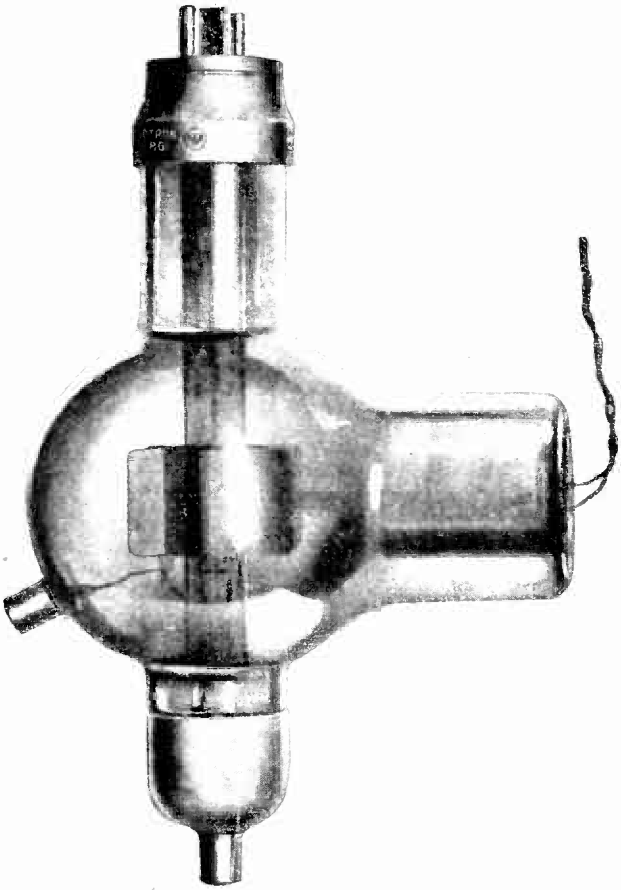


FIG. 11 - PHOTOGRAPH OF A TYPE UV-861 TUBE

so that during the process of tuning the transmitter the plate voltage may first be reduced and then later increased to normal as the various radio-amplifier stages are adjusted for maximum output in the antenna. The normal d-c plate current is 172 milliamperes, but under certain conditions of service this current reaches values as high as 350 ma. The X-L tungsten filament takes 10 amperes at a normal terminal e.m.f. of 11 volts.

In a majority of transmitting circuits, power tubes are connected in parallel, which is also known as multiple arrangement. The actual manner in which tubes are connected in parallel is in itself a simple method of connecting all the grids together and all the plates together. The filaments are energized from the same source of supply. When power tubes are operated in multiple, a small radio-frequency choke coil or a resistance of suitable size, for instance, one with a resistance of from 10 to 100 ohms should be inserted in the grid circuit of each tube as shown in Figure 10. These coils, or resistors (if used) should be placed as close as possible to the grid terminal of the socket for the purpose of suppressing parasitic oscillations. The unwanted oscillations are ultra-high frequencies which would circulate through the circuits and cause undesirable effects if no provision were made to suppress them. They are set up under certain resonant conditions existing between the tubes and the coupled circuits.

An amplifier circuit may consist of six or more tubes connected in multiple in order to supply an antenna system with a large power; the sum total of the watt output of the individual tubes used in the system. Multiple arrangement provides a practical means for dividing the load among several low-powered tubes, and in this way the need for a very large expensive tube and power plant is eliminated. A photograph of the UV-861 is shown in Figure 11.

1000 WATT TRANSMITTING TUBE, TYPE UV-851.

One of the largest sized air-cooled transmitting tubes has an output rating of 1000 watts. This power is obtainable without any increase in plate voltage over the 250 watt tube. The plate of the UV-851 requires 2000 volts d.c. and its plate power dissipation is 750 watts when the tube is worked as an oscillator.

We have already explained about the high efficiency of a thorium filament over a pure tungsten filament. This difference in materials, however, may be better appreciated after reviewing the following facts in regard to the practical operation of the UV-851. The X-L filament of this tube requires a power consumption of 170 watts to give a total electron emission of approximately .20 ampere whereas, on the other hand, a pure tungsten filament requires at least 600 watts to give an equal electron emission. In the latter case, that is, with a tungsten filament, the high emission could be obtained only by considerably overheating the tube; the additional power required would have to be dissipated at the plate. When operated under certain conditions this tube is capable of delivering a radio-frequency output of 1 kilowatt or more.

The mechanical construction of the 1000 watt type tube differs somewhat from that of the ordinary tube. There are four parallel filament wires used, each wire being supported by a helical spring to maintain proper tension at all times. The grid is constructed of a heavy square mesh of molybdenum wire, it being mounted in a frame which is anchored to the plate structure with an insulator for the purpose of holding the grid in correct mechanical relation to the plate. The heat generated by the plate or anode is dissipated with the aid of narrow wings attached to the plate. These thin metal pieces are called "radiating fins". A similar tube is manufactured by the Western Electric Company listed as type 251-A.

20 KILOWATT WATER-COOLED TRANSMITTING TUBES UV-207 AND UV-858.

These tubes are adaptable to either broadcast or telegraph transmitting circuits. Although the 20 kw. tube is one of the largest of the family of vacuum tubes, yet it functions exactly similar to its smaller brothers in the lower power classes. The tube is well suited for use as an oscillator, power-amplifier, or modulator. The enormous power which this water-cooled tube is capable of delivering can be appreciated by noting the magnitude of its various operating voltages. For instance, the plate is energized with 15,000 volts and the current in the plate circuit when the tube is oscillating is 2 amperes or 2000 milliamperes. The radio-frequency current, or oscillations generated by this tube, circulates through the grid circuit and reaches values up to 30 amperes. A grid d-c current of about 100 milliamperes can be safely carried by the grid. The filament e.m.f. is 22 volts which gives a filament current of nearly 52 amperes. A

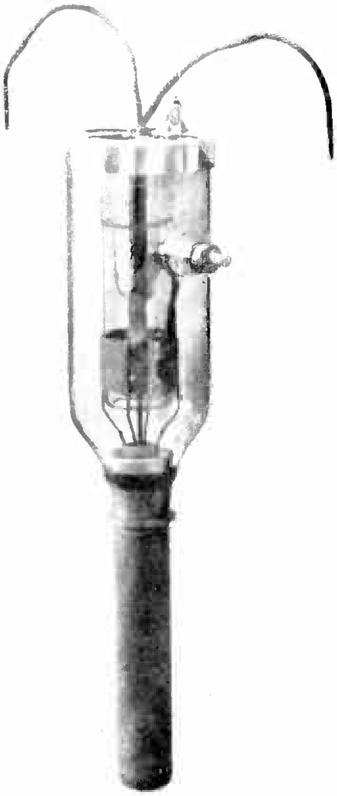


FIG. 12 - A 20 KILOWATT WATER-COOLED TUBE

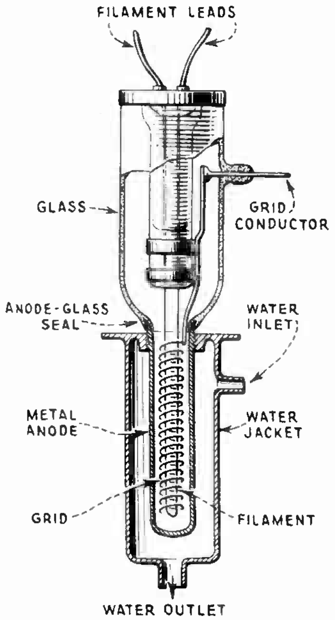


FIG. 13 - TUBE AND WATER-JACKET ASSEMBLY

filament starting resistance is necessary in order to raise the filament temperature gradually, and when the normal operating point is reached the plate voltage is automatically applied.

While the rated output of these tubes is 20 kw. the maximum safe plate dissipation is 10 kw. It will be recalled that lost power is generally dissipated in heat. The long copper cylinder shown at the bottom in the photograph of the tube in Figure 12 is the anode or plate. By inserting the anode in a water-cooled jacket the heat produced at the plate is quickly extracted. The complete water-jacket assembly is so arranged that a flange screwed to the threaded portion of the plate holds the plate in the jacket and special precautions are taken to insure a water tight joint by the use of a suitable gasket of rubber or other material between the flange and jacket. The tube is supported only by the water jacket — see Fig. 13.

There is sufficient space between the inside of the jacket and the copper cylinder or plate to permit a column of water to circulate freely around the plate for the extraction of heat generated at this point. About two or three gallons of water per minute is constantly pumped past the surface of the copper anode and through the system from cooling coils. The water circulation is maintained by electrically driven centrifugal pumps. The temperature of the water is usually measured after it has passed the hot anode. This is known as the outlet temperature, 70 degrees Centigrade generally being set as the limit. It is obvious then that the thermometer is located at the point of highest water temperature. The cooling water is never permitted to boil nor are air pockets allowed to form around the anode which might cause overheating of the water. This condition

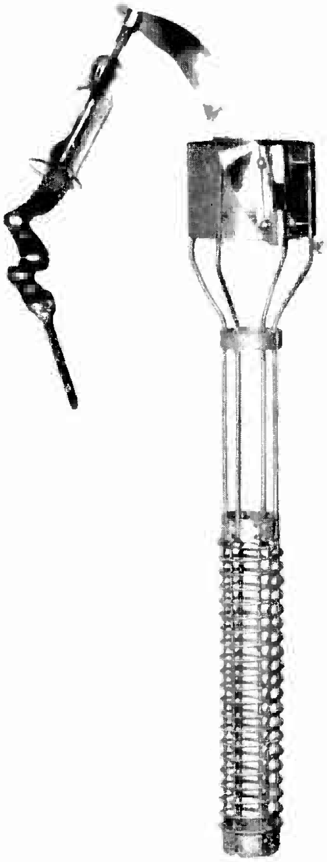


FIG. 14 - GRID CONSTRUCTION

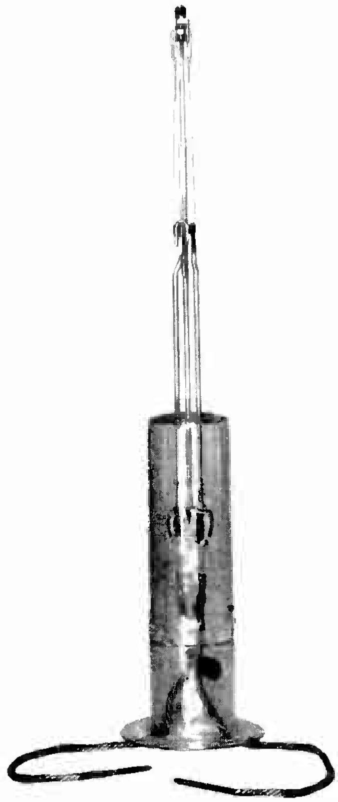


FIG. 15 - CATHODE CONSTRUCTION

would be evidenced by a singing or buzzing noise from the jacket while the power is on, this noise indicating the presence of steam bubbles at the surface of the anode.

Only water surrounds the metal anode and as can be seen in the photograph the other elements are supported by the glass cylinder with the conductors brought out at safe distances from each other. A simple cross-sectional sketch of the water-cooled vacuum tube is shown in Figure 13. The grid and cathode of a 20 kw. tube are shown in Figs. 14 and 15 respectively. It can be seen in Fig. 13 that the plate itself is a hollow cylinder with filament and grid mounted inside. An air-tight seal is made between the copper edge of the cylinder and the glass shell. The tube is very thin and delicate where this union between glass and metal is made.

It may be interesting to note the dimensions of this tube in order that we may compare it with the small receiving tubes which we so frequently handle. However, when we consider the immense amount of d-c power which is converted into radio-frequency power by this tube, its dimensions do not seem unduly large. The maximum overall length of the tube is 19 5/8 inches, the diameter of the glass bulb is $4\frac{1}{4}$ inches, while the weight of the tube alone is 2 pounds and 12 ounces. The dimensions given seem relatively small and are made possible because of the special means of keeping the temperature within safe limits by both water and air cooling. The air cooling is the natural heat radiation which takes place at the outside glass walls and water-jacket while the water cooling is due to direct conduction from the hot cylindrical plate to the water. It will be remembered that it is the electronic bombardment which causes the plate or anode to become the hottest element in the tube outside of the filament which is a normal condition for the latter.

An interlock or circuit breaker between the water circulating system and the electrical circuits is set to open if the water supply fails for any reason or if the tube develops trouble. The filament and plate voltages are instantly disconnected by the opening of the interlock.

Because of the high plate potential of several thousand volts, the plate must accordingly be insulated from the water tank and metal piping which is normally grounded. The use of a fairly long length of rubber hose connecting the water-jacket to the water source and also, by using pure water in the circulatory system, the insulation and resistance is built up to the order of several hundreds of thousands of ohms. This resistance is between the high potential anode, which is in direct contact with the water, and the cooling system and, in turn, the ground.

A tendency for a heavy scale or deposit to form on the outside of the anode (the scale being similar to that collecting on the boiler tubes) may be attributed to the use of water containing a high percentage of mineral matter, especially sulphates and carbonates. The chemical content of the cooling water should be determined by analysis. The water must be pure and have a fairly high specific resistance. A length of about 15 feet of $\frac{1}{2}$ inch rubber hose is all that is required with high resistance water (4000 ohms per centimeter cube) in order to build up the necessary high resistance between the jacket and the inlet and outlet pipes. A length of hose is wound around a cylindrical form with each coil of hose being located under a water-cooled tube in the transmitter.

It can be readily understood that the need of pure water is a very important feature in the operation of large broadcasting stations or any station employing water-cooling for vacuum tubes. The water used in a certain radio station had a specific resistance of only one-tenth that of the water recommended for such purposes.

The table below shows the chemical content held in solution in this water, and we give this list for those of our students who may be interested in work of this kind.

	Per 100,000	Grains Per Gallon
Silica	1.08	.63
Iron oxide alumina	.25	.15
Calcium carbonate	2.16	1.26
Magnesium carbonate	5.00	2.92
Potassium carbonate	3.86	2.25
Sodium sulphate	3.65	2.14
Sodium chloride	14.00	8.17
Total Solids	30.00	17.52

Specific Resistance 359 ohms.

If the composition of cooling water is such that scale cannot be avoided then it is obvious that the tubes must be removed and cleaned at frequent intervals, the frequency of cleaning depending, of course, upon the rate at which the deposit is formed. The danger of accidental breakage is always entailed in the removal of these tubes because they are apt to stick in the water-jacket. A gentle twisting back and forth and at the same time raising the tube carefully will usually loosen it sufficiently to permit its removal.

In order that the glass envelope will not be subjected to an electrostatic strain the external wiring from the transmitter circuits and the leads attached to the electrodes are kept at reasonably safe distances from the glass.

You will recall that glass is a dielectric material, hence, electrostatic strains set up by the relatively large oscillating currents are likely to puncture the comparatively thin walls of the glass. Again observe the photograph of the 20 kw. tube and note how the two filament leads are brought out at the top whereas the grid conductor comes through the center of the glass bulb. If the filament leads swing and strike the glass at any time trouble would arise from corona, resulting in almost certain puncture of the glass.

A transmitter employing tubes of this power may have the oscillating frequency, allocated by the Radio Commission at Washington, maintained within the prescribed limits of 50 cycles by the use of a quartz crystal. A circuit consisting of a quartz crystal, an oscillatory circuit, and a low-power amplifier tube, may be set up to supply the initial oscillating current of the desired frequency. This frequency, after being stepped-up through several stages of intermediate amplification, finally provides a satisfactory amount of radio-frequency voltage for excitation of the grid of the 20 kw. tube

A special tube of the water-cooled variety for use on high frequency has been developed and is known as the UV-858. An x-ray photograph of this tube is shown on the inside front cover page.

MEASURING VACUUM TUBE CHARACTERISTICS

There are several constants by which vacuum tubes of similar type may be compared when operating under exactly similar conditions. We will explain in the following paragraphs how to calculate the amplification constant, plate impedance and the mutual conductance. Although these constants do not enable us to determine exactly how a particular tube will perform in a circuit under certain operating conditions, yet they do provide a very convenient means for us to determine the relative efficiency to be expected from tubes of similar type.

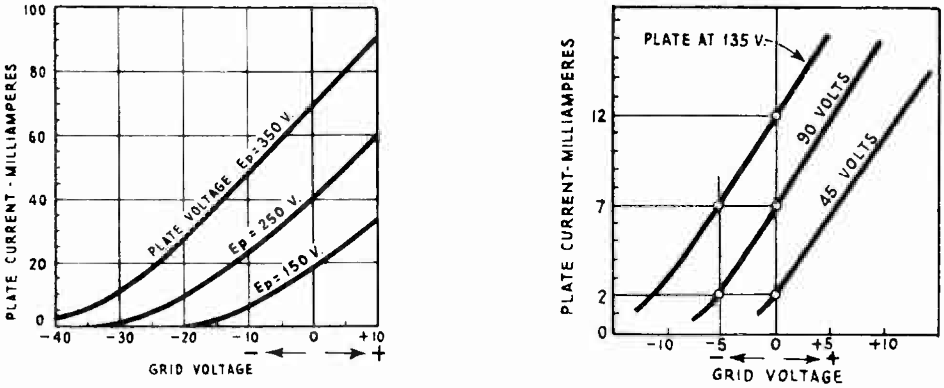


FIG. 16 - CHARACTERISTIC CURVES OF A UX-210 TUBE

AMPLIFICATION FACTOR OR CONSTANT. Mu (μ) is the symbol for this constant. Amplification constant may be defined as the measure of the effect of the grid voltage on the plate voltage, or stated more fully, it is the ratio of the change in plate voltage to a corresponding change in grid voltage which produces the same effect in the plate current. This relation may be expressed as a formula in the following manner:

$$\text{AMPLIFICATION CONSTANT} = \frac{\text{CHANGE IN PLATE VOLTAGE}}{\text{CHANGE IN GRID VOLTAGE}}$$

With the aid of the curves at the right in Figure 16 we will work out an example that will enable anyone to calculate the amplification factor of any tube whose characteristic curve is available. The three curves show the characteristics of the same tube, a UX-210 tube. when worked at three different plate potentials. The first curve is the 135 volt curve, the second 90 volts and the third 45 volts.

In our example let us consider only the 135 and 90 volt curves in order to find the ratio of change in plate voltage to a corresponding change in grid voltage which would give a change in plate current exactly similar for each grid and plate variation. Reference to the curves tells us that when working the tube with the grid at zero potential the flow of plate current is 12 ma. (milliamperes) with the plate at 135 volts. It is readily seen that by reducing the plate voltage from 135 to 90, a difference of 45 volts, we obtained a reduction in plate current of 5 ma.

Let us now locate a point on the 135 volt curve which tells us the value of plate current for a grid bias of negative 5 volts. To do this we follow the vertical line upward from the −5 location on the bottom horizontal line (the line upon which the grid voltages are marked) until the vertical line crosses the curve. Beginning at the point of intersection we follow the horizontal line to the left until it meets the vertical line upon which the plate current values are marked. The plate current value is seen to be 7 ma. However, this same 135 volts, as previously shown with the grid at zero potential, gives a plate current of 12 ma. Hence, it should be clear that with the tube operating under these two different grid voltages, zero and −5, the plate current dropped from 12 to 7 ma. Observe now, that we have the same value of change of plate current, or 5 ma., for two different plate voltages, 135 and 90, corresponding to the two different grid voltages, zero and −5. Briefly, it could be stated that it required only 5 volts change of grid to make the same plate current change that was obtained by a difference of 45 volts on the plate.

Any set of values might be taken from the curve for our example, providing these values are somewhere along the linear or straight portion of the curve. It will be recalled that amplification is obtained by working a tube at some location where the slope of the curve is a straight line.

The numerical values in the preceding paragraphs may now be substituted in the formula and then solving we get:

$$\text{AMPLIFICATION FACTOR} = \frac{135 - 90}{5 - 0} = \frac{45}{5} = 9$$

Then 9 is the amplification constant of this particular 210 type tube.

PLATE IMPEDANCE. This constant is the measure of the change in plate voltage to the resultant change in plate current under conditions of a constant grid potential. The term "constant" means that grid voltage remains unchanged or fixed during the procedure of plotting the characteristic curve. Note that grid voltage will not be varied this time, as for instance, in the case of preceding explanation. In this example we can use the same plate voltages and plate current values as in the foregoing examples, when the plate voltage was lowered from 135 to 90 and it was shown that the plate current decreased from 12 to 7 ma.

After first changing milliamperes to amperes, all of the necessary values can be substituted in the plate impedance formula as follows:

$$\text{PLATE IMPEDANCE} = \frac{135 - 90}{0.012 - 0.007} = \frac{45}{0.005} = 9000 \text{ ohms.}$$

Note: 12 ma. = 0.012 ampere.
7 ma. = 0.007 ampere.

Then 9000 ohms is the plate impedance for this particular tube.

MUTUAL CONDUCTANCE. The mutual conductance value of a tube is a good indication of the efficiency of a tube used as an amplifier, because this value represents the effect of the applied grid voltage upon the plate current. Now then, a certain relationship exists between the plate current and grid voltage which the characteristic curve shows in pictorial form. This relationship is when the quotient of the change in plate current divided by the change in grid voltage produces a certain change in question in plate current, providing the plate voltage is maintained consistent. Or, it can be said that mutual conductance is the ratio of the amplification factor (mu) to plate impedance. This statement may be written:

$$\text{MUTUAL CONDUCTANCE} = \frac{\text{AMPLIFICATION CONSTANT}}{\text{PLATE IMPEDANCE}}$$

We shall again use the curves of the UX-210 tube to obtain our working values. Observe that with the plate at 90 volts the plate current is 7 ma. and with the plate at 45 volts the current is only 2 ma Thus, a 45 volt reduction on the plate causes a 5 ma. reduction in current. It can also be seen from the curve that it requires the grid to be changed 5 volts (that is, from a zero value to −5 volts) in order to effect a similar change of 5 ma. in plate current. Of course, the plate voltage must in this case remain constant or unchanged when the grid voltage is shifted from zero to −5.

To work out this example we must multiply the 5 ma. change in plate current by 1000, or 5 x 1000, and then divide this result (5000) by the required grid voltage change of 5 volts: we then have $\frac{5000}{5} = 1000.$

Then 1000 micromhos is the mutual conductance for this tube when operating at these particular "B" and "C" voltages, that is to say, at 90 volts plate and zero grid.

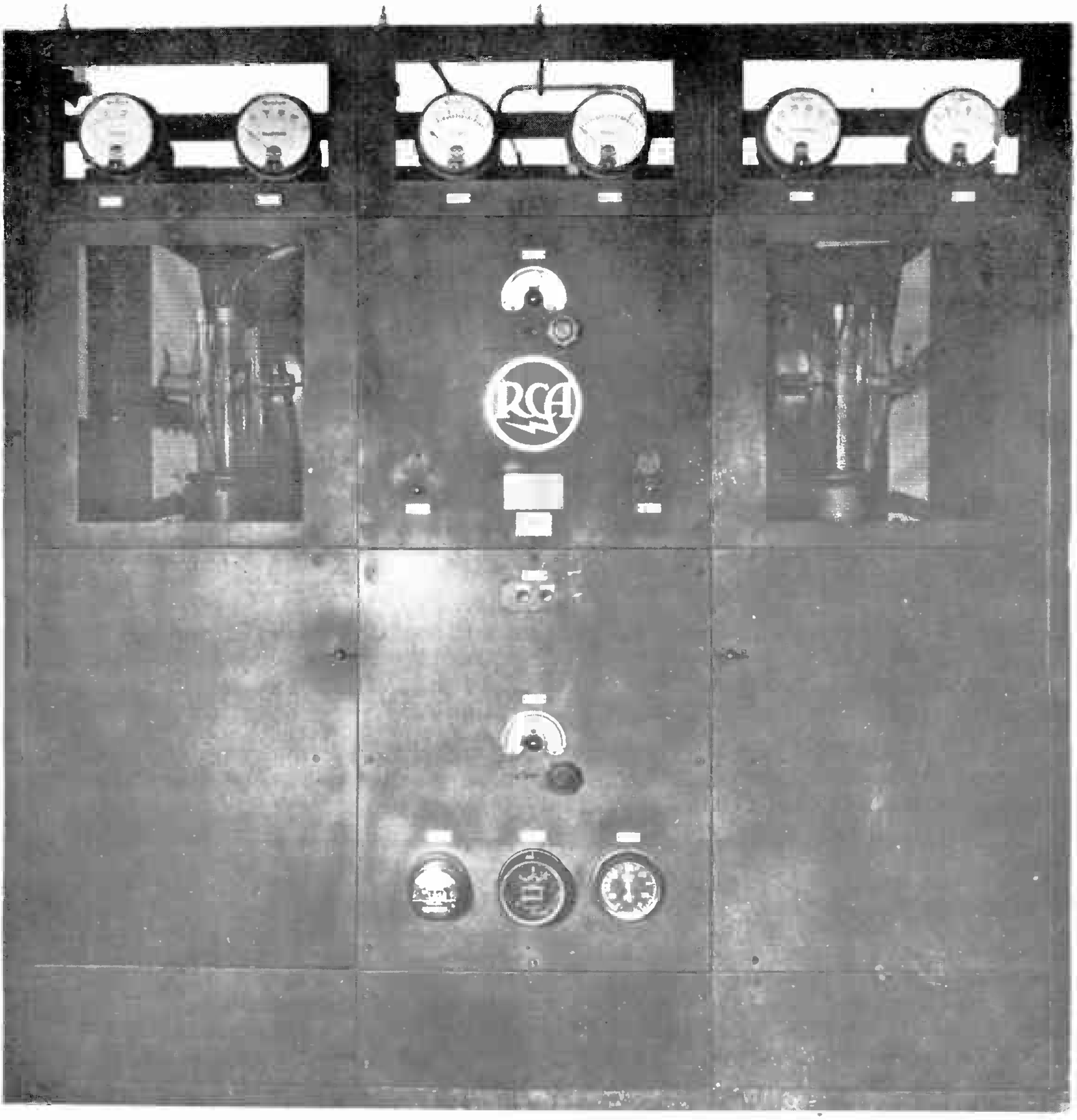
The unit "micromhos" expresses the conductance value which is the opposite to resistance. Resistance is measured by the unit "ohm", and notice that "ohm" is spelled backwards or "mho" to express conductance. Furthermore, the prefix "micro" indicates a millionth part of the unit "mho".

Any change in either plate voltage or grid voltage will cause the mutual conductance to vary, and consequently mutual conductance can be expressed only for one set of conditions, that is, with the tube working at particular "B" and "C" voltages.

At the left in Figure 16 are three curves which show the characteristics of a UX-210 when operated with plate voltages of 150, 200 and 350 volts respectively.

EXAMINATION QUESTIONS

1. What is the advantage of class C amplification over class A?
2. Where is class A amplification generally employed?
3. Why cannot class C amplifiers be used in audio-frequency work?
4. What is the advantage of a single tube of large rating over several small tubes giving the same total rating?
5. How may several power tubes of similar type be connected in order to supply a large output power to an antenna system?
6. Draw a simple sketch showing three tubes connected in the manner suggested by your answer to Question 5 immediately above.
7. Should a fuse be placed in series with the grid of a power tube and why?
8. (a) What practical indication have you that a tube has reached its limit of plate temperature and what limit should never be exceeded?
   (b) What actually causes a plate to become hot and show color?
9. What features make it possible to build and operate a tube of such relatively small dimensions but having the enormous power rating of 20 kilowatts?
10. How is the high voltage plate of a water-cooled tube maintained at a safe operating potential with regard to the water supply tank and other parts which are normally grounded?



50-KILOWATT HIGH-POWER AMPLIFIER.

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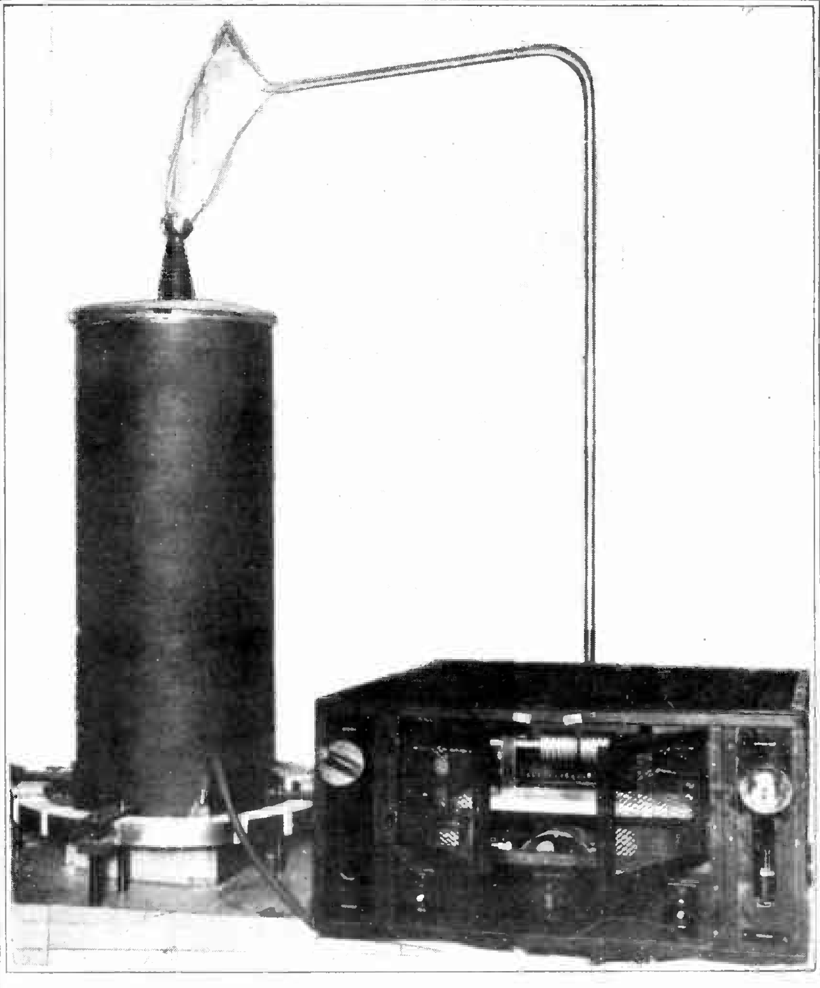

DEMONSTRATION OF A HIGH-VOLTAGE OSCILLATORY CIRCUIT PRODUCING A SPARK DISCHARGE ACROSS AN OPEN GAP.

Resonance and the Oscillatory Circuit

VOL. 14. No. 1

Dewey Classification R 140

THE OPERATOR IN THIS PHOTOGRAPH KEEPS A SHARP WATCH FOR STRAYING FREQUENCIES AND IS SHOWN MANIPULATING MICROMETER TUNING CONTROL IN THE LABORATORY OF R.C.A. COMMUNICATIONS AT RIVERHEAD, LONG ISLAND.

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RESONANCE AND THE OSCILLATORY CIRCUIT

IMPEDANCE

A coil of wire possesses a property called INDUCTANCE, and it may be made of such a wire that it offers a measurable OHMIC RESISTANCE to current flow. A condenser possesses the property called CAPACITY; if the conductivity of the leads and plates is not good, the OHMIC RESISTANCE may be of measurable value.

If we connect a coil of wire, first to a source of direct current and then to a source of alternating current, both of the same voltage, the flow of resulting current measured in amperes is greater when the coil is connected to the direct current source than when connected to the alternating current source. This result is obtained because the counter-electromotive force of self-induction in the direct current circuit is only of momentary duration, the effect being noticed only when the current is turned on or off. The effect produced when the coil is connected to an alternating source, however, is quite different. Since the current intensity is continually changing the effects of self-induction are found to be continuous. This results in a back pressure or counter-electromotive force, which must always be taken into account in determining the net voltage which causes the current to flow.

The flow of steady direct current through the coil is opposed only by its ohmic resistance, ($I = E \div R$). The flow of alternating current is impeded not only by the ohmic resistance, but by an additional obstacle due to self-induction and called REACTANCE. This is measured in equivalent ohms, and is considered positive when due to an inductance coil, and for this we use the term inductive reactance.

When a condenser is connected across a source of direct current, it will charge up to the line voltage, but will not pass any current then unless its dielectric insulation is defective. If the leads to the condenser plates have a measurable resistance, the charging rate will be slower, but the condenser voltage will finally equal the line voltage. When the condenser is connected across a source of alternating current, the flow of current is impeded not only by the ohmic resistance but by the additional obstacle called REACTANCE, which is due to the back pressure or counter e.m.f. caused by the opposition of the condenser to any change in the quantity and polarity of its charge. Since this counter e.m.f. is opposite in direction to the counter e.m.f. which would be developed in an inductance coil at that point, the reactance of the condenser or capacitive reactance. is considered negative with respect to inductive reactance.

Reactance Values. The fundamental formulas for (1) Inductive reactance and (2) Capacitive reactance are as follows:

(1) Coil reactance formula $X_L = 6.28 \times \text{Frequency} \times \text{Inductance}$.

(2) Condenser reactance formula $X_C = \dfrac{1}{6.28 \times \text{Frequency} \times \text{Capacity}}$

Where: Reactance is measured in ohms,
Frequency " " " cycles per second,
Inductance " " " henries,
Capacity " " " farads.

Impedance Values. Any inductance coil will have some value of resistance, though sometimes small, and in effect the coil resistance is in series with the coil inductance. When these two properties are present in the same material, their combined effect is termed IMPEDANCE. The relation between the values of the impedance (Z). reactance (X) and resistance (R) is given in the equation:

$$Z^2 = R^2 + X^2$$

Now this relation may be conveniently shown by what is known as the "impedance triangle", for the equation above represents Z as the hypotenuse of a right-angled triangle having X and R as its other

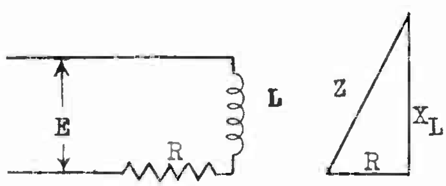


Fig. 1 - SERIES INDUCTANCE AND RESISTANCE

two sides, as shown in Fig. 1. This is for the combination of a resistance with an inductive reactive(X_L) which, as we stated before, is considered positive, and is drawn upwards from the resistance line in the figure.

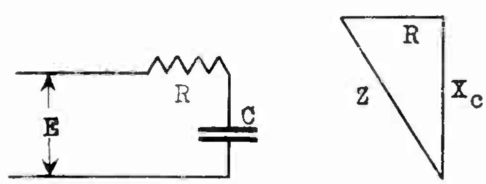


Fig. 2 - SERIES CAPACITY AND RESISTANCE

The same general equations hold good for the condenser having poor conductors, which is in effect a perfect capacity in series with a resistance. The impedance triangle for this condition is shown in Fig. 2, with the capacitive reactance (X_C) graphed downward from the resistance line because capacitive reactance is exactly opposite in effect to inductive reactance.

We have shown the resistance as being part of the coil or condenser construction. Usually the reactance of a choke coil is very high compared to its resistance; likewise the resistance of a condenser is usually low compared to its reactance. Even if they were perfect the rules would still hold for any external resistance in series with the terminals of the pure reactances.

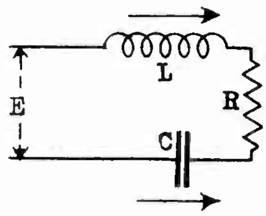


Fig. 3 - SERIES INDUCTANCE, CAPACITANCE AND RESISTANCE

Consider the impedance of a path containing a condenser, a coil and a resistance in series, as in Fig. 3. The equation for this is:

$$Z^2 = R^2 + (X_L - X_C)^2$$

because the net reactance is the difference between the inductive and the capacitive reactances.

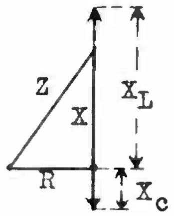


Fig. 4

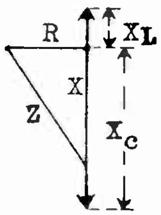


Fig. 5

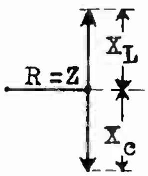


Fig. 6

There will be three conditions possible as follows:

1. X_L is greater than X_C as in Fig. 4.

2. X_L is less than X_C as in Fig. 5.

3. X_L is equal to X_C as in Fig. 6.

An inspection of the foregoing conditions shows that the impedance becomes smallest when it is equal to R, which happens when X_L and X_C have exactly the same numerical value as in Fig. 6; then $(X_L - X_C)$ becomes zero, and

$$Z^2 = R^2$$

$$\text{Whence } Z = R$$

Returning to the paragraph on reactance values, we find that lowering the frequency of an applied alternating current will decrease the inductive reactance of a coil, and increase the capacitive reactance of a condenser. Applying this principle, we can change Fig. 4 into Fig. 6 by merely lowering the frequency of the supply line. We could also change the impedance triangle of Fig. 5 by raising the frequency of the line, which decreases X_C and increases X_L until they are equal and this condition would be as shown in Fig. 6.

SERIES RESONANCE

From the foregoing we see that whenever an alternating voltage is applied to a circuit consisting of a capacitance and inductance in series there will be some frequency at which their reactance values are exactly equal, and being of opposite signs, will balance out. The alternating current flow is then determined only by the ohmic resistance of the path. This condition is called RESONANCE, and the particular frequency at which it occurs for a given circuit is called the "resonant frequency" of that circuit.

To determine this frequency in terms of circuit constants we note that the conditions at resonance may be expressed as follows:

$$X_L = X_C \text{ which is the same as: } 6.28fL = \frac{1}{6.28fC}$$

$$\text{Whence } f = \frac{1}{6.28\sqrt{LC}}$$

For currents of that frequency, the series arrangement is known as an "acceptor circuit."

Voltages in Series Resonant Circuit. If we let E equal the line voltage then line current I equals $E \div Z$. At resonance, I equals $E \div R$.

$$\text{The voltage across the coil: } E_L = IX_L = \frac{X_L E}{R}$$

$$\text{The voltage across the condenser: } E_C = IX_C = \frac{X_C E}{R}$$

From these equations we realize that in a series resonant circuit the voltage across the coil is numerically equal to the voltage across the condenser, and that each may be many times greater than the line voltage, depending on the ratio $X_C \div R$.

PARALLEL RESONANCE. In Fig. 7 we show a diagram of an inductance and a condenser connected in parallel with respect to the applied voltage. This is known as an "anti-resonant" or "rejector circuit" because this combination offers an extremely high impedance to the flow of line current at the frequency at which the inductive and capacitive reactances are numerically equal.

The difference between series and parallel resonance is determined by whether the same current set up by the e.m.f. at the source flows

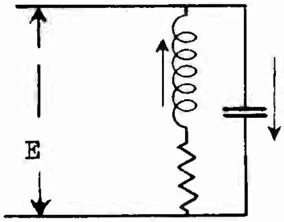


Fig. 7 - PARALLEL RESONANT CIRCUIT

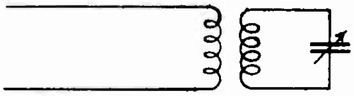


Fig. 8 - SERIES RESONANT CIRCUIT INDUCTIVELY COUPLED TO CURRENT SOURCE

through both the coil and condenser in succession, or whether the current from the source divides into two separate currents, part flowing through the coil and part through the condenser. A comparison of Figs. 7 and 8 will help you to understand this point.

Voltage in Parallel Resonant Circuit. The voltage across the coil, and likewise the voltage across the condenser, is identical with the line voltage. But we find that the current through the coil may be quite high, as shown by an ammeter connected between one side of the coil and one side of the line. In the same fashion we may insert an ammeter between one side of the condenser and the adjacent side of the line, and find a very high current there indicated. This occurs in spite of the fact that an ammeter in the other supply lead will indicate that the net current coming from the source is quite low. This sounds curious, but no more so than the case of the series resonant circuit, in which the voltage across a reactance was appreciably higher than the supply voltage. In the parallel resonant circuit, the currents through the coil and through the condenser are each about 1/4 cycle different in phase from the impressed electromotive force. The coil current lags behind the voltage, and the condenser current leads the voltage. The currents are in an opposite sense to each other, and the net current from the line can be found either by mathematical calculations or by graphing the values in a "vector diagram," of which the impedance triangle is one form.

What causes the high current we mentioned, and where does it flow? The counter-electromotive forces developed by the coil and by the condenser are opposite in direction, or 180 degrees different in phase. This is illustrated on the circuit diagram of Fig. 7 by drawing an arrow pointing up alongside the coil, to indicate the direction of the counter e.m.f. there at a given instant, and drawing an arrow pointing down alongside the condenser, indicating the opposite direction of its counter e.m.f. Forgetting the presence of the supply line, the coil and the condenser form a continuous series path, in which two counter e.m.f.'s are being simultaneously developed, and in the same direction around the coil-and-condenser circuit. This addition of counter-electromotive forces causes the flow of a quite considerable circulating current, which is limited by the resistance of the circuit, since the reactances balance out from the series standpoint. So you see that the circulating current is opposed by very little series impedance, while the line current is opposed by quite a high parallel impedance.

THE OSCILLATORY DISCHARGE — ANALYSIS

Fig. 9 represents a condenser of fairly high capacitance connected to a direct current charging source. After charging in this way, the condenser may be discharged within a reasonable time by making a metallic connection across the two plates of the condenser as shown in Fig. 10.

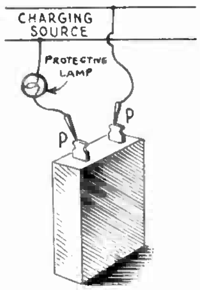


Fig. 9 - CHARGING A CONDENSER

When making the connection at plate A first, and then bringing the free end of the wire to plate B, a spark will be seen to pass between the free end of the wire and plate B just prior to the actual contact being made. This spark is only momentary and upon completion of the spark the condenser will be found to be discharged.

In watching the discharge during the short interval of time the spark is visible, it would seem that there had been but one rush of current. In reality there were many backward and forward rushes of current while the spark was in evidence. Starting with the positive plate this discharge moves through the connecting wire to the opposite plate making it positive. This plate then discharges back into the first plate. This backward and forward rush of current continues, giving up some of its energy at each reversal, which is manifested by light, heat, and sound, until the energy originally stored in the condenser has been dissipated. This back and forward motion of current (or oscillations) finally ceases.

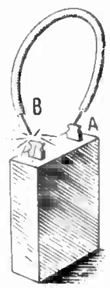


Fig. 10 - DISCHARGING CONDENSER

The number of oscillations taking place with a given charge will in this case depend mainly upon the resistance of the path between the two plates. When this path is of low resistance, there will be several cycles of current with each succeeding cycle becoming smaller in amplitude than the preceding cycle until the current dies out entirely. This gradual dying out of the oscillations is called damping.

A high resistance path will noticeably affect the discharge taking place between the two plates because the initial discharge may produce few or no reversals of current since the energy is dissipated in heat in flowing through the resistance.

For simplifying our explanation again charge the condenser as indicated in Fig. 9 and place it in series with a coiled conductor and a spark gap as in Fig. 11. A spark discharge will occur across the gap if it is properly adjusted for the condenser voltage. This discharge will consist of a series of cycles of alternating current of constantly decreasing amplitude. The events taking place during one complete cycle are explained with the aid of sketches as follows:

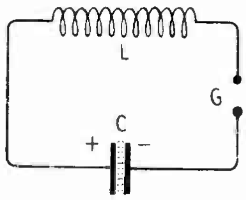


Fig. 11

Fig. 11. Just prior to the first spark, the charge in the condenser takes the form of an electrostatic field stored up between the plates. When the gap breakdown voltage is equal to the condenser terminal voltage, a spark will occur across the gap, causing current to flow through the inductance.

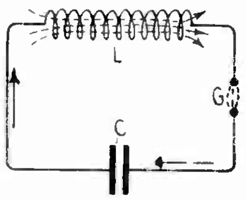


Fig. 12

Fig. 12. The flow of discharge current has set up a strong magnetic field around the inductance. As the electrostatic field reaches zero, the current reaches its maximum, and the magnetic field flux is at its maximum. This field collapses, inducing an e.m.f. which is opposite to its original counter e.m.f. and therefore in the same direction as the original impressed e.m.f.

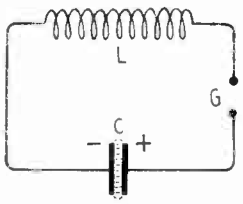


Fig. 13

Fig. 13. The e.m.f. induced in the inductance by the collapse of the magnetic field causes a current to flow in the same direction as the original discharge current. This continued current charges the condenser to the opposite polarity, but with somewhat less than the original charge, due to power losses in resistance, and the creation of sound and light energy at the gap.

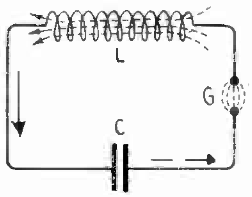


Fig. 14

Fig. 14. The first spark heated the air in the gap, lowering its resistance and lowering the critical breakdown voltage; so the gap will break down under the lessened voltage to which the condenser is now charged. The current flow resulting will be in the opposite direction to its first flow, and will build up a magnetic field again about the inductance coil but opposite in polarity to Fig. 12.

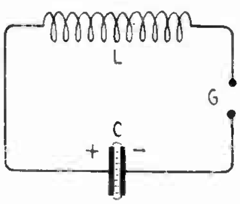


Fig. 15

Fig. 15. When the condenser is completely discharged and the current reaches its maximum, the collapse of the magnetic field will continue this second discharge current in the same direction. This charges the condenser again to its original polarity, but with a somewhat lessened charge.

This action continues, with each reversal of current becoming smaller in amplitude than the preceding one, as shown in Fig. 16.

The foregoing may be summed up by saying that when an isolated charge of electricity is applied to a condenser and the plates are connected together by an external circuit the charges do not completely neutralize at the first instant of discharge but, in fact, several alternations of current take place before a state of equilibrium is restored. When we have an inductance coil connected in series with a charged condenser as shown in Fig. 17, in which the inductance and capacity can be adjusted to various values, we can, by making the proper adjustments, cause the current to oscillate many times before it finally ceases.

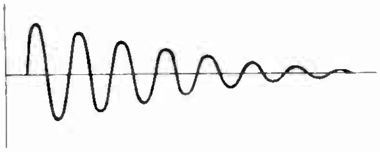


Fig. 16 - DAMPED OSCILLATIONS— EACH REVERSAL OF CURRENT IS SMALLER IN AMPLITUDE THAN THE PRECEDING ONE

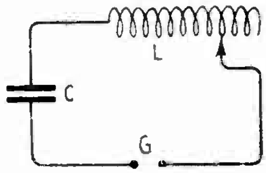


Fig. 17 - AN OSCILLATORY CIRCUIT WITH VARIABLE INDUCTANCE

In the circuit just described resistance has a marked effect upon the damping of the oscillating circuit.

EFFECT OF RESISTANCE ON OSCILLATIONS

It is clear that some work is done, with the expenditure of electrical energy, when a charge of electricity moves through a circuit such as Fig. 17. Heat is generated to a certain extent in the condenser plates, leads, and the coil; appreciably more heat is generated in the spark itself. The energy loss in sound and light radiation also represents an effective resistance.

The energy-consuming effect of all these resistances is evidenced in the fact that the current intensity for each successive half-cycle is less than the preceding one, because some of the charge is wasted during each flow from plate to plate. It is simple to see that the greater the resistance of the circuit, the less will be the charge that gets through on each reversal.

Feebly damped oscillations are desired as a general rule, and therefore the resistance of a circuit must be kept low. As the resistance is increased there are fewer and fewer cycles before the charge is so reduced that the condenser voltage becomes less than the voltage required to break down the gap.

When in any given circuit a certain critical value of resistance is exceeded, relative to the other factors of the circuit, the circuit will fail to oscillate. The first discharge of the condenser will be its last, for the charge will leak off the condenser at such a low rate that a negligible magnetic field is built up, and the condenser is not charged at all in the opposite direction.

On page 4 you were given the following formula for the frequency of a typical circuit of this kind:

$$f = \frac{1}{6.28\sqrt{L\,C}}$$

This is sufficiently accurate for most of the circuits you will use, in which the demands of efficiency require low losses in resistance.

In laboratory work, when very close measurements are taken of an oscillatory circuit, the damping factor R/2L is always considered. The formula for frequency then becomes:

$$f = \frac{1}{6.28}\sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}}$$

This formula is also useful in determining whether the circuit will oscillate. The last term of the above equation is the square of the damping factor. The equation may be worked out to determine just how high a value of resistance may be used and still have an oscillatory condition. If R is greater than $2\sqrt{L/C}$, the circuit will not oscillate.

If the resistance R is barely less than $2\sqrt{L/C}$ the circuit is just oscillatory. When the resistance is appreciably less the circuit will oscillate and it can then be put to practical use.

In the foregoing equations the fundamental units were used, namely, the henry and the farad. Since the oscillatory circuits we are chiefly interested in are for providing radio-frequency currents, it is well to have a formula for frequency in terms of the micro-units generally used, and neglecting the damping factor we have

$$\text{Frequency (in kilocycles)} = \frac{159.2}{\sqrt{LC}}$$

where L is in microhenries and C in microfarads.

RESONANCE APPLIED TO AN OSCILLATORY DISCHARGE

In order to bring out the idea of resonance as applied to radio-frequency circuits we will consider three types of systems.

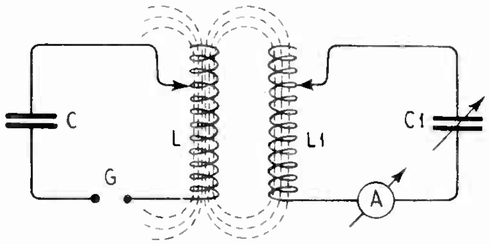


Fig. 18 - AN OSCILLATORY DISCHARGE CIRCUIT COUPLED TO ANOTHER OSCILLATORY CIRCUIT

The first consists of an oscillatory discharge circuit coupled as in Fig. 18 to another circuit having a variable capacitance, a variable inductance and a current indicating meter. The coupling is secured by placing the inductance of the latter circuit in the field of the inductance of the discharge circuit.

Let us assume the circuit LCG is set into oscillation by charging the condenser; the variable capacity C_1 is left set at some convenient value and the inductance L_1 carefully adjusted. A point will be found where the milliammeter will give a maximum deflection. At any other adjustment of the inductance the meter will indicate a lower reading. It can be shown that when the current indication is maximum, the values of L_1 and C_1 are such that their circuit has the same natural frequency as the discharge circuit. It is under such adjustments only that large values of current can be induced in the circuit L_1-C_1-A.

The same reasoning applies to the above when the inductance tap is left fixed at some value, and the condenser C_1 varied through the range of its values. Since a variable condenser provides a better means for obtaining a continuous change of values by small amounts than is afforded by the usual coil, a still more accurate determination can be made of the resonant condition of the circuit by varying C_1. Due to this fact, it may be possible to bring the circuit so closely into resonance that the current will read higher than when the frequency change was made by connecting to different turns of the coil.

The flow of current through the coupled circuit is attended by a certain loss of energy in the resistance of that circuit. This energy, being supplied by the oscillatory discharge circuit, will cause

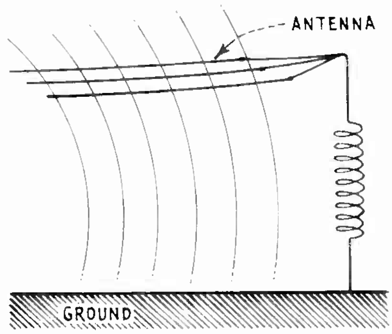


Fig. 19 - A LARGE CONDENSER IS FORMED, IN EFFECT, BETWEEN THE ANTENNA WIRES AND THE GROUND

the energy of each cycle of current in the latter to be decreased by that amount. This means that the damping of the oscillatory discharge will be greater than if the resonant circuit were removed from the influence of the discharge circuit.

The second illustration of resonance at radio frequency is given in the use of an inductance between an antenna and ground. Instead of a small condenser we have, in effect, a large condenser which is formed by the antenna wires as one plate, and the ground as the other plate. The air between constitutes the dielectric. As shown by Fig. 19 the condenser will be charged by the electrostatic field which is one component of the energy sent out into space in the form of radio waves from a transmitting station. In addition, there is an electromagnetic field component of those waves which induces currents in the antenna wires and leads due to their small inductance, even though they are straight wires. If the inductance coil has the proper value for resonating a receiving antenna with the frequency of the incoming waves, a maximum current will flow through the coil.

As a third case, if we inductively couple to the antenna coil L another circuit containing a coil L_1 and a variable condenser C, as shown in Fig. 20, the magnetic field set up about the coil L will cut the coil L_1 and induce therein an e.m.f. This will cause current to flow in the circuit L_1-C. The value of this current will be

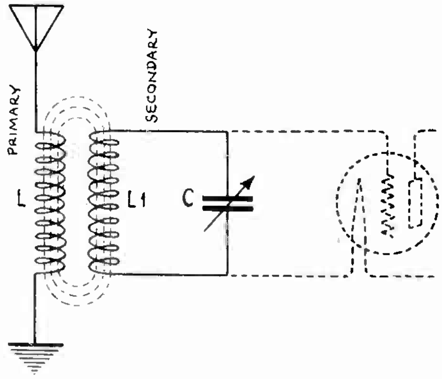


Fig.20 - MAXIMUM TRANSFER OF SIGNAL ENERGY WILL RESULT IF THE PRIMARY AND SECONDARY CIRCUITS ARE IN RESONANCE

small unless we make use of the principles of resonance again. A value may be found for the variable condenser which will make the natural frequency of its circuit the same as the frequency of the incoming signal. At this point of resonance the maximum current for that signal will flow; at the same time an appreciably high impedance is offered to currents of any other frequency which may exist in the antenna circuit. Tuning can be accomplished by using either a variable inductance or a variable capacitance, or both. Convenience in manufacturing and the fine degree of variation allowed has led most manufacturers to use variable condensers for tuning receivers. When a wide range of frequencies must be received, it is sometimes good practice to have the inductance variable in steps, with the condenser providing the fine variation for accurate tuning.

INDUCTANCES IN SERIES IN AN OSCILLATORY CIRCUIT

In practice we find oscillatory circuits which require more than one inductance coil for their operation. If the inductances have no

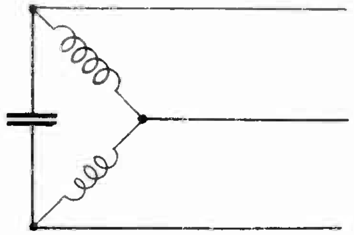


Fig.21 - DIVIDING INDUCTIVE REACTANCE INTO TWO SECTIONS, AS IN THE ORIGINAL HARTLEY CIRCUIT

mutual field flux (zero coupling between them) the total inductance will be the sum of the separate inductances.

However, dividing the total inductance into separate units permits us to use these units in different ways. In Fig. 21 is shown the resonant circuit used in a particular vacuum tube oscillator known as the "Hartley" oscillator. The resonant voltages across the coils are numerically in direct proportion to their inductances. The usefulness of the circuit consists in the phase difference between the voltages across the coils. Whenever the top condenser plate is positive, the lower plate is negative. The upper lead is then positive with respect to the center lead, and the lower lead is negative with respect to the center lead. Opposition of phase of these voltages holds good throughout all the polarity reversals of the oscillating current.

CAPACITIES IN SERIES IN AN OSCILLATORY CIRCUIT

Just the opposite use of reactances is found in the resonant circuit of the "Colpitts" oscillator, shown in Fig. 22, in which a single inductance is used, but the net capacity for resonance is secured

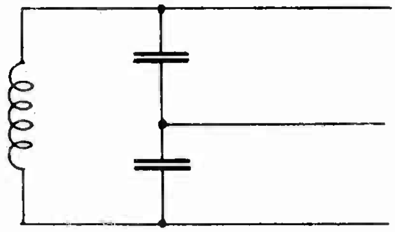


Fig. 22 - DIVIDING CAPACITIVE REACTANCE INTO TWO SECTIONS, AS IN THE COLPITTS CIRCUIT

through the use of two condensers in series. When the charges of the condensers are such that the upper lead is positive with respect to the lower lead, then the upper lead is positive with respect to the center lead, and the lower lead is negative with respect to the center lead. Phase opposition of these two voltages holds good throughout the current reversals of the oscillatory circuit.

The voltages across the condensers are in direct proportion to their capacitive reactances, and therefore in inverse proportion to the capacities of the condensers.

EXAMINATION QUESTIONS

1. What conditions must be met in a series type alternating current circuit, which contains both inductance and capacity, to obtain a maximum current flow?

2. Will a perfect condenser retain its charge over a period of time?

3. When a condenser is discharged is there only one rush of current?

4. How will a high resistance path affect the discharging of a condenser?

5. Explain briefly in your own words the action of the discharging condenser when inductance is in the circuit.

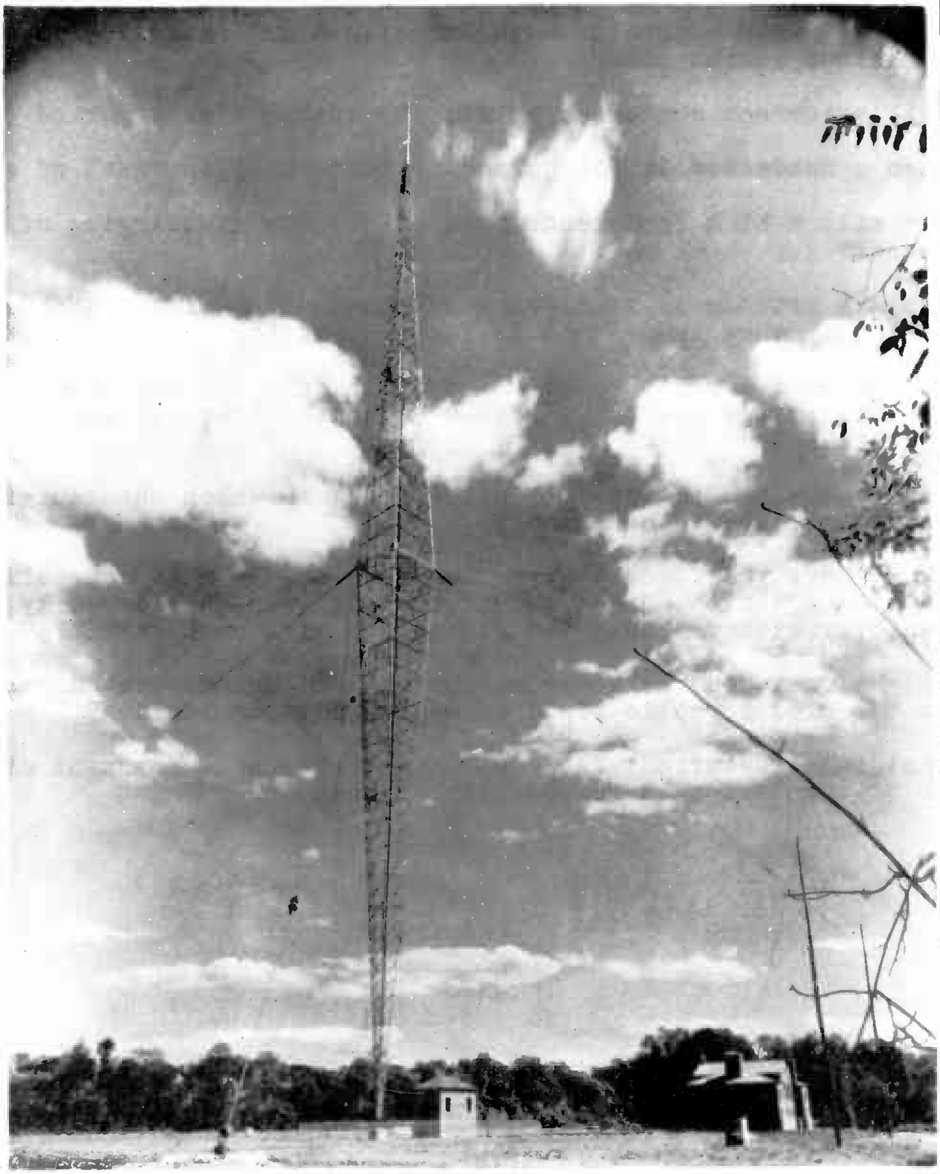
6. In tuning a circuit to resonance with only one variable reactance what advantage has the variable condenser over the usual variable inductance?

7. Is it possible to tune a receiving set in which the capacity and inductance are both variable?

8. Which have you found by experience to be the most generally used method of tuning, fixed inductance with variable capacity, fixed capacity with variable inductance, or with both variable?

9. In what way does a receiving antenna and ground system respond to the electrostatic field of a transmitting station?

10. What rule of current flow determines whether a resonant circuit is of the series or the parallel type?



THE 665-FT. VERTICAL ANTENNA OF STATION WABC AT WAYNE, N. J., IS RESONATED BY MEANS OF INDUCTANCES AND CAPACITORS HOUSED IN THE SMALL BUILDING AT THE FOOT OF THE MAST.

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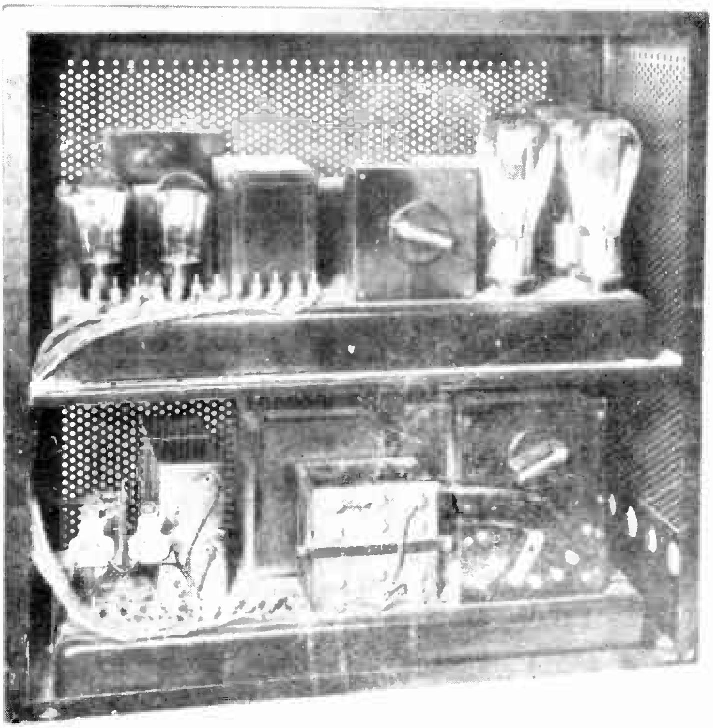

BOTH THE VOLTAGE AND POWER AMPLIFIERS IN THIS EQUIPMENT ARE BUILT INTO A SINGLE UNIT LOCATED IN THE UPPER COMPARTMENT. TWO UX-112A TUBES (LEFT) AND FOUR UX-200 TUBES (RIGHT) ARE IN PUSH-PULL ARRANGEMENT.

Audio-Frequency Power Amplifiers
Principles of Push-Pull Amplification

VOL. 14, No. 2

Dewey Classification R 140

FOREWORD

This lesson deals with the principles underlying the theory of push-pull audio-frequency amplification. The text, written by members of the instruction staff at R.C.A. Institutes for "Motion Picture Projectionist" and "Radio News", is presented with illustrations by courtesy of these publications.

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AUDIO-FREQUENCY POWER AMPLIFIERS

PRINCIPLES OF PUSH-PULL AMPLIFICATION

Although numerous amplifier circuits have been brought out from time to time which are departures from generally accepted practice, there is one type of circuit that has been accorded a steadily increasing popularity since its invention and introduction to the field. Today it is more firmly entrenched in technical favor than ever before. We refer to the push-pull circuit.

The characteristic that a push-pull amplifier has of delivering large amounts of undistorted voltage or power output has led to its almost universal adoption in systems where a high-grade quality output is not only desirable, but essential. Such systems, as referred to above, exist in high-quality broadcast transmitters and receivers, talking picture and public address amplifiers, etc.

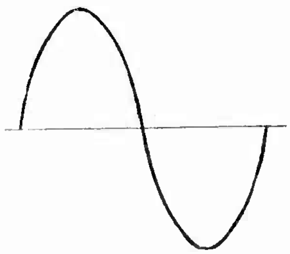


Fig. 1 - THE SCHEMATIC ILLUSTRATION OF A-C SINE WAVE FORM.

Before proceeding with the study of this type of circuit, it will be of great value to the student to review the subject of wave shape and harmonic analysis.

HARMONIC ANALYSIS.

Different shapes of curves have different names, and in the majority of simple curves the names given are obtained from their mathematical derivation. A wave is merely a graph which shows the relation (in a case of a voltage) between the value of the voltage and the particular instant of time at which the voltage has that value. The shape of the wave (voltage or current) existing in a-c work has the familiar shape shown in Fig. 1 and it is called a sine wave.

Just why the curve has the shape shown in Fig. 1 is as follows:

Assume a wire rotating in a magnetic field as shown in Fig. 2A. The upper pole is a north pole and the lower pole is a south pole. Now, a wire cutting a magnetic field at right angles to the field will develop a voltage between the ends of the wire. The amount of this voltage depends on (1) rate of cutting the field, (2) length of wire in the field, and (3) the strength of the magnetic field being cut. If the wire loop is being rotated at constant speed and the length of wire is always the same, then the voltage generated in this wire depends entirely on the angle at which the wire loop cuts the magnetic field. The intensity of the field being constant and from north to south, the voltage generated in the wire then is at maximum when it is moving at right angles to the field and zero when it is moving parallel to the field. The voltage for various positions of the wire is shown in the sketch at the right of Fig. 2C.

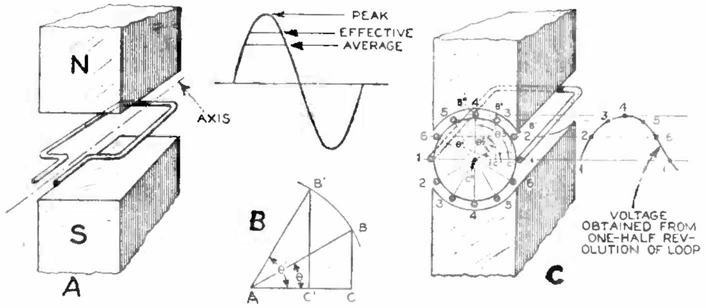


Fig. 2 - THESE FIGURES SHOW THE POSITION OF A WIRE LOOP IN A MAGNETIC FIELD, AND CURVES INDICATING THE VALUE OF VOLTAGE GENERATED AT THE VARIOUS POSITIONS OF THE LOOP.

In mathematics the sine of an angle in a right triangle is defined as the ratio of the length of the side opposite the angle to the length of the hypotenuse of the triangle.

This is indicated by the triangle in Fig. 2B. The ratio of the length of the side, BC, to the length of the hypotenuse, AB, is called the sine of the angle. In symbols:

$$\sin \theta = \frac{BC}{AB}$$

If the size of the angle be increased from θ to θ_1 , and if the length of the hypotenuse remains the same, then the sine of the angle θ_1 is larger than the sine of the angle θ. Or in symbols:

$$\frac{B^1C^1}{AB^1} = \theta_1 \text{ is greater than } \sin \theta.$$

This can be seen from an inspection of Fig. 2B. In this figure $AB = AB^1$, but B^1C^1 is greater than BC. Therefore $\sin \theta_1$ is greater than $\sin \theta$. The larger the angle θ becomes the greater the sin of θ becomes, until $\theta = 90^{\circ}$. At this point

$$\frac{B^1C^1}{AB^1} = 1 \text{ and } \sin \theta_1 = 1.$$

If θ is made larger than 90°, then the sin of θ decreases from its maximum value to zero.

Consider now the diagram of Fig. 2C. When the ends of the wire are in position 1 no voltage is generated, since the wire is moving parallel to the main field. In position 2 the voltage generated is small, being given by the length B^1C^1. When the wire reaches positions 3 and 4 the magnitude of the voltage generated is given by the lengths B^2C^2 and B^3C^3, respectively. For position 4 the voltage generated is at maximum, the wire cutting the field at right angles. The lengths B^1C^1, B^2C^2, B^3C^3 correspond to the instantaneous values of the voltage generated when the wire reaches positions 2, 3 and 4, which also correspond to angles θ_1, θ_2 and θ_3.

For any position of the loop, the sine of the angle made with respect to the horizontal position (which corresponds to zero voltage in the wire) is given as the ratio of instantaneous value of the voltage to the maximum value. Thus:

$$\text{sine } \theta = \frac{\text{instantaneous value}}{\text{maximum value}}$$

or, in symbols:

$$\text{sine } \theta = \frac{\mathcal{E}}{E_m}$$

where:
$\mathcal{E}$ = instantaneous value
E_m = maximum value

or: $\mathcal{E} = E_m \text{ sine } \theta$

The shape of the curve merely shows the manner in which the instantaneous value of the voltage varies as the loop completes one revolution. It must not be supposed that if it were possible to see the voltage existing between the terminals of the loop, it would have the shape as shown in Fig. 1. The proper viewpoint to assume is that the intensity of the voltage existing would vary from instant to instant in the manner pictorially represented by Fig. 1. The effective (r.m.s.) average and peak values are as indicated in Fig. 2.

By definition any wave is a distorted wave if it does not follow the variations specified by a sine shape. Since all calculations are based on the assumption of a pure sine wave, then, if a distorted wave is present, the proper corrections must be applied to compensate for this irregularity. Distorted waves result from various causes, such as unsymmetrical design of an alternator, overloading of a vacuum tube or by the use of iron-core inductances. The latter two will be discussed more in detail later.

If a distorted wave is present, then formulas which were originally derived on the assumption of the application of a pure sine wave will yield erroneous results if a distorted wave is used. For convenience a distorted wave may be resolved into a pure sine wave of the same frequency as the distorted wave (which pure sine wave is known as the fundamental), plus pure sine waves of frequencies which are multiples of the fundamental frequency. These latter waves are known as harmonics. Any distorted wave is a composite of a fundamental and harmonic frequency. This is illustrated in Fig. 3.

Referring to the figure, the original distorted wave can be completely resolved into a fundamental and a second harmonic, but this is a rare occurrence. Usually not only the second, but the second, third, fourth, fifth, etc., harmonics must be added together with the fundamental to obtain the original distorted wave. However, different types of distortions can be resolved into a fundamental and either even or odd harmonics. By this is meant that if a given distorted wave can be conveniently resolved into a fundamental and, let us say, even harmonics, then it must not be supposed that absolutely no odd harmonics exist, but rather that the maximum amplitude of the odd harmonics that must be added to give the original distorted wave is so small compared to the maximum amplitude of the even harmonics that the odd harmonics may be completely neglected. The reverse, of course, is also true regarding a distorted wave containing a predominance of odd harmonics.

It cannot be stressed too strongly that even though we speak of a distorted wave as containing harmonics, that these harmonics exist as separate waves distinct from the distorted wave, but rather the

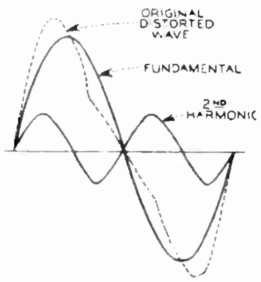


Fig. 3 - ILLUSTRATING THE BREAKING DOWN OF A SINE WAVE.

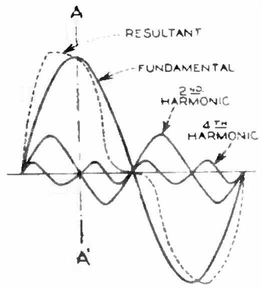


Fig. 4 - SHOWING A DISTORTED WAVE COMPOSED OF THE FUNDAMENTAL, 2ND AND 4TH HARMONIC FREQUENCIES.

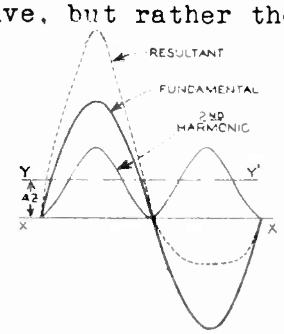


Fig. 5 - CURVES SHOWING THE PRESENCE OF A STRONG 2ND HARMONIC WITH THE FUNDAMENTAL.

reaction of the distorted wave upon the circuit is exactly the same as if the distorted wave were replaced by a fundamental frequency and associated harmonics.

It can be determined from the shape of the distorted wave whether it contains even or odd harmonics or whether it contains both even and odd harmonics.

Distorted waves, as previously stated, result from various causes. Let us first consider the shape of a wave resulting from a vibration originating, let us say, from a violin string. Also let us suppose that this wave contains a predominance of even harmonics. If only the second harmonic is considered, then the shape of the resultant wave is as shown in Fig. 3. If the second and fourth harmonics are great enough to be considered, then the resultant wave will have the shape shown in Fig. 4.

An inspection of the resultant curves of Figs. 3 and 4 reveal that the general shape is exactly the same. Each loop of the wave is unsymmetrical about a line drawn through the center of the loop such as AA^1 in Fig. 4. The left side of the loop has not the same shape as the right side of the loop. This type of resultant curve containing even harmonics is present in outputs of musical instruments and voice. The currents flowing through the primary of a transformer, with the secondary open and no direct current flowing through the primary, has the shape of the curve in Fig. 3, which is due to the hysteresis loop of the iron. It should be noted that the amplitude of the upper loop is equal to the amplitude of the lower loop.

There exists another type of distorted wave which bears a very definite relation to quality of reproduction. This type of wave is the main cause of distortion in amplifiers and is shown in Fig. 5. An analysis of the above shape reveals the presence of a very strong second harmonic. This shape would result if an amplifier tube were worked below the midpoint of the straight portion of the grid voltage-plate current curve. The flux variation in the core of a transformer would have this shape if the core were first saturated by sending d-c through the primary winding and then superimposing the pure sine wave of voltage. The fundamental and second harmonic of this type of distortion is as indicated in Fig. 6. Both Figs. 5 and 6 are similar in shape except that they are 180° out of phase.

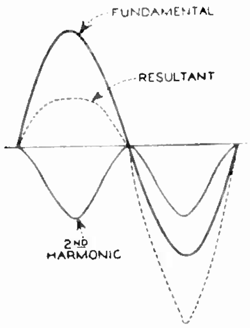
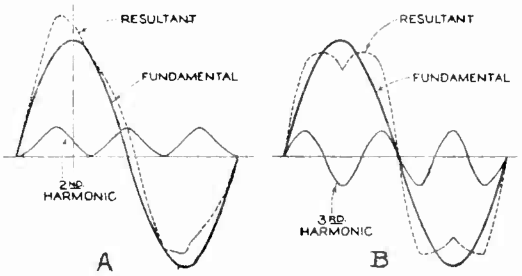


Fig. 6 - DEPICTING THE PRESENCE OF A STRONG 2ND HARMONIC, BUT 180° OUT OF PHASE IN COMPARISON TO FIG. 5.



Figs. 7A and 7B - TWO TYPES OF WAVES CONTAINING ODD HARMONICS WHERE IN ONE CASE (7A) THE ODD HARMONIC LIES ENTIRELY ON ONE SIDE OF THE ZERO AXIS WHILE IN THE OTHER (7B) IT IS SYMMETRICALLY ABOUT THIS AXIS.

It is to be particularly noted that in these types of distortions the second harmonic is entirely above or below the zero axis. This must be so if the amplitude of one loop is greater than the amplitude of the other loop. A physical explanation of this is as follows.

Let the line XX^1 in Fig. 5 represent the normal plate current in a vacuum tube with no signal impressed. Then if a signal now be impressed on the grid of the tube and this tube is worked on the curved portion of its characteristic, the shape of the distorted wave will be as shown in Fig. 5. The average plate current is now raised from the line XX^1 to the line YY^1, an increase of ΔZ. This is evident from the different amplitudes of the wave. The increase in plate current being greater than the decrease, the average value (as read by a d-c meter) will be higher. This is similar to the action which takes place in a detector tube. When a signal is impressed, the average plate current rises (in a linear detector). Incidentally it is a known fact that the detector introduces a strong second harmonic. It is also to be noted that the fundamental does not produce an average increase in plate current, since both loops are equal, but it is the harmonic introduced that is the cause of this increase. The steady increase must rise to the axis of the second harmonic since a line drawn through this axis is the average of the harmonic wave. It therefore follows that if in any wave shape having one loop greater than the other a strong second harmonic exists which lies on the side of the zero line having the greater loop.

The shape of a wave containing harmonics is dependent entirely upon the manner in which the harmonics have been introduced. If these harmonics have been introduced by the device producing the sound, then the resultant wave form, even though it departs from a true sine wave, is not ordinarily spoken of as being distorted, but it is said to be complex, for the reason that the harmonics so introduced are essential for naturalness and intelligibility. It is only the harmonics present that enable one to discriminate between one instrument and another or one voice and another. Since the harmonics introduced by a vacuum tube or any electrical device are of a parasitic nature and were not present in the original sound itself, the waves resulting from these parasitic harmonics are said to be truly distorted.

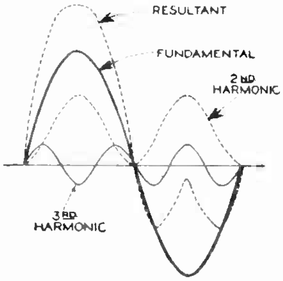


Fig. 8 - THE RESULTANT WAVE OBTAINED BY THE COMBINATION OF A FUNDAMENTAL, A THIRD AND SECOND HARMONIC

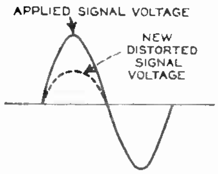


Fig. 9 - DISTORTION DUE TO GRID GOING POSITIVE.

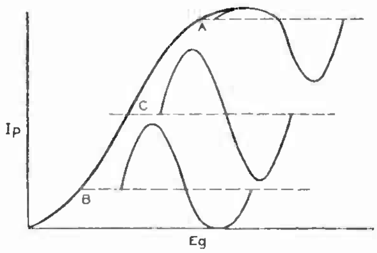


Fig. 10 - CURVES TO ILLUSTRATE PLATE CIRCUIT DISTORTION.

A study of waves containing odd harmonics indicates the presence of two general types. One where the odd harmonic lies entirely on one side of the zero axis and one where it is symmetrical about the zero axis. These two types are indicated in Figs. 7A and 7B, respectively. An examination of the resultant distorted wave of Fig. 7A shows that the upper loop is not symmetrical about a line drawn through the center of the loop, the amplitude of the upper loop is greater than the amplitude of the lower loop and that the base width of the upper loop is greater than that of the lower loop.

A study of the resultant wave of Fig. 7B shows that each loop is symmetrical about a line drawn through the center of the loop and the amplitude of both loops are the same.

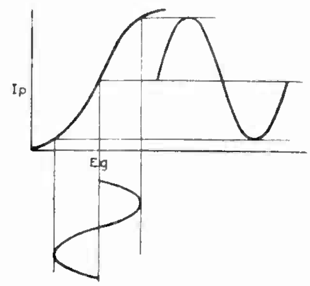
It is extremely difficult to obtain the distorted wave indicated in Fig. 7A, but the shape shown in Fig. 7B is of a more common complex nature and is present in sound produced by voice, musical instruments, etc. The resultant obtained by a combination of a fundamental, a third harmonic symmetrical about the zero axis and a second harmonic which lies entirely above the axis is shown in Fig. 8.

There are, of course, many other types of distorted waves which may result from the addition of even and odd harmonics, but all of them cannot be taken up in a discussion whose scope is somewhat limited. The above types, however, have a direct application in push-pull amplifiers.

Let us consider first the various types of harmonics and the manner in which they may be generated by a vacuum tube. Of this there are two types, grid distortion and plate distortion.

GRID DISTORTION. If a sine wave of alternating voltage be applied to the grid of a tube, and during a portion of the cycle the grid goes positive, the shape of this voltage will be distorted due to the grid going positive, causing grid current to flow, which in turn causes a decrease in the signal voltage by the impedance drop. The shape of the sine wave will be changed to the form shown in Fig. 9.

It is to be noted that the grid only goes positive during the positive half of the cycle. If the grid is positive during both halves of the cycle, then both halves of the wave will be reduced in amplitude. In general, however, the upper loop will be smaller than the lower loop. From a previous analysis of this type of wave, Fig. 5, this distortion signifies an introduction of a second harmonic.



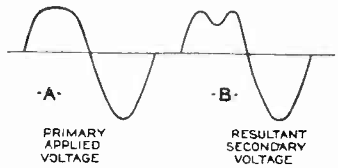


Fig. 12 - CURVE "B" IS THE RESULTANT DUE TO PRESENCE OF A DISTORTED WAVE

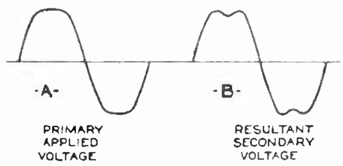


Fig. 13 - THIS TYPE OF WAVE CONTAINS ONLY ODD HARMONICS

Fig. 11 - THIS TYPE OF WAVE CONTAINS A PREDOMINANCE OF ODD HARMONICS

PLATE CIRCUIT DISTORTION. Assume a grid voltage, plate current characteristic as shown in Fig. 10. If for some reason the tube is worked at point A or point B and the form of the grid voltage is sinusoidal, then one-half of the plate current loop will be greater than the other half, as shown in Fig. 10. Such a plate current form also contains a second harmonic; this, as previously pointed out, is what happens in a linear detector.

If the tube now be worked at the center of the curve, point C, which is the proper operating point for an amplifier tube, and a large signal is impressed on the grid so that both the upper and lower bends of the curve being used then the form of the plate current will be as shown in Fig. 11. This type of wave contains a predominance of odd harmonics.

If a pure sine wave of voltage is applied to the primary of a loaded transformer, then the secondary voltage will also be a sine wave. If a distorted wave of the type shown in Fig. 5 is impressed, then the form of the wave of the secondary will be as shown in Fig. 12B. The secondary voltage therefore contains not only a second but a third harmonic, this latter harmonic having been introduced by the transformer. This type of wave is discussed under Fig. 8.

If a distorted wave which has both top and bottom loops flat is applied to the primary of the transformer the form of the secondary voltage will be as shown in Fig. 13. This type of wave contains only odd harmonics. This type of wave is discussed under Fig. 7B.

In any case where the primary voltage is flat-topped the secondary voltage contains a dip. This is evident from the fact that the secondary voltage depends upon the change in primary voltage. During the flat portion of the wave the change in voltage is practically zero, which means that during this flat portion the secondary voltage will drop.

Inductance wire carrying a current generates a magnetic field around it in a direction given by the right-hand rule. If this current be alternating, then the intensity of this magnetic field is in time phase with the current. Since the intensity of the field is measured by the number of magnetic lines per square inch, then the number of magnetic lines per square inch is in time phase with the current. A wire, if it is being cut by a varying magnetic field, has induced in it a varying voltage; and the magnitude of this voltage is dependent upon the length of the wire in the field being cut, the flux density and the frequency of variation of the flux. The generated voltage is given by the formula

$$E = B f l$$

where B = flux density
f = frequency
l = length of wire.

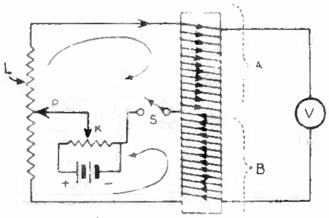


Fig. 14 - VOLTAGE IS APPLIED TO THE COIL BY MEANS OF POTENTIOMETERS.

If this wire is wound in a coil and if the practical system of potential difference (the volt) is desired, then the formula for generated voltage becomes

$$E = \frac{4.44 \, f \, N \, B}{10}$$

Where:
N = Number of turns.
4.44 = Constant based on the assumption of sine wave.
B = Flux density.

Since the current through an inductance lags the impressed voltage by 90°, the voltage generated in the coil is maximum when the current is passing through itz zero value. This also follows from the statement previously made that the generated voltage is always a maximum when the change in current is greatest. No voltage is generated in a coil when the current is not changing in value.

It is important to remember that the direction of the induced voltage is dependent upon the direction of current flow through the coil. If the coil has more than one applied voltage, each one of these voltages being applied to a different section of the coil, then the direction of the induced voltage in each section of the coil not only depends upon the direction of current flow through each section, but also upon the direction in which each section is wound and whether this current be increasing or decreasing.

Consider the coil depicted in Fig. 14. This coil is wound continuously in one direction and is tapped at the exact center of the winding; the end terminals of the potentiometer P are connected across the extreme terminals of the coil. A variable voltage is interposed between the slider on P and the center tap of the winding. The variable voltage is obtained by means of an additional potentiometer K placed across the battery. The voltmeter V is placed across the ends of the coil to indicate the total generated voltage across the coil.

CASE I. Suppose both potentiometer sliders be kept in their center positions and switch S suddenly closed, current will flow through the circuit and through the coil in the directions shown in Fig. 14. Since the coil is wound continously in one direction and the current in section A is flowing in the opposite direction to the current in section B, the voltage generated in section A will be opposed to the voltage generated in section B (these being 180° out of phase) and the voltmeter V which indicates the total voltage generated across the entire coil will not show any indication.

CASE II. Suppose switch S be open and the potentiometer slider be moved to point L, then if switch S be suddenly closed the current through section A of the coil will be greater than the current through section B. The voltage generated across section A will be greater than the voltage generated across section B. The voltmeter V will indicate and its indication will be equal to the difference between the voltages generated in sections A and B.

It should be noted that thus far the circuit is merely a simple bridge affair and the considerations outlined in cases I and II apply when the bridge is balanced and when it is unbalanced.

CASE III. Suppose switch S is now closed and the sliders of both potentiometers be kept at their center positions. A steady current will flow through the windings of the coil. If the slider of potentiometer P now be moved to position L the current through section A increases above its normal value, generating a certain voltage across section A. At the same time the current through section B decreases below its normal value, generating a voltage in section B which adds to the voltage generated in section A, producing a voltage across the entire coil which is the sum of the voltages in each section. The reason for the voltage generated in section B now being additive is that, whereas, in case II the currents in each section were increasing in opposite directions, the voltages generated were 180° out of phase, while in this consideration the current through section B suffered a different type of change. That is, it was decreasing instead of increasing, which resulted in a reversal of the polarity of the voltage generated in section B.

With the above facts in mind, we can now proceed to study the push-pull amplifier, and the reasons for its use.

In the early days of the art, if more power was desired from an amplifier, there were two means of obtaining it. One way was to double up on the number of output tubes used, i.e., connect another tube in parallel with the first. This meant that the two grids and the two plates were connected together respectively. In operation, the pair of tubes functioned practically as one tube of twice the dimensions and hence twice the power output.

The second method was actually to use a larger tube. This, however, is essentially the same as using two tubes in parallel, at least from a theoretical viewpoint.

The push-pull circuit was invented by Colpitts. Basically, the arrangement was such that the grids of the two tubes acted opposite to each other upon their respective plate currents, and the latter were so coupled to the load as to have an additive effect. The net effect was that the two tubes acted as if they were connected in series to the load, much like two locomotives coupled to a freight train.

CIRCUIT EMPLOYED. In order better to understand the operation of this system, let us examine the circuit employed. Refer to Fig. 15.

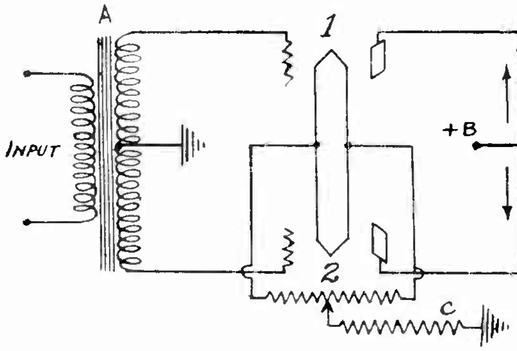


Fig. 15 - PUSH-PULL AMPLIFIER CIRCUIT DIAGRAM.

Two tubes, 1 and 2 are employed, together with an input transformer "A," and an output transformer "B." As can be seen from Fig. 15, the secondary of "A," and the primary of "B" are center-tapped. The signal—from whatever source we desire—is fed into the primary of "A." An alternating voltage is induced in the secondary. If we ground the mid-point, as shown, then at one instant, the end connected to the grid of tube 1 will be positive with respect to ground, and simultaneously, the other end, connected to the grid of tube 2, will be negative with respect to ground. A half cycle later, conditions will be reversed. The grid of 1 will be negative, and the grid of 2 will be positive with respect to ground.

Let us suppose for the moment, that the filaments are connected in parallel and grounded at the mid-tap of their supply. Then, when one grid is positive with respect to the filaments, the other will be negative, since these are their potentials with respect to ground, and both filaments are grounded.

The plate current of the tube whose grid at that moment is positive with respect to the filament, will increase; the plate current of the other tube will decrease, because its grid at that moment is negative with respect to its filament.

It will be noted that the plate current is fed to the primary of the output transformer "B" through its center tap. The two arrows show the direction of the current to the plates of the two tubes. It can be seen from the arrows that the two currents are opposite. As long as the currents are steady (direct current), the flux produced by either will be steady. However, if the two currents are equal, the flux produced will be zero, since the currents flow in opposite directions through the primary windings, and nullify each other magnetically.

EFFECTS ADDITIVE. If the current to tube 1 increases for instance, its flux increases. This change in flux induces a voltage in the secondary of "B" in the direction, let us say, toward the top of the drawing. Now if the current to tube 2 decreases, it will not "buck" the current going to tube 1 as much as before, so that the latter current can produce more flux than it otherwise could. The result is that the flux change will be greater than before, and the voltage in the secondary of "B" will be increased. Thus, an increase in the current to tube 1, or a decrease in the current to tube 2, will each induce a voltage in the same direction in the secondary of "B," i.e., the current changes are additive in effect, and one current change is just as effective as the other in inducing voltage in the secondary. Thus, the two tubes act in series, as far as the secondary is concerned, since their voltage inducing effects in the secondary are in the same direction and hence additive.

When the grids of the two tubes assume polarities opposite to those assumed above, the current in tube 1 decreases, and that in tube 2 increases, and a voltage is induced in the secondary in the opposite direction but, nevertheless, the two tubes are still additive in their effects.

In this way twice the alternating voltage is induced in the secondary by the two tubes as compared to that which one tube alone could produce, so that the two tubes at all times act in series. By a similar method of reasoning it can be seen that the internal plate resistances of the two tubes are in series, so that we have twice the plate voltage of one tube acting through twice the plate resistance of one tube to feed current into the output transformer and load.

APPLICATION OF BIAS. So far we have considered the circuit as operating without any grid bias, i.e., if no signal is impressed upon the grids, they are at ground potential, and hence at the same potential as the filaments. By inserting resistor "C" between the center tap of the filament supply (here obtained by means of a potentiometer and ground) the plate currents, in flowing back to the filaments, have to pass through "C," and cause a voltage drop in it of such direction as to make the filaments positive with respect to ground. Since the grids are normally at ground potential, they are now negative with respect to the filaments, that is, have a negative bias with respect to the filaments. Resistor "C" is thus the well-known grid biasing resistor, only a by-pass condenser is not usually connected in parallel with it, as will be explained later.

In this arrangement, if one grid receives a positive voltage from the incoming signal, its negative bias is reduced. The other grid simultaneously receives a negative voltage from the incoming signal, so that its negative bias is increased. The signal must be below the value that would make the first-mentioned grid go actually positive with respect to the filaments, or the other grid go so negative that the plate current is reduced to zero before the grid has reached its lowest negative value. These limitations to signal strength are exactly the same as those for a single tube amplifier operating without distortion. In short, a push-pull amplifier does not work the tubes any more completely than an ordinary amplifier, so that each tube delivers the same output in either case. Hence the output of the two tubes in push-pull arrangement is approximately twice that in a single tube amplifier, and not three to four times as much, as is so often claimed.

OUTPUT POWER. So far it would appear we have gained nothing by putting the tubes in push-pull arrangement instead of in parallel. It is seen that the transformers used require center taps, and hence are apparently more expensive to manufacture than those used in the ordinary cascade amplifier. Now suppose there is greater capacity between the turns of one-half the secondary of "A" than the other, the phase between the voltages applied to the two grids will not be the same, i.e., the voltages applied to the two grids will not go through their maximum values simultaneously.

A similar effect may be obtained if the leakage reactance between one-half of the primary of "B" with respect to the secondary is not the same as that of the other half. In either case the output will not be twice that of one tube, but somewhat less, depending upon the phase angle between the two voltages, so that the full benefit of the two tubes is not realized.

ADVANTAGES OF THE CIRCUIT. Nevertheless, this circuit has so many important advantages that the above consideration is of little comparative consequence. In the first place, examination of Fig. 15 shows that the steady or average value of the d-c current of either tube (as measured by a d-c milliammeter), flows in a direction through its half of the primary of "B" opposite to that of the plate current of the other tube. Thus, if the tubes have nearly equal plate currents, they practically balance each other magnetically, and produce little or no steady (d-c) flux in the core of "B." Thus, the core can be made smaller without any danger arising of its becoming saturated, and the importance of this may be appreciated when it is realized that the plate current of either power tube is quite large and would saturate even a larger core if present there by itself. Of course, on the other hand, care must be taken in operation to see that the plate currents are nearly balanced, otherwise saturation will occur. As an example in a certain output transformer designed for use with two UX-245 tubes, the difference between the two plate currents must not exceed five milliamperes. In the case of large tubes, they are arranged so that the grid bias of each may be adjusted independently, so that the plate currents can be matched.

The second advantage--that of cancellation of the second harmonic, is more generally appreciated. To demonstrate this effect, we shall refer to Figs. 16, 17 and 18. In Fig. 16 we have plotted the variation in plate current Ip with that of grid voltage Eg for an ideal tube. In such a tube the plate current (measured along the vertical axis) is strictly proportional to the grid voltage (measured along the horizontal axis), and the graph is a straight line, because only in the case of a straight line is the rise in proportion to the distance along the horizontal direction. In particular, if the voltage applied to the grid were of sine wave in shape, the variation in the plate current would be sine wave in shape.

In practice, however, tubes do not have such ideal characteristics. Instead, the graph is that shown in Fig. 17 (solid line). Here, as the grid voltage is increased from a negative direction, as it reaches the value at point "A," the plate current begins to rise rapidly, but still not as abruptly and sharply as in Fig. 16 "A." Thereafter, it increases up to the value "B" at a rate faster than the increase (in a positive direction) of the grid voltage. From "B" to "C" the plate current begins to taper off until finally it ceases to increase, and may even decrease.

The reason is that all the electrons emitted by the filament are now all drawn to the plate, and the current can increase no further, as the quantity of electrons are limited by the filament. Furthermore, if the grid potential be increased to a value greater than that of the plate, it will rob the plate of electrons, so that the plate current will then decrease.

NORMAL OPERATING RANGE. We are interested, however, in the values of plate current between points "A" and "B," as this represents the normal operating range of the tube. An ideal tube would have the characteristic or graph shown by the dotted straight line in Fig. 17.

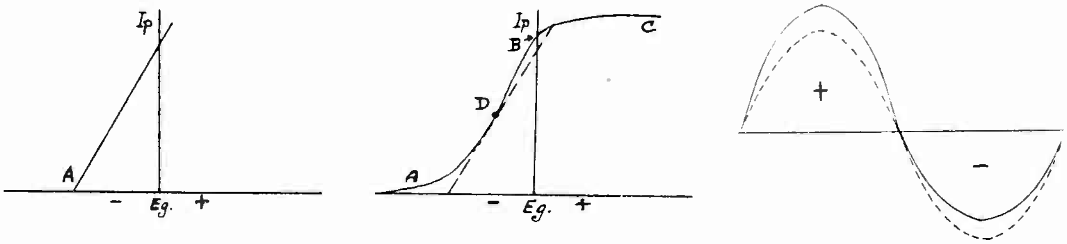


Fig. 16 - PLATE CURRENT IDEAL CONDITION. Fig. 17 - PLATE CURRENT ACTUAL CONDITION. Fig. 18 - ACTUAL AND IDEAL WAVE SHAPE.

From this we can see that if the normal value of plate current in the actual tube is "DA," then if the grid increases positively, the plate current is greater than that proportionately as the graph is above the dotted ideal line at "B."

On the other hand, if the grid becomes more negative, the plate current does not decrease as rapidly as it should for strict proportionality, that is, its graph is here too, at "A," above the dotted line. Hence, if a sine wave of voltage is impressed upon the grid, the plate current will not be sine wave in shape, but the positive half cycles, or alternations, will be peaked, and the negative alternations will be flat-topped. This is shown in Fig. 18. The solid line gives the actual wave shape of the plate current, and the dotted line the ideal, sine wave shape desired.

Now, referring to a push-pull amplifier, the plate current of one tube is going through a positive alternation when that of the other tube is going through a negative alternation. Since the currents in the two tubes are additive in their effect of inducing voltage in the secondary of the output transformer, it is evident that since one current is peaked, and the other flat-topped, the excess of one is balanced by the deficiency of the other, and their combined effect is to induce more nearly a sine wave of voltage in the secondary.

This can be checked by shifting the negative alternation under the positive one in Fig. 18 so that their ends coincide, and adding together corresponding vertical distances. The result will be a curve of approximately twice the height of either, and practically sine wave in shape.

Thus, by causing the plate currents of the two tubes to vary oppositely to each other, the distorting effect of one is balanced by the oppositely distorting effect of the other, and the net result is more faithful amplification. The distortion of either tube consists mainly of the second harmonic of the sine wave to be amplified, and it is this harmonic that is practically eliminated by a push-pull amplifier. Note that if the two tubes were in parallel, their plate currents would both simultaneously increase and decrease, so that no cancellation of the second harmonic could occur. Also, it is to be noted that both plate currents would flow through the same primary in the same direction, so that the d-c or steady flux would be doubled instead of cancelled, as is the case in the push-pull amplifier.

PLATE CURRENT. Since when the plate current of one tube is increasing, that in the other is decreasing, the sum of the two is practically constant, so that there is no audio component flowing into the center tap of the output transformer—"B," Fig. 15. This means that the last condenser in the plate supply filter circuit does not have to be so large, since it does not have to by-pass a large audio component coming from the power tubes. Also high regulation of the plate supply voltage has no bad effects, as it would on a single power tube, or two connected in parallel. Furthermore, since there is no appreciable audio component flowing through the grid biasing resistor, it does not have to be by-passed with a condenser, and this, too, represents a considerable saving, since for power tubes the plate current is large, the grid biasing resistor is low, and therefore otherwise has to be by-passed with a large condenser.

EQUALIZING EFFECT OF GRID BIAS RESISTOR. It was stated in the preceding paragraph that the increase in plate current in one tube was balanced by the decrease in the other, so that the total plate current is constant. This is, however, not strictly so, for it will be remembered that due to the curvature of the tube characteristic, as shown in Fig. 17, the increase in plate current is greater than the decrease for equal and opposite grid voltages. Consequently, there is a second harmonic current of small magnitude—flowing in the circuit, and in particular, through the grid biasing resistor.

Now, in general, an increase in plate current tends to increase the grid bias, and thus depress the grid voltage, and consequently decrease the plate current. In other words, as the grid tends to increase the plate current, the latter tends to prevent this through its action on the grid biasing resistor. This is known as degeneration, and is the reason for the large by-pass condenser across the resistor in single tube amplifiers.

In a push-pull amplifier, however, this opposing effect of the plate current of the tube on its own grid potential is an aiding effect upon the grid of the other tube, since that grid is swinging in potential in the opposite direction. Hence, each tube has a degenerating effect upon itself, and a regenerating effect upon the other tube.

The net consequence of all this is that the second harmonic current mentioned above, in flowing through the grid biasing resistor, tends to reduce the peak of the positive alternation of the one tube, and to peak the flat-topped wave shape of the negative alternation, and so tends to destroy itself. As a result, the second harmonic is even further wiped out, in addition to the cancelling effects of the two tubes, as described previously.

There is another beneficial effect due to this action. If one tube is stronger than the other, i.e., if the change in its plate current is greater than that in the other tube for the same grid swing, then the excess current will flow through the grid bias resistor, and cut down the excess current of the stronger tube, and raise that of the weaker tube, thus equalizing their outputs. Thus the grid bias resistor tends to make the mutual conductances of the two tubes more nearly equal.

It is evident that if the plate supply current, coming in through the center tap of the output transformer, increases, it increases in both halves of the primary. The two halves therefore induce equal and opposite voltages in the secondary, or no net voltage at all. The same argument holds for a decrease in plate supply current. Hence, if the voltage supply is not very perfectly filtered, no hum

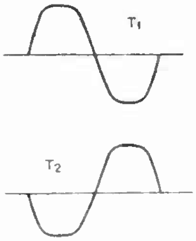


Fig. 19 - THE PLATE CURRENT IN EACH TUBE IS ABOVE SATURATION POINT.

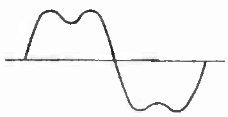


Fig. 20 - THIS IS THE FORM WHEN THE VOLTAGES OF EACH HALF ARE ADDITIVE.

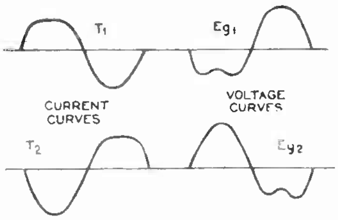


Fig. 21 - THE TUBES ARE BEING WORKED OFF THE STRAIGHT CENTER OF THE STRAIGHT PORTION OF THE CURVE.

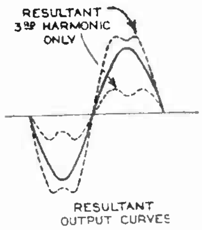


Fig. 22 - DEPICTING TOTAL VOLTAGE GENERATED ACROSS PRIMARY OF OUTPUT TRANSFORMER.

will be heard in the loud speaker anyway. A similar argument holds if there is a ripple in the grid bias voltage, or even filament supply, so that the push-pull amplifier is much more free from hum than the single tube or parallel tube type of amplifier.

Now that we understand the normal action of the push-pull amplifier, let us examine its action under abnormal conditions, such as excessively large signal applied to the grids of the tubes.

If a large signal voltage be applied to the grids of both tubes such that the plate current of each tube rises above the saturation point and down below the lower end of the curve, the form of the plate currents in each tube is as shown in Fig. 19.

The voltages generated by each half are additive and have the form shown in Fig. 20.

The dips in this curve are due, as previously explained, to the flat-top form of current. This voltage curve contains a large third harmonic which is passed on to the speaker.

If, however, the tubes are worked off the center of the straight portion of the curve, such as point A or B in Fig. 10, then the form of the plate current in each tube will be as shown in Fig. 21. The form of the total generated voltage across the primary of the output transformer is as shown in Fig. 22.

The form of the voltage curves depicted in Fig. 21 shows the presence of a second and third harmonic as was previously analyzed. The resultant of the two voltages shown in Fig. 22 indicates the presence of only the third harmonic, the second harmonic having been eliminated. The magnitude of the third harmonic that is usually present is small enough to be neglected.

It was previously mentioned that the current is about 90° out of phase with the voltage. This is true only in a simple inductance; but in a transformer under load the phase relation between primary current and the applied voltage depends upon the power factor of the load on the transformer, neglecting the magnetizing current. It is assumed in this discussion that the load on the secondary of an

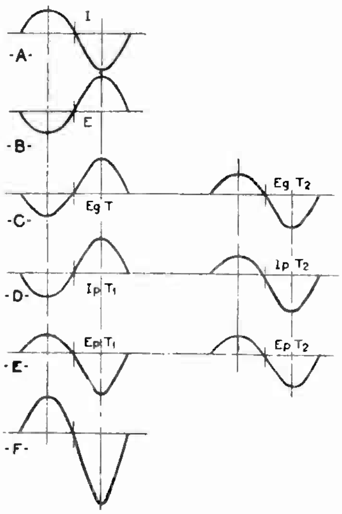


Fig. 23 - CURVES ILLUSTRATING VOLTAGES ACROSS VARIOUS TRANSFORMER WINDINGS.

interstage transformer is resistive due to loading resistors usually connected across it, hence, the primary current is practically in phase with the voltage. With this in mind it can be seen how the dip voltage wave is obtained from a flat-top current wave.

Suppose the form of the plate current of a stage of amplification previous to the push-pull stage is as indicated in Fig. 23A. The voltage generated across the primary is as indicated in Fig. 23B. The voltage across the secondary is shown in Fig. 23C, which is the voltage on each grid with respect to the mid point of the winding. The plate current of each tube is shown in Fig. 23D. The voltages generated in each half of the secondary is as shown in Fig. 23E and the resultant voltage across the primary of the output transformer is as depicted in Fig. 23F. An inspection of this final wave shape will reveal the presence of a second harmonic which existed in the wave impressed on the primary of the input push-pull transformer. The push-pull amplifier therefore does not eliminate harmonics originating in previous stages.

By a similar reasoning it is found that harmonics existing in a sound wave are not eliminated.

The sweeping conclusion is that the only even harmonics that are eliminated are those that would be present if push-pull amplification were not used.

Maximum power output is obtained from a tube when the load impedance equals the impedance of the tube. If the load impedance is made equal to the tube impedance in a straight amplifier, maximum output will be obtained, but the percentage of the second harmonic present due to the curvature of the characteristic prohibits the use of this one-to-one ratio. The ratio of load impedance to tube impedance is usually two to one, in order to minimize distortion. In a push-pull amplifier in which the second harmonics due to overloading are eliminated the load impedance may be equal to the tube impedance and so a greater output may be realized. Usually about $12\frac{1}{2}$ per cent more undistorted output is obtained with two tubes in push-pull than with two tubes in parallel.

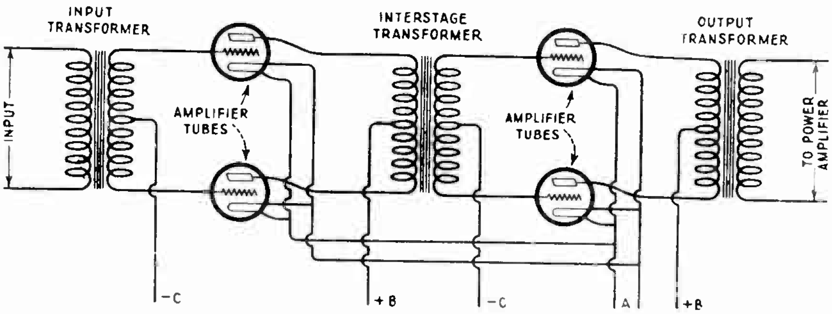


Fig. 24 - SCHEMATIC DIAGRAM SHOWING TWO STAGES OF PUSH-PULL AMPLIFICATION.

The formula for power output of two tubes in push-pull is

$$P = \frac{\mu^2 Eg^2}{2Rp}$$

where Rp is the tube impedance and is equal to the load impedance.

OUTPUT TRANSFORMERS. Output transformers for push-pull amplifiers are usually designed on the assumption that the d-c component of the flux in the core is zero. If the plate current of each tube is different a d-c component will be present which will tend to saturate the core. In a well-designed transformer a slight amount of d-c component of flux will not seriously impair the operation of the amplifier.

The location of input and output push-pull transformers and amplifier tube sockets in typical commercial power amplifier equipment is shown in the views on the cover pages of this lesson. In Figs. 24 and 25 are shown schematic diagrams of two types of push-pull amplifiers, one consisting of two stages of push-pull amplification and the other a stage of push-pull parallel amplification.

SUMMARY OF ADVANTAGES. We may now summarize the advantages of the push-pull amplifier:

(1) Saturation of the core of the output transformer is minimized.

(2) The second harmonic component in the output wave shape, due to the curvature of the tube characteristic, is practically eliminated.

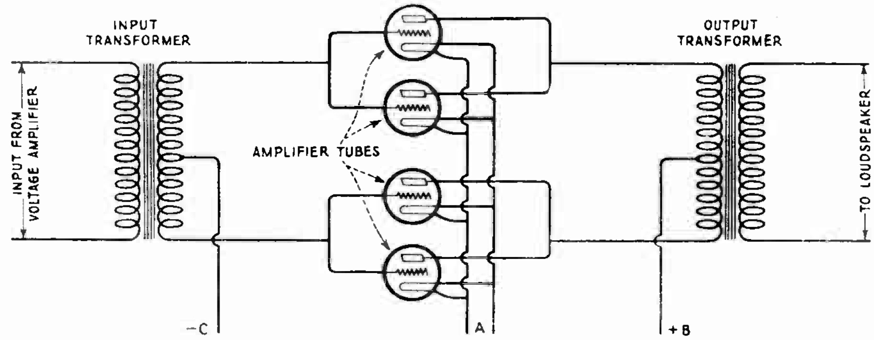


Fig. 25 - SCHEMATIC DIAGRAM SHOWING A STAGE OF PUSH-PULL PARALLEL AMPLIFICATION.

(3) When no by-pass condenser is shunted across the grid bias resistor, further cancellation of the second harmonic component is obtained, as well as equalization of the tube outputs.

(4) Ripples in the power supply tend to cancel out in the push-pull circuit, so that it is quieter in operation, or, for the same hum level, requires less filtering of the power supply.

EXAMINATION QUESTIONS

1. Name at least two advantages of a push-pull audio-frequency amplifier over other types.

2. If the d-c plate current is greater through one tube than the other in a push-pull circuit what is the resultant effect upon the output transformer when a signal voltage is applied?

3. Give a brief explanation of the operation of a push-pull a-f amplifier with the aid of a simple schematic diagram.

4. What is the comparative difference in the effect of the d-c plate currents which flow in two tubes when connected in parallel and when connected in push-pull?

5. (a) What causes the presence of a second harmonic in a distorted wave?
   (b) Is a second harmonic usually comparatively strong or weak?
   (c) If present, is a third harmonic usually strong or weak?

6. What means are employed to reduce the magnitude of a second harmonic?

7. Explain what is meant when it is said that the current changes are additive in effect in a push-pull amplifier.

8. Is it possible to obtain from two tubes in a push-pull amplifier much more than approximately twice the output provided by one of the tubes when operated in a single tube amplifier? Explain.

9. What is the effect on grid potential when plate current varies through the grid biasing resistor in a single tube amplifier?

10. In a push-pull amplifier what is the effect produced on the respective grids due to increases and decreases in plate current through each tube?

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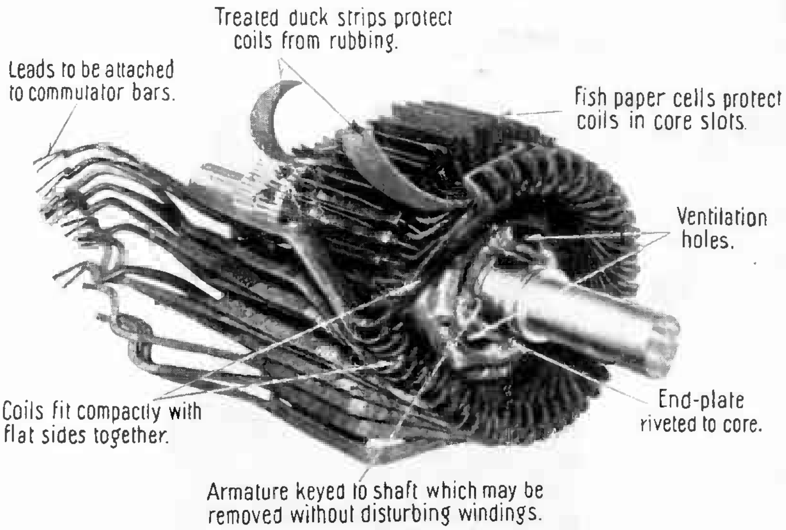

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D-C MOTORS

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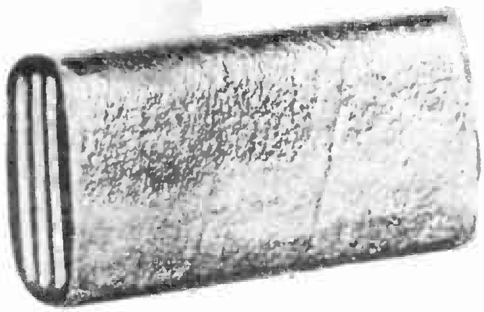

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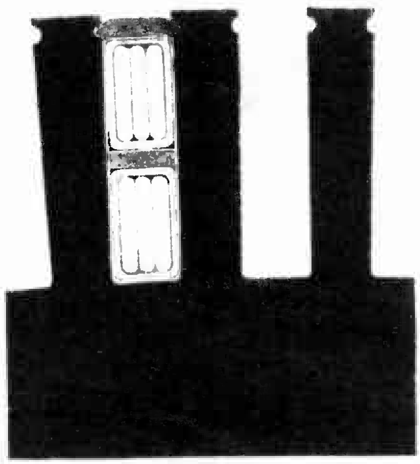

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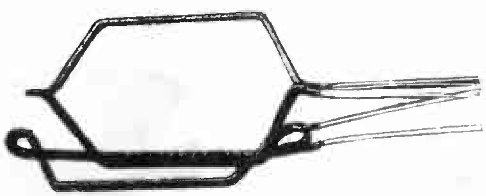

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D-C MOTORS

A study of the action of d-c motors is largely a study of magnetic and electromagnetic principles and, therefore, if the student is not thoroughly familiar with these subjects it is suggested that they be reviewed at this time.

THE PURPOSE OF THE D-C MOTOR

What is an electric motor and what is its purpose? The motor is a machine so designed and constructed that the electric power applied to it will be changed into mechanical power. Just what does that mean? Suppose we explain it as follows, taking for our explanation a trolley car. Over the track on which the car runs you notice a wire which is stretched from pole to pole. From this wire the trolley car pole collects current, as shown in Figure 1, and conducts it to the electric motor of the car causing the motor armature to revolve. The armature is geared to the wheels of the car.

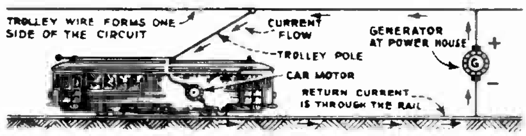


Figure 1

The current, after passing through the motor, is conducted through the wheels and passes into the rails, thence to the ground where it returns to the powerhouse generator. This simple explanation will serve to show you that electrical energy is converted into mechanical energy when the car moves.

THE PARTS OF A D-C MOTOR

In the electric motor there are three essential parts. The first part is the field pole, which is a piece of soft iron made into a particular shape for a definite purpose. On this field pole is wound a certain number of turns of wire making it an electro-magnet. The second part, known as the armature, is another electro-magnet made so that it can be revolved between the field poles. The third is a device called a commutator which leads the current into the armature windings.

In Figure 2 is shown a motor having four field poles of alternate north and south polarity. The armature bears a number of individual coils of wire which carry the current for magnetizing it.

That we may better understand the theory of why this armature revolves when placed in a magnetic field we are going to consider an armature coil of a single turn of wire, placed in the simple magnetic field provided by two magnet poles of opposite polarity.

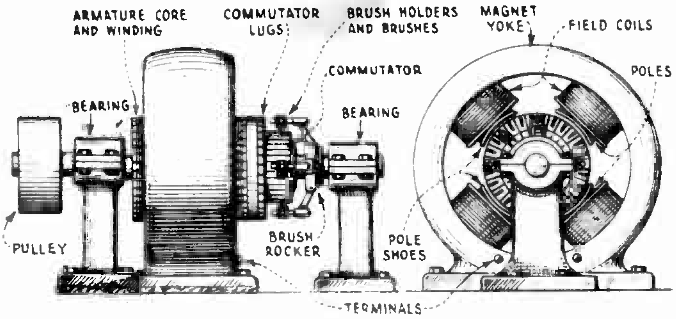


Figure 2

Referring to Figure 3, we show what is, in effect, a single electromagnet formed by the frame of a motor and the field poles. This magnetic structure is the first essential part of the motor. When current flows through the coils which surround the field poles a strong magnetic field is created (as shown by the dotted lines) which fills the space between the two pole pieces. The magnetic lines of force complete their circuit through the frame of the motor, which we see in this case provides two parallel paths.

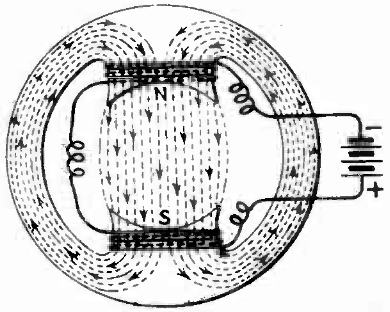


Figure 3

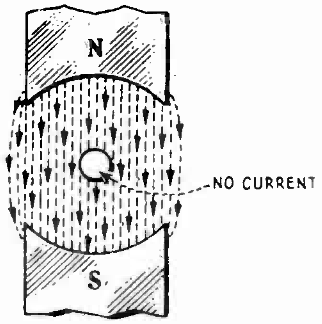


Figure 4

To further aid us in studying the motor action we will use only the field magnets and the space where the armature revolves, as in Figure 4. Here you notice a circle in the center of a field which represents only one side of an armature coil. Note carefully that the lines of force of the field are moving from the N to S pole of the magnets in a uniform manner, that is, they appear to be moving in straight lines ending on the S magnet very nearly opposite to the point at which they left the N magnet. This proves to us that although the armature coil is in the center of the field, the field has not been influenced by the presence of the coil.

This is the natural course a magnetic field assumes; it tends at all times to move in a straight line and should anything happen to divert it from this course it will endeavor to regain its natural state at the expense of whatever attempts to change it.

Now consider what happens if we remove the battery from the field windings; the magnetic lines of force cease to exist between the two pole pieces. Now let us connect the battery to the ends of the armature conductor which is shown between the poles in Figure 4. A magnetic field springs up at once about the armature conductor. In Figure 5 the circle marked with the cross indicates the conductor, and denotes that the current is moving through the wire away from you with its resultant field indicated by the arrowed lines.

Keeping the armature wire connected to the battery, let us now reconnect the field windings to the battery. As shown in Figure 6, the field of the armature wire is opposing the field of the magnets on the left side and moving with the magnet field on the right side of the wire. The lines of force between the north and south poles of the magnet are effective in a downward direction as shown in the figure. On the left side of the wire, they meet the lines of force caused by the current in the wire, and these are effective in an upward direction. This tends to neutralize or weaken the field at the point A.

At point B, to the right side of the wire, the lines of force due to the magnet poles are effective in the same direction as those due to the current in the wire. This causes a concentration or bunching of the lines of force at the right side of the wire, which is an increase in the field strength there. These distorted or

Figure 5

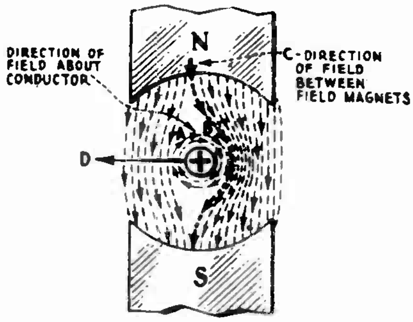


Figure 6

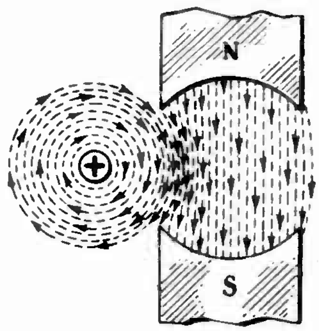


Figure 7

bent out lines of force act as taught rubber bands and at any instant tend to straighten themselves. This can only happen by the current-carrying wire moving away from the point where the lines of force are most concentrated, and toward the point where they are less concentrated. The wire will move in the direction shown by the arrow D.

This movement will continue until the wire has moved out of the magnet field as shown in Figure 7, or until it has moved so far that the pushing force which remains is too weak to overcome the natural friction between the wire and whatever supports it in position.

LEFT HAND RULE

There is a very handy rule for determining in just what direction the armature wire will move. Turn Figure 6 so that the normal left side of the page is toward you, and it is flat on a table with the Figure 6 exposed. Place the middle finger of the left hand on the crossed circle representing the current flow away from you. With the middle finger perpendicular to the paper, extend the fore-finger in the same direction as the lines of force of the magnet, that is, toward the pole marked S. Keeping the thumb horizontal, stretch it out. You will find that it points in the direction of motion as shown by the arrow D in Figure 6. This rule should be practiced and memorized. It will help you somewhat to use the following memory trick:

Center finger	Forefinger	Thumb
Current direction	Flux direction	Toward?

The three fingers used are to be held at right angles to each other during this practice.

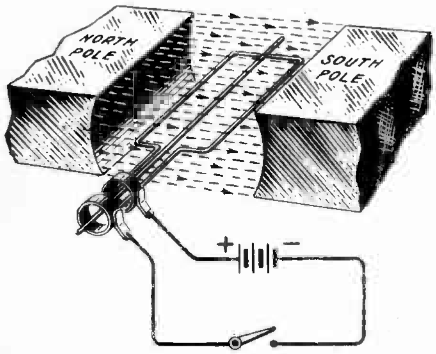


Figure 8

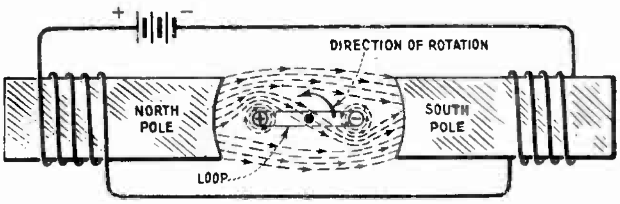


Figure 9

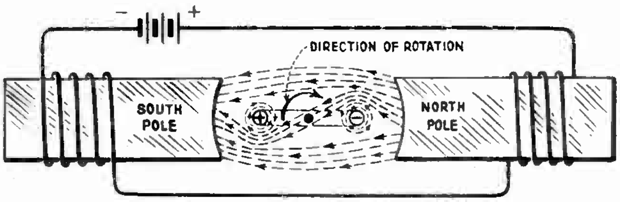


Figure 10

Let us study Figure 8 in order to understand more thoroughly how rotation of an armature takes place. You recognize the field magnets at once. A complete loop of wire (armature coil) has been drawn to show why a rotating movement is secured from the previously described simple displacement to one side (Figure 6). The loop is secured to an axle which passes through the center line of the loop, and centrally located with respect to the pole pieces. The loop is free to rotate about the axle, but not able to move in any other direction. Study the field as it leaves pole N in Figure 9. The small arrows show a bunching of lines of force over the top of the left wire of the loop, thus the magnetic field of the wire has added itself to that of the field magnets, making a strong concentration of lines above the wire. Underneath that wire its field is moving against the field of the magnets, thus weakening the field at this point. At the right-hand wire of the loop the opposite effect is evident. The concentration of lines of force is below the wire. We have stated that the loop is free to rotate on its axis. Applying the left-hand rule to both sides of the loop, we find that the left wire of Figure 9 will move downward and the right wire move upward. It is apparent that the loop will then turn in the direction shown by the arrow, or counter clockwise.

CONTROL OF DIRECTION OF ROTATION

Remembering the left-hand rule and the fixed relations between the fingers, it is seen that the direction of motion can be reversed by a reversal of either the field flux direction or the armature current direction, but not both. In Figure 10, the direction of current flow in the armature loop is the same as for Figure 9. The connections of the field windings to the battery have been reversed, and this reverses the polarity of the field magnet. The rotation is now clockwise as shown.

In Figure 11, the current in the armature wires has been changed in direction. Figure 12 has the same field polarity as Figure 9, but opposite armature current direction, so the directions of rotation are opposite. Figure 13 has the same field polarity as

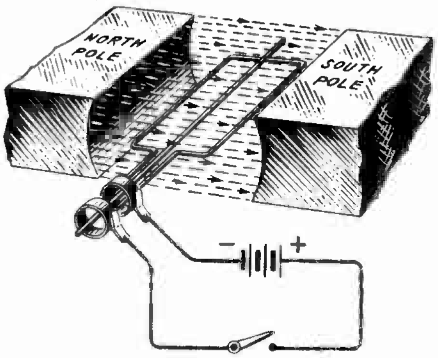


Figure 11

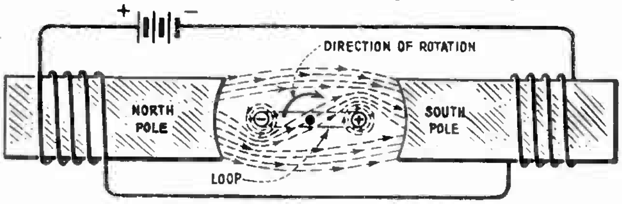


Figure 12

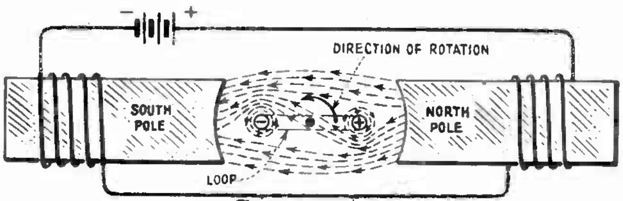


Figure 13

Figure 10, but opposite armature current direction, so the directions of rotation are opposite.

LIMIT OF ROTATIONAL MOVEMENT

The illustrations so far have shown merely in what direction the armature loop will turn when current passes through it in the presence of a separate magnetic field. To understand how far the loop will go we must return to the fundamental principle shown in Figure 6. We see here that the force exerted on the wire moves it out of the field of the poles, if it is free to move. In Figure 12, etc., the forces exerted on the two sides of the loop are such as to try to move the two sides of the loop out of the field and in directly opposite directions. But they are bound together at a fixed distance by their mechanical construction. Therefore, each wire will move as far from the center line of the field flux as it can. The limit of this movement is reached when the plane of the armature loop is perpendicular to the direction of the field flux. Then each wire is as far as it can go, with the arrangement disclosed to you up to this point. Maybe the rotational movement of the loop will have given it a certain momentum which carries it beyond that point. The wires will have then been carried on around a little way into the more intense sections of the field, and will be pushed back until they are in the neutral position; in Figures 12 and 13, for instance, the loop would come to rest in a vertical line.

COMMUTATION

In explaining the theory of the motor up to this point, we have used illustrations in which the armature received current from the battery through two wiping contacts resting on two separate rings (Figures 8 and 11). In Figure 14 we show a single ring split into two parts. These parts, called "segments", are insulated from the shaft and from each other. Each segment is connected to one end of the armature loop. The segmented ring is known as a "commutator". Pressing against opposite points of the commutator are two conducting strips, making a wiping contact with the commutator, and they are generally called "brushes". These are so mounted that each changes contact from one segment to another when the loop is at right angles to the lines of force. It will be remembered from our

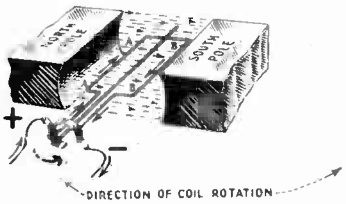


Figure 14

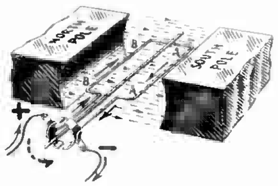


Figure 15

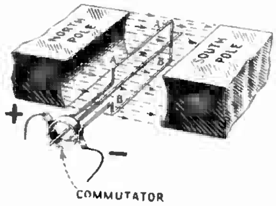


Figure 16

previous discussion that this is the limit to which the loop can turn with the armature current unchanged in direction. The momentum of the loop carries it across the neutral position a little ways. If the original direction of armature current were maintained the loop would then be thrust back into the neutral position. However, the direction of the armature current through the loop was changed by the commutator and brush arrangement when the loop crossed the neutral position. So instead of being pushed back, the loop is pushed forward in the same direction in which it started. (You may check this statement by applying the left-hand rule to Figure 15). It is now due to make a half-turn before coming into the next neutral position which is shown in Figure 16, and here again its momentum carries it across until the commutating action has again changed the direction of the armature current. This continuous pushing in one direction causes the armature loop to speed faster and faster until a steady speed has been reached.

COUNTER ELECTROMOTIVE FORCE

If we forget for the moment that the motor we are studying is rotating because of an electromotive force applied to the armature windings, we can consider the machine as though it were being rotated by some external source of mechanical power, such as a steam engine. In this case the machine becomes a generator, which is treated fully in a separate lesson. It is sufficient for our present purpose to state that when the armature loop is made to rotate in the magnetic field provided, the cutting of the lines of force by the two sides of the loop causes electromotive forces to be generated in them. The direction of these electromotive forces is opposite, as considered from the point of an observer outside the machine; the direction is the same considered from the standpoint of the series path provided by the loop itself. The electromotive forces generated in the two sides of the loop are, therefore, additive in their effect at the terminals of the loop (commutator segments). By the application of Fleming's Right-Hand Rule for the determination of the direction of an electromotive force induced in a moving conductor, we find that this is opposite in direction to the applied electromotive force from an external source which supplies the armature current and makes the rotation possible. The generated e.m.f. is, therefore, known as the counter e.m.f., sometimes called the back e.m.f. Its effect is very important in motor operation; it causes the effective or working electromotive force to become considerably less than the applied electromotive force. Just what the difference is, of course, depends on the numerical value of the counter e.m.f., and this depends on a number of factors, among which we can mention (1) the strength of the field, (2) the length of an armature conductor measured perpendicular to the field, (3) the number of complete turns in the loop, and (4) the rotating speed of the loop.

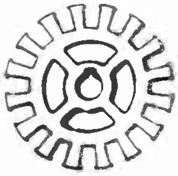


Figure 17

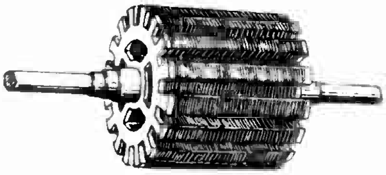


Figure 18

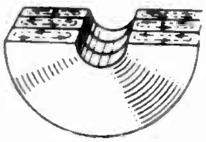


Figure 19

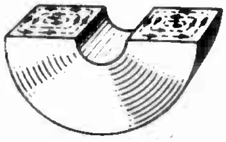


Figure 20

ARMATURE CONSTRUCTION

The armature core of the motor is made up of thin stampings of a good grade of soft iron or steel as shown in Figure 17. A number of these stampings are used to make up the armature core, and this core is then called a "laminated" core. Figure 18 will serve to show you how the armature core looks when all these individual discs have been placed, one against the other, making the completed core. The discs are held in place by various methods. In small motors, bolts are sometimes employed which run through the discs; in others, lock nuts which are threaded to the shaft, and in some makes a collar is shrunk on the shaft holding the discs in place under great pressure.

The armature is made up of laminations to reduce eddy current losses brought about when the armature revolves in a magnetic field. The induced currents within the revolving metal represent a part of the energy being used to operate the motor and do no actual good. In fact an armature constructed of one solid piece of metal would have eddy currents produced in it of such magnitude as to cause the armature to become very hot. This heat represents a large waste of energy. The armature coils absorb a considerable portion of this heat which causes damage to the insulation and overheats the bearings. It is then advantageous to see that such eddy currents are kept to a minimum. The losses are very materially reduced by building up the armature of thin discs of soft iron. By using laminations the magnetic conductivity of the core is reduced and the circulating eddy currents are confined to each disc, thus preventing these undesirable currents from becoming large enough to heat the armature excessively. The insulation between laminations is merely the coating caused by oxidation.

Figure 19 represents an iron core cut in half with the laminations purposely enlarged to show how the eddy currents are confined to each disc. Figure 20 represents a solid iron core showing how the eddy currents would move through the entire core.

When the armature coil is passing under one magnetic pole the eddy currents flow in one direction, but as soon as the armature comes under the influence of a magnetic pole of opposite polarity these currents are reversed in direction.

When the armature is revolving at high speed the eddy currents are rapidly reversed in direction thus causing friction between the molecules of the iron. Friction creates heat which, if allowed to become excessive, not only raises the temperature of the copper conductors, but may cause the insulation of the conductors themselves to burn. This rapid reversal of the molecules creates what is known as "hysteresis losses" and is considered as one of the harmful effects to be avoided in armature design and construction.

The slots along the outside of the laminated core carry the coils of wire on the armature, held in place by small pieces of wood which fit into the slots in the core, preventing the coils from being thrown out of the slots by centrifugal force. A cross section of how this is done is shown in Figure 21.

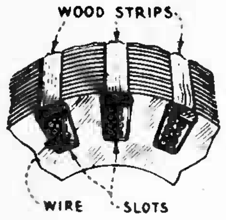


Figure 21

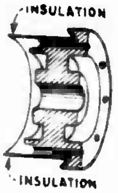


Figure 22

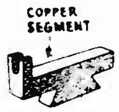


Figure 23

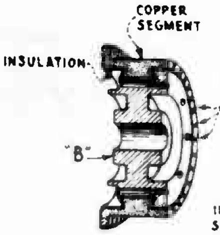


Figure 24

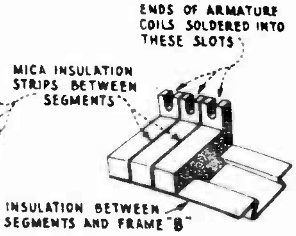


Figure 25

COMMUTATOR CONSTRUCTION

The commutator, the next and third essential part of the motor, is a very ingenious device. First we will see how the commutator is constructed. Figures 22 to 30 inclusive show the construction of the commutator. Figure 22 shows a locking ring which holds the segments in place. It is one solid piece of iron or steel cast in the shape shown. The commutator requires great care in assembling even though the principle of assembly is simple. The following building up process will give you the idea of how the parts are assembled. Figure 22 shows the part we begin with, the first requirement being to insulate the part. On this insulated section are then placed the copper segments which are insulated from each other; Figures 24 and 25 illustrate the alternate arrangement of mica strips and copper segments. After the required number of segments have been placed on the section and insulated perfectly, both from the holder and from each other, the locking ring, Figure 26 is moved into place as shown in Figure 27. The segments are locked into place by tightening the threaded studs which run through the locking ring, into the section, as shown in Figure 28. Figure 29 illustrates the segments as they would appear with a section cut out of a finished commutator, while Figure 30 is the finished commutator ready for fitting to the armature shaft and connection to the armature windings. The beginnings and ends of the armature coils are brought out and soldered into the slots of the segments as shown in Figure 25.

This completes the three major parts of the motor. Our next problem is to assemble these parts into a completed machine.

COMPLETE ASSEMBLY

Now let us consider one armature coil wound on an actual armature. In Figure 31 we can trace the position of this coil from the copper segment on which the top brush rests, across the armature core around the back of the core (as illustrated in Figure 32) into the armature slot on the opposite side of the core; and finally out where the end is taken to a copper segment of the commutator diametrically opposite the segment from which the coil started. Ordinarily coils are wound in all of the slots, but they have been omitted here to enable you to easily trace the position occupied by the one shown on the core. The continual rotation and speed of the motor is dependent upon a great number of coils as you will learn later.

In Figure 33 is shown a typical brush holder and brush, which rests on the rotating commutator and is connected to the power line used to supply the armature with current. For a view of a complete machine you are referred back to Figure 2 at the beginning of the lesson which shows a four-pole machine having four brushes. Two poles at opposite sides of the armature have North polarities; the other two poles, also opposite each other and in between the first

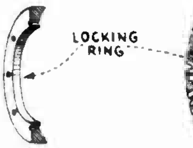


Figure 26

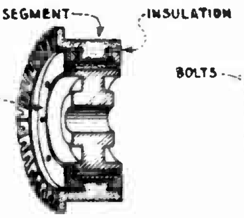


Figure 27

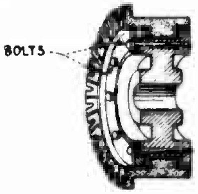


Figure 28

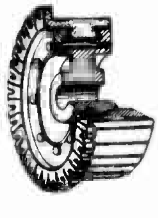


Figure 29

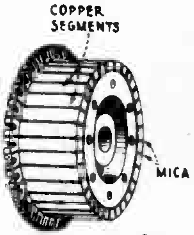


Figure 30

pair, have South polarities. We find also that the brushes are grouped into pairs, each brush being cross-connected to the one on the opposite side of the commutator. The positive power lead is, therefore, connected to the commutator at two places by two of the brushes; the negative lead to two other places on the commutator by the remaining brush pair.

A motor of this type may have six or any other even number of poles, and there will always be the same number of brushes as there are poles, if the power is supplied by a two-wire line.

TYPES OF ARMATURES

Armatures may be divided into three classes according to the core shape and the method of winding the wire on it. The classes are as follows:

1 - Drum Armatures
2 - Disc Armatures
3 - Ring Armatures

DRUM ARMATURES

This type is distinguished by having the entire winding external to the core, as shown in Figures 31 and 32. The core is of a cylindrical or drum shape. Each of the active wires is wound on the external surface of the drum in a direction parallel to the shaft. Such a wire is connected to another active wire by means of a connecting wire which is also external to the core.

DISC ARMATURES

The core for this type consists of a disc, and the active armature conductors are spread out radially on the flat sides of the disc. Armatures of the disc type are very seldom met with in modern practice.

RING ARMATURES

A ring-shaped core is used, and it is wound with a number of coils. Each coil consists of a number of turns of wire wound in and out aroung the ring. Figure 34 gives approximately the placement of a winding consisting of eight coils. This illustration is convenient for us to review the commutator action which it is so necessary for you to understand.

Tracing the current from the battery we see that it flows from the positive side to brush A, thence to commutator segment #1. At point K the current divides; part goes through coils 7-8-1-2 to point K1, thence to segment #5, and through brush B returns to the negative side of the battery. The other part of the battery current goes from point K through coils 6-5-4-3 to point K1, and hence to the negative side of the battery through segment #5 and brush B.

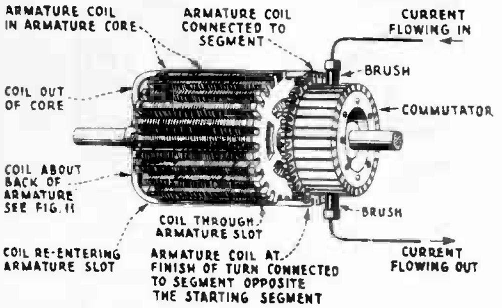


Figure 31

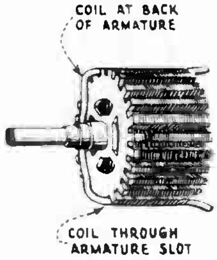


Figure 32

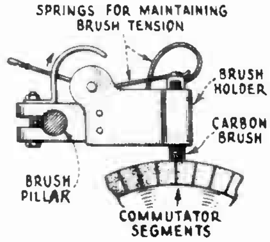


Figure 33

While the illustration does not show it, let us state that all the coils are wound around the armature ring in the same direction. When current enters coil 7 it sets up a North pole in the core ring near point K, and a South pole at that end of coil 7 which is next to coil 8. The current in coil 8 sets up a North pole at the end adjacent to coil 7, and a South pole at the end adjacent to coil 1. Likewise coils 1 and 2 set up magnetic poles in the same direction. This actually means that all the coils 7-8-1-2 and each turn of them works in the same direction to establish magnetic lines of force which make a North pole in the ring at point K, and a South pole in the ring at point K1. Taking the other path from K, the current through coil 6 goes through it in the opposite direction from that through coil 7, and sets up at point K a North pole also, making a South pole in the core on the side toward coil 5. The current passing through coil 5 sets up a North pole on the side toward coil 6, and a South pole on the side toward coil 4. This principle holds for coils 4 and 3. Therefore, the magnetizing effects of the coils 6-5-4-3 are additive, and the lines of force in that half of the ring are concentrated. Their direction is such as to also establish a North pole at K and a South pole at K1. We see then that the magnetizing effect of all the coils combined is the same as though a strong permanent magnet were used with its axis practically at right angles to the line of direction of the flux between the two field poles.

In accordance with your previous study of magnetism, such a magnet would tend to turn and get in line with the direction of the field poles, the North pole of the armature being attracted to the South field pole, and vice versa. But since we are using a commutator on a wound armature we get a more continuous effect. As segment #1 turns up to the right, and segment #5 turns down toward the left, we find that segments #2 and #6 have come under brushes A and B respectively. The current through coil 7 has been reversed and it now has a North pole at its left end where it previously had a South pole. Likewise coil #3 now has a South pole at its right end, where it previously had a North pole. We see then that the North pole of the armature ring has been shifted to a point between coils 7 and 8, and the South pole to a point between coils 3 and 4, with the armature rotated one-eighth of a turn. Therefore, the relation between the direction of the field flux and the armature flux is the same as before, and the turning effect continues.

The commutator is of course the secret of the continual motion produced. It keeps the directions of the current through the various coils such that the combined effect of all the coils is the same at all times as far as directions of magnetic forces are concerned.

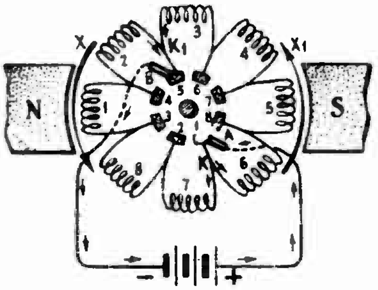


Figure 34

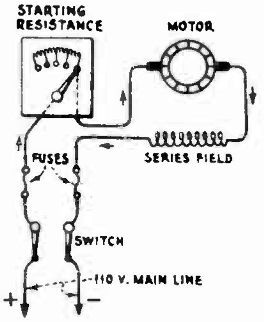


Figure 35

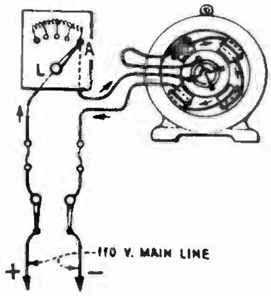


Figure 36

TORQUE AND SPEED

The motor is designed to produce a turning motion as a result of a twisting force which we call TORQUE, and on this torque depends the work the motor is capable of doing. We are interested not only in the work which can be done, but also in the SPEED of the motor in revolutions per minute. The formulas for these are as follows:

Speed: $n = \dfrac{E_a}{\Phi Z'} = \dfrac{V - I_a R'}{\Phi Z'}$ revolutions per minute

Torque: $T = 7.05\, Z' \Phi I_a$ lb. - ft.

where: E_a = counter e.m.f.

V = line voltage

Φ = field strength or flux

Z' = a factor which depends on the number of poles, the length and the number of the armature conductors.

I_a = armature current

R' = the sum of the armature resistance and any other resistance in series with the armature and the line.

These equations are important for our understanding of the operating conditions of various types of motors.

TYPES OF MOTORS

There are three types of direct current motors used in radio practice. They are the series, shunt, and compound.

The different types are used according to the work they have to perform.

The series motor, although not found extensively in radio use, will be briefly explained here in order to enlighten you on the field winding connections. This motor is used mostly in electrical hoisting equipment and in electric traction work. It derives its name from the fact that the field coils are connected in series with the armature.

The series motor connection is shown in Figures 35 and 36; it is noted that all the current for the motor flows through the armature circuit and the field circuit in succession. Inspection of the equation for the speed of a motor shows that the speed of the series type must decrease rapidly with increasing load. When a load is thrown on the motor the twisting force or torque must increase, and from an equation above this can happen only through increasing either the field flux or the armature current. In the

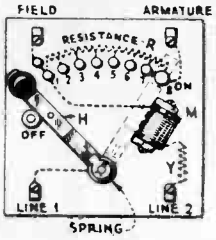


Figure 37

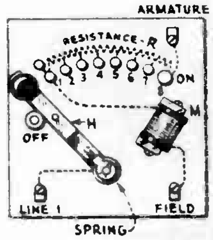


Figure 38

series motor the field flux is proportional to the armature current, so we see that the current will increase to supply the additional power required. Now look at the equation for speed; we have decreased the value of the numerator (above the line) by increasing the IR which is to be subtracted from the line voltage V; we have increased the denominator (below the line) because the field flux is increased in proportion to the current. These two things combine to make an appreciable decrease in the motor speed.

On the other hand, if the machine is designed to run at a certain speed when connected to some minimum load which can be increased, if that minimum load is entirely removed, as by the slipping of a pulley belt off the pulley of the motor, the decrease in work performed will so decrease the armature current that the machine will speed up to a dangerous extent. We, therefore, find a series motor should be coupled to its load either by direct shafting or by sturdy gears, and never by a belt.

SHUNT MOTOR

This type of motor is used where a close regulation of speed is required under loads which are constantly varying. The field coils of the shunt motor are wound with many turns of fine wire, thus making the resistance of the field coils high. This allows only a small current to flow of more or less constant value no matter how much current is flowing in the armature circuit. This is illustrated in Figures 39 and 40. When a load is thrown on such a motor we can interpret its action also in terms of the two equations given you. Looking at the equation for speed, we find again that the IR drop in the armature is increased, decreasing the value of the numerator, and the motor, therefore, slows down slightly under load. This decrease in speed is appreciably less than it would have been for a series motor, in which the field strength would also have been increased by an increase in armature current.

Caution should be exercised in the operation of this type of motor regarding the speed control; the regulation of the speed may be accomplished by the use of a variable resistance in series with the field coil, or by a resistance in series with the armature circuit. The field circuit must not be opened thereby cutting the current off suddenly. If the field circuit suddenly opened the field would become very weak and the motor would operate by the residual magnetism in the field magnets. The armature would increase its speed because sufficient counter e.m.f. could not be generated to reduce the applied e.m.f. and the armature might possibly be torn apart if abnormally high speed were attained. Precautions to guard against an open field will be described later under motor control.

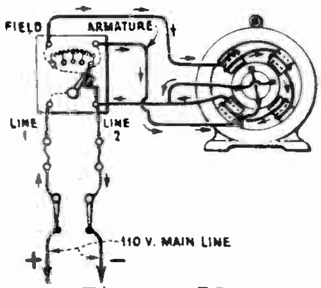


Figure 39

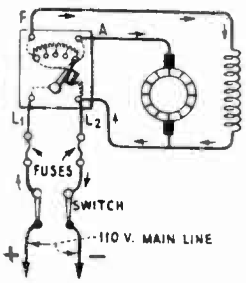


Figure 40

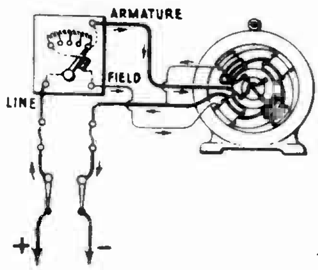


Figure 41

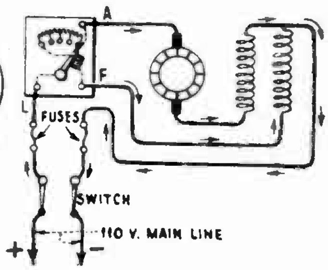


Figure 42

COMPOUND MOTOR

The purpose of this type of motor is to obtain constant speed under all load conditions. It differs from the two types just described because the field is composed of two sets of windings, a series and a shunt winding, as shown in Figures 41 and 42. Most of the field flux is due to the shunt winding. The series winding is so connected that its field flux opposes that due to the shunt winding. Under this condition, when a load is applied the armature current increases, and from the speed equation we see that this decreases the numerator (top part) of the term. At the same time the armature current flowing through the series field winding has increased its opposition to the field flux created by the shunt winding. The net result is a decrease in the strength of the field, which is part of the denominator (lower part) of the term in the speed equation. By design, the decreases in the upper and lower parts of the term are made proportional, and the speed of the motor remains constant. It is even possible to so proportion the strengths of the shunt and the series fields that the speed of the motor is increased somewhat when a load is applied.

When the field due to the series winding bucks the field due to the shunt winding, the motor is said to be differentially compounded. It is, of course, possible to change the connections of either the series or the shunt field winding which will make the two fields add. The motor is then said to be cumulatively compounded. With this type the speed falls considerably with increasing load. Its characteristics may be said to be intermediate between those of the shunt and the series motor. One particular advantage of the cumulatively compounded motor over the series motor is that the former will not "run away" when the normal load on the machine is suddenly removed, but will instead increase its speed to a definite safe limit.

In a compound motor the shunt winding may be connected across the line, in which case it is called a long shunt. It may, on the other hand, be connected right across the armature terminals, (short shunt) and in this case the shunt field current passes first through the series field winding where it has little extra effect as it is small compared to the full armature current passing through the series winding. One terminal of the shunt winding always connects to that side of the armature which goes straight to the line. The other terminal of the shunt winding may connect to the side of the armature which goes to the series winding, or it may pass over the series winding and connect to the second line wire. The first of these methods is the short shunt and the second is the long shunt.

STARTING A MOTOR

The resistance of an armature coil is very low and to place the line voltage, of say 110 volts, on an armature coil when it is not in motion would be the same as connecting a short wire around the terminals of a battery; that is to say, the armature would cause a short-circuit on the 110-volt line. In our study of the motor, however, we discovered that as soon as an e.m.f. was applied to the commutator segments through the brushes, current moved into the armature coil and the coil at once was forced to move.

In this starting of the motor armature the current taken by each coil is more than is required to drive it. If you connect an ammeter in the circuit it may read 25 amperes at first, but as the armature gains speed, you will see the ammeter needle gradually drop back until, when the armature is revolving at full speed, the meter may only read 4 or 5 amperes.

Now why did the current drop from 25 to 5 amperes? At the start the armature coils were practically a short circuit, which allowed an excessive current to flow; but as this excessive current flows in the coils for a very short period of time no damage is done in the case of a small motor.

As the motor armature begins to revolve its coils act similar to those of a generator, that is, an electromotive force is developed in the coils, called counter e.m.f. This counter e.m.f. opposes the current which is causing the armature to revolve, and by virtue of this opposition limits the amount of current flowing in the armature. As the speed increases this back or counter e.m.f. becomes greater and greater, allowing less and less current to flow into the coils.

This continues until the full speed is reached when the back e.m.f. may, for instance, reach a voltage of 105 volts. If there is 110 volts applied and 105 "bucking" or opposing it then, $110 - 105 = 5$ volts, which will be the total e.m.f. forcing current through the armature coils. Suppose the resistance of the armature is one ohm. By Ohm's Law $I = \frac{E}{R}$. $I = 5 \div 1 = 5$ amperes, or the total current flowing in the armature when it is up to full speed. By Ohm's Law figure out what the current flow would be in the armature coils if the armature did not rotate.

$$I = \frac{E}{R} \text{ or } I = \frac{110 \text{ volts}}{1 \text{ ohm}} = 110 \text{ amperes.}$$

This would certainly place a short in the line and cause the fuses to blow, thus protecting the armature coils from burning. Therefore, you can realize the importance of c.e.m.f. as applied to the motor; it acts to regulate the current.

So far the motor has merely been revolving without driving any machinery. Suppose now the motor is connected to a load; the motor will momentarily slow down and the counter e.m.f. will at the same time become less, and more current will flow into the armature windings. Now disconnect the load; the speed of the armature increases and so does the counter e.m.f. thus reducing the current flowing into the armature. Any variation in the speed of the armature will cause a variation in the counter e.m.f.

This counter e.m.f. then acts to automatically regulate the flow of current into the armature when the load on the motor is varied.

Motors such as we are going to use require some means of controlling the e.m.f. applied to the armature at the time of starting the motor, therefore, a resistance is placed in the motor line to regulate the current flow to the armature coils. When the normal speed of the motor is reached this resistance is cut out of the circuit.

This regulating device is called a starting box and is shown in Figures 35 and 36. Further explanation of starting boxes will be taken up later in this lesson.

MOTOR STARTING BOXES

Controlling the start and stop of electric motors and generators is accomplished by either the manual type of control or by the automatic or remote control. The modern radio transmitter is equipped with the latter type so that the operator may start and stop the apparatus from the operating table. Other methods require that the motor generator sets be started and stopped by manipulating the lever of the starting rheostat.

The starting resistance of direct current motors, as explained, controls the current flowing in the armature of the machines. A further control of this applied current to the armature is effected by the counter e.m.f. developed by the armature after it begins to rotate. The starting resistance may be cut out of the circuit gradually as speed is attained. As the resistance of the armature is low the starting resistance is necessary to limit the current to a safe value until the armature has attained its full speed.

Figure 37 illustrates what is known as a four-terminal starting box while Figure 38 shows the three-terminal box.

The difference between the two starting boxes is in the connection of the holding magnet in the circuit. In Figure 37 the holding magnet is connected in series with the resistances Y and R and across the 110-volt circuit as shown. The starting box of Figure 38 has the holding magnet connected in series with the shunt field of the motor and resistance R.

Figure 39 illustrates the method of connecting a shunt motor to a four-terminal starting box. Figure 40 is a schematic diagram of the same motor and box.

Figure 41 shows the proper connections for a compound wound motor and a three-terminal starting box with a schematic diagram shown in 42. When it is desired to start a motor with this type of control the starting arm H, Figure 38 is moved slowly across the contacts. When the armature is on contact Number 1 current flows from line 1 to the starting arm through the arm to resistance contact 1, through all the resistance coils to contact 8 where it is led to the terminal marked armature and from there to the motor armature. As the arm is slowly moved over the contacts the resistance is gradually cut out. When arm H reaches the holding magnet M and rests on contact 8 all the resistance is out and current flows directly from line 1 to the armature.

The magnet M holds the arm H which is made of soft iron, in the running position as shown by the dotted arm in Figure 37. This magnet is connected to the first contact and it receives full voltage at first, but as the arm moves over the contacts less e.m.f. is im-

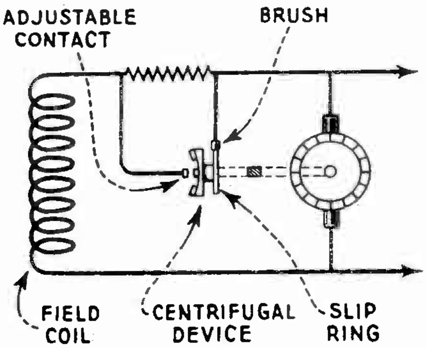


Figure 43

pressed across the magnet windings due to the increased resistance through R as the arm is moved to full running position. Hence, when the arm is in full running position, just enough current flows through the magnet windings to attract and hold the arm. The resistance protects the magnet winding from heating.

If the shunt field circuit or the line switch is opened for any reason the magnet current is cut off and the arm is pulled back to the "off" position by a spring located in the shaft supporting the handle.

AUTOMATIC SPEED CONTROL

In some uses of motors an evenness of speed is desired which must be better than can be achieved merely by the design of the motor itself. Mechanical principles are then brought to bear on the problem, as in the case of a small motor which is used to move the film in a sound picture projection machine. Steadiness of speed is essential here as any speed change will change the musical pitch of the sound program being picked off the film.

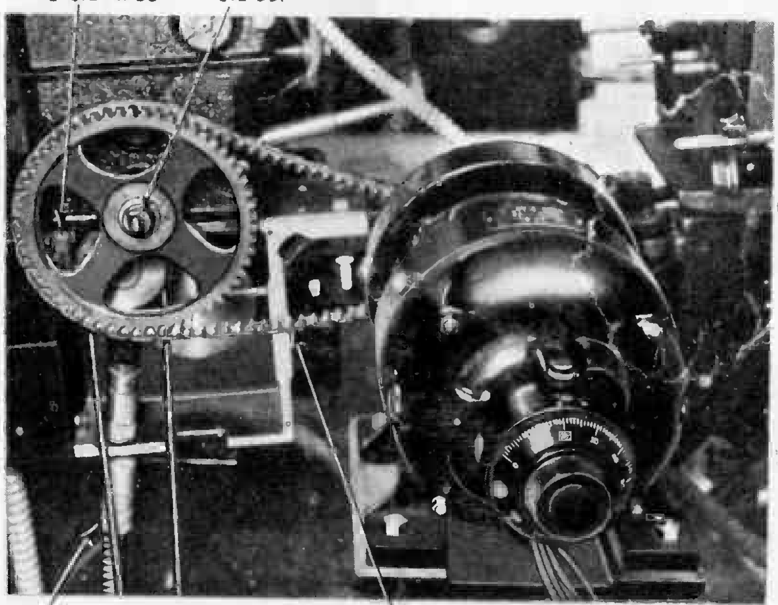
In Figure 43 is shown the schematic wiring of such a machine. It is shunt wound, and a resistance is placed in the lead from one side of the line to one side of the field winding. The effect of the resistance is to decrease the current which would otherwise flow through the winding. At one end of the motor shaft is a centrifugal device consisting of two fly-weights secured by hinges to a disc on the end of the shaft. At the center of the spring which joins the fly-weights there is a contact, connected to a slip ring on which rests an ordinary brush. When the motor is not running the spring holds the fly-weights in toward the shaft. As the motor picks up speed, the centrifugal force tends to throw the weights out away from the shaft, which action is resisted by the spring holding the weights together.

Opposite the contact which is central to the fly-weights, there is another contact and this latter can be adjusted by means of a dial so that its distance from the moving contact can be changed. The two contacts will touch when the machine has reached a certain speed which is sufficient to extend the fly-weights away from the shaft enough to thrust the moving contact over against the fixed one. This operation places a short across the resistance which is in series with the field winding, the field strength is increased and the motor slows down, as previously described. The slowing down of the motor makes the fly-weights draw in closer to the shaft and this opens the contacts again. The resistance is once more inserted in series with the field winding, weakening it so that it speeds up again slightly.

The success of such a device depends on a very accurate design and a sturdy construction, so that very small changes in speed will operate it to cause an effect which will be opposite to the change.

EXAMINATION QUESTIONS

1. What are the principles underlying the operation of electric motors?
2. What is the function of an electric motor?
3. Name the essential parts of a d-c motor.
4. (a) What is the purpose of the armature?
   (b) How is it constructed?
5. What is the meaning of torque?
6. Give an equation for torque, and explain what each symbol represents.
7. What advantage has a cumulatively compounded motor over a series motor?
8. What is the purpose of the commutator? How is it constructed?
9. How is the speed of a shunt motor regulated?
10. Explain the action of a motor starter.



DC Motor Drive in a Sound Motion Picture Machine

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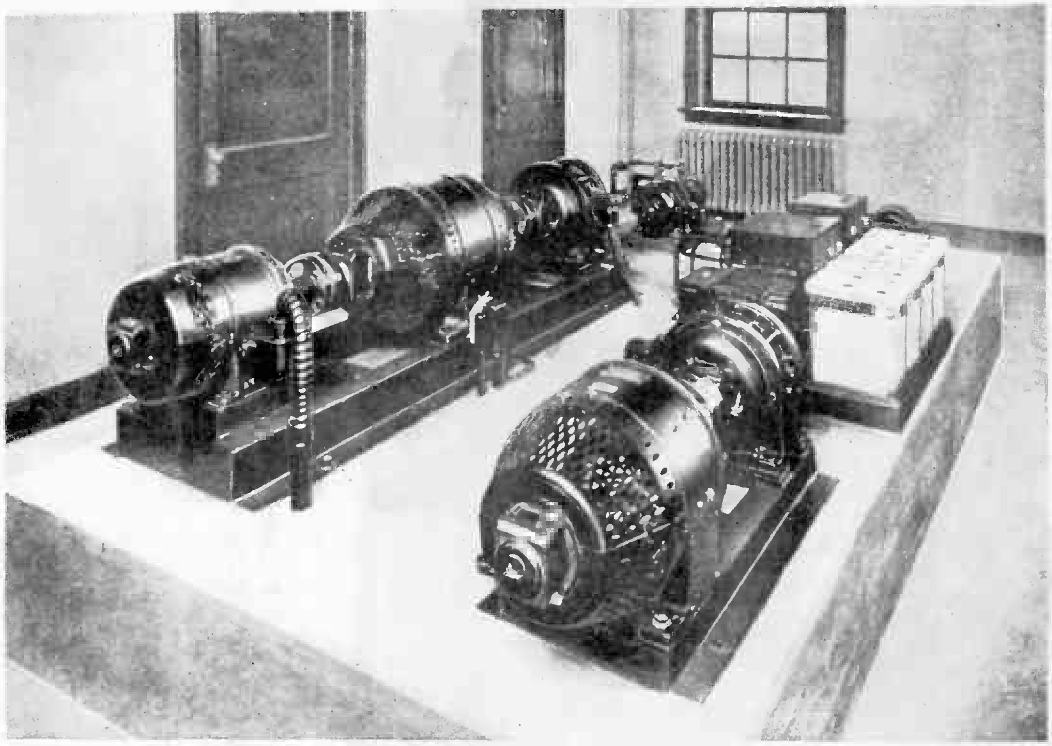
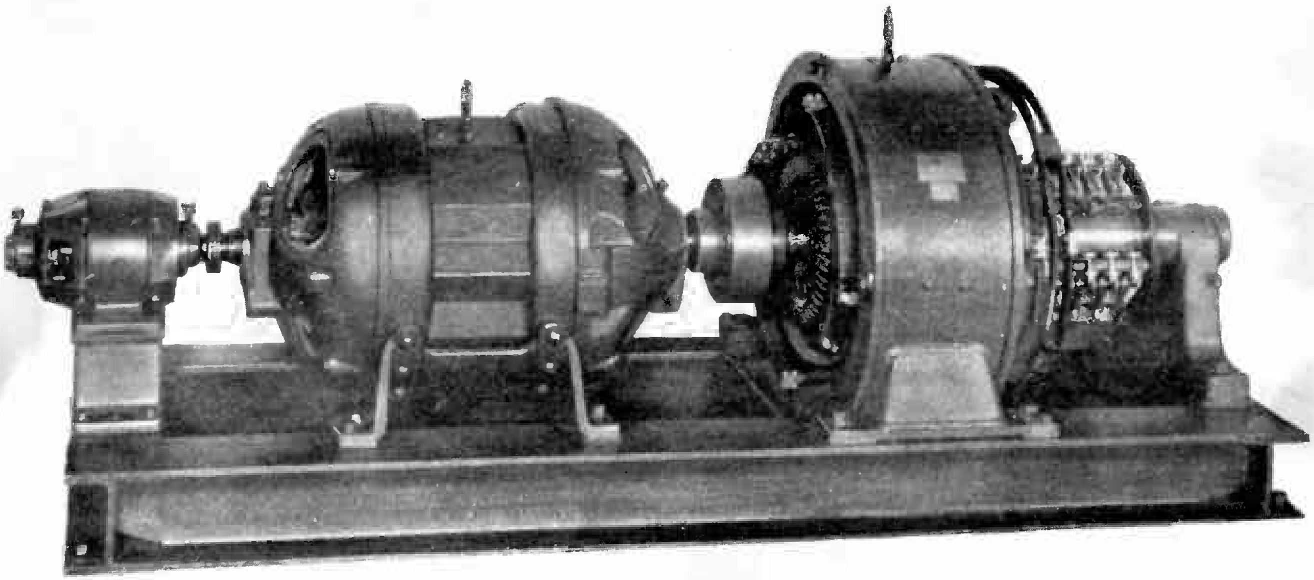


Typical Broadcast Station Power Room

D. C. GENERATORS

VOL.10,No.9

Dewey Classification R100



Filament Motor Generator Set
The unit is capable of furnishing 600 amperes at 35 volts. Exciter is shown at left

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D.C. GENERATORS

The theory of the electric generator and the electric motor are very closely related and the construction of both is practically the same.

The action, however, of the generator is opposite to that of the motor. The generator, or dynamo, as it is sometimes called, converts mechanical energy into electrical energy while, the motor converts electrical energy into mechanical energy.

Electrical energy is taken from a generator when it is driven by an electrical motor or by other means such as a steam or gas engine, or by a water turnbine.

The dynamo can be used either as a generator or motor. The term used to designate a machine depends upon whether it is to be used as a motor or as a generator. In shop practice this method of having one machine which can be either used as a motor or generator is employed to some extent.

HISTORY OF THE GENERATOR

We have to look backward a good many years to find when the first generator was used. In 1821 Michael Faraday, an English scientist, found that he could produce rotation of a magnetic needle when it was brought near a conductor carrying an electric current. He did this while experimenting and applying the discoveries of Oersted in electromagnetism. In 1831 Oersted's great discovery of electromagnetic induction was made and, from that date, you might say the electric generator was born, for it was on this principle that the dynamo was founded. Since then many men have contributed to this discovery and it has taken years of constant study and application to bring the generator to its present-day perfection.

THE PRINCIPLE

Generator:—From the name many people think the dynamo generates electricity. To entertain this idea, however, is wrong. A dynamo can no more generate electricity than a water-pump can generate water. The water is there; the pump merely forces it out of the well. Electricity is already there, and the dynamo only generates a pressure which moves the electric current through a wire.

In your earlier lessons you spent some time with electromagnetic induction, learning how an E.M.F. was induced in a wire when it moved through a magnetic field. You were then acquiring knowledge which will now enable you to understand the principle of the generator.

If you make a loop of wire and bring the ends out to two "collector" rings as shown in Figure 1, and place this loop in a magnetic field, and so arrange the loop that it may be rotated in this magnetic field, you will have an experimental device suitable to illustrate the principle of a simple generator.

If this loop is now revolved so that the lines of force between the two magnets are cut, an E.M.F. will be induced in the loop and current will flow through the loop "AA" and "BB". The current which is being forced around this loop by the induced E.M.F. will

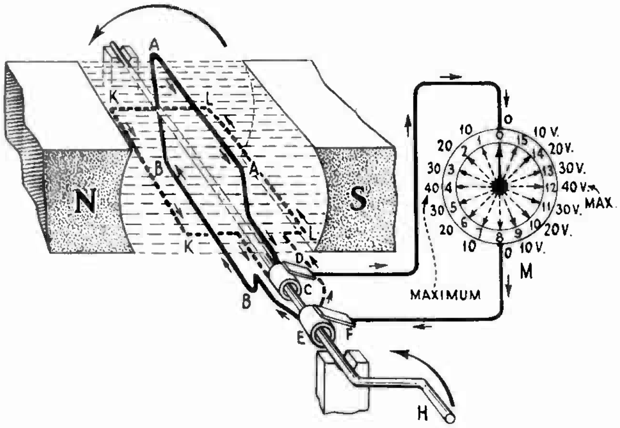


Fig.1-Diagram illustrating the operating principle of a simple generator

flow to the collector ring "C", to the brush "D", and through the meter "M" to brush "F", to collector ring "E" and return to side "BB" of the loop. The current has caused the meter needle to move so we know that current flows in the loop.

If the loop is turned from the position as shown in the diagram by the handle "H" to the left, the side "A.A." of the loop will begin to move through and cut the lines of force at an angle.

As the side "AA" moves in the direction shown by the large arrows the induced E.M.F. will cause current to flow through the loop as shown by the small arrows on the loop. More lines of force are cut as it moves toward the dotted lines "KK", which represents the loop at the point where it cuts the greatest number of lines of force or at right angles, and when it reaches this position the maximum E.M.F. is induced and the greatest current flow naturally results.

As the loop moves out of this point of greatest field strength toward position "BB" less and less E.M.F. is induced as the loop gradually approaches the point "BB"; at point "BB" the loop moves parallel to the magnetic field and no lines of force are cut consequently no E.M.F. results.

While side "AA" has been moving down, side "BB" has been moving up, and the induced E.M.F. in side "AA" is in the opposite direction to that in side "BB".

We said that when the top of the loop moved downward from point "AA" to point "KK" E.M.F. was induced in that side of the loop which increased in strength until at point "KK" the maximum E.M.F. was reached. As the loop continued beyond position "KK", the induced E.M.F. gradually became less until, at point "BB", it dropped to zero.

The induced E.M.F. gradually increased from zero at point "AA", to a certain point and then decreased again to zero.

Suppose we study Figure 2 and see what we can get out of that picture to help us understand this E.M.F., or voltage rise and fall.

Here we have something that looks like a cart wheel; at the center is a hub and from this hub are radiating lines or arrows which point at figures around the rim of the wheel. Start at the hub now and

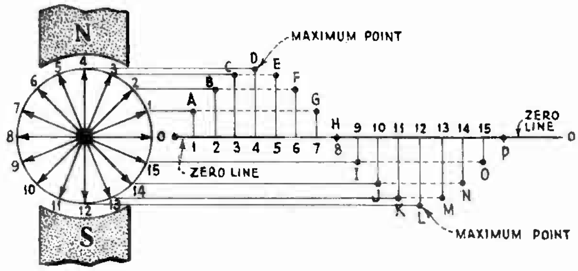


Fig.2-Diagram illustrating voltage increase and decrease in a simple generator

study the arrow which points to zero. Just opposite zero you will see a line which we will call the zero line; this zero line extends, we will say, for 15 inches, and the numbers, 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, will then be at intervals of an inch.

The arrow above and to the left of arrow 0 points to 1, the next arrow above and to the left of arrow 1 points to 2, and so on around the rim of the circle until we return to arrow zero.

We are going to let the arrow which points to zero represent the position of side "AA" of the loop in Figure 1.

We want you to follow this very carefully for you are going to construct a curve which is the method used by all electrical men to show how electric current moves in an A.C. circuit. It is important for you to know this for you are going to see many similar curves before you finish this work and we want you to understand how the curve is obtained.

The loop will be rotated through the magnetic field. Before moving the loop, however, let us look over the special meter we have arranged at M, Figure 1, to indicate the amount of the induced voltage as it increases and decreases in the loop during its journey through the lines of force.

On the inner circle of the meter you find numerals 0 to 15; these correspond to the movement of the loop. On the outer circle 10v (10 volts) 20v, 30v, 40v appear and, following the circle around, 40v, 30v, 20v, 10v, 0 volts appear. Now let us start the loop and, if it were possible to observe the individual readings as the loop is turned, the following results would be noted.

The loop moves from point zero, the neutral or zero position, to point 1, and has cut lines of force for a distance of one inch. Glancing quickly at the meter M, Figure 1, we find that the voltage has increased from zero volts to 10 volts. At this position, or point "A", Figure 2, place a dot. The loop moves on, and our next point of observation is at point 2. Again reading the meter we find the voltage has increased to 20 volts, so at point "B", Figure 2, another dot is placed. As the loop revolves, and arrives at point 3, Figure 2, we take our reading of 30 volts, and another dot is placed at point "C", (Note that the voltage is increasing as the loop approaches the point where it is cutting more lines of force at right angles). At point 4, another reading is taken and we find the meter reads 40 volts. So we place a dot at "D".

The arrow pointing to Number 4, Figure 2 represents the loop in position "KK", of Figure 1.

As the loop moves downward from point "KK" in Figure 2 to point "BB", the resulting positions are shown in Figure 2 by numbers 5, 6, 7, 8. We find that at point 5 the voltage has dropped to 30 volts, or 10 volts less than at point 4, and a dot is placed at point "E". Our next reading is at 6. The meter reads 20 volts and a dot is placed at "F"; at point seven the voltage has dropped to 10 volts and a dot is placed at "G" and, as point 8 is reached, the meter shows zero volts and a dot is placed at "H".

The foregoing is called one alternation; the voltage at the start was zero and it gradually increased until the maximum of 40 volts was reached when it receded again to zero value.

As the portion of the loop "BB", Figure 1, continues it begins to travel upward through the lines of force inducing an E.M.F. opposite in polarity to that induced on its downward travel. Naturally the current will change its direction of flow. We will show you how to plot this by using Figure 2.

The loop is now moving from position "BB" towards "LL", Figure 1 and as it leaves point 8, Figure 2, and reaches point 9 we find that the meter reads 10 volts. Following out our line to point "I" another dot is placed. (Note that the voltage is increasing again, but in the opposite direction). Point 10 is now reached in the upward travel of the loop as it comes under the influence of the "S" pole of the magnet, and our meter reads 20 volts; another dot is placed at "J". when 11 is reached the meter reads 30 volts and another dot is placed at "K"; point 12 is next with a meter reading of 40 volts or the maximum voltage of the alternation.

The voltage now begins to drop and, as points 13, 14 and 15 are passed, we read a voltage of 30, 20 and 10 volts respectively, with dots placed at "L", "M", "N" and "O". Finally when the loop reaches zero, the starting point, the voltage has dropped to zero and, with a final dot at "P", a cycle of values has been completed, i.e., two alternations.

Now starting with the dot at zero draw a continuous line through A, B, C, D, E, F, G, H, I, J, K, L, M, N, O, to P and you will have a curved line as shown in Figure 3. Draw a straight zero line beginning at zero through "H" to "P" and a true sine curve is the result, shown in Figure 4.

From this study it is seen as the portion of the loop leaves the point "AA", Figure 1, it moves downward and cuts the lines of force under the influence of the magnet "N", (north polarity) and the

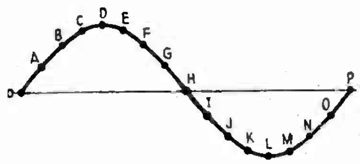


Fig.3-Voltage curve diagram

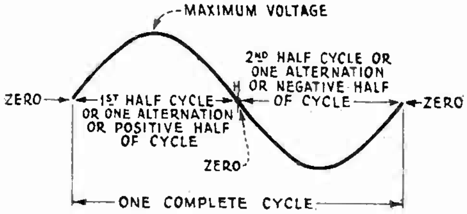


Fig.4-A true sine curve

induced E.M.F. is in one direction while the loop leaving the position "BB" is cutting the lines of force under the magnet "S" (south polarity) upwards, inducing an E.M.F. in the opposite direction.

To lead this induced alternating current out of the loop two collector rings "C" and "E" are mounted on the shaft, insulated from each other, to which are connected the ends of the loop and on which rest the brushes "D" and "F" as shown in Figure 1. Leads connect the brushes to the meter and, as just explained to you, as the loop

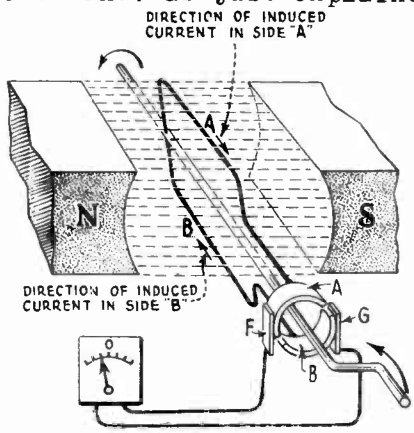


Fig.5-Diagram of a simple direct current generator

revolves, the needle of the meter indicates the rise and fall of induced current at the various parts of the revolution or cycle. These results may be plotted similar to the curve you have just made.

Alternating current is used to a great extent, and we will discuss that in another lesson. However, at this time we are dealing with direct current dynamos, therefore it is necessary to provide some means for changing alternating current to a direct current, or a current which flows in the external circuit in one direction.

This may be done by removing the collector rings, shown in Figure 1, from the shaft and substituting a commutator about which you have alreadv studied. This is shown in Figure 5. Here only one loop is used. Therefore only two segments are needed. The metallic ring is split into two segments A and B and, where they are split insulation is placed, which is flush with the outside face of the segment. The ends of the coil are soldered to each segment as shown in Figure 5. The loop "A" and "B", as shown in the diagram is parallel with the magnetic field and this is the position where no E.M.F. is induced as indicated by the small meter. (Also note the brushes short circuit both segments; that is the neutral or no voltage position).

Now by turning the handle in Figure 5 so the loop revolves counter-clockwise, or to the left, side "A" of the loop begins to cut the magnetic field of the magnet under the "N" pole inducing an E.M.F.

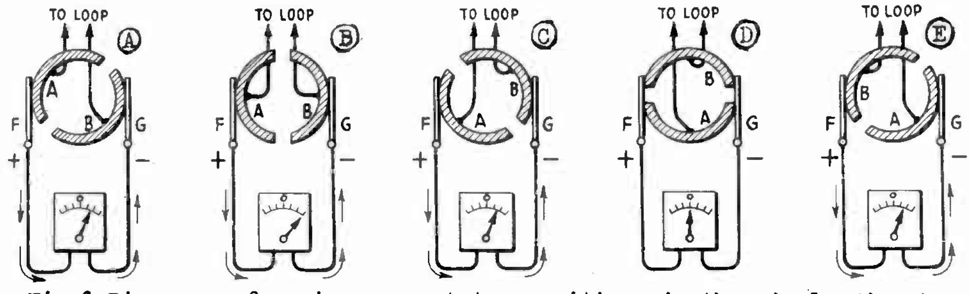


Fig.6-Diagrams of various commutator positions in the simple direct current generator

which causes an induced current to flow in this half of the loop as shown by the arrow. The commutator segments which are secured to the shaft have moved into the position as shown in Figure 6A, and the induced current is flowing to segment "A" and out brush "F" through the meter to brush "G", into segment "B", and to the "B" side of the loop.

At the same time, the "B" half of the loop has moved upward, as shown by the arrow in Figure 5, cutting the magnetic field of magnet "S", inducing an E.M.F. in this half of the coil causing an induced current to flow through "B" half of the loop, as shown by the arrow, which is opposite in direction to that of side "A".

The coil has now taken the same position as shown in Figure 7 by the arrows 2 and 6.

As the loop rotates it reaches the position 3 and 7, Figure 7, with the commutator as shown in Figure 6B. Position 4 and 8, Figure 7, is the next position of the loop with the commutator in position Figure 6C.

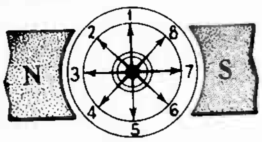


Fig.7-Loop positions

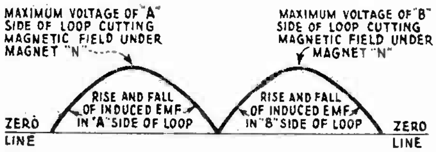


Fig.8-A direct current sine wave

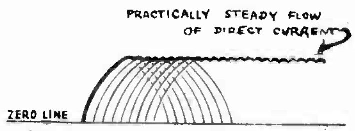


Fig.9-A pulsating direct current graph

At position 1 and 5, Figure 7, the "A" side of the loop in Figure 5 is at position 5, while "B" side is holding the position that "A" formerly held at the start. The loop is again in the neutral plane, at which point no E.M.F. is induced in the loop.

The "A" side of the loop and the "A" segment of the commutator could be considered positive at this point, and the "B" side of the loop and "B" segment of the commutator negative. The commutator is shown short circuited at 6D and in this position the loop is parallel to the magnetic field at which time no current flows.

Continue to rotate the loop (Figure 5), however, and side "B" and segment "B" now becomes positive, while side "A" and segment "A" are negative, Figure 6E, and the same cycle of events take place over and over again as the loop continues to rotate.

Thus, you can readily see that at each half revolution the current changes direction in the loop as it comes under the influence of the different magnetic poles. The commutator, however, keeps the current flowing in the external, or meter circuit, always in the same direction, thus supplying direct current to the external circuit.

Thus, with only one coil on the armature and using a commutator the current would rise and fall, but would not reverse its direction. This condition is shown in the curve Figure 8, and is called a pulsating direct current. This condition is not desirable, because if a lamp is connected in the circuit instead of the meter the lamp would appear dim at first then bright at the point of maximum voltage, then grow dim again and at each half revolution of the loop the lamp would go out. In order to eliminate this undesirable feature of alternate increase and decrease of the E.M.F. a great number of loops are used with a correspondingly great number of segments.

With more loops revolving in the magnetic field the pulsating current becomes as shown in Figure 9, giving a greater number of pulsations per second of time.

The loops are so arranged that each coil replaces the preceding loop coming into the magnetic field so rapidly that the E.M.F. is practically constant. One coil no sooner passes out of the maximum voltage point than another is arriving at the same point.

However, even with a large number of armature coils, and a correspondingly large number of segments, these slight fluctuations of the current will still be present. Such fluctuations of the current are known as "commutation ripples," but are so small in value that, as far as ordinary circumstances are concerned, they are of no importance.

If we revolve the armature through the magnetic field and the armature coils are self supporting, the reluctance which the air gap between the poles offers to this magnetic field will materially reduce its strength.

All armature coils are wound on a soft iron laminated armature core. This iron core practically fills the space between the magnetic field poles, reducing the reluctance offered to the magnetic field and therefore a greater number of lines of force may be cut. The distance between the revolving armature core and the field magnet pieces is usually 1/64 of an inch.

FIELD POLES

The field magnets of motors and generators are generally large electromagnets. The core in most cases is either cast iron, wrought iron or soft steel. In some types of small motors the frame and pole pieces are permanent magnets and these require no field winding.

In the larger types that we are dealing with the field magnets are electro-magnets and are made up separately and bolted to the frame of the motor or generator. The field pole is machined carefully to fit closely to the frame, because a tight joint reduces magnetic leakage. The field pole, "A" in Figure 10, is soft iron cast into shape, and then machined as shown. Holes are drilled for the holding bolts and provisions made to countersink the heads of the holding bolts into the shoe of the pole piece.

The form wound field coils are next prepared as shown in B. In series wound motors the field coils consist of heavy insulated wire. As each turn is wound on the form, shellac is applied. Upon completion of the winding as shown at "B", Figure 10, it is wrapped with cotton tape shellacked again and baked. The completed winding is then ready for the pole piece, which is removed from the frame, and the field coil is slipped over the pole piece fitting close up to the shoe of the core, as shown at "C", Figure 10. The completed field coil is then placed inside the generator frame, bolted into place and the terminal of each coil connected as shown at "D", Figure 10. The placing of the pole pieces as to polarity, together with the path of

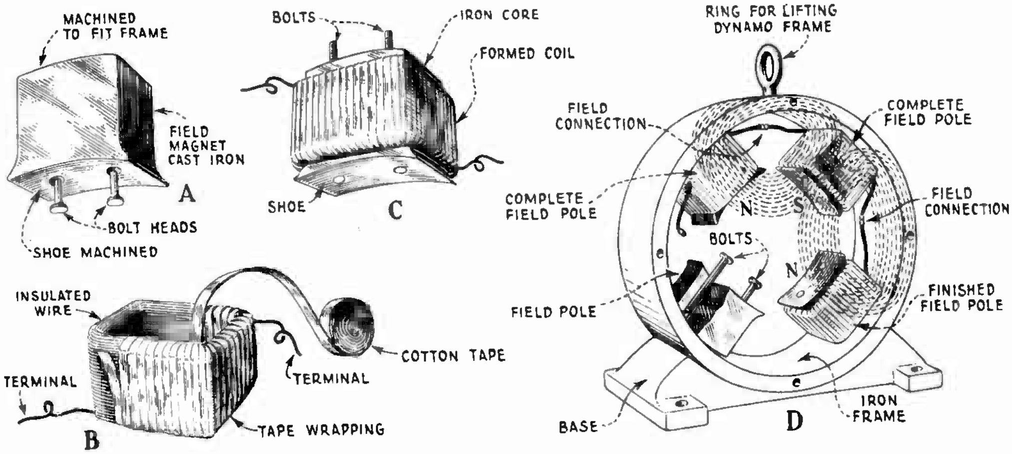


Fig.10-Details of the field magnets in a direct current generator

the magnetic field through the frame, is also shown at "D", Figure 10. This figure shows a four pole generator. Bipolar (two pole generators) are also used.

The field coils are connected in different ways according to the design of the machine. In most commercial direct current generators the fields are self excited; that is, they are energized from the current generated in the armature. In alternating current generators the field is generally excited separately by a small D.C. generator connected directly to the armature shaft of the alternator, or from the D.C. supply mains.

The soft iron used in the field magnet retains a small amount of magnetism, called residual magnetism, after the generator is shut down. On starting the generator this residual field makes it possible for the armature coils, as they cut this weak field, to generate an induced E.M.F. thereby starting an induced current. As soon as current begins to flow in the armature it strengthens the field winding, gradually building up the magnetic field strength until it becomes normal.

There are times when this residual magnetism fails; that is, the pole pieces lose their magnetism to such an extent that the E.M.F. will not build up. In this case it is necessary to separately excite the field magnet winding by connecting several dry cells in series with the field coils to produce a field strong enough for the armature to develop an E.M.F. As soon as the E.M.F. starts to build up the dry cells are disconnected and with the field circuit restored, the machine will operate normally.

Let us observe some of the ways the generator field coils are connected with the armature, which designates the type of D.C. generator. To make this as easy as possible we will use three drawings; all three slightly different in appearance but, nevertheless, the circuits are the same.

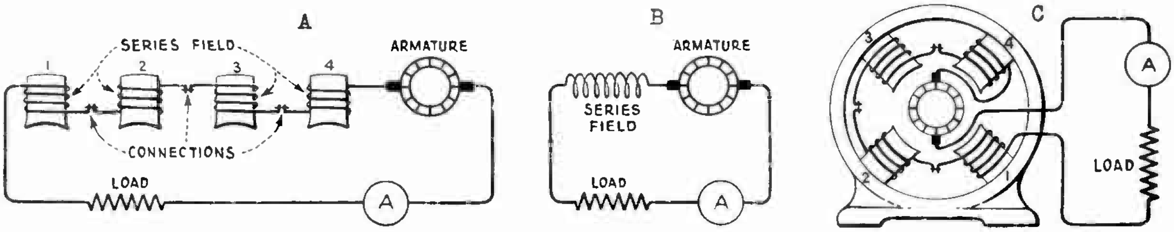


Fig.11-Diagrams illustrating series wound field coil connections

Figures 11A, 11B, and 11C show the connections for a series generator in which the field coils are connected in series with the armature; all the current passing through the armature windings must pass through the field windings as well.

Suppose first we lay four field magnets out in a row as shown in Figure 11A. Connect them all in series and then connect No. 4 to the armature brush; the other field winding terminal, No. 1, goes to the load and meter. The other armature terminal goes to the meter. This is a series connection. Figure 11B is a schematic drawing of the same thing, while in Figure 11C we have placed the coils and armature in a frame. By tracing the circuits you will find "A" and "B" the same.

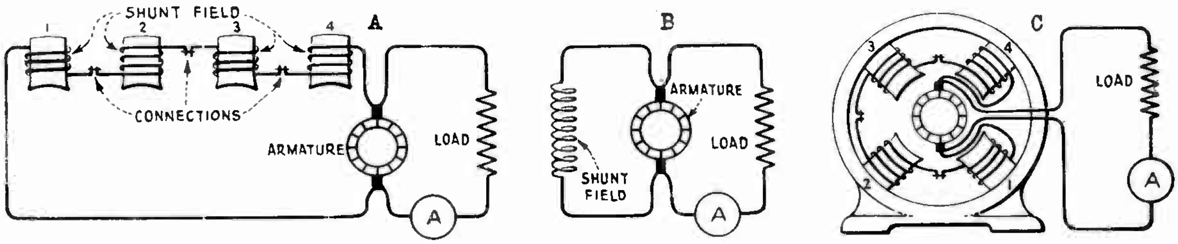


Fig.12-Diagrams illustrating shunt wound field coil connections

The shunt type of D.C. generator is shown in Figures 12A, 12B and 12C. Notice that the field coils are wound in series with each other and connected across, or in parallel with, the armature coils and NOT IN SERIES. The coils are wound with a large number of turns of fine wire as only a small portion of the armature current flows through the field. Figure 12A shows the field coils in a row. Figure 12B is the schematic drawing, and in Figure 12C the field coils are shown placed in the generator frame.

The compound wound generator is a combination of both the series and shunt generators, having both a series and shunt field. The characteristics of both the series and shunt machines are thus combined in one machine and much better regulation of the voltage is secured under all conditions of varying loads.

The series winding is connected in series with the armature and the load as shown in Figure 13A,B and C, while the shunt field is connected in parallel or in shunt, with the armature.

The action of the windings is as follows: When a load is thrown on the generator the shunt field is weakened and at this point the series field helps out by strengthening the shunt field thereby automatically maintaining a constant voltage under a varying load.

The current in the compound wound windings must flow through both the series and shunt windings in the same direction in order that the resultant field will be strengthened.

The electromotive force or voltage generated depends upon the following factors:

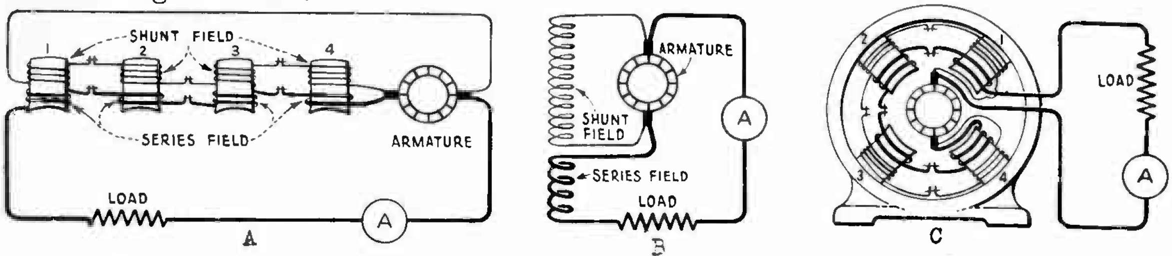


Fig.13-Diagrams illustrating compound wound field coil connections

1st. The number of loops or conductors on the armature revolving in the magnetic field.

2nd. The strength of the magnetic field or lines of force.

3rd. The rate at which the armature carrying the loops or conductors move through this magnetic field.

It is necessary therefore that these factors be given careful consideration to obtain maximum voltage from a generator.

For a detailed explanation of the commutator refer to Figure 9 and the text associated therewith on D.C. motors. Both the assembly and discussion of the commutator is presented.

The brushes used in nearly all types of generators are made of carbon. The hardness and softness depends upon the copper segments of the commutator. A soft copper segment requires a soft carbon brush while on hard copper a hard brush can be used. The degree of hardness of the copper is not changed intentionally; this variation occurs during manufacture and different grades of carbon brushes are made to meet this condition. The size of the brushes primarily depends upon the amount of current being taken from the armature of the generator. If the current is high in value then brushes large enough to easily pass such current must be used. Conversely, if the current is low in value then proportionately smaller brushes are used.

The device holding the brush in the proper place and bearing on the commutator is called the brush holder, a diagram and explanation of which is shown in Figure 14.

This brush holding device is secured to a brush frame from which it is insulated, fitted with a handle, and so arranged as to allow the brushes to be shifted around the commutator. This is called the rocker arm and allows the brushes to be moved at times in order to compensate for distortion of the magnetic field. This is explained under the subject of "armature reaction".

ARMATURE REACTION

Armature reaction is caused by the effect of the magnetic field about the rapidly revolving iron armature and its coils upon the main magnetic field set up by the field coils and this reaction distorts or draws the main magnetic field out of its natural position. The neutral point is thereby changed and the brushes must be shifted to compensate for this reaction. This change in the setting of the brushes is shown in Figure 15.

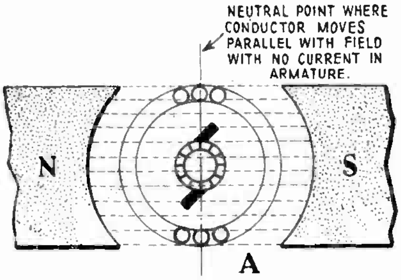


Fig.14-Diagram showing the use of the brush holder

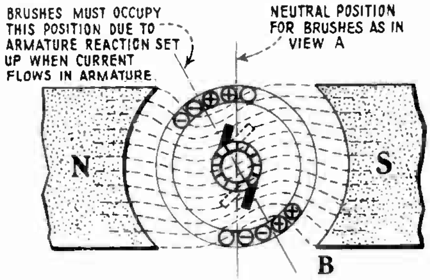


Fig.15-Diagram illustrating required adjustment of brushes to compensate for armature reaction

By referring to the cycle of events in the loop as shown in Figure 6 and the neutral point mentioned there, armature reaction may be more readily understood with the following explanation. The neutral point or plane, you remember, is that point where the armature loop or coil moves parallel with the magnetic lines of force and is the point of zero voltage or where no induction occurs. The current changes direction in the loop at either side of zero position. Armature reaction changes this neutral point, or point of commutation, as it is most generally termed.

Suppose that an armature revolves in a magnetic field with the external circuit open or not connected to the brushes on the commutator. The main field will in this instance remain normal, that is, the lines of force will extend from N to S, or from north to south magnetic poles as shown by the dotted lines in Figure 14. When a load is thrown on the generator the circuit through the armature coil is closed and reaction between the field proper and the field of the armature results. This reaction between the armature field and the magnetic field of the pole pieces causes the normal neutral plane to shift, and it is readily seen that the coils, which are passing the point where the neutral plane formerly existed without any load on the armature, are not moving parallel with the magnetic field but are cutting the lines of force at an angle; see Figure 15. Therefore the brushes must be moved to that new position of the neutral point which results from such distortion of the magnetic field, for at this new point the coils on the armature will be travelling parallel with the distorted magnetic field. The proper adjustment for the brushes is at the "point of commutation". The brushes must be shifted on both generators and motors.

FIELD CHARACTERISTICS

Each of the aforementioned types of field winding produces a generator with different output voltage characteristics.

A voltage characteristic curve for a series wound machine is shown in Figure 16. It will be seen that the voltage output increases with load until a certain load current is reached; at this point the voltage starts to fall off rather rapidly. The reason for this is that the field windings have reached a condition of magnetic saturation so that further increase in current gives no further increase in excitation. In addition the armature reaction is increasing causing a reduction in effective excitation flux. The armature IR drop is also increasing.

The output voltage characteristics of a shunt wound machine are shown in Figure 17. Here it will be noticed that a comparatively high value of E.M.F. is produced even at no load, but the curve falls off gradually until a certain value of current is reached at which point it falls off abruptly. This curve can be kept relatively flat by the use of a rheostat in series with the field which could be used to adjust the amount of excitation for each change in load.

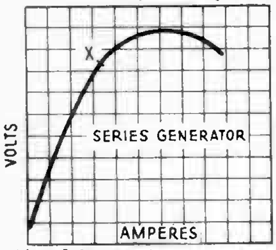


Fig.16-Series wound generator voltage curve

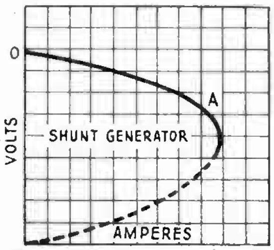


Fig.17-Shunt wound generator voltage curve

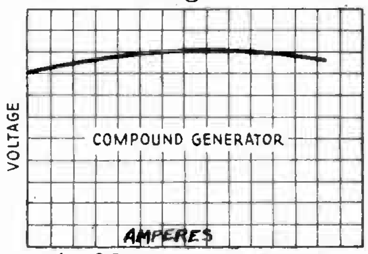


Fig.18-Compound wound generator voltage curve

As the load through the armature increases there is an increase in armature reaction as well as an increase in IR drop through the armature. This causes considerable voltage drop at the armature terminals or brushes reducing the impressed voltage on the field resulting in rather a large decrease in field excitation. The sharp dip in the curve shows where this excessive excitation drop takes place.

By reference to the two curves it will be seen that Figure 16 shows a rising voltage characteristic and Figure 17 a falling voltage characteristic. The compound wound generator which is a combination of the two windings produces a voltage characteristic which is a combination of those shown in Figures 16 and 17. This characteristic is shown in Figure 18 and it will be readily seen that this approaches the ideal characteristic where the generator is to be operated under varying load conditions.

TYPES OF COMPOUNDING

There are in use three types of compound windings:

1. Flat compound; a winding so designed as to keep the voltage constant under wide variations in load.
2. Over-compound; a winding designed to permit the voltage to increase slightly as the load increases.
3. Under-compound; voltage drops slightly as load increases.

THE EFFICIENCY OF D.C. GENERATORS varies from 77% in the smaller sizes to as high as 94% in the larger size units. Efficiency of a generator may be stated as an equation as follows:

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}}$$

or since it is sometimes difficult to measure the input to a generator the equation may be stated:

$$\text{Efficiency} = \frac{\text{Output}}{\text{Output} + \text{Losses}}$$

It is desirable at times to express the voltage regulation of a d.c. generator in terms of percentage. This is stated as a formula as follows:

$$\text{Voltage regulation} = \frac{\text{No load voltage} - \text{full load voltage}}{\text{Full load voltage}}$$

The losses in a generator are three in number, namely:

1. Iron losses (hysteresis and eddy currents)
2. Copper losses (I^2R in armature and field)
3. Mechanical losses (bearing friction and windage)

The watts lost in the iron of the armature are caused by hysteresis and eddy currents.

Hysteresis losses it will be remembered are losses incurred by the reversal of the molecules of iron each time the direction of magnetic flux is reversed. The amplitude of these losses in a generator are dependent upon the number of reversals made per second of the magnetism in the armature core, the amount of iron in the core, the quality of the iron and the density of the magnetism in the iron. Generally the softer the iron the lower the losses due to hysteresis.

Whenever a conductor cuts lines of force an E.M.F. is induced in it. This applies to the armature core as it does to the conductors. These currents tend to flow from one end of the armature to the other under one magnetic pole and return under an opposite magnetic pole. These currents require power to establish and maintain them. This power is expended in the form of heat which tends to heat up the armature and might reach a point where it would prove damaging to the insulation. However by making up the armature of laminations of thin discs and insulating each disc from its neighbor this trouble can be largely eliminated.

The copper losses are the watts lost in the excitation of the field and the losses due to resistance of the armature coils.

The mechanical losses are made up of the friction of the brushes rubbing on the commutator, friction of the bearings and the friction of the air which is called windage.

POSSIBLE TROUBLES

Generators should be watched carefully to correct troubles which may appear unimportant at first but which may later become serious. The most important possible troubles follow:

The bearings of a generator and motor should be kept in good condition; the oil should not be allowed to become gummy. The oil rings should be watched at all times to see that they are carrying oil to the shaft and bearing.

Figure 19 illustrates a bearing and oil rings. "A" is the bearings with the oil rings in the slots fitted loosely on the shaft. The dotted lines show the shaft which carries the rings; as the shaft turns in the bearing the oil rings which rest on the revolving shaft also turn, picking up oil as they rotate and thus splashing the oil onto the shaft. "B" shows the pillow block, the lower half containing the oil well (the rings are shown in dotted lines) the upper half of which is held in place by bolts and is called the "housing" which covers the bearing.

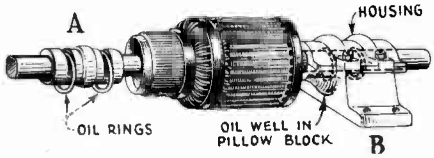


Fig.19-Armature bearings and oil rings

The brushes must be given special care. They should fit into the brush holders in such a manner as to prevent "chattering" and still be free to move up and down.

The spring holding the brushes in contact against the commutator should be examined and adjusted for proper tension to avoid scoring of the commutator by the brush.

Keep the brushes and brush holder free from dust and see that the face of the brush resting on the commutator is fitted properly to the commutator in order that the brush bears evenly at all points against the segments. Should it become necessary to refit the brush to the commutator do so as shown in Figure 20. Lift the brush and place a piece of double O (OO) sand paper with the smooth side against the commutator. Allow the brush to drop back against the rough or sanded part of the paper, then allow the sand paper to follow the curvature of the commutator and with a back and forth movement the sand paper will cut away the carbon brush, insuring a close fit. The tension of the spring will keep the brush against the sand paper while you are moving it back and forth. This is the only abrasive that should be used for the purpose. DO NOT USE EMERY PAPER. The machine should be so left that it cannot be accidently started during the process of fitting the brushes.

Keep all abrasives, especially those of a metallic nature, away from the commutator and bearings; emery paper will cause short circuits between the segments of the commutator and will cut the bearings if allowed to come in contact with them.

Sparking at the brushes can be caused by high spots on the commutator which should be remedied. Rough or pitted commutators should be turned down on a lathe. Excessive loads at times cannot be avoided, but after such instances the brushes and commutator should be examined and cleaned and given as good care as possible. The mica insulation between the copper segments is often higher than the segments themselves; the mica should then be cut down on a lathe. If the brushes are out of the neutral plane, i.e., point of commutation, they may be correctly adjusted by shifting the

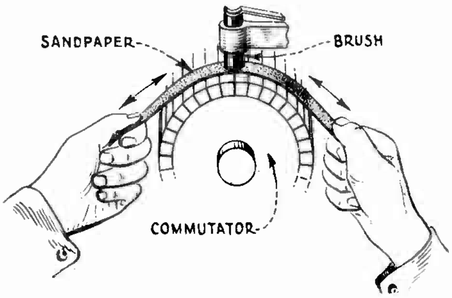


Fig.20-Illustrating method of cleaning and shaping brushes

rocker arm. If a brush becomes wedged in its holder it should be removed and be given a thorough cleaning.

An armature coil which is partially short circuited will cause sparking; this must be located and repaired.

The commutator may at times become extremely hot due to excessive current being drawn from the generator. There is, in this case, only one remedy; reduce the load on the generator to normal.

The armature loops or conductor terminals may become loose in the segments; this raises the resistance of the contact and produces heat.

At times metallic particles become lodged between the segments of the commutator due to gummy oil which has been splashed there from the bearings. The particles come under the brushes and being deposited between the segments, they cause sparking. The commutator and brushes should be cleaned, using clean gasoline on the commutator and polishing with a piece of heavy canvas.

A burned out, or shorted, or grounded armature coil will cause sparking. Tests for locating such trouble will be given you later, together with tests for locating short circuits, grounds and broken connections.

EXAMINATION QUESTIONS

1. Is there any major difference between an electrical motor and an electrical generator?

2. What is the purpose of an electric generator?

3. What grade of emery paper should be used to clean a commutator?

4. What is the purpose of field poles?

5. What is meant by the term "residual magnetism"?

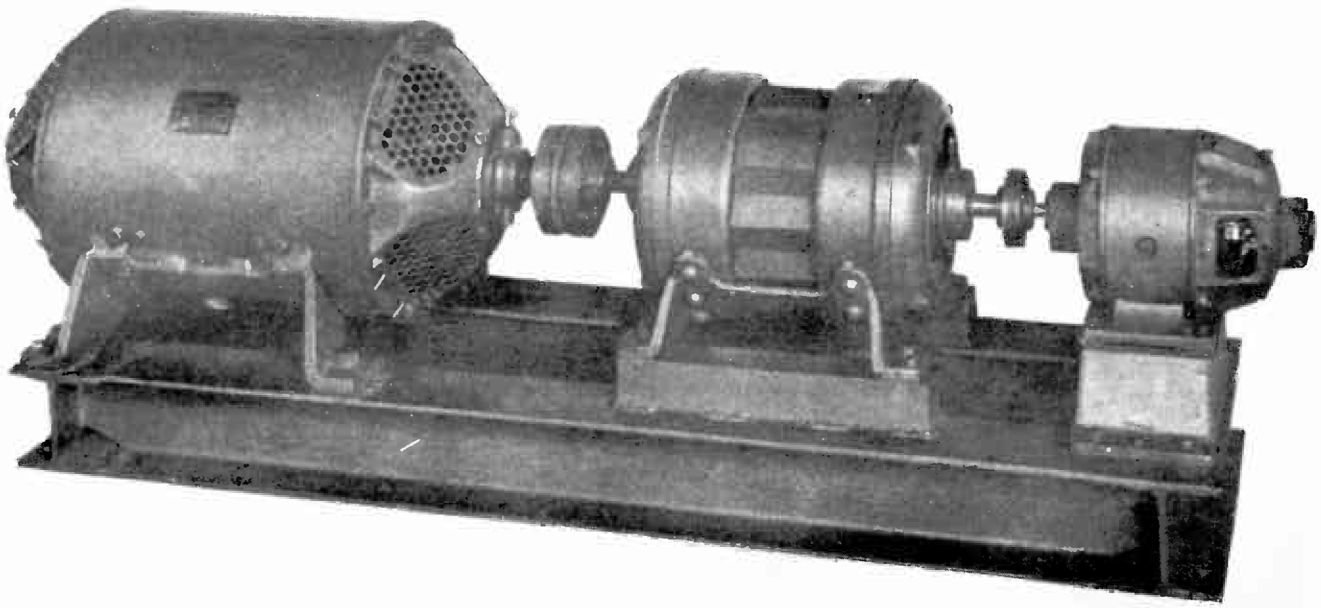
6. Draw a diagram of a shunt generator.

7. (a) What are brushes used for? (b) What care should they receive?

8. Are the bearings of a generator considered important?

9. Suppose the field poles lose their residual magnetism, how would you proceed to overcome this difficulty in order that the generator might be used?

10. What is the purpose of collector rings?



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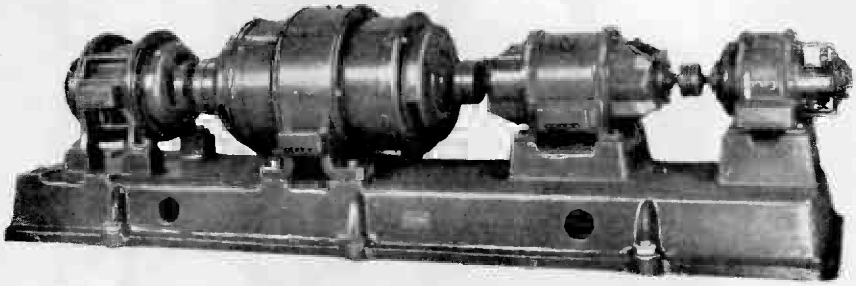

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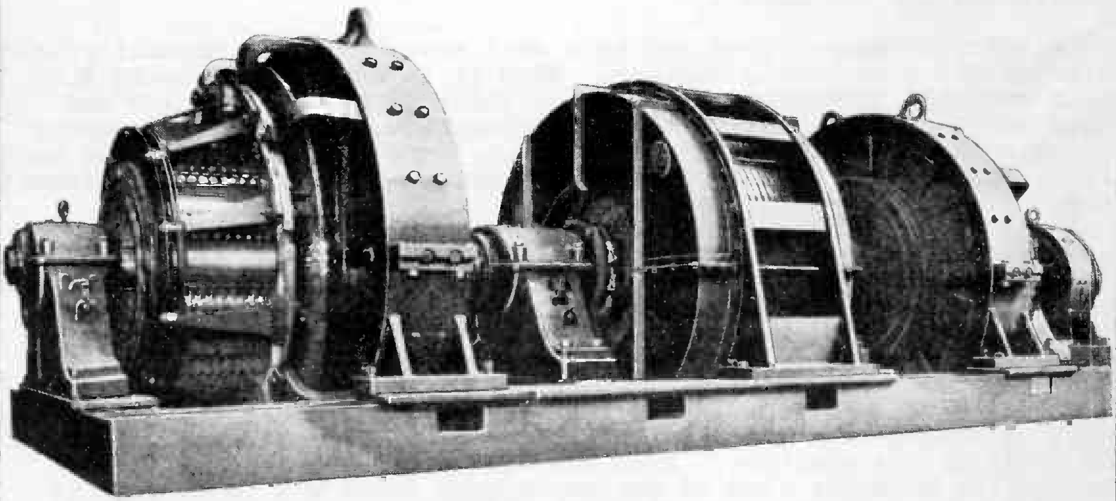

Westinghouse 12,000 Ampere, 3-Unit Synchronous Motor Generator

ALTERNATING CURRENT

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ALTERNATING CURRENT

Generators may be classified as follows; alternating current generators and direct current generators. More specifically A.C. generators are often called "alternators", and D.C. generators are called either "generators" or "dynamos".

The electrical energy produced by a coil revolving in a magnetic field is primarily alternating current. When it is desired to obtain D.C. in an external circuit, i.e., current which is steady in value and which moves continuously in the same direction, it becomes necessary to equip the generator with a commutator. The commutator, as you know, allows the current to flow through the external circuit in one direction only.

In radio telegraphy and telephony it is often necessary to utilize alternating current therefore we do not equip the machine with a commutator, but employ slip rings which permits the induced current to flow from the coils of the armature into the external circuit just as it is generated, or as alternating current.

In your lesson on direct current generators you learned that the armature, revolving in a magnetic field, produced alternating currents in the coils of the armature. When one side of the closed coil moved through the magnetic flux of the north pole there was induced in it an E.M.F. which caused current to flow through the armature coil in one direction. The other half of the coil begins to cut the magnetic flux of the south pole of the magnet at the same time which also causes a current to move in this half of the coil for the same reason as caused current flow in the first half.

If the terminals of this revolving coil are connected to a pair of brass rings, or slip rings, and a pair of brushes rest against and make contact with these rings, (to which is connected the external circuit), the induced current can be made to follow the conducting wires forming the external electrical circuit.

In order to better explain the fundamental action going on in the alternating current generator, or alternator, we will consider a single coil instead of an armature containing many coils, and study each effect as it takes place during the revolution of a closed coil, or conductor, through the magnetic field or flux.

Now refer to Figure 1. Here we have arranged a single armature coil; the terminals, as shown, are connected to the slip rings. The rings themselves are held in place by an insulated shaft. The brushes and external circuit are clearly shown and marked.

As the coil is forced to revolve in the magnetic field the slip rings must move with the armature coils, all being mounted on a common shaft. The brushes are stationary and merely serve to provide a sliding contact on the rings.

Side "A" has induced in it an electromotive force as it cuts through the magnetic field, causing the induced current to flow in a definite

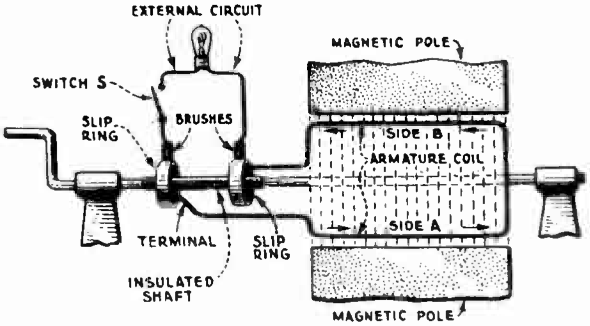

Figure 1

direction as shown by the arrow, if the circuit is closed by closing the switch "S". Likewise side "B" also has induced in it an E.M.F. with current flowing as shown by the arrow.

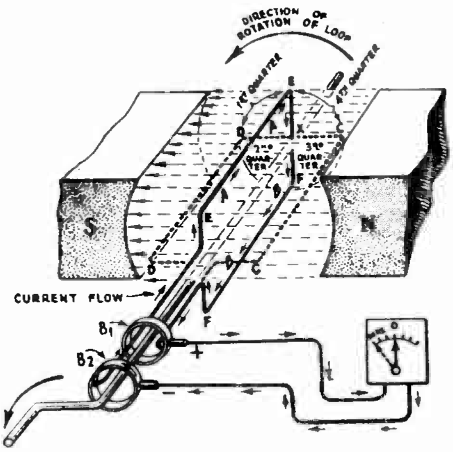

Figure 2

Remember this,-- any wire cutting a magnetic field will have induced in it an induced electromotive force and the current flow is a direct result of this induced E.M.F. but it will not flow until the coil forms a closed loop. Since we know the parts of this simple alternator we can go further and trace the current as it alternates or reverses its direction through the circuit.

Let us study Figure 2 where we have the same piece of apparatus as shown in Figure 1 but drawn in a different position allowing us to see the full circular path of the loop or armature coil through the magnetic field. The side of the coil marked "AA", you will notice, is at the top of the magnetic flux or field at position "EE" while the side "BB" is at the bottom of the field, position "FF".

The meter needle is pointing to zero indicating that while the loop is in this position relative to the magnetic field there is no induced E.M.F. and consequently no induced current will flow because the sides of the loop "AA" and "BB" are parallel with the lines of force and are not cutting the flux.

Before we consider the flow of current suppose we first cause the loop to revolve to show the positions the side "AA" will assume during a complete revolution of the coil. "AA" side of the loop is shown at the position "EE". The loop begins to revolve in a counter clockwise direction, shown by arrows, on its shaft "X", and immediately begins to cut the lines of force or flux of the "S" pole of the magnet.

When it arrives at position "DD", the end of the first quarter revolution, it will be cutting the maximum number of lines of force, leaving position "DD" it cuts less lines of force until at position "FF", the end of the second quarter of revolution, it is again parallel with the lines of force, cutting no flux.

Continuing into the third quarter of revolution it again cuts the magnetic flux, upward this time, gradually cutting the lines of force at a greater angle each fraction of upward movement until at position "CC", or end of the third quarter of revolution, it will be cutting the greatest number of lines of force under the "N" pole or magnetic field of north polarity.

Leaving position "CC", and continuing into the fourth and last quarter of revolution, less and less lines of force are cut per unit of time and, upon arriving at position "EE", the end of the fourth quarter of revolution, it is again parallel to the magnetic field and no lines of force are being cut.

This completes one revolution of the coil through the magnetic field. The loop can be rotated another full revolution and the same cycle of events would be repeated over again.

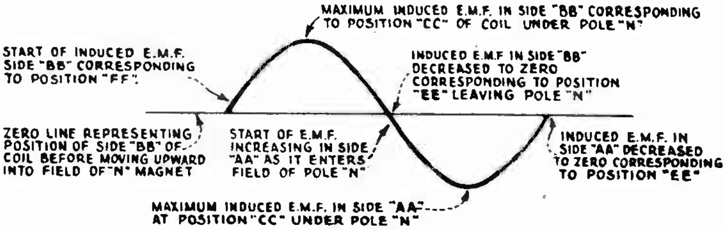

Figure 3

On the second journey of the loop we are going to study how the induced E.M.F. is affected by the cutting of the lines of force,- how it rises from zero strength to maximum strength, and then falls again to zero value.

On the second revolution we will concentrate upon side "BB". The armature starts, "BB" moves upward into the north magnetic field and, because of the cutting of the lines of force, it has induced in it an electromotive force, the strength depending upon the speed it moves and upon the strength of the magnetic field through which it travels.

The induced electromotive force will cause current to flow in this side of the loop in the direction shown by the arrows, making brush "B1" positive. The current increases in strength due to the increased electromotive force induced by the greater number of lines of force cut per unit of time, until the coil reaches position "CC". Here the maximum number of lines of force are cut and the maximum electromotive force is induced. Therefore the maximum current strength possible is obtained at this position, assuming the field to be uniform and the speed constant.

While side "BB" has moved to position "CC", side "AA" has moved into position "DD". An E.M.F. and current is induced in "AA" exactly as in side "BB", but opposite in direction, as shown, making the brush "B2" negative. The resulting induced current has moved through the circuit causing the meter needle to move to the left, pointing to maximum.

Side "BB" now moves out of the maximum field position "CC", cutting less lines of force per unit of time as it moves toward position "EE", therefore less E.M.F. is induced and consequently the induced current decreases in strength, until it reaches "EE" where no lines of force are cut and the E.M.F. drops to zero as indicated by the needle of the meter when it returns to zero position.

We may plot this rise and fall of current taking place in side "BB" of the coil as it passed under the north pole of the magnetic field, as shown in Figure 3, by a curved line which moves upward from zero to a maximum height and then as gradually decreases again to zero.

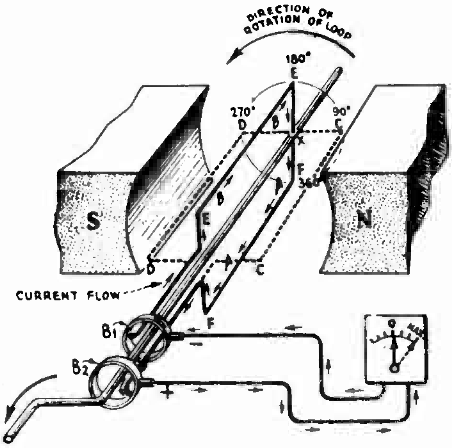

Figure 4

The position of the loop now indicates side "BB" at position "EE" and side "AA" at position "FF". "BB" now moves downward, under the influence of the south magnetic field, and the current induced flows through "BB" and the external circuit opposite to the direction of flow when "BB" was under the north magnetic field. See Figure 4.

The induced E.M.F. rises from zero to maximum and falls again to zero as the coil was moving under the "N" pole, and as shown by the meter needle which has moved across the scale, this time to the right, returning to zero when side "BB" has reached position "FF"; this reversal of current flow will cause the needle to move in the opposite direction.

In Figure 3 we have shown a sine curve which graphically illustrates the continuously varying values of E.M.F. induced in the conductor as it moves through the magnetic field.

VALUE OF E.M.F.

The value of the induced E.M.F. depends upon the following factors:

1st. The number of conductors revolving in the field.
2nd. The strength of the magnetic field.
3rd. The rate at which these lines of force constituting the magnetic field are cut.

In our simple alternator only one conductor was used and we assumed the field strength to be constant.

TIME A DETERMINING FACTOR OF INDUCED E.M.F.

We may now consider the rate at which the lines of force are cut and why the value of the induced E.M.F. varies as the armature coil completes a revolution through the field.

In Figure 5 we have a diagram intended to show how time, or the rate of cutting the field, and the field strength, determines the value of the E.M.F. It is obvious, after studying Figure 5, that a conductor moving through the magnetic field, either from "A" directly to "C" or along the path "A", "B", "C", will cut exactly the same number of lines of force, both having moved through the entire field, and both having cut every line of force in the field. The distance, however, from "A" to "C" is shorter by approximately two thirds the distance than along the path A, B, C.

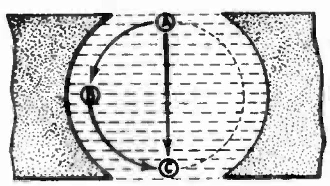

Figure 5

Now assume that the conductor is moving at a speed requiring one second of time to travel from "A" to "C" thereby cutting through all the lines of force with a definite value of E.M.F. being induced. At the same speed it now follows the path A, B, C, and, this path being fifty percent longer than path A, C, it requires 1 1/2 seconds of time to complete the distance. All the lines of force are cut, but at a slower rate, therefore less lines of force are cut in one second in this path than the path "A", "C", and less induced E.M.F. will be the result.

The rate at which the lines of force are cut then in a given time is also going to depend upon the angle at which the conductor moves through the field. When the conductor moves from "A" to "C" every line of force is cut at right angles and, at the given speed of one second , the induced E.M.F. is maximum.

Now revolve the conductor through path A, B, C; it is obvious that as the conductor leaves "A" it is moving nearly parallel with the magnetic field. As it progresses towards "B" its path becomes more nearly at right angles to the field and an increasingly greater E.M.F. is induced, until at "B" the conductor is moving directly at right angles to the field and, at this point, the induced E.M.F. is at its highest value.

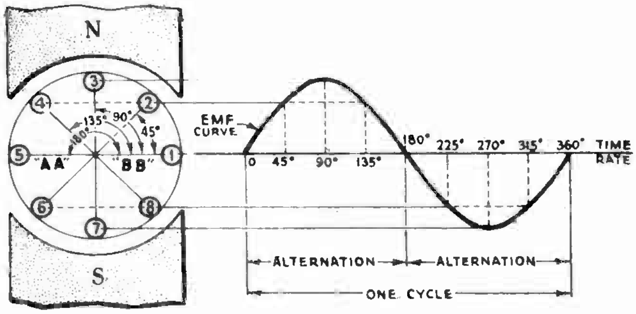

Figure 6

On leaving "B" the conductor ceases to cut the lines of force at right angles and, as it progresses from point "B" to "C", it cuts the lines of force less and less at right angles, consequently the induced E.M.F. gradually decreases until at "C" the conductor is again parallel to the field and induction ceases, with a consequent cessation of induced E.M.F. and current flow.

TIME RATE EXPRESSED IN DEGREES

The armature coil is so arranged on the armature core that it must describe a complete circle in the magnetic field. In the construction of a sine curve indicating alternating current this is expressed as the time rate in degrees.

In any complete circle there are 360 degrees and, if we wish to show the increase and decrease of induced E.M.F. in an armature coil in successive steps, we may do so by dividing the circle so described by the armature coil through the magnetic field into degrees of time. This will be explained with the assistance of Figure 6.

When the side of the coil "BB" is in position 1 Figure 6, in the magnetic field, no flux is being cut, hence no E.M.F. is induced in the coil. At this point of the base line representing time rate in degrees, we start our E.M.F. curve. The coil now moves from position 1 to 2, or 45 degrees, and cuts the flux and, the induced E.M.F., being of positive polarity, is plotted above the base line.

Now draw a vertical line from the base line until it intersects the horizontal line extending from position 2 of coil "BB" to the right and parallel to the base line. The point of intersection will indicate the rise of the induced E.M.F. of coil "BB" and by connecting this point and "45 degrees" on the base line we show graphically the rise in the induced E.M.F.

The coil now reaches position 3, or 90 degrees from position 1. A vertical line is erected from 90 degrees on the base line and the horizontal line drawn from position 3. From the point where these lines intersect another line is drawn to the 45 degree position indicating the amount of increase that has taken place.

As the coil proceeds we plot position 4, or 135 degrees, and from your study of Figure 2 you know that the induced E.M.F. is now decreasing. When position 5 is reached (180 degrees) no E.M.F. has been induced in the coil. This completes the first alternation of E.M.F. Side "BB" now continues to rotate and, upon passing through points 6, 7, 8 and back to 1, (the starting point), it completes one revolution. During the last half of this revolution exactly the same inductive action takes place as in the first half revolution but with this difference; the current induced in the side "BB" now flows in the opposite direction, for the side "BB" is now under the influence of the south pole and not the north pole as in the first half revolution. This reversal of the current flow is clearly shown in Figure 6. As already mentioned, the inductive action is the same and, therefore the procedure of plotting the value of the induced current upon the curve is the same as for the first half revolution of this coil.

ALTERNATIONS, FREQUENCY AND CYCLES

The induced E.M.F. in side "BB" rises from zero to maximum value between 0 degrees and 90 degrees then falls in value from 90 degrees until zero is again reached at 180 degrees; this is termed an alternation. From position 5 to position 1 side "AA" has induced in it an E.M.F. which changes in value similar to that in side "BB".

This rise and fall in the value of the induced E.M.F. takes place twice during each complete revolution of the armature coil. In every cycle, then, there are two alternations of E.M.F., i.e., one positive and one negative alternation. The frequency of an alternating current generator is expressed in cycles per second.

When the coil "AA", "BB", rotates 60 complete revolutions per second 120 separate reversals of current per second are induced therein and since one cycle consists of two alternations, or reversals, the FREQUENCY of the current is said to be 60 cycles per second.

This is only true in the case of our simple alternator which employed two field poles. In most commercial alternators, however, you will find more than two field poles and, as the speed and the number of field poles determine the frequency, we are going to give you a simple formula whereby you can easily determine the frequency of any alternating current generator.

The frequency will equal the number of poles in the alternator multiplied by the speed at which the armature revolves and divided by the alternations per cycle - which is always two. We must not overlook the fact that if we wish to know the frequency in cycles per second, the speed of the generator must be given in revolutions per second. In working out this formula for cycles per second it is necessary, therefore, to change the speed of the generator to revolutions per second and this is easily done by simply dividing the speed (as stated in RPM) by 60.

Assume that our simple two-pole alternator of Figure 2 revolves at the speed of 3600 RPM, what will be the frequency of the generated alternating current?

Write down your formula in this fashion; $F = \frac{N \times S}{2}$, where F = frequency, N = number of poles and S = the speed of the machine in revolutions per second.

If the speed of the alternator is 3600 RPM then its speed in revolutions per second will equal $\frac{3600}{60}$, or 60 revolutions per second.

Substituting these values in the formula we have $F = \frac{2 \times 60}{2} = \frac{120}{2} = 60$.

Therefore, F (frequency) is 60 cycles per second.

The majority of commercial alternators have more than two poles and it is just as easy to find the frequency of a multi-pole machine as it was to find the frequency of our simple two-pole alternator. Simply substitute the known number of poles for N and also the other known values in the formula and solve as shown above.

PHASE

The phase of an alternating current wave can be any point on that wave.

You learned in plotting the sine curve of Figure 6 that degrees were used to denote time as regards the values of the E.M.F. and current as they rise and fall during each alternation. Hence, the term "phase" may also refer to time. More specifically, phase may also be said to be the time instant when some maximum, zero, or any intermediate value is reached by the wave.

In Figure 6 we used 45 degree intervals so in further describing phase we will also use 45 degree intervals of time and illustrate it in Figure 7. The phase, "A" "A'", unless otherwise specified in such a curve, is regarded as a 360 degree phase; that is, the phase begins at 0 degrees and ends at 360 degrees.

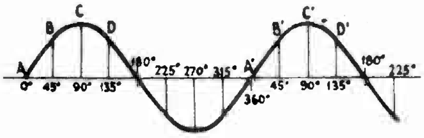

Figure 7

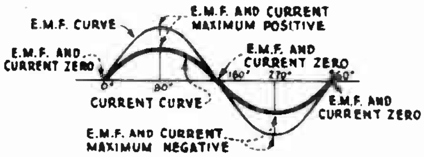

Figure 8

Any other point may constitute the phase of the curve, such as "B" and "B'" which is a 45 degree phase, "C" and "C'" a 90 degree phase, "D" and "D'" a 135-degree phase, and so on.

PHASE RELATIONS, CURRENT AND VOLTAGE

The current of the alternator alternates as well as the E.M.F. and will have the same general form as to frequency etc., and both current and E.M.F. can be plotted from the same base line. The circuit through which the alternating current flows will have, however, an influence on the current and will either cause the current to lag or lead the electromotive force. Capacity and inductance are the determining factors in regards to the lag or lead of the current. This will be taken up in detail in a later lesson.

In this lesson we will show you three curves having different phases. The first, shown in Figure 8, is one which would be obtained in an alternating current circuit where resistance only is present in the circuit. Notice the E.M.F. and current curves. Both start to rise at the same instant and continue to rise and fall keeping in step with each other throughout the cycle. In other words, they are in phase with each other. This condition, as stated, results only when pure ohmic resistance is present in the circuit.

Figure 9 illustrates the resulting effect on the current when pure inductance only is in the alternating current circuit, and in this case causes the current to lag behind the voltage or E.M.F. by 90 degrees. In other words the retarding effect of inductance prevents the current from starting through the circuit until after the E.M.F. has increased in value corresponding to 90 degrees.

Figure 10 illustrates the phase relationship between the current and the E.M.F. when pure capacity only is present in the circuit. In this instance the action is quite the opposite of that when the alternating current was flowing through pure inductance, i.e., the current now leads the voltage by 90 degrees.

These curves simply show graphically how, first, a current and E.M.F. which is in phase is depicted and, second, how the current is out of phase with the E.M.F. by 90 degrees with the current lagging the E.M.F. and, third, the current leading the E.M.F. by 90 degrees.

The reasons why this phenomena is apparent will be taken up in detail later on.

EFFECTIVE CURRENT AND VOLTAGE

The ampere is the unit of electrical current flow and we told you that it was the rate of unit flow that would pass through a resistance of one ohm at a pressure of one volt. More correctly it is stated as follows: "The ampere is that unvarying current which, when passed through a solution of nitrate of silver in water, will deposit silver at the rate of 0.001118 grams per second." From this standard method we may determine exactly the amperes flowing in a D.C. circuit.

We are, however, dealing with alternating current and you know alternating current varies, changing its value every instant of the cycle and reversing its direction every 180 degrees, or each alternation. This standard of measurement cannot, therefore, be used in determining the amperes in an A.C. circuit. The first alternation would deposit a certain amount of silver, true enough, but the next alternation would be opposite in direction to the first and it would take away the silver just deposited. For that reason some other means of finding the current in amperes in an A.C. circuit must be used.

This may be determined by the heat produced. We know the effect of heat is entirely independent of the direction of the current producing it and as alternating current has no special unit of its own we will use the direct current ampere as a unit for comparison purposes.

With that in mind we can say than an alternating current is equivalent to a direct current when it produces the same average heat effects, contingent upon exactly similar conditions. This is called the effective value of alternating current, measured in amperes, and is the value which is measured by alternating current measuring instruments. Heat is present in a current carrying wire regardless of the amount of the current flowing. Heat is produced even though you may not be able to physically detect it. It is known that the heating

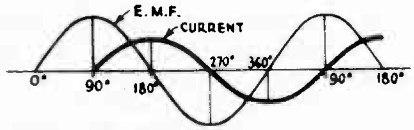

Figure 9

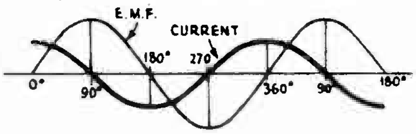

Figure 10

effect of an unvarying current in a circuit of fixed resistance varies as the current squared. For example, Figure 11, we have shown a current curve and heat curve; at any instant the heat effect is equal to the current squared.

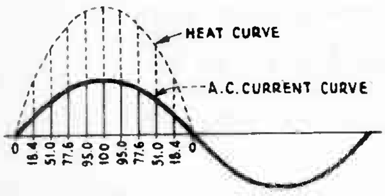

Figure 11

Since the heating effects of an electric circuit is equal to the current squared (I^2), then to find the heat effects of our curve, Figure 11, we must find the square of each individual current value over the alternation. This we do and then extend dotted lines above the verticals proportional to each squared current value. Connecting the ends of these extensions by a line we have a second curve which is the heat curve. It is necessary now to obtain the average of these heat squares which is done by dividing the sum of the squares by 9, since we have 9 instantaneous values of current.

The square root is now found of this average which gives us the final result,- the effective current. It is this result which is read by all electrical meters and is the current useful in calculating the power of the circuit.

It is not likely you will, in your practical work, have occasion to do work of this kind. It is done here simply to show you how it is calculated because this forms the basis from which all alternating current and voltage values are found. The step by step solution follows: Taking the values of instantaneous current values from the curve we write:

1st	instant	of	value	18.4
2nd	"	"	"	51.0
3rd	"	"	"	77.6
4th	"	"	"	95.0
5th	"	"	"	100.0
6th	"	"	"	95.0
7th	"	"	"	77.6
8th	"	"	"	51.0
9th	"	"	"	18.4

and squaring the above current values we have:

18.4	=	338.56
51.0	=	2601.
77.6	=	6021.76
95.0	=	9025.
100.0	=	10000.
95.0	=	9025.
77.6	=	6021.76
51.0	=	2601.
18.4	=	338.56

The sum of these squares equals:

```
   338.56
  2601.00
  6021.75
  9025.00
 10000.00
  9025.00
  6021.76
  2601.00
   338.56
 ---------
 45972.64
```

Dividing the sum of the squares by 9 to obtain the average of these squares:

```
9)45972.64(5108.071
  45
  --
   9
   9
  --
   72
   72
   --
    64
    63
    --
     1
     9
```

Extracting the square root of the average squares:

```
   71.47
 √5108.0710
  49
  ---
   208
   141
   ----
    6707
    5696
    ------
    101110
    100009
```

which equals 71.47 the effective current.

The effective voltage has the same relation to the maximum voltage that the effective current has to the maximum current and is found in the same manner. You will note that the effective current is less than the maximum current.

In dealing with voltage the effective voltage is also less than the maximum voltage, because the maximum voltage reaches a higher potential than the effective voltage. This accounts for the insulation requirements of an A.C. circuit being higher than in a direct current circuit.

POWER

The power of an alternating current circuit is expressed in watts just as in direct current circuits and is found by multiplying the current by the voltage. Thus, W = I x E.

This only holds good in a circuit where resistance only is present; in other words, the current must be in phase, or in step, with the voltage, as illustrated in Figure 8. When the current lags or leads the E.M.F. due to the presence in the circuit of inductance or capacity, or both, a power factor is used which is the ratio of the true watts to the apparent watts (the watts you would obtain by multiplying the volts by the amperes). In other words it is the ratio between the useful current and total current.

The formula for finding the POWER FACTOR follows: $\text{POWER FACTOR} = \frac{\text{RESISTANCE}}{\text{IMPEDANCE}}$

EXAMINATION QUESTIONS

1. Is alternating current necessary for the operation of a radio transmitter?

2. What are "slip rings" and why are they used instead of a commutator?

3. Explain the fundamental action of an A.C. Generator.

4. Upon what factors does the value of E.M.F. of a generator depend?

5. (a) What is an alternation? (b) A cycle?

6. (a) What is frequency? How is frequency determined?

7. What is the meaning of "Phase"?

8. What is meant by "effective value" of A.C.?

9. What is meant by the term "power factor"?

10. What is the relation of voltage and current when only actual (ohmic) resistance is present in an A.C. circuit?

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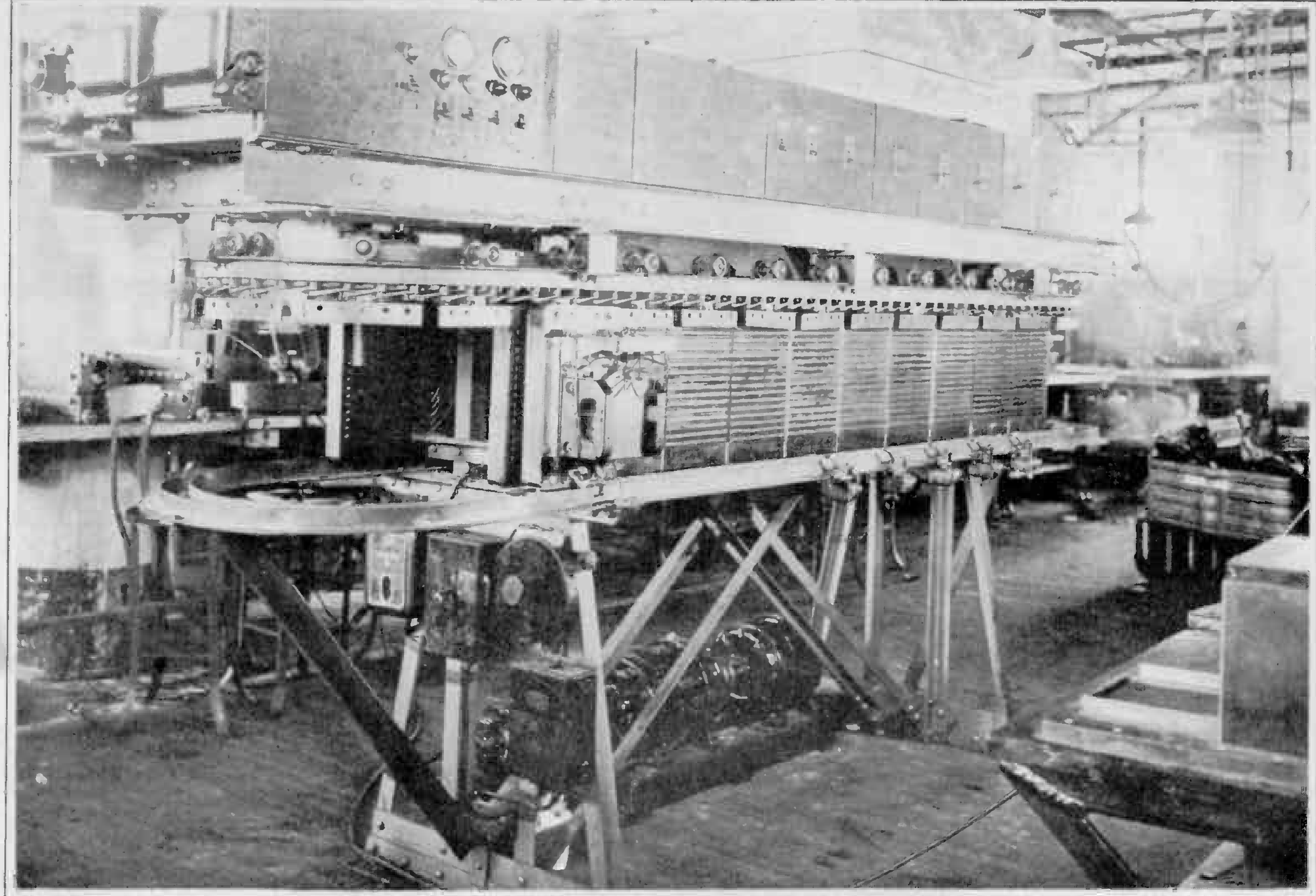
Motor-Generators and Other Machine Converters

VOL. 10, No. 11

Dewey Classification R 100



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MOTOR-GENERATORS AND OTHER MACHINE CONVERTERS

Along with the many varieties of electrical circuits which require either a-c or d-c for their operating power we frequently encounter different types of rotating machines used for the conversion of electrical energy from a-c or d-c sources into the a-c or d-c form at different voltages and frequencies according to requirements. In this lesson we deal with three principal types of converting machines which are named and defined as follows:

I. MOTOR-GENERATOR, consisting of a motor and one or more generators which have their shafts coupled together for a mechanical transfer of power, but which have no magnetic fields in common. This means that each machine is complete in itself as far as armatures, armature conductors, and field structures are concerned.

II. ROTARY CONVERTER, which is a single machine with one armature, one magnetic field, and only one set of armature conductors, which serve for both the driving and the generating functions of the machine.

III. DYNAMOTOR, which is a single machine with one armature and one magnetic field, but whose armature bears two sets of conductors, insulated from each other. One set acts with the common magnetic field to provide the driving action; the other set acts with the common field to generate the desired voltage.

The usual forms of conversion may be classed according to their purpose as follows:

A. Direct current to direct current of a different voltage.

B. Direct current to alternating current of a desired frequency and voltage.

C. Alternating current of an available frequency and voltage to a direct current of a desired voltage.

D. Alternating current of one frequency to alternating current of another frequency.

It is to be understood that alternating current at a certain voltage and frequency may be converted to a.c. at another voltage but of the same frequency by means of a machine, and such a conversion may be accomplished without rotating parts by employing a power transformer. The theory of power transformers is outside the scope of our present lesson, which will be limited to the three machine types listed above.

MOTOR-GENERATORS

When the shaft of a motor is coupled to the shaft of a generator, there is no difference in the fundamental design of either the motor or the generator. For purposes of mechanical rigidity they are mounted on a common base.

Fig. 1 shows a common form of motor-generator, the motor being at the left of the illustration. The method of coupling the two machines together is clearly shown, together with the housing for the bearings used to support the shafts of the motor and the generator. In this case the motor and generator have independent bearings.

In some machines the coupling plate used is a specially prepared disc of flexible material which will withstand the twisting strain of the motor shaft turning the generator armature. This allows for small irregularities in the alignment of the shafts. Where a solid mechanical connection is made the tightening of the bolts in the coupling device might easily throw the shaft out of alignment causing it to bind on one or more of the bearings. In Fig. 2 is illustrated the general outline of the motor-generator, all bearings and bearing housings being omitted for the sake of clearness.

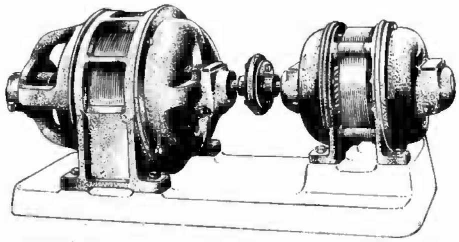


Fig. 1 - A MOTOR AND GENERATOR COUPLED TOGETHER

The general features of a machine employed for the conversion of direct current to alternating current can be grasped from the sketch in Fig. 2. Note the names and purpose of various parts which go to make up a machine of this kind as outlined in the legend given below

1. The switch controlling the direct-current supply.
2. The leads connecting the main line current supply with the motor armature.
3. The direct-current motor.
4. The armature of the motor.
5. The commutator of the motor.
6. The motor brushes.
7. The motor shaft.
8. The leads running from brushes supplying current to the motor field windings.
9. The motor field coils.
10. Motor coupling plate secured to motor shaft.
11. Flexible material used between metal coupling plates.
12. Leads from direct-current source supplying the field coils of the alternator.

13. Alternating-current generator.

14. A-C generator field coils.

15. A-C generator armature.

16. Generator coupling plate secured to generator shaft.

17. Collector rings of generator.

18. Generator shaft to which collector rings are secured.

19. Collector ring brushes which lead current from collector rings into external circuit.

20. Alternating-current leads to external circuit.

The motor shown is of the shunt wound type and receives its power from the available d-c power mains, usually at 110 volts. Note, at

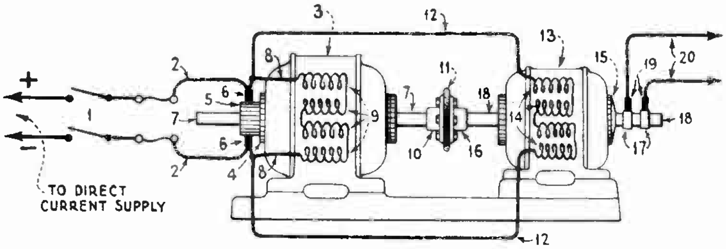


Fig. 2 - SHUNT-WOUND MOTOR COUPLED TO AN ALTERNATOR WITH ITS FIELD IN SHUNT TO THE D-C SUPPLY

this point, that the a-c generator field coils are connected with the same d-c supply which is driving the motor, direct current being necessary to excite the field coils of the alternator. In some installations, however, a small exciting generator is used which is driven from the motor shaft by a belt or directly coupled thereto. In practical work we find machines rated at different frequencies and voltages according to the design and purpose for which they are intended. The few examples which follow will serve to illustrate this point: Motors designed for 110-120 volt, 60 cycle a-c operation are extensively used; d-c generators which supply voltages from about 15 volts to 1000 volts are used to operate certain types of vacuum tube circuits; generators supplying 500 cycle a-c to power transformers have limited use in certain older types of radio telegraph (spark) transmitters; in certain sections of the country 25 cycles is the standard frequency used for industrial electrical equipment and so on. In sound picture practice the load on the alternator is practically constant and, therefore, the simple shunt-wound units in the above assembly will be satisfactory.

The requirements for a motor-generator used in radio telegraph communication are constant frequency and steady voltage under varying load conditions. The load on the generator is caused by the closing of the telegraph key which allows current to flow to the alternating-current transformer of the transmitting set. The load, therefore, is intermittent in character and when the key is closed the full amount of current is drawn from the generator immediately. There is no gradual increase of load; it is thrown on suddenly and discontinued just as abruptly.

Hence, it can be readily appreciated that some means must be provided to maintain a constant frequency output and constant voltage and, where possible, both conditions should be met. This calls for a self regulation which is secured by the manner in which the field coils of the motor generator are designed.

It now becomes necessary to divide the motor-generator equipment into three separate classes according to the field coil connections.

The first type, shown in Fig. 2, is a shunt wound motor coupled to an alternator with its field in shunt to the d-c supply; second, the same type of motor coupled to an alternator having compound field windings; third, the simple a-c generator of the first type driven by a motor having compound field windings. Let us consider these three divisions by studying the simple schematic drawings of Figs. 3, 4 and 5.

Before proceeding further, let us advise that if you are not already familiar with the electrical symbols, place the sheet bearing these symbols before you when studying the motor-generator diagrams.

Fig. 3 is the diagram of a simple shunt wound motor-generator set; it has the same field and generator connections as shown in Fig. 2. The parts are all clearly labeled. You will notice two field current regulating rheostats — one in the motor field circuit and one in the generator field circuit. We will explain the operation of these two rheostats.

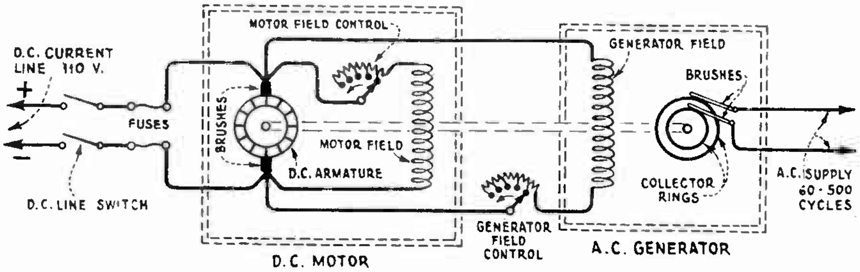


Fig. 3 - SIMPLE SHUNT WOUND MOTOR-GENERATOR SET

Beginning first with the motor field, if we turn the rheostat to the left as indicated by the arrow more resistance will be added to the field circuit, and this will reduce the current flowing in the motor field windings. This weakens the magnetic field which results in the motor speeding up, and since the generator is coupled to the motor the generator speed will also increase. It is very evident that the frequency output of the generator will be increased because its frequency depends upon its speed. By reversing this procedure, that is, decreasing the motor field resistance by turning the rheostat arm again to the right, the opposite effect is produced. In this case the motor and generator both slow down and, therefore, the frequency of the generator is reduced.

Now go through the same procedure with the generator field rheostat; turn it to the left as shown by the arrow thereby cutting in more resistance. Naturally, the result is a decrease in the current intensity in the generator field which reduces the generator output voltage. Reversing this process, that is, decreasing the generator field circuit resistance, will increase the field strength and consequently raise the output voltage.

Keep in mind the results just explained when introducing resistance in a generator field circuit and in a motor field circuit. Be sure that you fully comprehend the two actions and do not confuse them.

In Fig. 4 we have a shunt wound motor and compound wound generator; the motor and generator shunt fields have adjustable rheostats connected in their circuits enabling the speed of the motor to be regulated and the voltage of the generator to be controlled. When the desired speed of the motor is secured and the proper voltage output of the generator is obtained, these rheostats are left in that position.

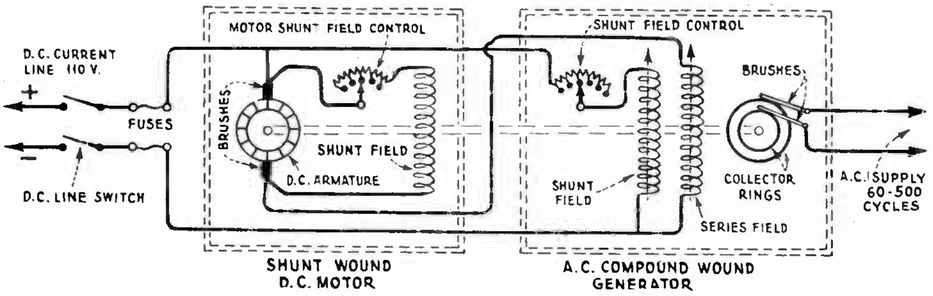


Fig. 4 - SHUNT WOUND MOTOR AND COMPOUND WOUND GENERATOR

The shunt and series field windings of the generator are connected in such manner that the field of the series winding and that of the shunt winding are in the same direction, i.e., of the same polarity. The motor-generator is subject to sudden loads when the telegraph key is closed and when this happens there is a tendency toward a decrease in speed. A decrease in speed causes an increase of current flow through the series winding, because the series winding is in series with the armature of the motor. This increased current flow through the series winding strengthens the field of the generator at once and it tends to restore the voltage to normal. Thus, in this type of motor-generator the speed of the motor and voltage output of the generator are maintained fairly constant under sudden variations of the load.

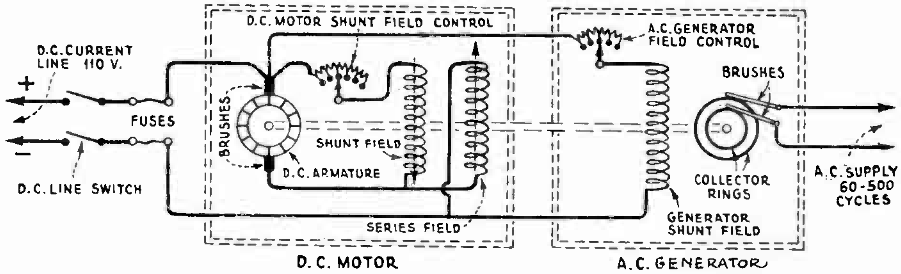


Fig. 5 - A DIFFERENTIALLY COMPOUND WOUND MOTOR COUPLED TO AN A-C GENERATOR

Now let us look at Fig. 5. The motor in this case is differentially compound wound. In other words, the magnetic field due to the shunt winding is opposed by the field due to the series winding, as determined by the relative directions of their turns about the field poles and the direction of current flow through the windings. Let us analyze the effect when the field of the series winding opposes the field of the shunt winding of this motor.

When a load is thrown on the generator in Fig. 5 the speed of the motor is reduced, thereby decreasing the counter e.m.f. As the shunt field winding is connected across the line, its current tends to remain normal, and the field flux due to the shunt winding, therefore, does not change. However, as the series winding is connected in series with the armature, the series winding will receive the increase in current caused by the lowered counter e.m.f. of the armature. The field flux due to the series winding will, therefore, increase. Since this flux opposes the main field flux which is due to the shunt winding, we find that the motor field as a whole will be weakened. This allows the motor to gain speed at once, building up the counter e.m.f. until a steady state has been reached with the motor running at its normal speed.

There is even a condition under which the generator will produce a higher frequency under load than when the load is removed. This occurs when the motor is "over-compounded". This term describes the effect of having the series winding wound with so many ampere-turns that the field flux created by it offers a considerable opposition

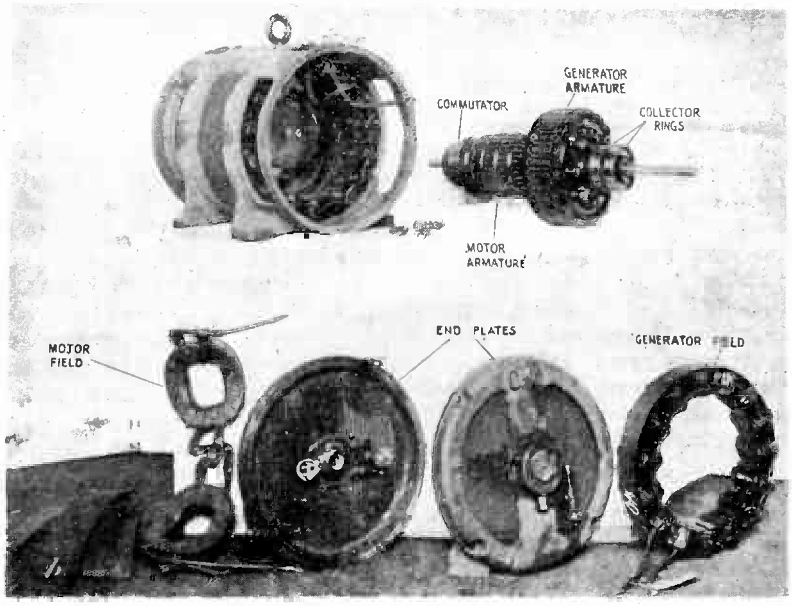


Fig. 6 - A DISASSEMBLED VIEW OF A CROCKER-WHEELER MOTOR-GENERATOR SET

to the field flux due to the shunt winding. Under this condition, when the load is applied, the motor field as a whole is so weakened that the machine comes up to a steady speed in excess of its no-load speed. This causes the generator frequency to increase as the load is applied; for a radio transmitter this is as objectionable as for the frequency to shift lower, under load.

In Fig. 6 is shown a disassembled d-c to a-c motor-generator of the 2 kw. Crocker-Wheeler type as used in some shipboard installations. It will be noted that the shaft is in one piece and carries both the motor armature and the generator armature. Their magnetic fields are effectively separated by suitable spacing along the shaft, which maintains the distinguishing quality of a motor-generator as compared to rotary converters and dynamotors. These latter have a common armature and common field structure for the motor and generator functions.

It is often difficult to tell the three types apart from a casual inspection of their exteriors.

D-C TO D-C MOTOR-GENERATOR SETS

When a d-c generator is driven by a d-c motor the generator field may be supplied by the d-c power mains (as in the case of the alternator previously described) or the generator may be self-excited. When several generators are coupled to the same motor a further variation in practice may occur. One d-c generator of the group may provide the field excitation for another generator, whether the latter is d-c or a-c as to its output. The use of such a connection is dictated by common sense in the designing by the manufacturer.

This might occur especially in the case of a high-voltage d-c generator, whose field is designed for separate excitation at a much lower voltage as a measure of safety and economy in the use of wire and insulation. If the voltage of the supply mains is lower than the normal voltage required for that field, the latter may be excited by another d-c generator. This may have been added for that purpose alone, or it may have been required for some other electrical purpose concerned with the equipment.

An example of this practice is shown in Fig. 7, which shows the four-unit motor-generator set used with early sound-picture installations of the type PG-1 and PG-2. The 15 volt d-c generator is

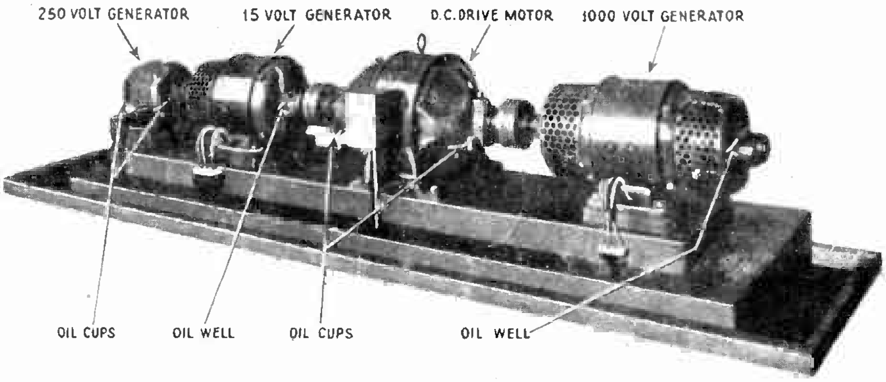


Fig. 7 - A FOUR-UNIT MOTOR-GENERATOR SET DESIGNED FOR SOUND PICTURE EQUIPMENT

required for filament voltages, the 1000 volt d-c generator supplies plate voltage for the last several stages of the amplifier, and the 250 volt d-c generator provides grid bias voltage for the output stage. This 250 volt machine is self-excited, and in addition provides the field excitation voltage for both the 15 volt and the 1000 volt generators.

One of the main reasons for having a d-c generator separately excited has to do with a difficulty encountered in getting a self-excited generator to build up its terminal voltage, starting out with only the residual field magnetism in its poles. If the normal load for which it is installed happens to be connected to the generator terminals when the motor-generator is started up, the terminal voltage might not build up. In the set described above, the current load on the 250 volt generator is small, and its terminal voltage easily rises to normal. However, the filament load on the 15 volt machine is very heavy, so its field is separately excited to insure operation, even with the load on, when starting up.

The 1000 volt generator has two commutators, one on each end of the armature, and each delivers 500 volts. These commutators are connected in series to give a total of 1000 volts. This construction not only reduces the insulation requirements and the sparking at

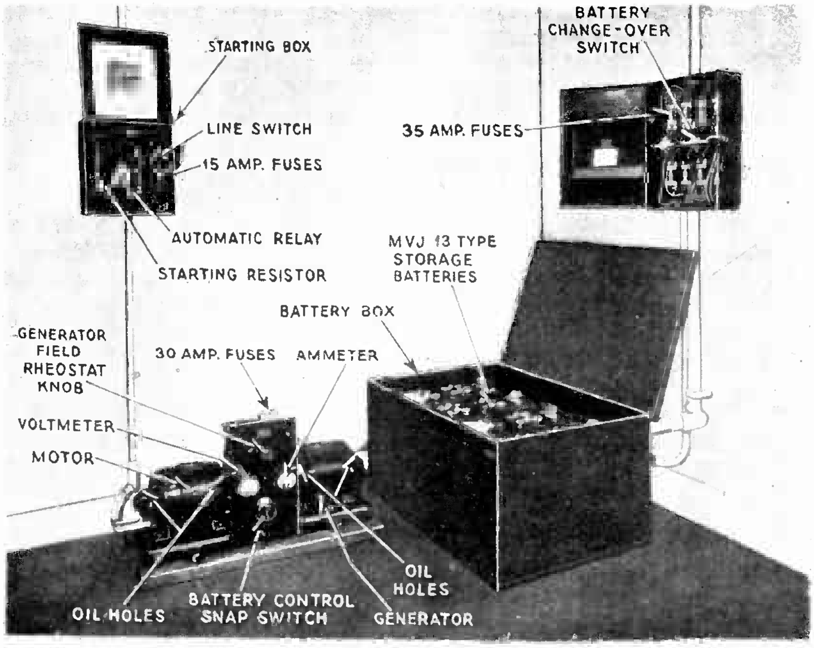


Fig. 8 - ARRANGEMENT OF BATTERY CHARGING EQUIPMENT USED WITH A SOUND-PICTURE INSTALLATION

the commutators, but provides economically the intermediate voltages of 500 and lower which would otherwise have to be secured through series resistances or voltage dividers applied to the total 1000 volts generated.

Even when the power mains provide direct current for the charging of storage batteries, it is found more economical to reduce the vol-

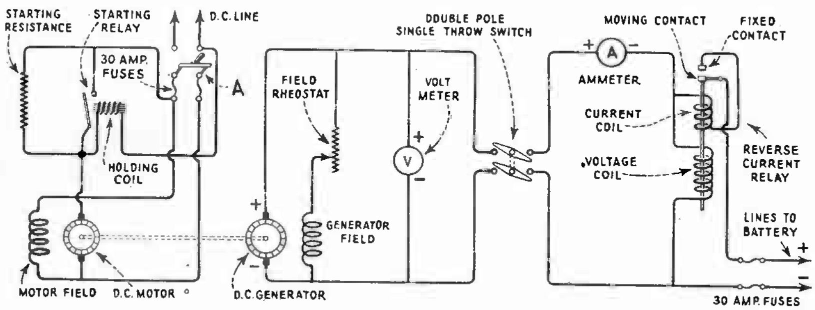


Fig. 9 - SCHEMATIC DIAGRAM OF A D-C MOTOR-GENERATOR CHARGING UNIT

tage by the motor-generator method than by the use of series resistance in the circuit. This is particularly true when the battery terminal voltage is small compared to the line voltage. This is demonstrated in the case of a battery-charging arrangement used for certain sound-picture installations, as illustrated in Fig. 8. A schematic drawing of the connections is shown in Fig. 9, including the starting equipment and a reverse current relay for the charging circuit, designed to prevent the battery from discharging into the generator circuit when the e.m.f. generated by the machine becomes less than the internal e.m.f. of the battery, due to slowing down or other causes.

A-C TO D-C MOTOR-GENERATOR SETS

It is easier to understand the many variations that come under the head of motor-generators if we bear in mind these fundamentals:

1. The electrical characteristics of the motor are determined by the available electric supply.

2. The power rating of the motor is determined by the shaft power required to drive the generator or generators under their normal loads.

3. The electrical characteristics of each generator coupled thereto are determined by a specific load requirement of the device or apparatus to be operated.

Manufacturing economy has long since dictated that standard parts be used for as many purposes as possible. This has resulted in identical frames being used for motors produced for a variety of voltages, and including both a-c and d-c types. Only the field and armature structures may differ. With the frame mounting holes and shaft heights identical for motors of widely different electrical characteristics, we see that the motor-generator becomes a very handy and convenient device for matching load requirements to an available electric power supply.

We find, therefore, that motor-generator sets for use with certain installations will vary in different localities mainly in the motor equipment and the necessary starting and control accessories. A further difference enters in the case of a-c mains, in that the generator fields will not be excited from the power mains.

The photograph on the back cover page shows a three-unit motor-generator set of which one generator develops 600 volts d.c. and the other 12 volts d.c. The field of the low-voltage machine is excited by the terminal voltage of the high-voltage machine. With such an arrangement, when the set is started up, the field rheostat of the 600 volt machine is always adjusted first for its normal voltage, because the voltage of the second generator will depend on its 600 volt field excitation. Then the field rheostat of this 12 volt machine is adjusted to its normal voltage as shown by the panel voltmeter. A novel construction enters here, in that the two field rheostats are mounted on the same center line, and a single control knob serves for both, being shifted in or out a short distance to engage the contact arm of the rheostat which is to be moved.

A-C TO A-C CONVERSION

The conversion of alternating current of one frequency into alternating current of another frequency is met with less often than the other forms of conversion. This change may be made with or without an accompanying change in the number of phases and the voltage. This might occur where the power mains were 25 cycle single-phase alternating current, and it is desired to operate standard radio transmitting equipment of the 60 cycle three-phase type.

THE ROTARY CONVERTER

Rotary converters have several uses. In commercial practice they are generally used to convert alternating current into direct current for use on traction lines, in the charging of storage batteries, and in electro-plating plants. In the communication fields, such a conversion is usually accomplished by electronic or gas discharge devices.

For a-c to d-c operation, the machine may be designed, as a motor, for single-phase, two-phase or three-phase alternating current. There are no new principles with which you are not familiar in the fundamentals of this machine other than its physical construction. Just remember when you think or hear of a rotary converter that it is simply two machines in one. There is one armature and on this is placed a simple winding which serves to revolve it and from which generated current is collected. This generated current is the result of what was, in the independent motor or generator, the counter

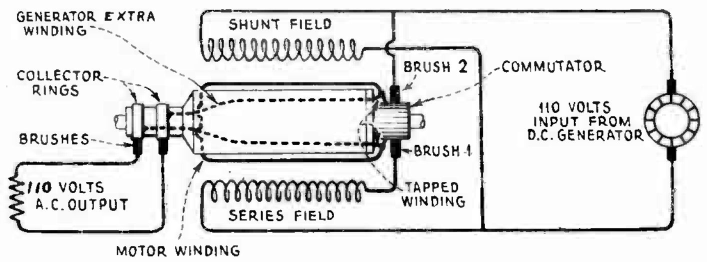


Fig. 10 - FUNDAMENTAL CIRCUIT OF A ROTARY CONVERTER

e.m.f. Furthermore, only one set of field windings is used to supply the magnetic field for both the motor and generator functions of the machine.

The use of a commutator, properly connected to the individual sections of the armature winding, makes available the counter e.m.f. developed in these sections, as a direct current.

If arrangements are made to revolve the armature by mechanical means, such as a gasoline motor, both alternating and direct current will be delivered. In this case the field windings of the machine would, of course, be excited from the d-c brushes of the commutator end.

By applying direct current to the windings and field from an external source, alternating current can be obtained from the collector rings. When used in this way, the machine is referred to as an inverted rotary converter and sometimes more briefly as a rotary inverter.

The distinguishing feature, as just stated, is the use of a single armature for both alternating and direct current. There are only two bearings needed, and it requires less space for installation. Therefore, the construction and installation of the machine as a whole is simplified.

There is the disadvantage, however, of not obtaining full control of voltage. For this reason it is often better to use the motor-generator than the rotary converter, even though the cost of the motor-generator is higher. When 110 volts is used as the supply, the alternating voltage delivered (which is really the counter e.m.f. of the armature) will reach a maximum of approximately 78 volts. When higher voltages are desired a step-up transformer may be used on the a-c side. It is possible to secure a greater voltage output than that stated, by means of an auxiliary winding. This is used especially when it is desired to have about the same a-c voltage as the d-c voltage supply.

This is shown by the fundamental circuit of Fig. 10. The current flows from the power mains, indicated as a 110 volt d-c generator, through the series field winding into the armature at brush 1, through the armature coils and out at brush 2. The shunt field is connected across the line as in any compound wound machine. As current is applied to the armature coils rotation results, and a counter e.m.f. is generated. If single-phase alternating current is desired, two

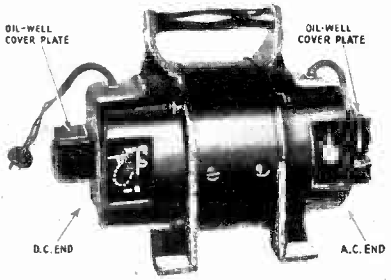


Fig.11 - A D-C TO A-C ROTARY CONVERTER, RATED AT 3/4 KVA, USING THE AUXILIARY WINDING PRINCIPLE

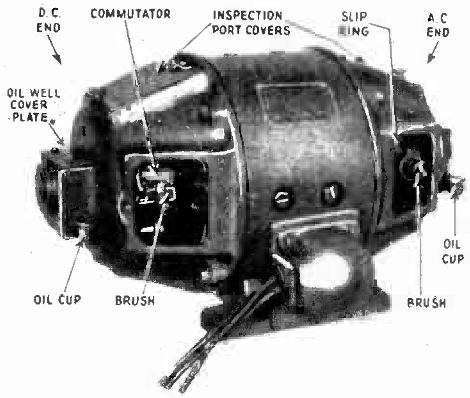


Fig.12 - THIS MACHINE IS DESIGNED TO FURNISH TWICE THE POWER OF THE ONE SHOWN IN FIG.11

taps are taken from the armature windings at points 180 degrees different in phase. These taps are connected to the slip rings through additional turns of wire on the armature which are not in the direct current circuit.

The extra conductors are so placed on the armature that the voltage generated in them adds to the voltage secured from the taps on the main armature winding. By proper selection of the number of turns in the extra winding, the desired voltage output can be secured. This construction is used on machines operating from 110-120 volt d-c mains to supply 60 cycle alternating current at 110-120 volts for radio sets of the latter kind. It might be considered that the combination of armature windings on this machine makes it a cross between a rotary converter and a dynamotor. The principles of the latter type of machine are described on the following page.

In Figs. 11 and 12 are shown two rotary converters using the auxiliary winding principle. The chief difference in the two machines is that one is designed for twice the power of the other. Otherwise there are no important differences.

THE DYNAMOTOR

The circuit of the dynamotor is shown in Fig. 13. The armature carries two separate windings wound in separate slots on the core, one to revolve the armature as a motor and the other for the production of e.m.f.

In the sketch shown the direct current used to drive the armature is obtained from a 30 volt storage battery outfit. (Commercial machines can be run on 110 v. d.c.and other voltages.) Voltages ranging from 350 to 2000 volts d.c.may be secured from the generator end, depending upon the design and type of dynamotor. The field is compound wound and is used as both the motor and generator field windings. The speed of this type of machine is 2000 r.p.m. and, to reduce vibration, the entire unit is suspended in a spring suspension saddle shown in Fig. 14.

The dynamotor is practically free from trouble due to armature reaction, and has an appreciably higher efficiency than the motor-generator. It suffers under the same handicap as the rotary converter, i.e., the output voltage can be controlled only by changing the input voltage to the motor side.

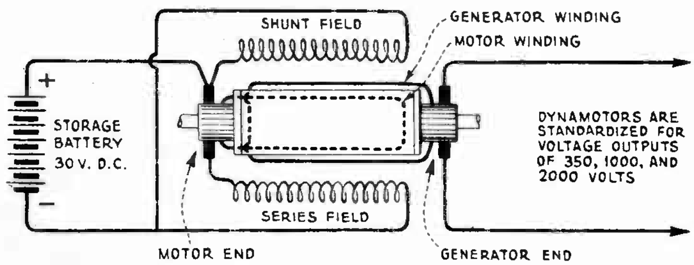


Fig. 13 – FUNDAMENTAL CIRCUIT OF A DYNAMOTOR

This type of converting machine is particularly useful in securing high d-c voltages for operation of airplane transmitters and receivers, when only a storage battery is available as a main power supply; the same holds good for automobile radio receivers when dry batteries for plate supply are to be avoided. Another important use is in sound picture work, where a 110 volt d-c supply is converted to a lower voltage for supplying exciter lamps, field supplies, and filaments of vacuum tubes, through a filter circuit designed to eliminate the commutation ripple.

In such uses, it will be seen that the dynamotor performs the same voltage step-up or step-down function for direct current that is performed for alternating current by a power transformer. In fact, we can truthfully carry this comparison still further. When a direct current is applied to the dynamotor armature and it rotates, the individual motor coils of the armature receive a current which continually changes direction, that is, it alternates, due to the commutator action. The motor coils, therefore, serve as the primary winding of a transformer whose iron core is the armature structure itself. The generator winding acts as the secondary of this transformer action, having induced in it an alternating e.m.f., the voltage of which depends on the relative number of turns in the primary and secondary windings (the motor and generator armature conductors). The second commutator then serves to rectify the alternating current, producing a direct current output at the generator terminals.

In the electrical entertainment industries, a dynamotor is used for a particular function, but we must remember that the principles of its operation are such that its function can be reversed in direction. By that is meant the conversion of voltages can be made in the

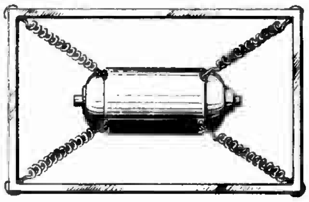
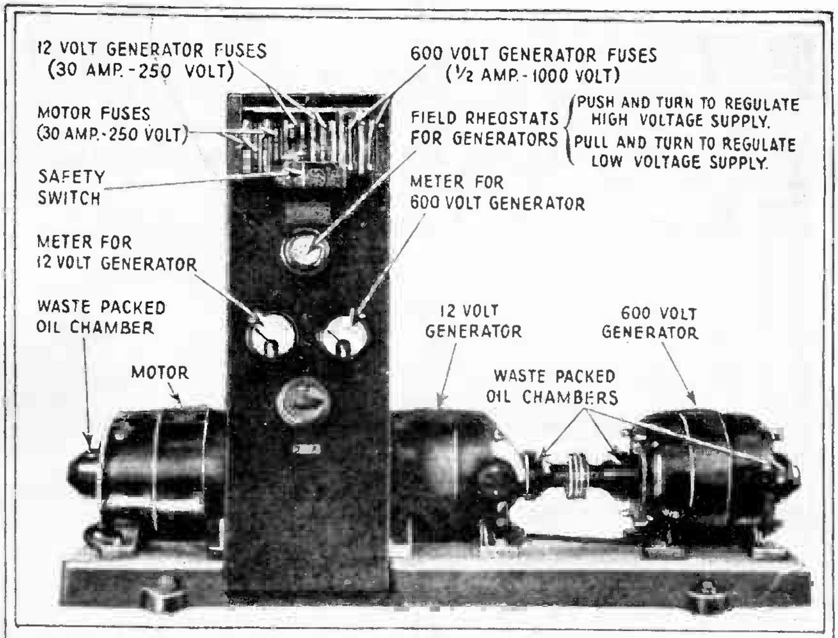


Fig.14 - DYNAMOTOR MOUNTED IN A SPRING SUSPENSION SADDLE TO REDUCE VIBRATION

opposite direction. If the input voltage to the motor side is 30 volts, with an output of 350 volts at the generator side, it would be possible to have the same machine supplied from an outside source with a potential of 350 volts or greater applied to what was the generator side of the first case. Then we would secure a voltage of about 30 generated by what was previously the motor side of the machine. In the technical subjects we are studying there is very seldom an occasion for doing this.

EXAMINATION QUESTIONS

1. What is a motor-generator?
2. What are the electrical requirements of a motor-generator set?
3. Draw a diagram of a shunt wound motor generator.
4. What are the three types of motor generators?
5. Draw a diagram of a compound wound generator set.
6. How would you regulate the speed of a shunt wound motor-generator?
7. Explain how the voltage output of the generator is controlled in a motor-generator set.
8. What is a dynamotor? Explain fully.
9. What is a rotary converter? Explain fully.
10. What advantage has the motor-generator over the rotary converter and the dynamotor?



PANEL BOARD AND MOTOR-GENERATOR SET USED WITH CERTAIN SOUND-PICTURE EQUIPMENTS. THE MOTOR IS A-C OPERATED AND THE GENERATORS SUPPLY D.C.

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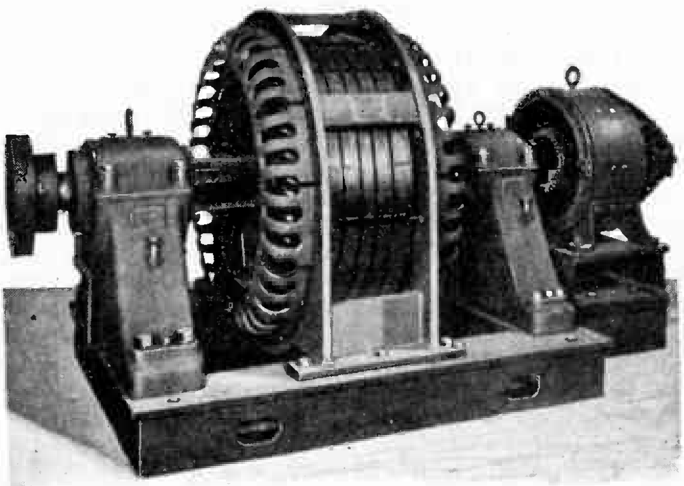

Westinghouse Synchronous Motor

A. C. MOTORS

Vol.10#12

Dewey Classification R100

A.C. MOTORS

In the operation of Sound Motion Picture projectors and in Sound Picture recording work A.C. motors are used to a great extent. In recording they are used almost exclusively due to the fact that if a number of A.C. motors of the type known as "synchronous" are connected to the same source of alternating current they will all run at exactly the same speed due to the fact that the speed of each motor is controlled by the frequency of the power supply, or in other words the number of times the supply current alternates per second. In most cases the supply line furnishes 60 cycle current so that every synchronous motor designed to run at a certain speed on 60 cycle current will absolutely keep in step with every other motor of the same type connected to the same power supply. This enables the picture camera to run through the same number of feet of film per minute as is being run through the sound-on-film recording machine, for if the motor which drives the camera and the motor which drives the recorder are connected to the same power supply they will run at identical speeds. This makes it possible to take the motion pictures on one film and record the sound on a different film.

Later on in the process the pictures and sound track are photographically printed side by side on one positive film. It can easily be seen that if the speed of the film as it runs through the camera is not the same as the speed of the film that passes through the recorder then it would be impossible to reproduce the sound in correct relation or "synchronism" as it is called, with the picture. By synchronism is meant the timing of the sound and picture so that when a subject on the projection screen speaks, for instance, the words will be heard coming from the stage speaker directly behind the screen at the exact moment the lips of the speaker move.

The A.C. synchronous motor has thus made it possible for the motor driving the camera to be at one place on the "set" while the recorder is being driven by another motor in the recording booth which is placed out of the way at some distance from the action.

The very term "synchronous" means "in unison" or "in step" so that in general a synchronous motor is said to be one that operates in step with the phase of the alternating current which operates it. Any A.C. generator will run as a synchronous motor when it is supplied with current at the same voltage and frequency as it produces when run as a generator. It must be borne in mind that a single-phase machine must be brought up to so-called synchronous speed before being put "in circuit".

A standard synchronous motor consists primarily of an armature and a field. The field is "excited", that is, its magnetic field is established, by a separate source of direct current which produces a magnetic flux of unchanging polarity. This field flux is shown in Figure 1, which is a sketch of an elementary alternator which generates single phase current (shown at the left) and of an elementary single phase synchronous motor (at the right). The

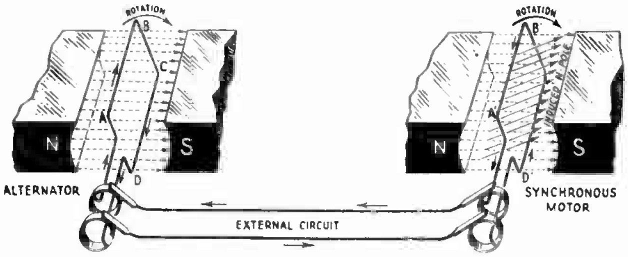

Figure 1

armature circuit of each is connected through slip rings to that of the other forming an external circuit. Assuming both armatures are at rest, if the armature of the alternator be turned slowly, in a clockwise direction as shown, a current will be generated which will flow through the external circuit and through the motor armature in the direction indicated by the arrows. The current flowing through the motor armature will produce a magnetic flux or induced N pole as shown by the line of arrows pointing upward to the right. As like poles repel and unlike poles attract, the S pole of the field will pull the induced N pole of the armature toward it while the rotation of the armature will be aided in this

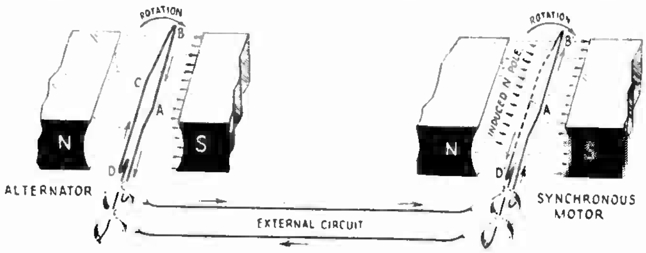

Figure 2

direction by the attraction of the N field pole pulling on the induced S pole of the armature. The conditions just stated hold true while the side A-B of the alternator armature is nearest the N pole during the upward journey of side A-B and the downward journey of side C-D. As the alternator armature continues to revolve the side A-B cuts the field flux near the S pole in a downward direction while side C-D sweeps upward through the field flux near the N pole. This we know results in a reversal of the current through the alternator armature and as it is connected to the motor armature through the external circuit the induced armature N pole becomes reversed in direction. The armature of the motor having passed through its vertical position the direction of the induced magnetic flux is such as to cause the N pole of the field magnet to repel the nearby induced N pole of the armature and the S pole of the field to repel or push away the nearby S armature pole. This condition is as shown in Figure 2.

By referring to Figures 3 and 4 and remembering what we have just learned, it is easy to see why a single phase motor is not self-starting when connected to an A.C. power main without first having been "brought up to speed". In this case the alternator itself is not at rest to start with because it is required to be in continuous operation for the general public using that power line. The alternator is therefore always "up to speed" as far as the line supply is concerned.

Due to the fact that an armature possesses "inertia" it cannot be moved instantly, and the speed of 60 cycles per second is too great

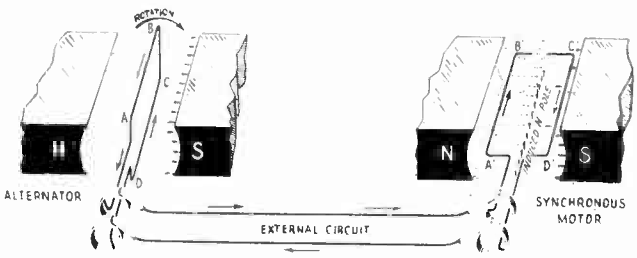

Figure 3

to allow the motor armature to get into motion before the polarity of the induced pole of the armature reverses and produces a torque, or tendency to rotate, in the opposite direction. This is demonstrated by Figure 3 which shows the alternator armature at one position and by Figure 4 in which the armature is shown in a reversed position. During one-half the cycle or revolution of the alternator armature the current flows through the motor armature producing armature poles as shown in Figure 3. This tends to rotate the armature in a counter-clockwise direction as shown by the motor arrow 1/120th of a second later (the next half cycle) and before the armature has had a chance to move, the current through the generator and the motor armature reverses and an induced armature polarity is set up in the motor as shown in Figure 4, changing from its direction in Figure 3 to that in Figure 4 and back again

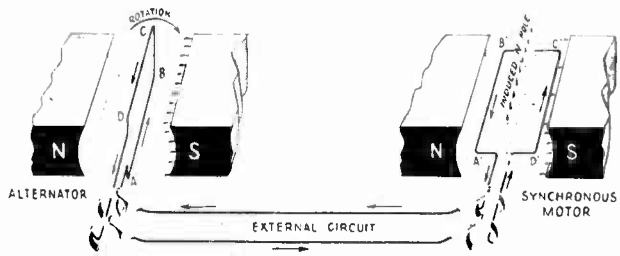

Figure 4

at the rate of 60 times per second. It can be seen that the torque or tendency toward rotation of the motor armature is opposed in the two figures. The only movement that results is a vibration as the armature is shaken back and forth 60 times per second with no chance to get into continuous rotation due to its inertia. If some means were provided, however, by which the armature of the motor could be brought at least nearly up to speed so that its inertia would not be a large factor in pulling it into synchronism, then it would have its armature in the correct position to produce torque or turning effort continuously in one direction as shown in Figures 1 and 2.

If a motor could operate in exact synchronism with the A.C. supply the armature of the alternator and the motor would always make equal angles with their respective fields as shown in Figure 5. This condition could only be realized if there were no mechanical load on the motor which is impossible because even the friction of the armature shaft in the bearings constitutes a form of load. If the ideal condition of no mechanical load were possible, however, the alternator and motor armatures would revolve at exactly equal angles with their fields and the counter E.M.F. generated by the motor armature as it cut the field flux would exactly equal the impressed E.M.F. that is furnished to the motor armature by the

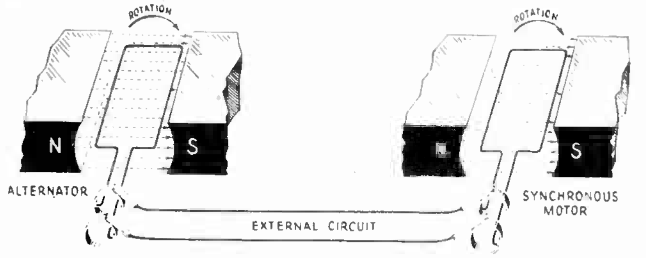

Figure 5

alternator; the two E.M.F's. impressed in opposite directions across the same armature would cancel each other and no current would flow.

Now what actually happens when a load is thrown on the motor is that the mechanical resistance holds back the motor armature so that instead of rotating in the same plane as the alternator armature it lags a certain number of degrees so that it takes a position as shown in Figure 6. In this condition the counter E.M.F. generated by the motor armature will lag the impressed E.M.F. by the same angular amount the motor armature lags the alternator armature. We found that, in Figure 5, when the counter E.M.F. from the motor equalled the impressed E.M.F. from the alternator and they were in phase opposition, no current flowed; but now that the

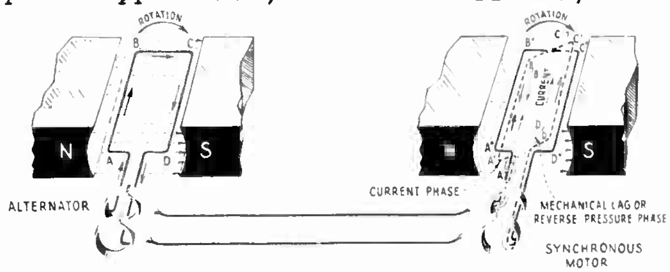

Figure 6

phase of the counter E.M.F. lags behind that of the impressed E.M.F. there is a resultant difference in potential, and current from the alternator flows through the motor armature inducing poles in it and producing torque. It will be seen from Figure 6, that the impressed E.M.F. is the alternator terminal voltage, the current lags just behind it, and the counter E.M.F. of the motor lags behind the current. The greater the mechanical load put on the motor, the more will it lag behind the alternator armature, and the greater will be the current which flows through the motor armature. The motor will continue to run under a load increasing up to the point where the lag of the motor armature is 90 degrees (one-quarter revolution) behind the alternator armature.

When the load on the motor becomes greater, so that the lag becomes greater than 90 degrees, the motor will "pull out of step" with the current supply and quickly come to a stop. Figures 7 and 8 show why this is so, Figure 7 showing a condition of motor load that causes a lag slightly less than 90 degrees. The motor will still continue to rotate and pull strongly due to the fact that the field poles and the induced poles of the armature are in the correct relation to produce rotation by repulsion of like poles and attrac-

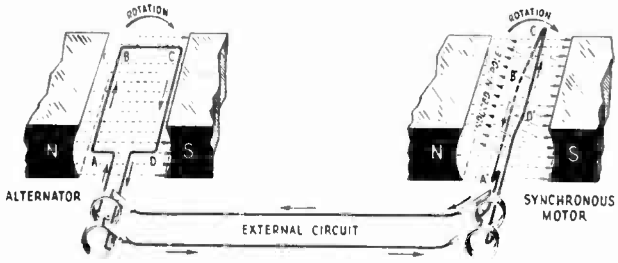

Figure 7

tion of unlike poles. Figure 8 shows the condition which prevails when additional load on the motor has caused it to lag more than 90 degrees behind the current supply phase. The induced poles will be as shown but now, due to the fact that their positions have been changed in relation to the field poles, the repulsion effect of like magnetic poles produces a torque or turning effort in a direction opposite to that of its former rotation. In actual operation this brings the motor to rest very quickly acting in a manner similar to a brake.

The synchronous motor is usually brought up to synchronous speed without load and a starting compensator is used to limit the starting current. If the motor is provided with a self-starting device,

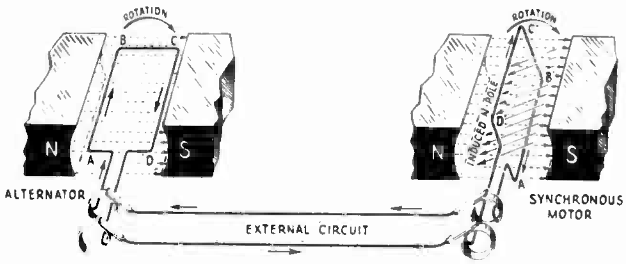

Figure 8

the device must be cut out of circuit at the proper time. A three-phase synchronous motor as used in certain Photophone equipments to drive projector motors is seen in Figure 9. This type of synchronous motor differs from the above in several respects. Two of the most important differences are: first, it requires no D.C. field excitation and, second, the rotating part serves as the field. These motors are sometimes called "hysteresis" motors because they depend on the hysteresis or molecular inertia of the iron for their operation. This type of motor will be studied later in this lesson.

INDUCTION MOTORS

An induction motor is quite different from other forms of motors especially in that, while D.C. motors and some synchronous A.C. motors have some kind of electrical connection between the rotor (which corresponds to the armature in a D.C. motor) and the source of current supply, the induction motor will operate with no electrical connection between the rotor and the power source. The currents which flow in the rotor winding are caused by the voltage induced by the action of the field magnetic flux as the rotor sweeps past the field poles in a rotating path. According to the kind of current that an induction motor is designed to operate on, it may be classified as a single phase or as a polyphase motor. A single phase motor is, as the name implies, one that will run on single phase current while a polyphase motor may be designed to run on two phase current or it may be designed to operate on three phase supply. The magnetic field produced in a motor by a single phase current is said to be oscillating in character while the field resulting from two or three phase current is said to be rotating. The principles of polyphase motors can be best understood by means of elementary diagrams showing how polyphase currents produce a rotating magnetic field.

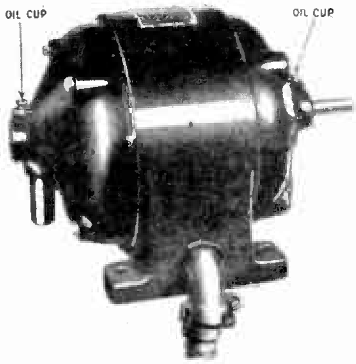

Figure 9

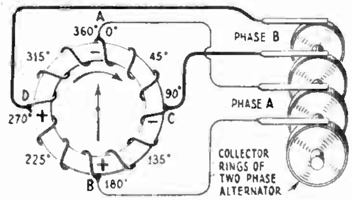

Figure 10

PRODUCTION OF A ROTATING MAGNETIC FIELD BY TWO PHASE CURRENT

Figure 10 represents an iron ring wound with coils of insulated wire, connected to a source of two phase current at the points, A, B, C and D. It will be remembered that two phase current requires four leads or line wires to conduct the phases separately to the point where current is to be used, and so four leads, two coming from phase A and two from phase B, are connected as shown in Figure 10. Remembering also that current B differs in phase 90 degrees from phase A, we find that if only one current (a) entered the ring at A with a return at B, a negative pole (-) will be produced at A and a positive pole (+) at B causing a magnetic needle pivoted in the center of the ring to point vertically upward towards A. If at this instant, corresponding to the beginning of an A.C. cycle in phase B, this second phase is connected to the ring at C and D the needle will still point upward toward A because the current in phase A is at maximum while that in phase B is passing through its zero value. As the cycle continues, however, the current strength of phase A will grow less while that of phase B increases thus moving the induced pole toward C until phase B reaches its maximum current strength and phase A falls to its zero value, which will be at 90 degrees as seen in Figure 11 or at the end of the first quarter of the cycle. At this time phase A reverses in direction and produces a negative pole at B and as its strength increases from 90 degrees to 180 degrees and that of phase B diminishes the negative pole is moved past C toward B until phase A reaches its maximum and phase B falls to its minimum at 180 degrees.

When this condition is reached the needle points toward B. At the 180 degree part of the cycle phase B reverses in direction and produces a negative pole at D and as the variations in the amplitudes of the currents of the two phases in the second half of the cycle bear the same relation to each other as during the first half, the resulting poles of the rotating magnetic field thus produced carry the needle around in continuous rotation so long as the two phase current passes through the windings of the ring.

By referring to Figure 11 the direction of the rotating field for each of eight different phase relations may be seen. Thus the

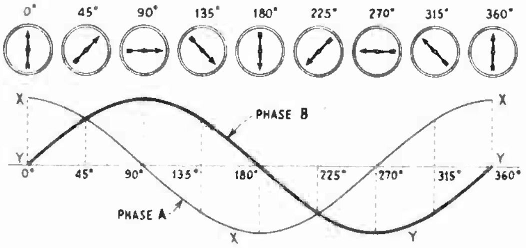

Figure 11

rotating field of a polyphase motor is not something that can be seen as for instance the rotation of an armature, but merely a constant shifting of polarity around a circular path within the motor field. A mechanically rotated magnetic field would be one produced by, say a horseshoe magnet turned by hand or other means, which would drag a needle around in much the same manner as the electrically rotated field just studied. The mechanically rotated fields, of course, are not used in motor practice; it is mentioned only to show that the magnetic field would in both cases have a similar

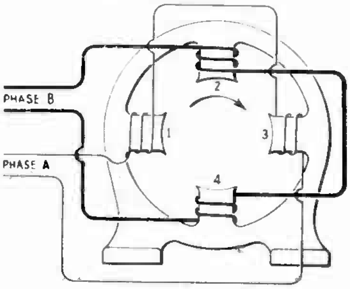

Figure 12

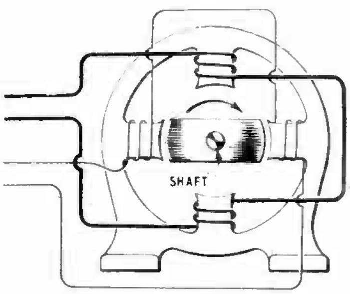

Figure 13

effect on a needle. Figure 12 shows how a 2-pole 2-phase motor is connected to a supply line to obtain a rotating field. Its action will be evident from its similarity to the ring type field which type, however, is not used in motor practice.

During one cycle of current the polarity will be as follows 0 to 90 degrees pole 1 will be a N pole while pole 3 will be S; 90 to 180 degrees Pole 2 will be N and pole 4 will be S; 180 to 270 degrees Pole 3 will be N and pole 1 S and during the remaining quarter of the cycle from 270 to 360 degrees pole 4 will be N and pole 2, S. The change in polarity is not accomplished in jumps, however, but proceeds smoothly as the current strengths of phase A and phase B vary from 0 to maximum. This results in a smooth movement of the needle around the circle. If now the needle were replaced with a solid iron bar fastened to a shaft as shown in Figure 13, and this bar were so centered that it furnished the shortest path possible for the magnetic flux from N to S then, from what we previously learned about the tendency of an iron bar to place itself lengthwise in the path of the magnetic flux we know that it would move around as the induced pole rotated. This kind of a motor amounts practically to a synchronous machine for the speed of its armature depends upon the speed of rotation of its revolving field. Figure 14 is a graphic method for visualizing the resultant magnetic field of two-pole, two-phase motor field at different phases of the currents during a complete cycle showing how an armature, represented by the arrow, is dragged around as the field rotates. A two-pole motor is easier to study when learning rotating field principles, but of course,most

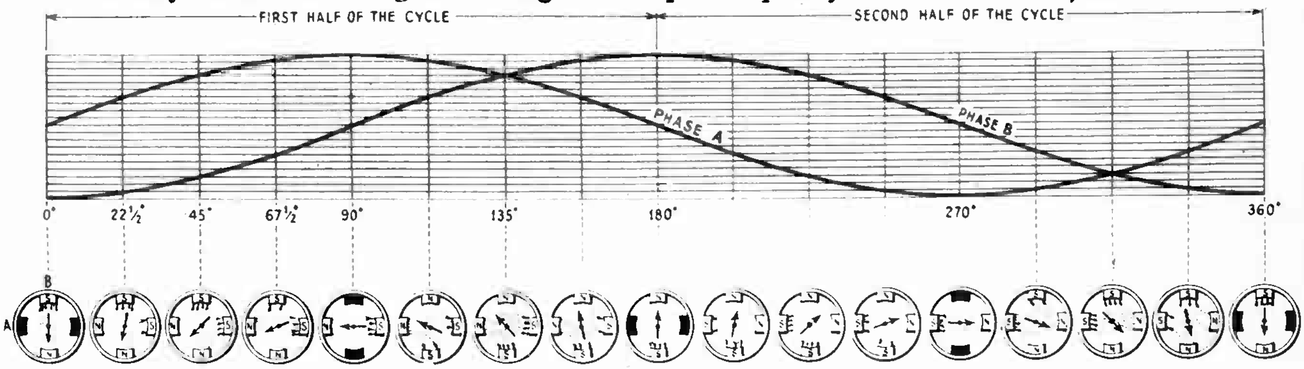

Figure 14

motors are constructed so as to have more than two poles in order that they may operate at lower speeds in producing mechanical power. Figure 15 shows a two-phase, six-pole field winding and it can be seen that the operating principles have not changed, the field poles in phase A being wound oppositely so as to produce alternate N and S

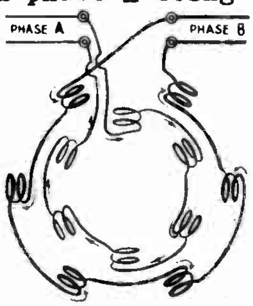

Figure 15

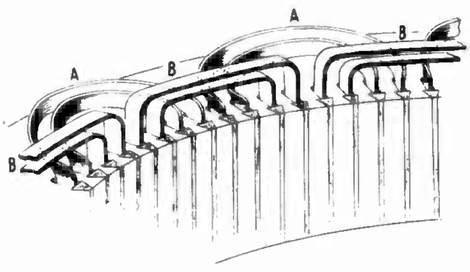

Figure 16

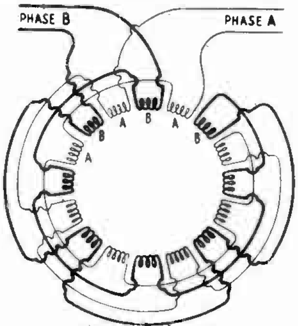

Figure 17

poles in that phase, while the phase B windings are also connected in like manner. Figure 16 is a pictorial representation of the two windings of Figure 15 placed in a motor field showing how the slots are closed with wooden wedges to keep the coils in place. In Figure 17 an eight-pole, two-phase winding is shown and although the circuit is slightly different if the wires are traced through it will be found that each alternate pole in phase A is wound in such a direction as to make each phase A pole opposite in polarity to the following pole in the same phase. The same arrangement is followed in the wiring of phase B.

Now that we have studied the action of two-phase current in producing a rotating field we may pass on to the subject of how a rotating field is produced by three-phase current. The action is quite similar to that of a two-phase current and can be better visualized if we first consider an iron ring wound as shown in Figure 18 with the winding supplied with three-phase current at the points A, B. and C. which

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are 120 degrees apart. When current is flowing into the winding at A, two currents, each of which is 120 degrees out of phase with it and with each other, will flow out at B and C, producing a negative pole at A and a negative pole at E. The needle will thus point toward A, but as the cycle advances the relationship of each current to the other as regards strength and the time each reverses in direction will be such that when current is flowing in at one of the points A, B, or

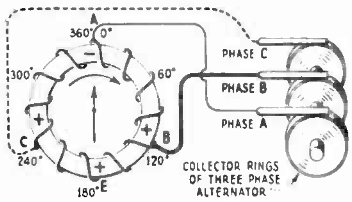


Figure 18

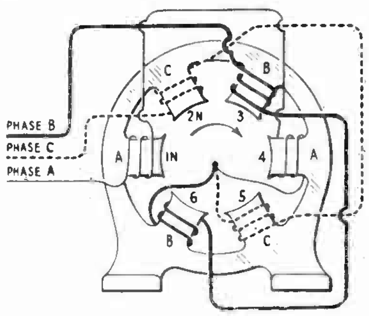


Figure 19

C, two currents 120 degrees out of phase with the first mentioned current and with each other, will flow in or out at the other two points. This action will result in a complete rotation of the magnetic field at each cycle of the current. The action is analogous to that of three cranks set at 120 degrees with respect to each other on a crank shaft. Figure 19 shows a three-phase, two-pole motor field winding, and by referring to Figure 20 the magnetic field flux condition of the field may be visualized at various periods. In Figure 21 a Y-connected winding is seen on the four-pole field.

In order to understand the action of an induction motor it is necessary to know why the rotating field has a tendency to revolve the armature with it. This is best demonstrated by using a copper cylinder for the armature and considering the magnetic field to be produced

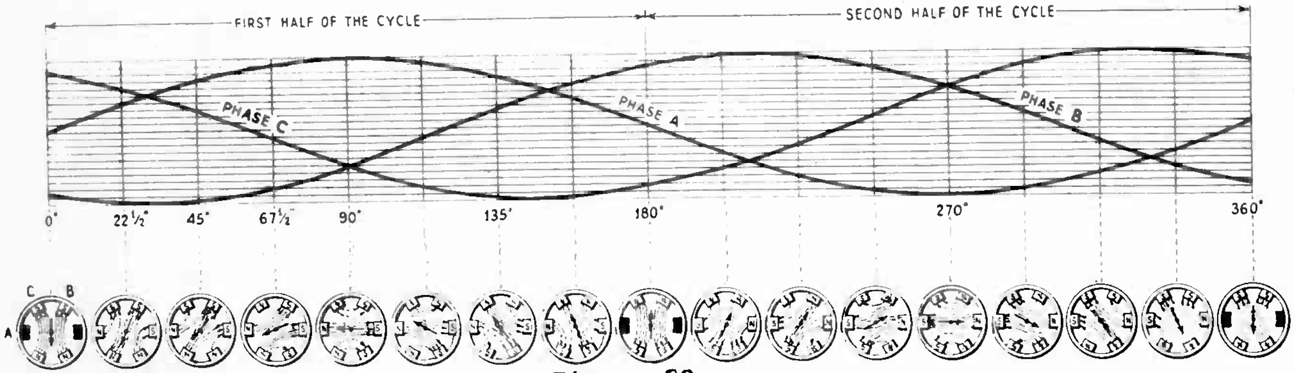


Figure 20

by the poles of a permanent magnet, the N pole of which is on one side of the cylinder, the S pole being directlyopposite on the other side, shown in Figure 22. If the whole magnet is now rotated mechanically the magnetic field will move across the face of the copper cylinder and as we learned previously, whenever a magnetic flux is cut by a conductor a current is generated according to well-defined laws. In the case of Figure 22 currents are generated on the surface of the cylinder in a direction shown by the arrows which produces magnetic poles in the areas marked by N and S. As the N pole of the field magnet rotates it pushes the N pole of the armature by the repulsion effect of like poles while at the same time it pulls the S pole by the attraction effect of unlike poles. This results in the rotation of the cylinder. It is easily seen that the greatest driving effect or torque is produced while the cylinder is at rest and decreases as the cylinder more nearly attains the speed of the field even up to the point where there is no driving effect or torque at all, at which time the cylinder revolves at the same speed as the field.

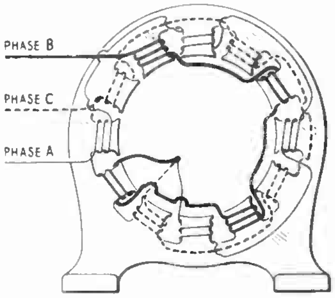


Figure 21

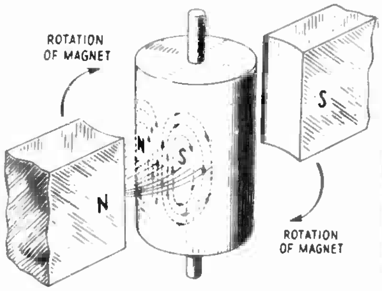


Figure 22

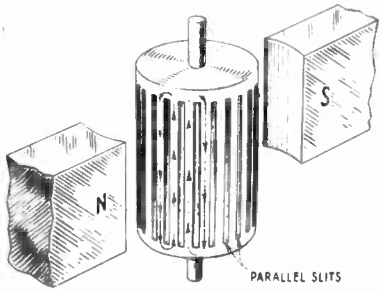


Figure 23

This follows from the fact that in the first place the currents generated in the cylinder are due to the action of the magnetic field in sweeping past the cylinder, in other words, the current generated varies as the difference in speed between the rotating field magnetism and the cylinder. When the cylinder is at rest the field flux sweeps rapidly over its surface, but when the cylinder is revolving at the same speed as the field then the field flux does not pass over the surface of the cylinder, and with the cylinder cutting no lines of force no current can be generated. This latter condition can hardly exist because the force that drives the cylinder results from the difference in speed between the field and cylinder and when that difference in speed is no longer present the driving force is removed, the cylinder begins to slow down and this immediately re-establishes a driving force. If a mechanical load is put on the cylinder shaft

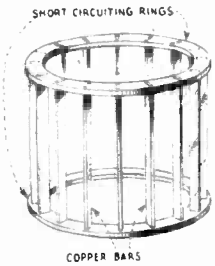


Figure 24

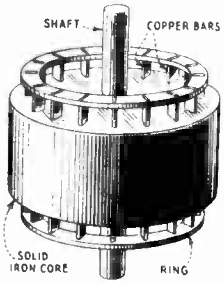


Figure 25

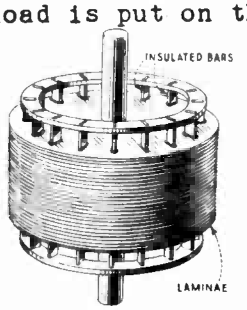


Figure 26

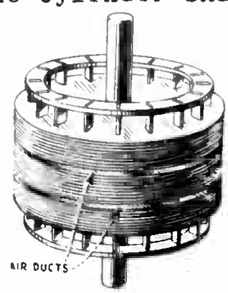


Figure 27

then it will be slowed and as it decreases its speed the increased sweep of the field past it generates more current in it and greater torque results. This establishes a rule of the action of induction motors which says that the more "slip" (difference of speed between rotating field and armature) there is, the greater will be the torque.

The copper cylinder armature used in the early experiments with this type of motor failed to provide a restricted path in which the induced currents could flow because the surface of the copper was continuous and thus the currents spread out considerably. Another defect was that there was no iron present to furnish a path of low reluctance to the magnetic flux produced by the induced current. The first attempt to get over the former difficulty was the cutting of the slots in the cylinder as shown in Figure 23 which confined the induced currents to the path shown, the effect of which was to produce stronger magnetic poles in the armature. Then an iron core was added to a cage-like contrivance made of copper bars and connecting end rings, the "squirrel cage" appearing as in Figure 24 and the core and cage assembled as in Figure 25. Further stages were the insulation of the copper squirrel cage from the iron core and the building of the iron core out of laminated sheets of iron which reduced loss from eddy currents as seen in Figure 26, then the provision for ventilation to cool the armature as seen in Figure

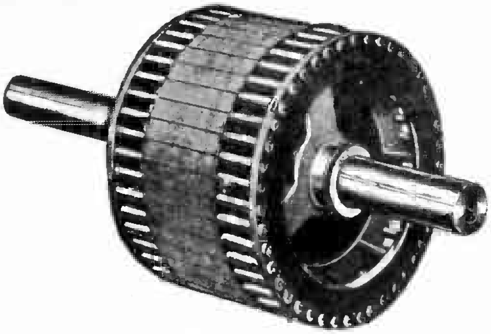


Figure 28A

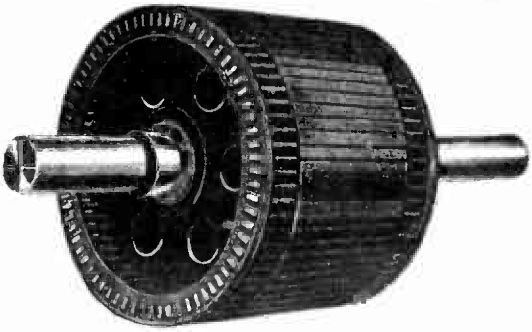


Figure 28B

27 and finally the modern "squirrel cage" armature was developed, the designs used by several leading motor manufacturers appearing as in Figure 28-A and B.

In Figure 29 is seen the field construction of a three-phase induction motor, each of the tube-like squares shown in close-up view in Figure 30, being a coil of wire taped into a bundle and set into place in the proper slots.

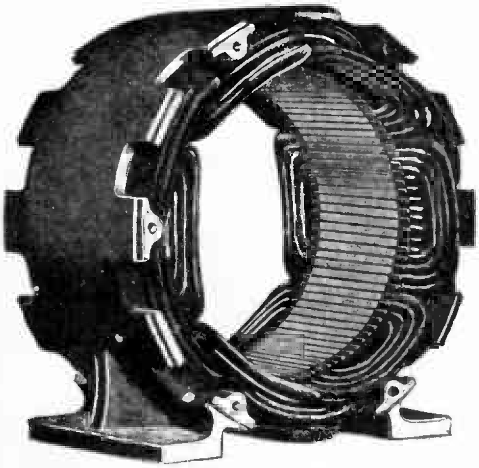


Figure 29

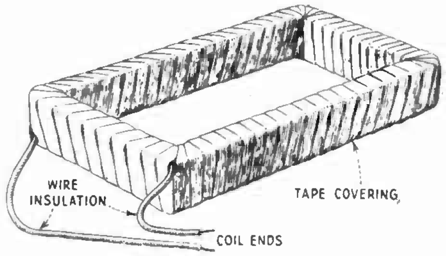


Figure 30

Now that we understand how a rotating magnetic field is produced by a polyphase current and also how that rotating field acts upon a squirrel-cage armature to cause it to follow the magnetic field we have only to place an armature such as the one shown in Figure 28-B into the field shown in Figure 29 and when the shaft is properly supported by bearings a commercial motor is the result which appears as shown in Figure 9. This motor is generally called a synchronous motor because the iron core is so shaped that after the motor is brought up to speed by action of the revolving field on the squirrel cage armature, the core finds itself in such relation to the lines of force in the rotating fieldthat it furnishes the path of least reluctance to the magnetic field and therefore is dragged around in synchronism with the rotation of the field. When it is operating in this fashion, at synchronous speed there is no inductive action between them and therefore it runs purely as a synchronous motor. If however, such a load should be put on the motor as to cause it to fall out of synchronism with the revolving field, then the field, sweeping past the squirrel-cage inductors, will induce a current in the armature and this will cause the motor to run as an induction

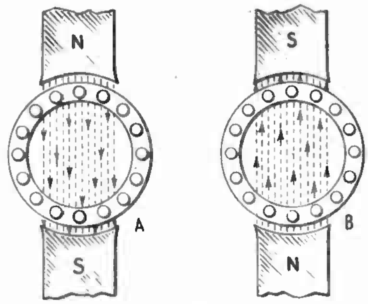


Figure 31

motor only until it gets to synchronous speed once more. Thus we see that a motor of this type has many desirable characteristics, for it is self-starting due to its squirrel-cage inductors which will bring the motor up to synchronous speed and in addition will take up the load should the armature lose synchronism with the field, besides which it will run as a synchronous motor under normal load, producing the constant speed desired for Sound Picture projection.

Single phase A.C. motors are used extensively in this field and they are run on the induction principle, various methods being used

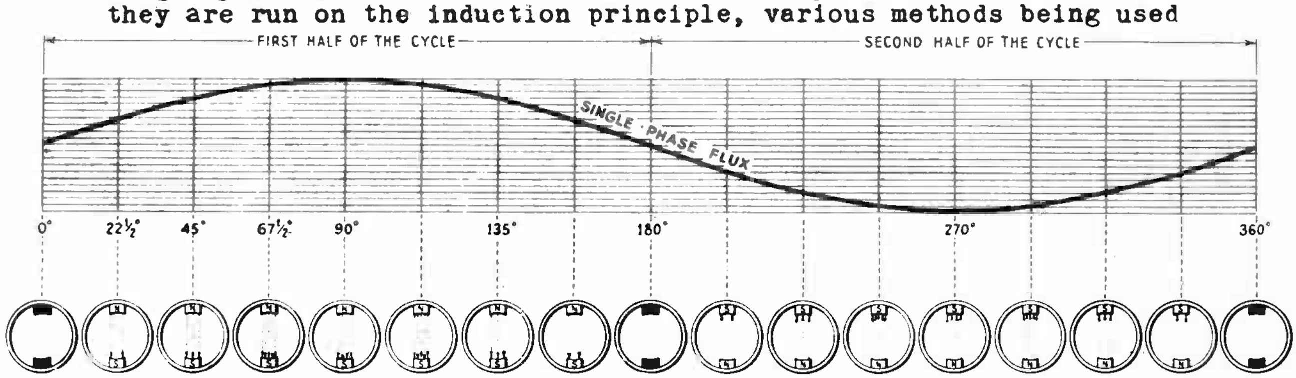


Figure 32

for starting and bringing the armature up to speed. The problem of starting a single-phase motor is different than in the case of a three-phase motor due the fact that a single phase current is not able to produce a rotating magnetic field without some special form of winding of the field or a method of starting the rotor to revolve by means of a commutator. Before we go into an explanation of the operation of each type of starting arrangement it will be well to understand why a single-phase current cannot produce a rotating field without some special arrangement of wiring. In Figure 31 is shown a diagram illustrating how a single phase current produces a vibrating or alternating magnetic field rather than a rotating field as is the case with two or three phase current. Sketch A in Figure 32 shows the condition of the magnetic field during the first half cycle, a N pole being produced at the top and an S pole at the bottom.

In the second half of the cycle the polarity of the magnetic field is reversed and the top becomes an S pole while the bottom becomes an N pole. It can be seen by the arrows denoting the magnetic flux that the inductors of the squirrel cage (shown by the small circles in the rim of the large circle) are cut by the field lines of force equally on each side of the center which means that whatever pull or torque is developed is equal on each side of the armature and therefore no rotation can result.

Figure 32 shows the condition of the magnetic field at various times during a complete cycle of single phase current. Although the strength of the magnetic field changes as shown by the number of arrows there is no production of a rotating field. The figure shows only two poles, but even if there were six poles as shown in Figure 20 and they were wound in pairs, due to the fact that the current is only single phase the magnetic field would not rotate, but would simply oscillate back and forth directly through the center of the armature gap and no turning effect or torque would be produced. At the beginning of this lesson we explained why a single phase current is unable to start an armature revolving and how, after the armature is speeded up to synchronism it has power to keep it revolving in synchronism with the power supply.

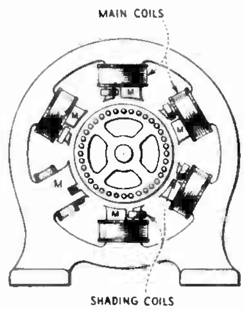


Figure 33

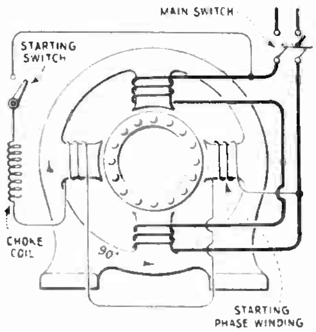


Figure 34

We will now consider the most widely known methods for producing the rotating field effect from a source of single phase current. We know that when magnetic poles are near each other in which the strength of the current in one phase to that in the other phase is used to produce in progression magnetic fluxes varying in intensity in separate sets of coils this will produce an effect of a rotating field. With single phase current we are not able to take advantage of the variation of two distinct currents from a source of supply, therefore we must produce the effect of a double source of supply from a single source. One method is known as the shading coil method of "splitting the phase", a diagram of which is shown in Figure 33. The main coils, which are the six large ones shown, are wound with copper wire and produce magnetism, the strength of which rises and falls and reverses as the strength of the single phase current rises and falls and reverses. This action in itself produces a reciprocating or pulsating field, in the main or large pole pieces M. An auxiliary pole-piece A is provided beside each main pole piece, however, and this has a "shading coil", which may be either short-circuited coils of wire or a solid copper cylinder placed over the auxiliary pole piece. Now, the effect of this shading coil is to keep the strength of the magnetic flux from dying out of the auxiliary pole pieces as rapidly as it leaves the main pole pieces.

It follows then, that the desired effect of adjacent poles having magnetic flux of different strength, which varies as the strength of the current varies, has been attained by this method. The rotating field thus produced is not as smooth nor as symmetrical as that produced by two-phase current and two sets of field windings, but it is sufficient to start the motor and bring it up to synchronous speed where it will remain due to the fact that its rotation is correctly timed with that of the field to produce efficient torque. Another method of "splitting the phase" is by the use of two separate windings in which a phase difference of current is produced by introducing either inductance or capacitance in one of the windings.

Figure 34 shows in simple form a split phase motor in which the current in the running or main winding is considerably ahead of the current in the starting winding due to the choking or retarding effect of the choke coil shown. A choke coil opposes both the rise of current and the fall of current in its circuit due to generation of counter E.M.F. and this property of a choke coil is taken advantage of in this instance to produce a current in the starting winding which is out of phase with the current in the main winding. With the starting poles and running poles placed as shown in Figure 34 this produces the effect of a rotating field somewhat like that produced by two phase current. After the motor has been brought up to speed the starting

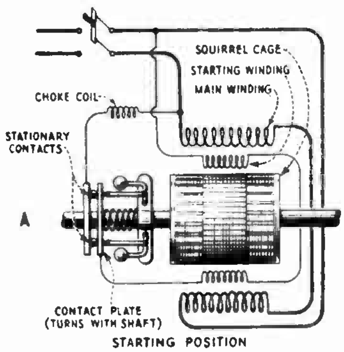


Figure 35A

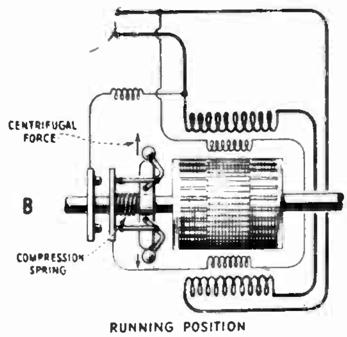


Figure 35B

windings are cut out of the circuit by opening the starting switch shown in Figure 34. In actual practice, however, the starting windings are cut in and out of service by an automatic device, the principle of operation of which is shown in Figure 35, A and B. In A the centrifugally operated switch is shown closed with the governor balls near the shaft. As the combination of the starting and running windings start the motor and bring it up to synchronous speed the balls fly apart against the force of the compression spring and pull the contacts open, cutting the starting windings out of circuit and allowing the motor to operate on its main windings. Figure 36 shows a split phase motor as used in certain Photophone Sound equipment.

Another starting device for a single phase motor is known as "the repulsion type", and when combined with a motor that runs on the induction principle after being brought up to speed the motor is called a repulsion start, induction-run motor. This type of motor consists of an armature, commutator and field magnets, the armature being wound exactly like a direct current motor armature the windings being connected to a commutator similar to that used in a D.C. motor.

The starting device consists of two brushes mounted so as to make contact with the commutator; a resistor to limit the current by-passed through the brushes; and a centrifugal mechanism for shorting out the entire commutator after the motor has attained sufficient speed to run as a single-phase induction motor. In Figure 31 we saw that the pull or torque exerted on the squirrel cage windings was equal on each side of the center or shaft of the armature, thus producing vibration,but no rotary motion of the armature. The brushes here used effectively by-pass a large portion of the current induced in part of the armature winding. This unbalance of the actual armature currents unbalances the torque set up by the rotor currents. The current in the rotor is due to the transformer action between the stator and rotor windings.

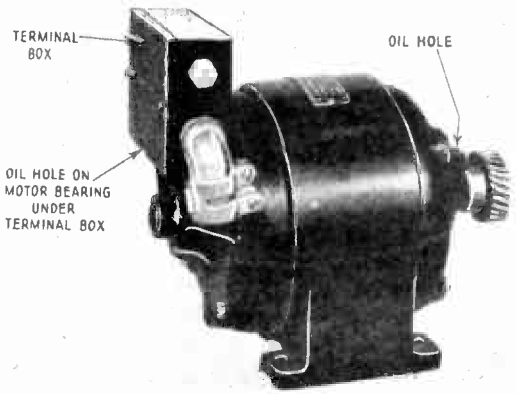


Figure 36

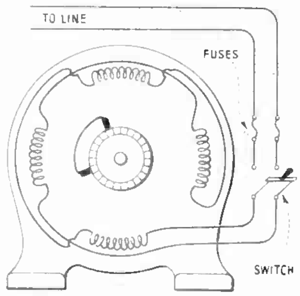


Figure 37

The unbalancing action gives a predominance of torque in a direction which depends upon the position in which the brushes are mounted. The running winding will keep the motor running in either direction once it is up to speed. If the brushes were short-circuited through a very low resistance, such as a copper wire, the starting torque might be too great for the particular load to which the motor was connected. In this case a resistor of several ohms is used to connect the two brushes together. As the armature rotates, succeeding armature coils are short-circuited while the armature is in continuous rotation in one direction. Figure 37 shows the field winding and the position of the short-circuiting brushes on the commutator.

After the armature is brought up to synchronous speed it operates as an induction motor, but in order that it shall be able to do this it is necessary to short circuit all the armature coils so that large currents may be induced in them by the field flux. To do this all the segments of the commutator must be connected together electrically and this is done usually by means of a copper plate that automatically presses up against all the segments of the commutator when the armature has attained a certain speed. The device for connecting electrically all the segments of the commutator as used in a Photophone projector drive motor is shown in Figure 38. In the top view the various parts of the device are shown assembled on the motor while the view at the bottom left shows how the commutator short-circuiting plate is pushed up against the commutator when the fly weights move outward causing the separator balls to thrust outward. The view at the bottom right is an enlarged view of the centrifugal

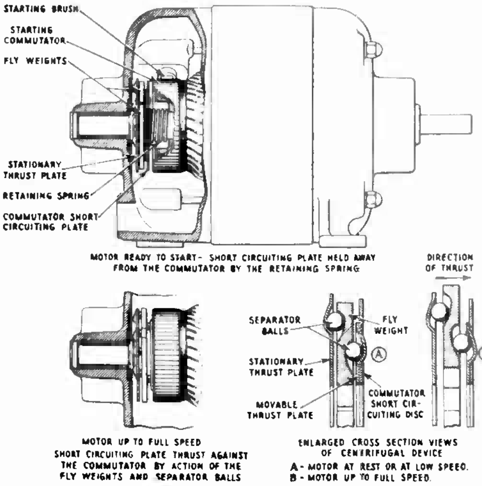


Figure 38

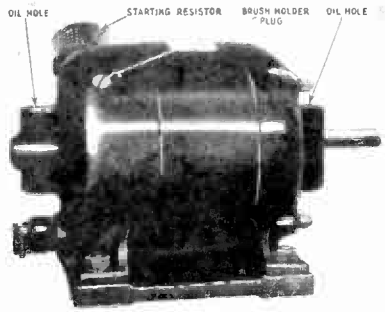


Figure 39

device with motor at rest and with motor up to full speed. A photograph of this motor is seen in Figure 39.

In order to reverse the direction of rotation of a two-phase, four-wire motor interchange the connections of the leads of either phase; of a three-phase motor interchange the connections of any two leads. The direction of rotation of a motor with "shading coils" cannot be reversed by any change in the leads, but single phase, split phase motors can be reversed by reversing either winding with respect to the other winding.

With the completion of this lesson the subject of motors as used in Sound Picture equipment is well covered and if the principles discussed are learned by the student it will be easy to "shoot trouble" in any motor he may be called upon to service.

EXAMINATION QUESTIONS

1. What is meant by the term "rotating field"?

2. What is the principle of operation of a squirrel-cage motor?

3. What is meant by "slip"?

4. Why does a single phase motor need some sort of starting device?

5. Name three methods for starting single phase motors and bringing them up to synchronous speed.

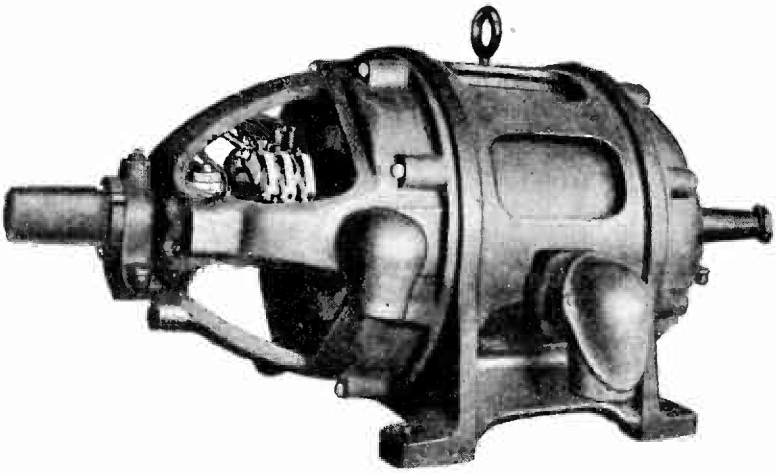
6. When has a squirrel cage motor the greatest slip, with or without mechanical load?

7. Why are A-C Motors especially adaptable to recording work?

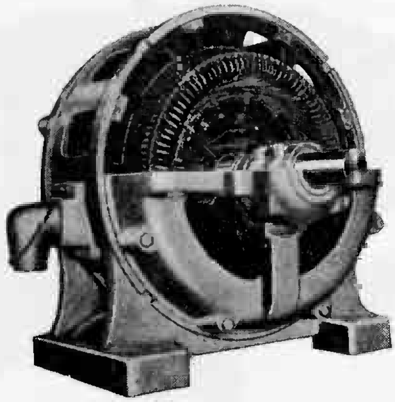
8. What will happen to a synchronous motor if too great a mechanical load is put upon it?

9. Explain the shading-coil method of producing a rotating field effect.

10. How is the current in the starting coils made to flow "out of phase" with that in the running coils in a split-phase motor?



Polyphase Wound-Rotor Induction Motor



Polyphase Induction Motor With Top Half Bracket Removed

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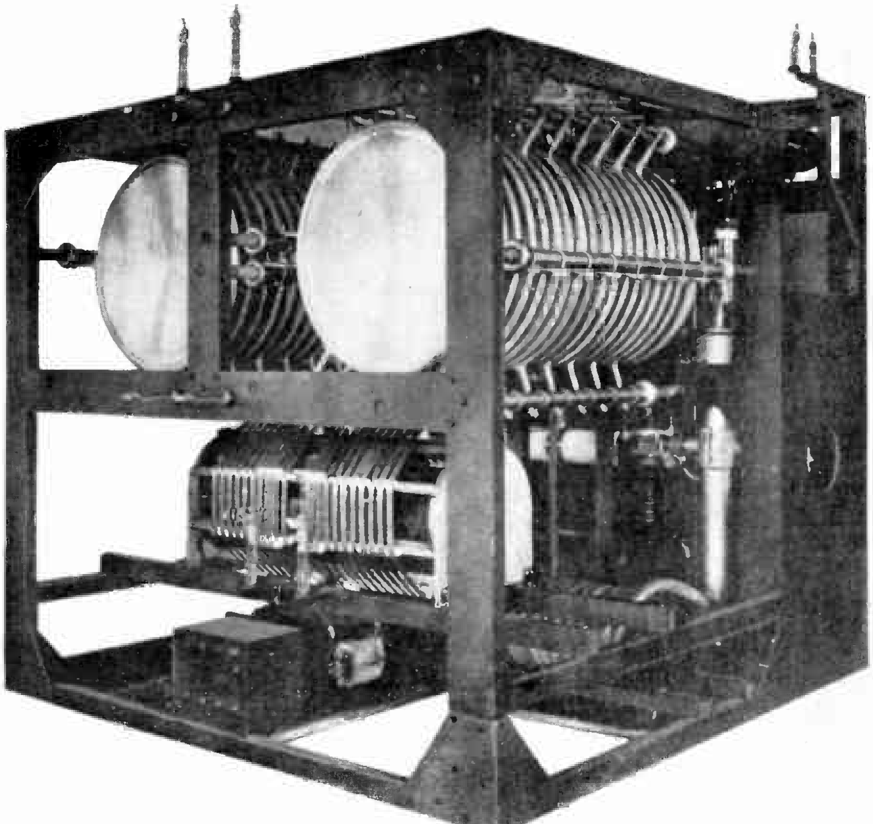

Rear View, 50-Kw. Amplifier showing tank-circuit inductance and air dielectric tuning condensers above

CAPACITANCE AND CONDENSERS

VOL.10,NO.15

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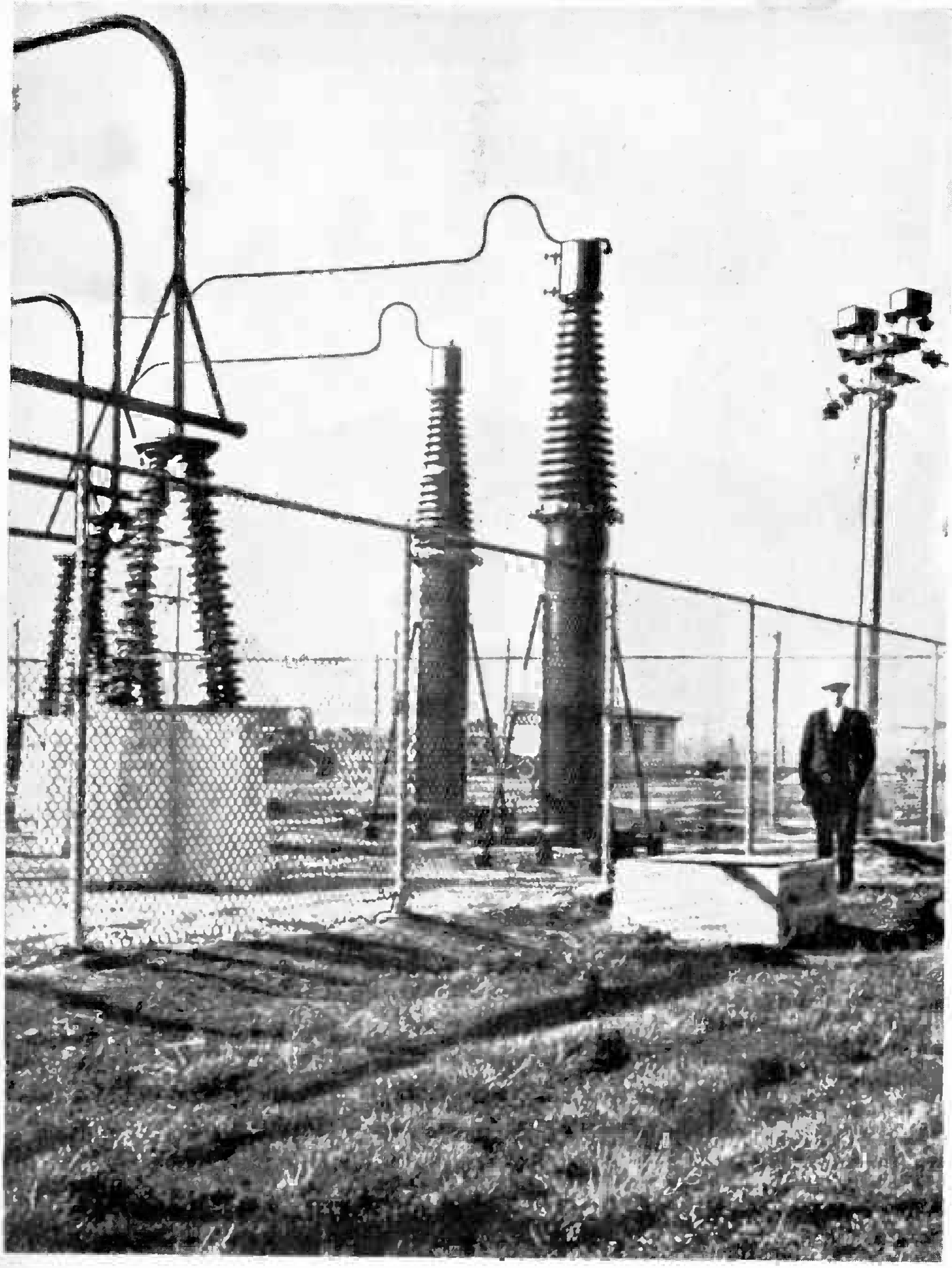

General Electric coupling capacitors for Carrier Telephony on 220,000-volt Power Transmission Line of the Southern California Edison Company

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CAPACITANCE AND CONDENSERS

What is capacity? Under what other names does it appear and where and why is it used? Capacity is the ability to receive, contain and store up energy. For example, a tank has the ability of storing water, oil and other forms of liquid. A condenser, in the electrical sense, stores electricity. It is used in power line transmission as well as in radio.

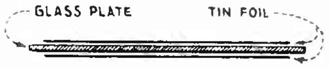


Fig. 1--Component unit of a condenser

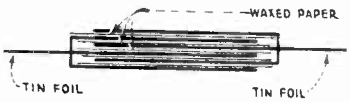


Fig. 3--Paraffined paper condenser

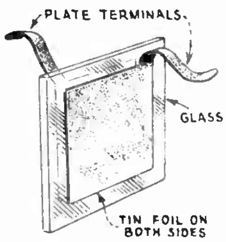


Fig. 2--Construction Details

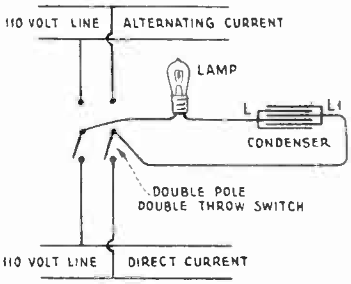


Fig. 4--Circuit used to illustrate condenser action

Capacitance is the term applied to the quality a device may have of being able to receive and store an electrostatic charge. As capacitance plays a large part in many ways and in various phases of the radio industry it may be well for you to know how simple it is to construct a device possessing capacity or capacitance. If you secure a piece of glass and two sheets of tinfoil you have the elements of a very simple condenser. Figures 1 and 2 indicate how this condenser is assembled. A large number of commercial condensers used with spark coils are made of tinfoil and paraffined paper, the tinfoil being the conductors and the paper being the insulator or dielectric, as it is called. Alternate layers of tinfoil and paper make up the condenser. A paraffined paper condenser with leads is shown in Figure 3.

Suppose we conduct an experiment, the purpose of which will assist us to visualize the effect taking place when a condenser of large capacitance is placed in a direct current circuit and then in a circuit carrying alternating current. We will use a hook-up as shown in Figure 4. Throw the double-pole double-throw switch down, thus connecting the circuit containing the condenser and lamp to the source of direct current. It is noticed that the lamp does not light. In a direct current the condenser acts as an open circuit exactly as though you had opened the circuit by cutting the wire with a pair of pliers, and this experiment proves it, for otherwise the lamp would have given off light. In tracing the circuit through the lamp you will find a connecting path for current as far as, and including, the plates marked "L", but the intervening dielectric, which is an insulator, prevents current from flowing to "L1". A potential difference does exist, however, and is available between the condenser terminals. This potential rose from zero (line disconnected) to a maximum value equal to the potential difference of the line wires, when the switch was closed. Before this value was reached, the coulombs of electricity entering the condenser per unit of time gradually decreased to zero. The lamp, if the capacitance of the condenser and resistance of the lamp were correct, might become incandescent for a fraction of a second giving a flash of light, but it would not remain illuminated. This would indicate that there was a momentary current flow after which the lamp ceased to glow.

Let us apply an alternating E.M.F. to the same circuit by throwing the switch up. The lamp at once burns at moderate incandescence and remains in this state giving off light until the circuit is opened. While we could obtain a single flash of the lamp when a direct E.M.F. was applied, we find that by applying alternating current a continuous illumination results, proving without question that a condenser, when of the correct capacity, does not produce in an a-c circuit the effect of an open circuit as it did in the direct current circuit. There is an electrical phenomenon taking place in the space between the plates of the condenser. This space together with the condenser plates constitutes capacitance. This space has the ability to receive and hold an electrical charge and is called the <u>Dielectric.</u> The plates of the condenser serve only the purpose of <u>distributing</u> the electromotive force over the dielectric.

The most common form of dielectric material is found in the shape of insulators. Air as a dielectric is frequently used, and it is from air that we base our standard for the "Specific Inductive Capacity" of the dielectric. Air, mica, glass, rubber, paper, and oil all may be utilized to form a dielectric for the condenser. As air is taken as a standard it is given the value of unity, or 1. To explain this value of Specific Inductive Capacity, suppose we determine by measurement the amount of charge a condenser using air as the dielectric will accumulate with a definite E.M.F. Then under the same conditions we will measure the amount of charge in the same condenser using glass as the dielectric. It will be found that when glass is the dielectric medium the condenser will take a charge from 5.4 to 10 times as great as the condenser having air as the dielectric, this specific inductive capacity depending upon the grade of glass used.

<u>SPECIFIC INDUCTIVE CAPACITY</u>

The following table indicates the Specific Inductive Capacity of some of the most commonly used dielectrics:

Air	has a dielectric constant	of	1.00	
Castor Oil	" " " "	"	4.67	
Hard rubber	" " " "	"	2.5	to 3.50
Glass	" " " "	"	5.4	" 10.00
Mica	" " " "	"	4.0	" 8.00
Paper	" " " "	"	1.5	" 3.00

We find that when different insulating material is placed between the plates of a condenser the capacity of the condenser will be changed.

To explain the charging action of the condenser it will be well for us to review briefly the subject of conductance, insulation, and a phase of the electron theory dealing with the atomic structure. The condenser circuit is composed of the conductor plates which are usually aluminum, tinfoil or copper.

The material selected as a conductor must have a low resistance, in other words, it should offer very little opposition to the movement of electrons which, as you know, produces what is termed an electric current.

Insulation is so named because of the opposition which it offers to the electronic movement and resulting electric current. Insulation in a direct current circuit produces the effect of an open circuit, but when the same insulation is used as a dielectric of a condenser and placed in an alternating current circuit it may have the effect of being a conductor, as you learned by the lamp and condenser experiment. The condenser does not permit an actual continuous passage of electrons in one direction; it has the effect of permitting a shifting back and forth of the electrons in an otherwise conductive path. This statement may, at first appear contradictory and somewhat confusing, but the effect of the conduction of alternating current through a condenser can be readily explained and made clear if we will but consider the nature of electric current flow as set forth in the electron theory.

According to the electron theory all bodies are considered to be made up of infinitesimally small particles of matter called Atoms and, revolving about the atom, much as the earth and other planets revolve about the sun, are much smaller particles called Electrons. The atom is considered to be made up of one or more charges of positive electricity. All bodies are made up of atoms and, since the atom is considered to constitute a positive charge of electricity and the electron negative electricity, all substances possess large quantities of electricity. We found in previous lessons that like charges repel and unlike charges attract. In nearly all cases, however, the positive electrical charge equals the negative electrical charge thereby neutralizing each other and from all outward effects no electrical charges are evident. This complete balance of positive and negative electricity may be upset and we then observe electrical effects.

Negative electricity, or the electron, is considered to be the only form of motional electricity. Therefore, if we can succeed in forcing an electron to leave an atom there will be less negative charge than positive, the system becomes unbalanced, and the atom predominates in positive charge. By returning the negative electron to the atom we again produce a balance and the atom is again neutral or uncharged. Now force an electron to the balanced atom; the atom now will have an excess of negative charge thus making it negative.

In a substance which is a good conductor of electricity, such as copper and some of the other metals, the electron can be moved easily from atom to atom and this is what takes place when an electromotive force is produced by either mechanical or chemical means.

As all electrons are negative charges of electricity any electron caused to move from one atom to the next will cause an electron adjacent to it to be repelled with great force, and as long as the electromotive force is applied this repelling of electrons continues. It is this movement of electrons which results in what is called current flow.

In insulators, such as we employ as dielectric mediums of a condenser, the atom has a far more stable structure and greater electromotive force is required to drive an electron from the atom.

Now suppose we have a condenser and a source of E.M.F., the value of which is not great enough to completely dislodge or drive the electrons from the atom, but sufficiently great to strain the electron from its normal orbit without completely dislodging it from the atom, that is, to a position just short of the complete breaking away point, as the E.M.F. forces the electrons from the circuit into one condenser plate, piling them in by the millions, the electrons in the atoms of the dielectric are repelled and displaced from their normal position. The second plate, being positive, attracts the electrons in the atoms of the dielectric. It is this moving away of the electrons from their normal position in the atom that is called the displacement current, and the condenser is said to be charging; that is, charging in the sense that electrons continue, as a result of the E.M.F., to pile up in the negative plate. The displacement of the electrons has produced a strain on the whole structure of the atoms. When the holding forces of all the dielectric atoms to their electrons is equalled by the repelling force of these electrons against the electrons moved into the negative condenser plate, the potential difference between the two plates has become equal to the electromotive force applied from the external source. Then the movement of electrons out of one plate and into the other through the external circuit will cease.

This action, so far, can be illustrated by imagining a tank of proper design used to store air. Let an air pump represent an electric generator and the particles of air the electrons. On starting, the pump air at once is set in motion and is forced into the tank; the tank is under pressure and becomes strained. This strain caused by the piling up of air particles begins to exert a back pressure on the air being forced into the tank. This continues to increase with every stroke of the pump until the stored up air reaches a pressure equal to the driving pressure of the pump, when the flow of air will cease.

A similar action takes place in the electric circuit. As the applied E.M.F. decreases in the alternating current circuit the strained dielectric is relieved, allowing the electrons to again assume their normal positions about the atoms. This reverse movement of the electrons produces a displacement current in the opposite direction and the condenser is discharging. As the applied E.M.F. passes through zero value and reverses, the charging movement of electrons is toward the plate which was positive during the first half-cycle; the electrons in the dielectric atoms are displaced in the opposite direction. As the alternating E.M.F. is constantly varying in strength and direction, electrons are continually moving back and forth through the circuit tending to keep the condenser plates at the same potential difference and polarity.

It is this movement of the electrons into and out of the condenser plates which results in the current causing the lamp to glow in the experiment of Figure 4. It is therefore clear that the electrons do not actually pass through the dielectric from one plate to the other, but simply move into and out of the plates, swinging through the circuit from one plate through the generator to the opposite plate. With this knowledge of the behavior of the condenser we are enabled to make an efficient test as to the worthiness of a condenser by using direct current for the test.

From a source of direct E.M.F., such as a 45 volt "B" battery, bring out two leads as suggested in Figure 5, one lead having a suitable voltmeter in series. Touch the terminals of the condenser and at the same time observe the voltmeter. The needle will be deflected once and then return to zero. Remove the test tips and at once bring them in contact with the condenser a second time; on the second contact there will be no deflection of the voltmeter needle. This proves, first, that the condenser is charged and, second, that it will not accept a further charge with the E.M.F. of 45 volts. Third, the current will not flow entirely through the dielectric.

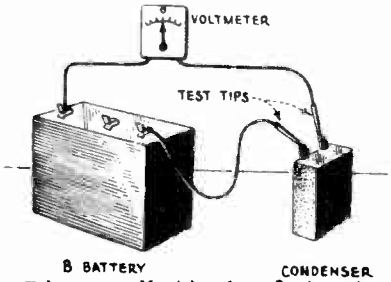


Fig. 5--Method of test-charging a condenser

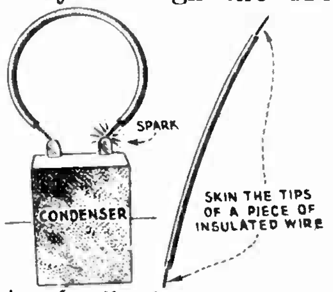


Fig. 6--Method of test-discharging a condenser

Take a piece of insulated wire, skin the ends and short circuit the condenser as shown in Figure 6. When testing certain condensers in this manner a bright spark will result, proving that the condenser held the charge until a path was offered to the charge to flow out, which it immediately did through the wire forming the circuit to the opposite plate, thus equalizing the charge until there was no difference of potential between the condenser plates.

Now secure a punctured condenser and follow the same procedure as before. The indicating needle of the meter will be deflected at every contact of the test tips indicating that the dielectric is broken down allowing current to flow directly through from one plate of the condenser to the other. A broken down condenser will not hold a charge.

A water analogy of the action of a condenser follows to illustrate displacement current. Refer to Figure 7. Here is a system of pipes "E" and "C", and a tank divided into two divisions, "A" and "B", by a rubber partition "R". A reservoir is shown at "D" (the use of which will be explained later). On filling this system with water it is clearly seen that the water will be divided and prevented from moving by the rubber partition "R". There will be the same pressure in the half of the system B-C-D as in the half A-E-D, therefore there is no distortion of the rubber partition "R" and no movement of the water through the system. The conflicting arrangement of the arrows is intended to picture the water as idle; that is, no particular direction of motion would be evident.

Figure 8 is the same arrangement but, in the reservoir "D", we have installed a centrifugal pump so designed that a continuous pressure is exerted on the water forcing it continually in one direction as long as the pump revolves. Revolving the pump in a clockwise direction the water will be forced into motion and will flow, as shown in Figure 8, from the reservoir "D" through pipe "E" and into the "A" section of the tank. Now what happens? The water cannot move beyond the rubber partition but, due to the nature of the rubber, it will stretch and become strained by the pressure of the water as shown. A displacement of water into section "A" takes place, resulting in a like displacement out of section "B".

We will assume that the pump has sufficient force to extend the partition to the limit, but not enough to rupture it. The water in "B" section of the tank will be displaced along the B-C-D half of the system by the forced distortion of the rubber partition, and will move toward reservoir "D". Now retain this: There has been a

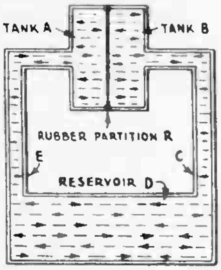


Fig. 7

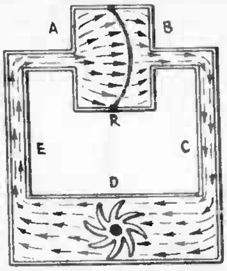


Fig. 8

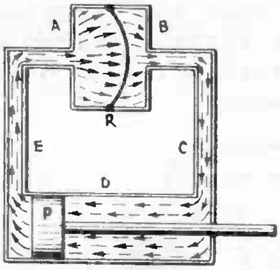


Fig. 9

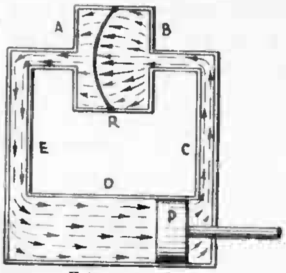


Fig. 10

Various Water Analogies of Condenser Action

displacement of water out of "B" through "C" to "D". Do not forget the word displacement because you will have to associate it with electronic movement later. Remember also that a stress has been placed against the rubber partition and, under this stress, it has been strained and because of this strain movement results in the rubber, causing a displacement of the water in "B" section of the tank.

As the pump continues to revolve continuously in the same direction it maintains a stress upon the rubber partition and the rubber remains in a fixed strained position. As it cannot be strained further there is no further displacement of the water in "B" section when the partition has reached its limit of strain and therefore only one surge of water takes place in the B-C-D half of the system as long as the water is forced to move in the same direction.

This action is similar to the action of a condenser in a direct current circuit. There is actually one surge of displacement current through a condenser in a direct current circuit just as there was one surge of displaced water in Figure 8, but that completes it because the condenser dielectric is strained by the E.M.F. displacing electrons sufficiently to cause one surge of current.

Explaining the water analogy for the alternating current we will use Figure 9 which is the same type of arrangement as shown in Figures 7 and 8 but, instead of the centrifugal pump, we have a piston "P" which fits closely to the walls of the reservoir. Water fills the system as it did in Figure 7. It is clearly seen that if the piston "P" is moved to the left, Figure 9, it will exert a pressure on the water in the "EA" half of the system thus placing a stress on the rubber partition "R", causing it to stretch and a displacement of the water in "B" follows, which moves all the water in B-C-D. The elastic rubber partition is exerting a back pressure against the water forced against it by the piston.

When the piston is returned toward the center of "D" the strain on the partition is relieved, and its back pressure is effective in aiding such a movement of the piston because of the tendency of the partition to straighten out. Therefore the suction effect of the returning piston and the back pressure effect of the partition combine to give back into section "ED" the energy stored up in "A". At the same time the movement of the piston has forced water back up through the pipe "C" into "B" until the partition is completely straightened out and at rest. As the piston continues its movement past the center of "D" and on to the extreme right position as shown in Figure 10 the extra quantity of water moved into "B" section bulges the partition to the left, being opposed by a back pressure due to the strain in the rubber. The water in the "A" section becomes displaced into the "ED" section as shown by the arrows. With this arrangement and by a rapid forward and backward movement of the piston water will move first in one direction and then in the other.

It must be apparent that we may insert in either the "E" pipe or the "C" pipe some device operated by water flow and have work done in this device, the energy used being provided originally by the pump plunger. In like fashion we may insert an electric device, such as a lamp, in one of the electron-conducting wires between a condenser and a source of alternating E.M.F., and energy in the form of heat and light may become available at the inserted device.

CAPACITANCE

The capacitance of a condenser is a measure of the relation between the amount of a charge in the condenser and the potential difference in volts required to produce that charge. We may say that: $C = Q/V$, where Q is the quantity of electricity measured in coulombs, V the potential difference, and C is the capacitance, the unit of which is the FARAD.

In Figure 9 the volume of water displaced varied directly with the pressure, the cross-sectional area of section AB, and the elasticity of the rubber partition, but inversely with the thickness of the partition. We might write this relation as follows:

$$\text{Water Volume Displaced varies as } \frac{\text{Pressure x Area x Elasticity}}{\text{Thickness of Partition}}$$

$$\text{or } \frac{\text{Water Volume Displaced}}{\text{Pressure}} \text{ varies as } \frac{\text{Area x Elasticity}}{\text{Partition Thickness}}$$

which latter term may be considered the "capacity" of the section. In the electrical case we find a closely similar relation:

$$\frac{\text{Quantity of Charge}}{\text{Potential Difference}} \text{ varies as } \frac{\text{Area x Dielectric Constant}}{\text{Dielectric Thickness}}$$

From the preceding paragraph we know that Q/V is the capacitance of the condenser, and the exact formula for it may be written:

$$C = \frac{8.85 \times K \times A}{t \times 10^8}$$

where C = Capacitance in microfarads
K = Specific Inductive Capacity
A = Area in square centimeters of one plate of a two-plate condenser as in Figure 2.
t = thickness of dielectric in centimeters.

If, instead of a single pair of metal plates, there are N similar plates with dielectric between (Figure 3) with alternate plates connected together into two groups, we find that:

$$C = \frac{8.85 \times K \times A \times (N-1)}{t \times 10^8}$$

It will be seen that the capacitance is expressed in MICROFARADS. A condenser having a capacitance of one farad is beyond construction, it would have to be so large. Condensers in actual use have capacitances of only a very small fraction of a farad. In engineering practice, decimal parts are expressed as microfarads and micro-microfarads. Micro means "one millionth of" and micro-micro means "one million-millionth of". Hence a condenser of one microfarad has a capacitance of one-millionth of a farad, etc.

The capacity of a condenser is sometimes expressed in centimeters, one centimeter of capacity being equal to 1.1124 micro-microfarads. This unit, however, is not so frequently used as the one explained in the foregoing paragraph.

When the physical dimensions of a condenser are measured in square inches and inches instead of sq. cms. and cms. the following formula holds good:

$$C = \frac{22.4 \times K \times A \times (N-1)}{t \times 10^8}$$

The area of the plates, the number of plates and distance between the plates can easily be found. The specific inductive capacity, or "K", however, must be determined by actual test and measurement when absolute accuracy is desired. When an approximation is desired a value of "K" may be used as given in specific inductive capacity tables. For example, suppose a condenser has a total plate area of 800 square inches. The dielectric is mica, one one-hundreth (1/100) of an inch in thickness. We now have all the necessary data from which to calculate the capacity of the condenser except the specific inductive capacity (dielectric constant "K").* This can be obtained from tables giving the dielectric constant of different materials. Referring to the table given previously we find the dielectric constant for mica varies from 4.0 to 8.0, depending upon the grade of mica.

*(Note: specific inductive capacity (K) is more often termed the "dielectric constant").

Let us assume that the mica being used in this condenser has a dielectric constant of 5. Substituting these known values in the formula for capacity, the formula becomes:

$$C = \frac{22.4 \times 5 \times 800}{.01 \times 100,000,000}$$

$$C = \frac{89,600}{1,000,000}$$

$$C = .0896 \text{ mfd.}$$

Capacity effects exist between any two conductors with a dielectric between them. As you learned, air or any insulating substance is a dielectric, and there is always a capacity effect between two electrical conductors. If they are bare wires, air is the dielectric; if covered with insulation the insulation acts as a dielectric.

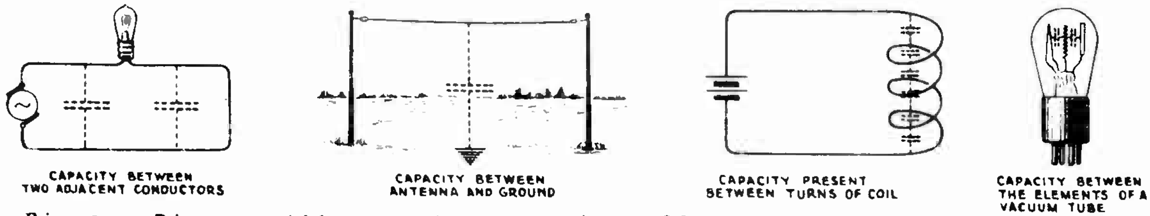


Fig. 11--Diagrams illustrating capacity effects in familiar circuits

In bare wires running from pole to pole or, on a ship, from mast to mast, the air around the wires acts as a dielectric, the ground acting as one side, or plate, of a condenser while the wire is the other plate, and capacity exists there exactly as between two conductors running close to each other, or as in a condenser. Figure 11 gives an idea of capacity in circuits familiar to you.

In determining capacity it is seen that formulae for all conditions under which capacity exists would be rather a complicated work.

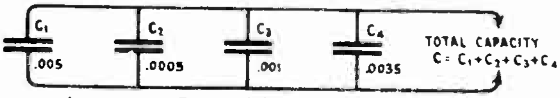


Fig. 12--Parallel connection of condensers

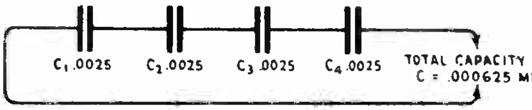


Fig. 13--Series connection of condensers

CONDENSER GROUPING

Condensers are grouped to obtain various capacities and to perform certain functions. Certain circuits may call for condensers in series and others in parallel.

When condensers are connected in parallel, as shown in Figure 12, the total capacity resulting from such a connection is the sum of the individual capacities. In this instance, the different condensers in the group are shown as having capacity of .005 mf, .0005 mf, .001 mf and .0035 mf. The total capacity of such a parallel arrangement is, as stated, the sum of the individual capacities, or .01 mf.

Assume that the four condensers of Figure 13, C1, C2, C3, C4, have a capacity of .0025 each. What would be the total capacity when connected in series as shown in Figure 13? To obtain the total capacity of a number of condensers of equal value connected in series simply divide the capacity of one of the condensers by the total number of condensers in the circuit. Applying this rule to Figure 13 we obtain the answer, .000625 mfd., the total capacity of these four condensers when connected in series.

It becomes necessary under certain conditions, to employ condensers of different values in series. When this is the case the formula of reciprocals is required to solve for total capacity.

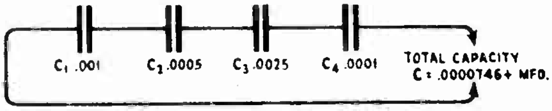


Fig. 14--Series connection of condensers having unequal values

In Figure 14 we have four condensers C1, C2, C3, C4 connected in series. What is the total capacity? The formula for condensers connected in series is as follows:

$$C = \frac{1}{\frac{1}{C_1}+\frac{1}{C_2}+\frac{1}{C_3}+\frac{1}{C_4}}$$

Substituting our known values as stated in Figure 14, the formula becomes:

$$C = \frac{1}{\frac{1}{.001}+\frac{1}{.0005}+\frac{1}{.0025}+\frac{1}{.0001}}$$

$$C = \frac{1}{1000. + 2000. + 400. + 10000.} \qquad C = \frac{1}{13,400}$$

```
C = 13,400)1.0000000(.0000746
             93800
              62000
              53600
               84000
               80400
                3600
```

C = .0000746 mfd. (microfarads), or C = 74.6 mmfd. (micro-microfarads).

CAPACITIVE REACTANCE

The effect of capacitance in an alternating current circuit, termed capacitive reactance, will now be considered. When inductance is introduced in an alternating current circuit, the effect produced is to retard or cause the current to lag the electromotive force.

Capacitance produces exactly the opposite effect, that is, the current leads the electromotive force.

Capacitive reactance is expressed in ohms, as is inductive reactance, and is written X_c (X sub c) while inductive reactance is expressed X_l (X sub l).

The capacitive reactance in any circuit changes with a change in frequency and the greater the frequency the less effect will capacity have on the circuit. An increase in frequency, when inductance is being considered, produces a greater reactive effect.

The formula is as follows: $X_c = \frac{1}{6.28fC}$

X_c = capacity reactance
f = frequency
C = Capacity in farads

In a 110-v., A.C. 60-cycle circuit, we have a .0025 farad condenser connected in series with the line. What is the capacity reactance?

By formula given: $X_c = \frac{1}{6.28 \times f \times C}$

Substituting: $X_c = \frac{1}{6.28 \times 60 \times .0025}$

Multiplying the denominator then $X_c = \frac{1}{.942000}$

```
    6.28
      60
  376.80
   .0025
  188400
  75360
 .942000
```

Dividing

```
.942000)1.0000000000(1.0615
        942000
         5800000
         5652000
          1480000
           942000
           5380000
           4710000
```

We find that the capacitive reactance in the circuit as given above amounts to 1.0615 ohms.

Now let us increase the frequency to 500,000 cycles using the same condenser of .0025 farads. This will show us that, with an increase of frequency, the reactance is lowered.

Again by formula $X_c = \frac{1}{6.28 \times f \times C}$

Substitute $X_c = \frac{1}{6.28 \times 500,000 \times .0025}$

Multiplying the denominator

```
 6.28
     500000
 3140000.00
      .00 25
1570000000
628000000
7850.000000
```

```
7850)1.000000000(.00012738
       7850
       21500
       15700
        58000
        54950
         30500
         23550
          69500
          62800
           67000
```

or X_c = .00012738 ohms.

The purpose in working out this problem has been to show how according to the formula, capacitive reactance decreases with an increase in frequency. You found that, with a frequency of 60 cycles, a capacitive reactance of a little over one ohm reactance was present. When the frequency was increased to 500,000 cycles, however, the reactance was reduced to a fractional part of an ohm.

The table below gives the capacitive reactances of condensers of various capacitances, at frequencies commonly met with in radio practice. For other frequencies it will be easy to determine the reactance of a condenser by proportion. For instance, the reactance of a .001 mfd. condenser at 50 cycles is 3,180,000 ohms. Then the reactance at 5,000 cycles $= 3{,}180{,}000 \times \frac{50}{5000} = 31{,}800$ ohms.

CAPACITIVE REACTANCE IN OHMS

CAP. IN MFDS.	FREQUENCIES					
	POWER SUPPLY		AUDIO		BROADCAST	
	60	120	50	8,000	700,000	1,500,000
.0001	26,500,000	13,300,000	31,800,000	199,000	2,270	1,060
.00025	10,600,000	5,300,000	12,700,000	79,600	910	425
.0005	5,310,000	2,650,000	6,370,000	39,800	455	212
.001	2,650,000	1,330,000	3,180,000	19,900	227	106
.002	1,330,000	664,000	1,590,000	9,950	114	53.1
.005	531,000	265,000	637,000	3,980	45.5	21.2
.01	265,000	133,300	318,000	1,990	22.7	10.6
.02	133,000	66,400	159,000	995	11.4	5.3
.05	53,100	26,500	63,700	398	4.55	2.12
.1	26,500	13,300	31,800	199	2.27	1.06
.25	10,600	5,300	12,700	79.6	.92	.42
.5	5,310	2,650	6,370	39.8	.46	.21
1.0	2,650	1,330	3,180	19.9	.23	.11
2.0	1,330	664	1,590	9.9	.11	.05
3.0	885	443	1,060	6.6		
4.0	664	332	796	5.0	.06	.03
8.0	332	166	398	2.5		
10.0	265	133	318	2.0	.02	.01

GENERAL TYPES OF CONDENSERS

Condensers may be divided into four or five general types according to the dielectric used in their construction. The "Leyden jar" type was, at one time, a very common form of condenser used in transmitting equipment. It consists of a glass jar with walls about 1/8" thick coated inside and out to within two inches of the top with a tinfoil, copper or silver coating. This type is shown in Figure 15. The "Leyden jar" was one of the first types of electro-static condensers developed and, although it is quite efficient it has been rendered almost obsolete by more modern condensers incorporating higher efficiency and greater capacity in units of smaller physical dimensions.

The Glass Plate Condenser for use with high potentials is constructed as follows: Plate glass is used as the dielectric to which is glued tinfoil plates and, after being thoroughly dried, they are coated with shellac or hot paraffine. A single plate is shown in Figure 2.

A number of plates, depending upon the capacity desired, are connected together and immersed in an oil container as shown in Figure 16. This type of condenser is not used to any great extent due to the inconvenience of assembly and the time and work required in replacing broken plates in case of break-down.

The Compressed Air condenser is a type that will be found in use in very few radio installations because expense in construction and upkeep does not warrant its general use. Briefly, the compressed air type is constructed as follows: A metal tank contains steel plates in which half of the plates are insulated from the tank and the other half connected to the tank. The tank is pumped to a pressure of 250 pounds providing a dielectric capable of withstanding a potential of 25,000 volts. Should a break-down potential be applied to this type of condenser no damage is done because the air simply fills in again making the dielectric perfect. This type of condenser is heavy, hard to handle and, in nearly all cases, trouble is experienced in maintaining the tank air tight.

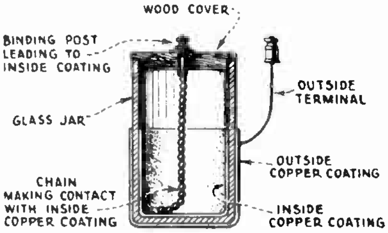


Fig.15--"Leyden Jar" Condenser

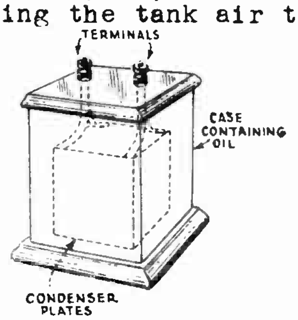


Fig.16--Glass Plate Oil Condenser

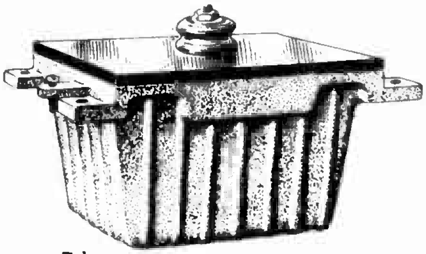


Fig.17--Mica Transmitting Condenser

The foregoing types of condensers were rendered obsolete, as far as modern radio practice is concerned, by the mica condenser. They have been mentioned because, at the period of their development, they each represented an advancement in good practice in radio condenser construction.

The mica condenser uses sheet mica as the dielectric and the plates are made of tinfoil, or copper foil. Properly designed and constructed, this condenser will withstand the high potentials encountered in radio transmitters; —its electrical efficiency is very good and large capacities may be secured within comparatively small physical dimensions. Furthermore, it is very sturdy as compared to the fragility of condensers employing glass as the dielectric — such as the Leyden jar and the glass plate condensers.

A modern mica transmitting condenser is shown in Figure 17. The condenser is enclosed in an aluminum case, the space between the condenser and the case being filled with an insulating compound to render the condenser moisture proof and to reduce brush discharges. The metal case is used as one terminal of the condenser while the other terminal is brought out to the binding post on the bakelite cover of the case.

THE WET ELECTROLYTIC CONDENSER

(The following information on the wet type of electrolytic condenser consists chiefly of an extract of an article by Mr. H. O. Siegmund printed in the Bell System Technical Journal. The material is reprinted here with permission.)

Since the discovery about 75 years ago of the unusual polarizing effect of aluminum it has become well known that certain metals, notably aluminum and tantalum, as anodes in a suitable electrolyte become coated with a film having remarkable electrical properties. Films formed in this manner are characterized by the influence of impressed potential on their electrical resistance.

This resistance characteristic imparts to the film the capability of conducting current more freely in one direction than in the other; of breaking down as an insulation between the metallic electrode and the solution when voltages above a critical value are applied; and, in combination with the thinness of the film, of holding a substantial charge of electricity at potentials below the break-down voltage.

Each of these characteristics provides the principle around which a distinctive class of electrical apparatus has been developed. The electrolytic rectifier, widely used in small direct-current supply sets for battery charging and radio purposes, employs the uni-directional conducting characteristic. The aluminum electrolytic lightning arrester, used extensively for protection of direct-current railway equipment, depends for its operation upon the break-down characteristic of the film. And finally the aluminum electrolytic condenser, now being used in direct-current telephone and radio power plant equipment, utilizes the dielectric property of the film to provide electrostatic capacity.

There are a number of electrolytes, including various concentrations of phosphates, borates, tartrates and carbonates in which films can be formed on aluminum to withstand potentials upwards of 300 volts,at least for limited periods. If a film is formed on a piece of aluminum to this maximum voltage and the metal is then made the anode (positive electrode) in an electrolytic cell across which variable potential can be applied, a current corresponding to a density of less than one microampere per square centimeter of filmed surface will flow when a potential of one tenth of the maximum voltage is impressed.

As the potential is increased this "leakage" current will increase at a rate somewhat greater than proportionate to the voltage. As the maximum or breakdown potential is approached it will be noticed, if the room is darkened, that the anode begins to glow uniformly over the surface with a pale light and with further increases in voltage sparks begin to scintillate over the entire electrode, being noticed first at the surface of the electrolyte. The current through the cell becomes appreciable under this condition and increases more rapidly until at voltages slightly above the sparking potential the cell acts virtually as a short circuit.

Upon reduction of the voltage, however, the insulating properties of the film are restored and the current decreases with decreasing potential in substantially the same relation to voltage as before. The sparking over the surface will be observed to cease at about the same potential at which it began, the glow will disappear and the low leakage-current values will be obtained when the voltage is reduced sufficiently.

Upon reversal of potential on the aluminum electrode there is a much larger flow of current, the value of which is limited by a counter voltage of several volts, and by the low internal resistance of the cell with negative potential applied.

CAPACITY OF ALUMINUM FILMS

Like the ordinary paper or mica static condenser, the electrolytic condenser consists of two conducting surfaces separated by an insulator. The high-resistance film constitutes the insulator in the electrolytic cell, and the electrolyte on one side of the film and the metal of the film-bearing electrode on the other provide the two conducting surfaces. The cathode in this type of cell merely provides a means for making electrical contact with the electrolyte.

When a film is formed upon a smooth polished aluminum surface the coating is transparent. If observed under favorable illuminating conditions the "filmed" surface is seen to be colored and may be either green, yellow, red or blue, depending upon the thickness of the film. The actual thicknesses of films on aluminum have been determined to be from 0.001 to 0.00001 mm., depending upon conditions of formation.

Because of this extreme thinness of the dielectric and its high insulation resistance when positive potential is applied, unusually large capacities per unit area of surface can be obtained. The capacity of a film formed to 30 volts on aluminum is about 0.18 microfarad per square centimeter of dielectric surface, or about 1,000 times that of paper condensers. The capacity per unit area is approximately inversely proportional to the potential at which the film is formed, indicating that the thickness of the dielectric is proportional to the voltage of formation.

EFFECT OF IMPRESSED VOLTAGE ON CAPACITY

When an electrolytic cell with a "formed" anode has impressed on its terminals a voltage greater than the formation voltage, the film must build up to the new potential before the electrical characteristics of the cell become stable. At this higher voltage the capacity of the cell will be reduced to correspond to the increased potential. Where large plate areas are involved the direct application of a potential above the formation voltage results in a heavy flow of current, which may overheat and damage the cell if not properly limited.

If a voltage is impressed on a condenser lower than the potential applied during the formation of the film, the cell will operate satisfactorily, but the capacity will not be immediately affected and will correspond to the potential at which the film was originally formed. However, if a condenser operates for a long time at a reduced voltage the excess film will be removed slowly by the chemical action of the electrolyte, and the capacity will increase gradually to a value depending upon the operating voltage.

When the second electrode of an aluminum cell is made of a non-film forming metal, current will be conducted freely when the aluminum electrode is made the cathode (negative line terminal connected to it). Accordingly this type of cell (called "asymmetrical") is capable of holding a charge of electricity and serving as a condenser only while the aluminum is at a higher positive potential than the electrolyte.

REQUIREMENTS FOR ALTERNATING CURRENT SERVICE

A cell with a non-film forming cathode makes a suitable condenser to operate on direct-current or pulsating-current circuits, in which the aluminum always remains positively charged. On alternating-current circuits, however, such a cell will operate as a rectifier rather than as a condenser, unless two similar units are connected in a series-opposed relationship. In this case, while one cell is acting as a condenser the other cell merely acts as a series resistance; when the current reverses the functions of the two cells are interchanged.

A suitable condenser for operation on alternating current service can also be made by having two electrodes of film-forming metal in the same solution, the electrical relations between the "formed" electrodes being the same in this case as in the series-opposed arrangement of two asymmetrical cells. In either case one or other of the film-forming electrodes opposes the flow of current during each half cycle and its film therefore serves as a condenser dielectric. As the alternating potential varies between maximum values in each direction, the charge is transferred from the capacity provided by one film-forming electrode to the other, the sum of the charges on these two electrodes at every instant remaining constant.

LOSSES IN ALUMINUM CELLS

In the matter of electrical impedance characteristics, the electrolytic condenser does not approach a perfect capacitance as nearly as the more familiar forms of static condensers. Three sources of energy loss in the electrolytic condenser impart to it an equivalent series resistance, as a result of which the condenser current leads the impressed voltage by a phase angle somewhat less than 90 degrees.

The first of these losses is the dielectric hysteresis loss, which, as in the case of the paper condenser, is approximately proportional to the frequency. The second loss is the heat dissipation in the electrolyte due to its resistance and, in the case of aluminum condensers, this may be of appreciable magnitude because of the low electrical conductivity of most suitable electrolytes. This electrolyte resistance remains practically constant over a wide range of frequencies. The third possible loss is heat dissipation in the film due to its leakage-resistance, which in its effect is similar to a high resistance in parallel with the condenser. Ordinarily this loss is negligible because the leakage current is of very low magnitude.

CONDITIONS AFFECTING THE LIFE OF CONDENSERS

To be successful from a commercial point of view an electrolytic condenser must have long life and must not require frequent attention. Otherwise the advantage in the matter of mounting space and the cost per unit capacity is offset by the depreciation and maintenance costs involved. There are two common conditions affecting the life of aluminum condensers that must be controlled if the cells are to operate satisfactorily.

The first concerns the chemical action of the electrolyte on the electrodes and the film. This action, which is merely a matter of the film dissolving and forming aluminum hydroxide in the solution, takes place when the cell is off circuit as well as when potential is impressed. With impressed potential, new film forms under the influence of the leakage current to replace that which is dissolved, but in time the fluid becomes saturated with aluminum hydroxide, which may precipitate as a white jelly and adversely affect the life of the condenser.

The second consideration involves corrosion of the positive electrodes. The susceptibility of aluminum to corrosion is well known, and in the use of electrolytic condensers corrosion of the anode is the most damaging irregularity that can occur.

Obviously then an electrolyte must be chosen that does not rapidly dissolve the film, and the material for the electrodes as well as for the electrolyte must be selected and prepared to prevent serious corrosion of the "formed" aluminum plates.

A COMMERCIAL APPLICATION AND DESIGN OF ELECTROLYTIC CONDENSER

In telephone systems and radio transmitters the principal application of this device involves its use in electric wave-filters. These filters are placed in the supply circuits associated with storage batteries at central telephone offices and at radio stations (used for vacuum tube filaments) and their purpose is to eliminate noise-producing ripples and pulsations introduced by battery-charging apparatus and signalling equipment

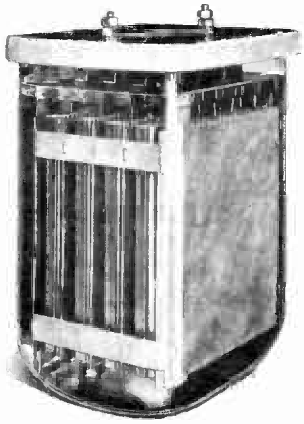


Fig. 18--Aluminum electrolytic condenser, designed for d.c. filter service

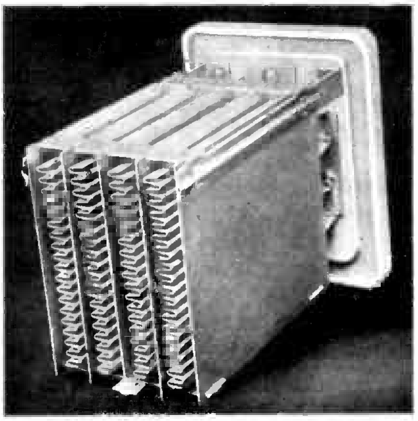


Fig. 19--Aluminum electrolytic condenser showing construction of electrodes

In Figure 18 is shown an electrolytic condenser of the type designed for direct-current filter service. When prepared for operation on 24-volt d-c circuits, the capacitance of this cell is nominally 1,000 microfarads at 1,000 cycles, and for 48 volts is about 600 mfd. at the same frequency. (The frequency of the ripple is stated because the capacity of a condenser of this type decreases with increasing frequency. This is due principally to the corrugated shape of the plates on which the film is formed).

The container for the condenser is made of heat-resisting glass which reduces possible breakage due to temperature variations. The electrodes, both of aluminum, are rigid and are bolted to a porcelain cover to keep them in proper space relation. Two supporting bolts, one from each electrode properly marked with respect to polarity, extend through the cover to provide the terminals for the condenser. A thin layer of high grade paraffine oil is used on top of the condenser fluid to prevent evaporation and to keep the inside of the cell from sweating under varying room temperature conditions. The cover is sealed to the glass jar with paraffine to provide additional protection against evaporation and to prevent dirt from getting into the cell.

ANODE CONSTRUCTION AND MATERIAL

The construction of the electrodes is shown in Figure 19. The positive electrode on which the dielectric film is formed is made of four corrugated aluminum plates, each supported by four integral ears. In an assembled condenser the positive plate surfaces are entirely immersed in the electrolyte, the ears extending up through the oil and providing contact with the positive terminal. The material for the positive plates is aluminum of special composition, selected on a basis of properties which influence the formation of the film, the leakage current, and the life of the metal. In general, the higher the purity of the aluminum the more rapid is the formation of the film and the lower is the resultant leakage current. In the matter of life, however, the purer metal seems to be more readily attacked by agencies capable of causing electrolytic corrosion.

THE NEGATIVE ELECTRODE

This consists of five rectangular flat plates, having a combined useful surface area about 35% of the total positive surface. They are also of aluminum, but they do not have a film formed on them because their sole function is to provide contact with the condenser fluid. In an ammonium borate electrolyte, such as is used in these condensers, there are a number of other materials, including tin and carbon, which can be used for the negative electrodes.

In normal operation with aluminum negatives there is a tendency for a film to occur, even though the condenser is operated on direct-current circuits, because the negative electrode becomes an anode during the interval that the condenser discharges. This disadvantage in the use of aluminum is overcome by making this negative electrode of an aluminum alloy containing other substances such as silicon which impedes the formation of a film on its surface.

WET ELECTROLYTIC CONDENSERS IN RADIO RECEIVERS

The lack of space in a radio receiver dictates that any electrolytic condenser used shall be small in volume even when there is an advantage of increased capacitance over those of the paper type. There are special construction features concerned, but the preceding information on the wet type holds good for these smaller units used in receivers. Since their external appearance is quite similar to a number of other condensers of the dry electrolytic type shown in Figures 23 to 30 inclusive, no particular illustrations will be presented here. It must be remembered that the wet type of condenser requires a safety valve, usually in the form of a live rubber disc with a number of pin hole vents, permitting the escape of gas, but not of liquid.

THE DRY ELECTROLYTIC CONDENSER

In our everyday experience we have become more or less acquainted with the use of the words "wet" and "dry" to distinguish between the storage battery as used for automobiles (also radio tube filament supply) and the ordinary No. 6 primary cell used for door-bell and amateur telephone systems. We can realize that both are in fact wet, since each depends for its operation on the presence of a chemical solution.

In the field of electrolytic condensers we find the same general misuse of the words "wet" and "dry" as applied to two different mechanical forms of the same electric principle. We may say that both wet batteries and wet electrolytic condensers are wet because they employ a mass of liquid as the electrolyte, whereas in dry batteries and dry electrolytic condensers the liquid electrolyte is absorbed in a chemically inactive medium. They may be considered "dry" for all practical purposes since the electrolyte will not splash around or spill.

The comparison of course does not hold in the sense of the electrical work performed. It will be remembered that in a battery electrical energy is taken from the cell as the result of a chemical or voltaic action in the cell. In a condenser the only energy given up by the condenser on discharge is the energy put into the condenser when it is charged.

In order to inform you more completely on this subject we continue with a summary of various technical articles prepared by the Aerovox Wireless Corporation on their particular make known as the Hi-Farad Dry Electrolytic Condenser. The illustrations included here as Figures 20 to 30 inclusive are reprinted by their permission. Certain technical features are found only in that particular make, but are included here for their general interest.

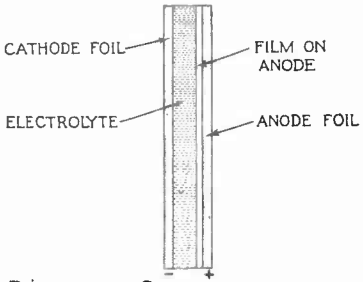


Fig. 20--Constructional detail of the Hi-Farad Dry Electrolytic Condenser

GENERAL

Essentially the Hi-Farad electrolytic condenser consists of:

1. The anode, an aluminum foil,
2. The film, formed electrochemically on the surface of the anode.
3. The electrolyte, which is the cathode proper,
4. Several layers of gauze saturated with the electrolyte, and
5. The second metallic electrode which forms the cathode terminal.

The relative disposition of these various parts is shown in Figure 20.

The foil used for anode and cathode is a particular alloy of aluminum which, in combination with a special electrolyte that does not attack aluminum, precludes any tendency for corrosion and facilitates the formation of a durable film on the anode.

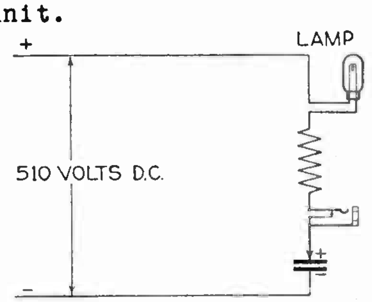
The gauze must also be devoid of any impurities which may affect the forming or the operation of the condenser. Two layers of gauze are placed between the foils. Not only do the two layers of gauze absorb the necessary amount of electrolyte, but the double layer minimizes the danger of breakdown in the case of severe overloads.

A stagger arrangement of the two foils is used for several reasons. In the first place the electrostatic field is most intense along the edges of the foil. Also the film cannot be formed on a sharp edge as effectively as it is formed on a smooth surface. The tendency for increased leakage currents and breakdown in the case of overloads is greatest along the edges, and these conditions are therefore taken care of by separating the edges by about ¼ inch.

The electrolyte ingredients are boric acid, glycerine and ammonia, either gaseous or as ammonia water. For producing the electrolyte the ingredients may be combined in the proportion of 1,000 grams of glycerine, 620 grams of boric acid and about 50 cubic centimeters of 26% ammonia water. With the use of this electrolyte, a condenser is formed in a relatively short time and it will, in use, withstand a voltage considerably in excess of 500 volts without breakdown.

WINDING THE CONDENSER

The condenser is made ready for winding by placing the gauze around the end of the cathode foil. The anode foil is then placed in position and the condenser wound up. The outer layer of foil which is the cathode affords quite complete effective electrostatic shielding and also aids in the dissipation of any heat generated within the unit.



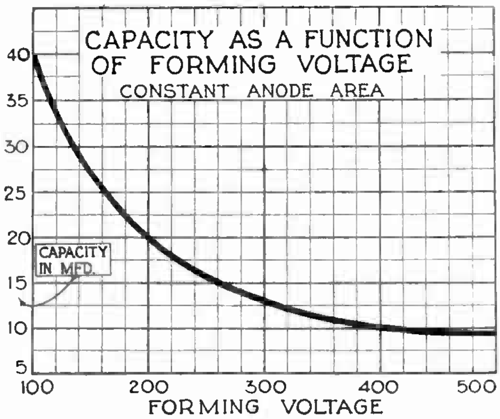


Fig. 21--Film Forming Circuit

Fig. 22--(Right) Capacity Graph

IMPREGNATION

After the condenser has been wound it is ready for impregnation in the electrolyte. As this is a liquid we can thoroughly and uniformly impregnate the sections by immersing them for a period of time in the hot electrolyte. The electrolyte has a relatively high specific resistance, but this does not appear as a disadvantage to the same extent as it would in a wet electrolytic condenser. The dry condenser has such a thin portion of electrolyte between the cathode and the film that the total series resistance is held to a comparatively low value.

FORMING

Before forming we have a unit consisting of two foils separated by two layers of gauze which is completely saturated with electrolyte. The next operation is the forming of the film on the anode. The condensers are formed at a d-c voltage somewhat in excess of that for which they will be rated to operate. Across the d-c supply there is placed in series a resistor, a small incandescent lamp and the condenser to be formed, as shown in Figure 21. Initially, that is before any film is formed, the current is limited almost entirely by the resistance of the resistor and the lamp. The lamp serves to visually indicate that the forming process is proceeding satisfactorily; it also indicates open circuits and high resistance contacts. Leakage currents are checked by means of a milliammeter inserted in series with the circuit. After removal from the forming bath the sections are individually tested for d-c leakage and capacity. They are then ready for final assembly.

The average capacity as a function of the forming voltage is shown in Figure 22.

ASSEMBLY

These condensers can be mounted in containers without any additional dipping or impregnating. Since there is no unabsorbed electrolyte they can be operated in any position and can be placed in either cardboard or metal containers.

Condensers to be mounted in cardboard containers are constructed in the same manner as for metal containers. The cardboard containers are thoroughly impregnated with wax of high melting point and the condensers with the contact tabs riveted to a fiber terminal are placed in the box. The unit is then sealed with an application of pitch over the end of the box.

When the condenser is to be mounted in a metal can the anode contact tab is secured to an aluminum stud projecting from a hard rubber cover. After the unit is mounted on the cover in this manner the section is wrapped in heavy waxed paper and assembled in the can. The grounding of the cathode tab to the can is then accomplished.

Fig. 23
Single Anode Unit
Large Size

Fig. 24
Double Anode Unit

Fig. 25
Triple Anode Unit

Fig. 26
Quadruple Anode Unit

TYPES OF CANNED CONDENSERS

In commercial practice from one to four condensers are included in a single protective can, and (in all cases of the Aerovox manufacture at least) every negative plate is connected to the can. The positive terminals are brought out to terminals on the insulating cover. Figures 23 to 26 inclusive show the external appearance of various types and sizes.

There are various methods of securing such condensers to the chassis of a radio set or other piece of apparatus where it is to be used. In Figures 27, 28 and 29 are shown several ways of mounting such condensers by means of a clamping ring. Figure 30 shows an ingenious method of securing a single-anode type condenser directly to the chassis. Through the chassis there is drilled a hole just large enough to provide clearance for the threaded section of the insulating cover. When the unit is mounted the edge of the can makes contact with the chassis, providing a negative contact thereto. The addition of a lock washer and nut to the threaded section projecting beyond the chassis makes a firm support for the condenser with the least trouble.

PAPER CONDENSERS

Practically every telephone in this country makes use of at least one condenser in which one or more thin sheets of paper act as the dielectric between two or more sheets of metallic foil. The same general type has also had a widespread use in radio receivers, particularly where low voltages are used, but an appreciable capacitance is required, as in by-passing radio frequency currents to prevent their wandering around into other circuits.

If a condenser were built up solely of tin foil and paper, the actual insulating material would be partly paper and partly air, since the paper itself includes air and in addition there are interstices between the layers of paper and foil which also contain air. The effective dielectric constant of the insulating medium of a wound paper condenser is small due to the large effect of air present. To raise this constant it has been customary to impregnate the condenser unit with a substance having a higher dielectric constant than air. Until recently paraffine has been used for this purpose.

How the mounting ring is used to mount a condenser upright above a subpanel.

Fig. 27

In this method of inverted mounting, the cover and terminals project through the bottom of the subpanel.

Fig. 28

Showing inverted mounting with terminals on bottom of subpanel with unit partly above and partly below the subpanel.

Fig. 29

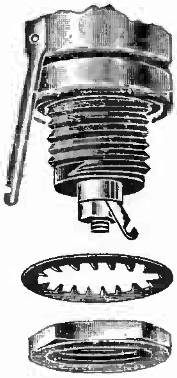

Mounting Method

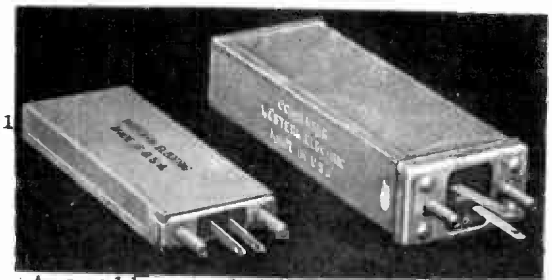
Fig. 30

Manufacturing methods in the past ten years have improved, and laboratory research has developed thin papers of high breakdown voltage, also improved impregnating compounds, particularly one called "halowax". We therefore find that very efficient and economical condensers using paper and foil are still in very good use in many of the radio and audio frequency communication systems. In Figure 31 is shown a comparison between the 1924 and 1932 models of a one mfd. condenser as used in the Bell Telephone System. The saving in space is obvious.

The actual winding process consists in rolling two sheets of tin foil and four sheets of paper so that the completed unit will have two layers of paper between adjacent layers of tin foil. After the winding operation the unit is pressed into compact shape, thoroughly dried in vacuum ovens, and then — while still in a high vacuum — is impregnated with the "halowax." Following this the unit is further pressed to the required size, which forces out all the excess wax, and soldering lugs are fastened to the metal contact strips that, at the beginning of the winding, were laid in contact with the sheets of tin foil. The unit is then ready for potting in the rectangular tin plate containers. Some manufacturers use small cardboard boxes instead of the metal. The containers are partially filled with a sealing compound which, when the condenser units are inserted, completely fills the container and seals the condenser against all entrance of moisture.

In Figure 32 is shown a view of the paper and foil sheets. Aluminum foil has come to replace the tin foil used in earlier condensers.

1932 Model



1924 Model

(Courtesy Bell Telephone Laboratories)

Fig.31--A smaller and better telephone condenser as a result of much research

AIR DIELECTRIC CONDENSERS

These are the simplest to understand, since they are merely a particular application of the fundamental principle that there exists a capacitance between any two conducting areas in air. A familiar type is the rotary variable condenser with which every one is fami-

Fig.32--Two sheets of paper between adjacent layers of aluminum foil form the elements of a telephone condenser

liar in the modern radio receivers and low-powered transmitters, an example of it being shown in Figure 33, the variation being by change in area.

An interesting example of condenser construction is that shown on the front cover, being a pair of tuning condensers for the tank circuit of a 50 k.w. radio transmitter. They are adjustable somewhat

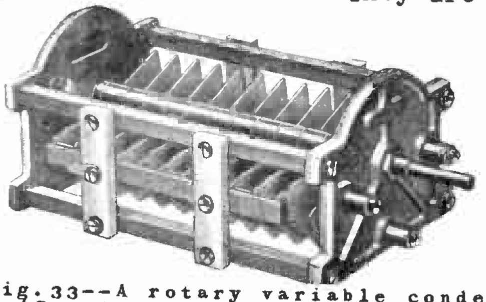


Fig.33--A rotary variable condenser (Courtesy Hammarlund Mfg. Co.)

roughly by loosening the clamps which hold the several plates fixed in position, and moving the individual plates toward or away from each other. In contrast with the preceding paragraph, this variation of capacitance is by change in the thickness of the dielectric. It is obvious that a variation of capacitance by area change could also be accomplished, by merely removing one or more plates from their supporting frame.

EXAMINATION QUESTIONS

1. What is a dielectric material?

2. Explain what happens when a condenser is placed in an A.C. circuit.

3. Describe a simple condenser.

4. What is capacitive reactance?

5. (a) Show by diagram how you would connect three condensers in series. (b) In parallel.

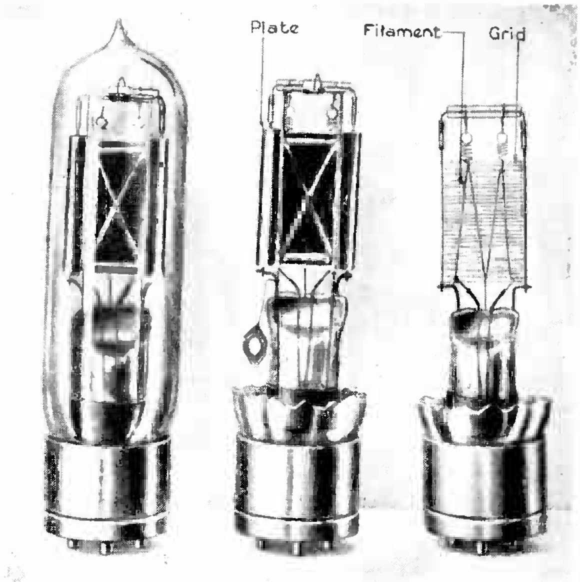
6. What is your understanding of the term "capacitance"?

7. When three condensers, each having a capacitance of .001 microfarads are connected in series what is the total capacitance?

8. Describe three types of condensers.

9. What is the action of a condenser when placed in D.C. circuit?

10. When four condensers, each having a capacitance of .002 microfarads are connected in parallel what is the total capacitance?



The closely-spaced metal elements of a vacuum tube provide capacitances which are of importance in amplifier design

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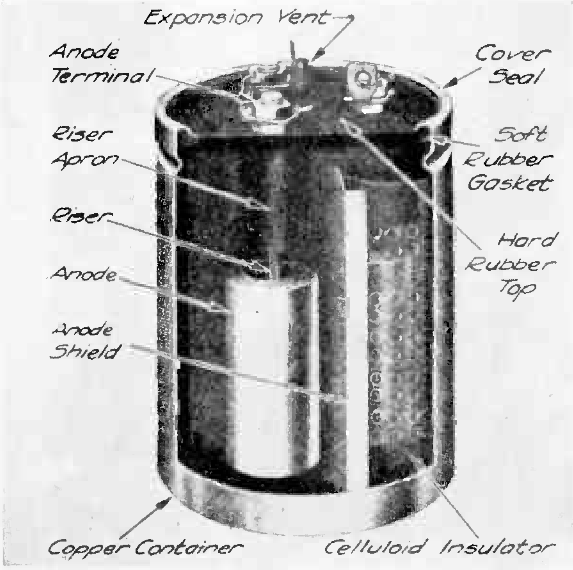

Interior Construction of
Amrad condenser

3212
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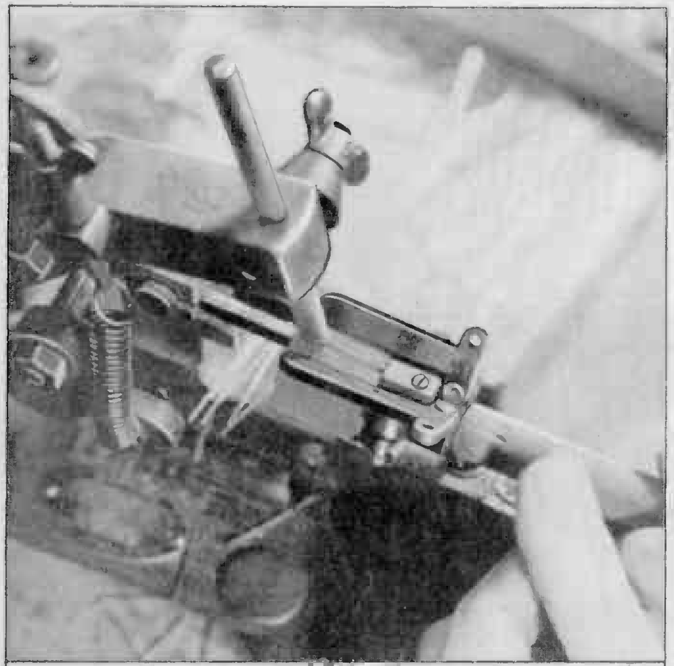
UNIVERSAL RACK FOR TESTING ALL TYPE RECEIVING TUBES UNDER VARIOUS VOLTAGE CONDITIONS

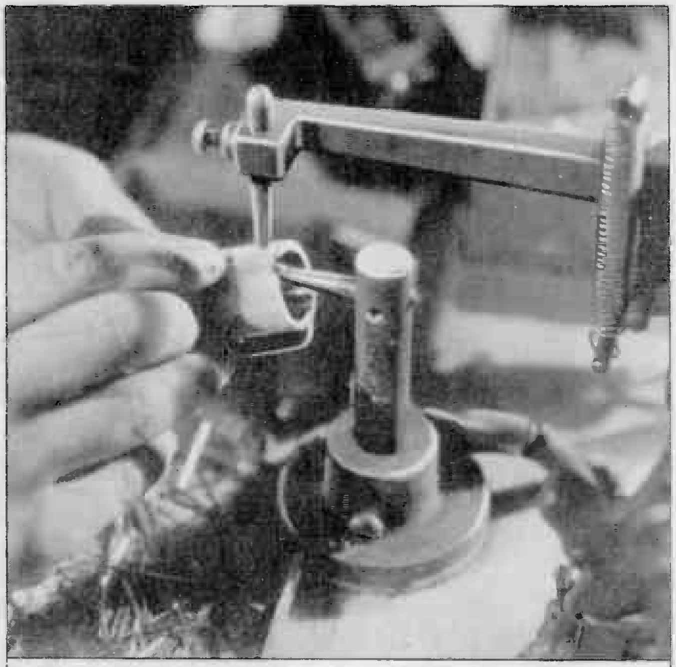
RECEIVING VACUUM TUBES

VOL. 13 # 1

DEWEY DECIMAL CLASSIFICATION R130

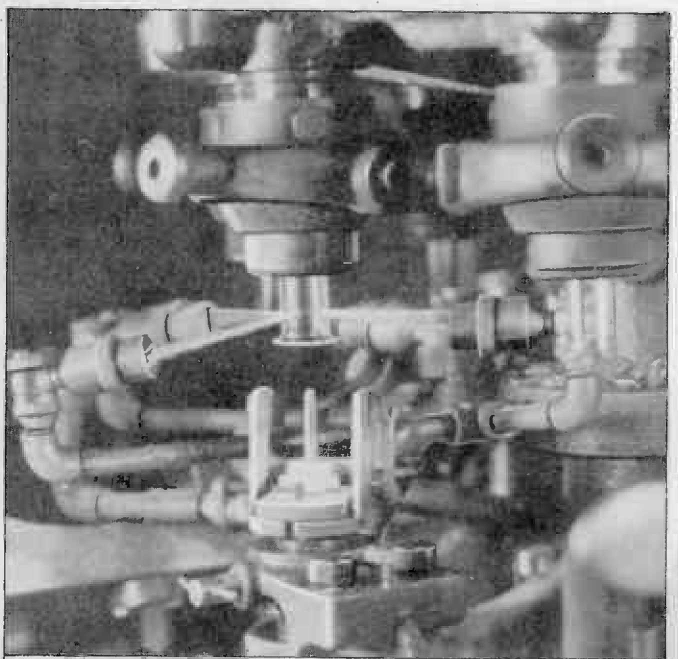


FORMING THE SCREEN BY ELECTRICAL WELD



IN SOME TUBES THERE ARE AS MANY AS 52 SPOT WELDS

THE STEM JUST AFTER THE MOLTEN GLASS HAS BEEN PINCHED TOGETHER, ENCASING THE LEAD-IN WIRES



AUTOMATIC, PRESSURE MEASURED GAS FLAMES HELP SHAPE THE FLARE OF THE GLASS STEM OF THE TUBE

HOME OFFICE : RCA INSTITUTES INC. 75 Varick Street, New York.

RECEIVING VACUUM TUBES

POWER OUTPUT PENTODE.....TYPE 247 FOR A-C SETS

Considerable interest exists at present in the pentode tube. The pentode, as its name implies, is a five-electrode tube. The outstanding characteristics of the tube are its high amplification factor, high internal resistance and high mutual conductance. These properties are obtained by the use of two electrodes or grids which are arranged in the tube as shown in Figure 1. In the illustration, the electrodes are identified as follows: F represents the filament; G1 is a conventional control grid; G2 is a grid or screen which is maintained at a high positive potential and serves to reduce the effects of "space charge" around the filament and to flatten out the plate current-plate voltage characteristics; and G3 is a grid or screen which is usually connected internally to the filament or cathode of the tube and is therefore maintained at essentially ground potential.

A very important function of grid G3 is to suppress or prevent the flow of electrons (liberated by secondary emission effects) from the plate P. The secondary emission is caused by the tremendous impact of electrons on the plate which liberates other electrons from the plate. These new secondary electrons would tend to move toward the screen grid because of its high positive potential were it not for the presence of the extra grid which is operated at the same potential as the filament and therefore does not exert an attraction for electrons. Hence, the secondary electrons return to the plate and together with the regular electrons that collect on the plate increase the flow of electrons in the plate circuit.

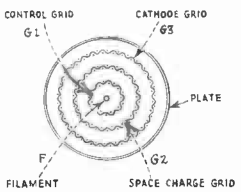


Figure 1

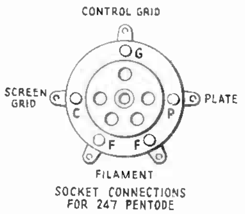


Figure 1-A

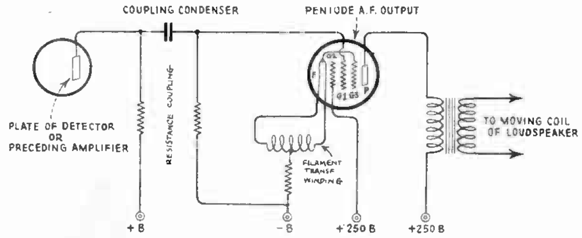


Figure 2

A schematic connection for the pentode tube is shown in Figure 2. A pentode is thus essentially a power amplifier tube having high mutual conductance and high "power sensitivity," that is, relatively small input voltage is required to control rather high power in its plate circuit. This tube employs a coated filament designed primarily for a-c operation. The filament should be operated at its normal rated voltage of 2.5 volts at the normal design line voltage. The socket required by the pentode is of the standard UY type and should be mounted to hold the tube in a vertical position. Grid bias for the 247 may be obtained either from a fixed voltage source or by automatic self-biasing from a resistor in the cathode circuit.

POWER OUTPUT PENTODE - TYPE 247

Tentative Rating and Characteristics

Filament Voltage	2.5	volts
Filament Current	1.5	amperes
Plate Voltage, Recommended	250	volts
Screen Voltage, Recommended and Maximum	250	volts
Grid Voltage	-16.5	volts
Plate Current	32	milliamperes
Screen Current	7.5	milliamperes
Plate Resistance	38,000	ohms
Mutual Conductance	2,500	micromhos
Load Resistance, Approximate	7,000	ohms
Power Output	2.5	watts
Base and Socket		UY

The pentode has possible applications (with different designs) in both the audio-frequency and radio-frequency amplifier circuits of broadcast receivers. When used as a radio-frequency amplifier the tube has the form of a screen-grid tube in which an additional grid is placed between the filament (cathode) and usual control grid. This additional grid serves to reduce the effects of "space charge" around the filament (cathode) and results in a tube having higher mutual conductance than screen-grid tubes now available. The theoretical advantage sought in tubes of this kind in the r-f stage of a receiver is that, because of their greater amplification factor, the total number of tubes used might be reduced. However, present broadcast conditions and selectivity requirements are such that a reduction in the number of tuned r-f stages is not permissible and therefore, if one tube is used per stage, as other practical considerations require be done, the total number of radio-frequency tubes cannot be reduced. Also, if too much amplification per stage is attempted it will likely result in a circuit whose operation is critical and unstable. The new 247 pentode has been developed for use as an audio-frequency output or last stage amplifier tube in a-c receivers designed for it. Due to its higher undistorted output (U.P.O.) this tube takes the place of the 245 in the latest model sets.

PENTODE FOR BATTERY-OPERATED RECEIVERS - TYPE 233

The power amplifier pentode, type 233, has been developed for use in the power output stage of battery-operated receivers designed especially for it. The filament employed in this new tube is of the coated type and its low filament current drain makes this tube particularly applicable for use in combination with the 230 and 232 when one or both of these types are incorporated in sets where economy of filament current is an important factor.

As in the case of other pentode tubes the large audio output of the 233 with relatively small input signal voltages on the grid is made possible by the addition of a "suppressor" grid between the screen and the plate.

POWER OUTPUT PENTODE - TYPE 233

Preliminary Ratings and Characteristics

Filament Voltage	2.0	volts
Filament Current	0.260	ampere
Plate Voltage	135	volts
Screen Voltage	135	volts
Grid Voltage	-13.5	volts
Plate Current	14	milliamperes
Screen Current	3	milliamperes
Plate Resistance	45,000	ohms
Mutual Conductance	1,400	micromhos
Amplification Factor	63	
Load Resistance	7,500	ohms
Undistorted Power Output	650	milliwatts
Base and Socket		UY

As we have already explained the suppressor is connected inside the tube to one end of the filament, and is effective in practically eliminating the secondary emission effects which limit the power output from four-electrode screen-grid type tubes.

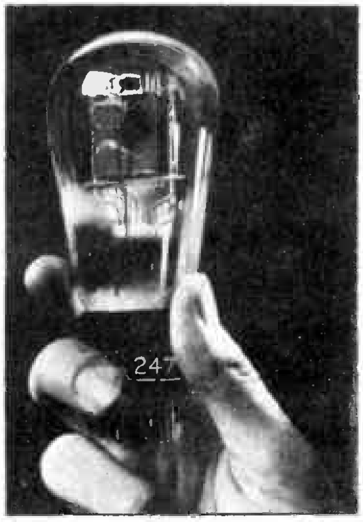


Figure 3

Figure 4

The tube illustrated in Figure 3 is the new 247 pentode which has been developed for use in the audio output stage of a-c receivers designed for it. The three tubes in the photograph in Figure 4 are the new series of indirectly heated cathode tubes designed especially for automobile receivers.

POWER AMPLIFIER TUBE - TYPE 171-A

The 171-A type vacuum tube is a power amplifier for supplying large undistorted power output to a loudspeaker. It is intended for use in the last stage of an audio-frequency amplifier. This tube is designed for use with the standard UX socket, which should be mounted so as to hold the tube in a vertical position. The socket should make firm contact on the filament prongs to minimize contact resistance. The socket connections are given in Figure 5.

The filament of the 171-A type may be operated from a storage battery or from the a-c line through a step-down transformer. In either case the voltage applied to the filament terminals should be the rated value of 5.0 volts. When operated at this voltage, the coated filament will glow at only a dull red color. If alternating current is used to operate the filament, the leads should be of twisted pair and should be kept away from other parts of the circuit where possible. It is recommended that the power be turned off before any tube is removed from the receiver so that excessive voltage will not be applied to the filaments, or heaters, of the remaining tubes.

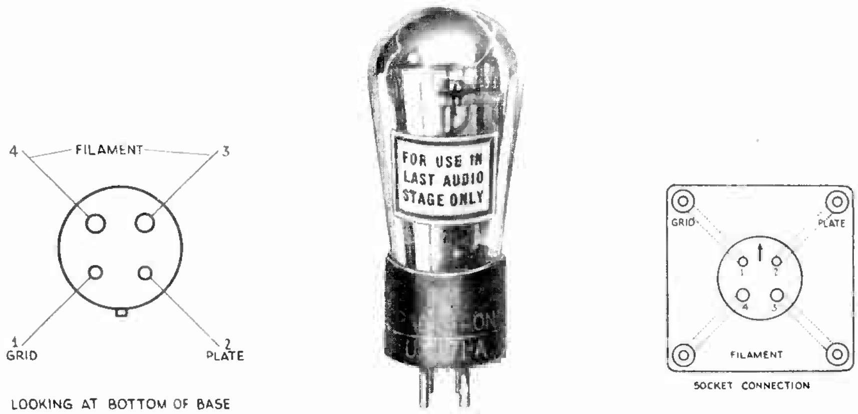


Figure 5

A-C LINE VOLTAGE. If the source of e.m.f. for operating the filament of the 171-A type is the a-c power line, precautions should be exercised to insure that the line voltage is the same as that for which the primary of the filament transformer is designed. To be sure that such is the case, the supply line voltage should be determined with a high grade a-c voltmeter having a range of 0 to 150 volts. If the line voltage measures in excess of that for which the transformer is designed, a series resistor should be inserted in the supply line to reduce the line voltage to the rated value of the transformer primary. Unless this is done, the excess input voltage will cause proportionately excessive voltage to be applied to the filament. Remember that any radio vacuum tube may be damaged or made inoperative by excessive operating voltage.

If the line voltage is consistently so much below that for which the primary of the transformer is designed as to make it impossible to ever obtain a filament voltage of 5.0 volts, it may be necessary to install a booster transformer between the a-c outlet and the transformer primary. Before such a transformer is installed, the a-c line fluctuations should be carefully measured. Many radio sets are equipped with a line voltage switch which permits adjustment of the power transformer primary to the line voltage. When this switch is properly adjusted, the series resistor or booster transformer mentioned above is seldom required.

CIRCUIT REQUIREMENTS. When the filament is operated from a d-c source, the grid and plate returns should be made to the negative filament terminal. When a-c is used on the filament, the plate and grid returns should be brought either to a mid-tapped resistor of from 20 to 40 ohms across the filament windings, or to the mid-tap of the filament winding itself.

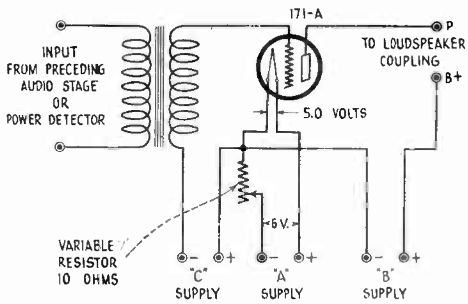


Figure 6

A negative grid bias, as shown in the table of "OPERATING VOLTAGES" on the following page, should always be used with this tube to prevent distortion and overloading. This bias may be obtained by means of a "C" battery or by means of the voltage drop through a resistor in the plate return lead, as shown in Figures 6 and 7 respectively. These diagrams show typical audio power amplifier circuits. The proper value of the resistor is 2150 ohms when 180 volts are used on the plate; 1700 ohms when 135 volts are used; and 1600 ohms when 90 volts are applied to the plate.

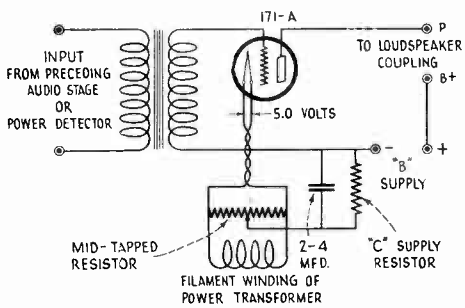


Figure 7

Either an output transformer or a choke coil and condenser should be used, as shown in Figure 8, to keep the high plate current of the 171-A from the windings of the loudspeaker driving unit.

Figure 8

In regard to the operating voltages and characteristics of this tube it can be said that the value of 180 volts with its corresponding grid voltage need be used only in cases where there is a sufficient signal to secure the full grid swing and where the maximum power of the tube is desired. Where maximum output is not essential, the use of either of the lower values of plate voltage with their respective grid bias voltages, is recommended. It should be noted that high plate voltage does not of itself produce appreciably greater volume. What it does is to allow the use of a larger negative grid bias and this in turn permits the application of a larger signal voltage to the grid. The combined result gives higher volume without distortion when the volume control of the receiver is advanced.

POWER AMPLIFIER TUBE - TYPE 171-A

Rating and Data

Filament Voltage			5.0	volts a-c or d-c
Filament Current			.25	amperes
Plate Voltage	90	135	180	volts maximum
Grid Voltage (C-Bias)*	19	29.5	43	volts
Peak Grid Swing	16.5	27	40.5	volts
Plate Current	12	17.5	20	milliamperes
Plate Resistance	2250	1960	1850	ohms
Amplification Factor	3	3	3	
Mutual Conductance	1350	1520	1620	micromhos
Undistorted Power Output	125	370	700	milliwatts
Approximate Direct Inter-Electrode Capacitances				
Grid to Plate			8.2	mmf.
Grid to Filament			4.5	mmf.
Plate to Filament			2.5	mmf.

*Values of grid voltage are given with respect to the mid-point of the filament operated on a-c. If the filament is d-c operated, each given value of grid voltage should be decreased by 2.5 volts and be referred to the negative end of the filament.

If it is desired to obtain, without an increase in plate voltage, more power output than one tube of this type will deliver then two tubes may be operated in parallel or in push-pull. The parallel connection permits increased power output without any increase in the signal applied to the power stage, while the push-pull connection for maximum power output requires that the input signal to the power stage be doubled, but it provides more freedom from distortion.

POWER AMPLIFIER - TYPE 245

The 245 vacuum tube is a power amplifier for supplying large undistorted output to a loudspeaker. It is intended for use in the last stage of an audio-frequency amplifier, in a socket whose filament voltage is 2.5 volts. It should be borne in mind that a 245 tube is not interchangeable with a 171-A tube or any other power amplifier tube.

The socket connections for this tube are like the standard UY socket. It is important to locate a tube of this kind in a set to allow sufficient natural circulation to prevent overheating. The filament may be operated from a storage battery or from the a-c line through a step-down transformer. In either case the voltage to the filament terminals should be the rated value of 2.5 volts. Concerning low resistance connections in the filament circuit splices and about turning the power off before any tube is removed to prevent excessive voltage from being applied to the filaments or heaters of the remaining tubes, the same conditions hold for the 245 as for the 226.

CIRCUIT REQUIREMENTS. To prevent distortion and overloading, negative grid bias as shown in the table of "OPERATING VOLTAGES," should always be used with this tube. It is strongly recommended that this bias be obtained by means of the voltage drop through a resistor in the plate return lead. See Figures 9 and 10 for the general arrangement of circuits utilizing a-c or d-c filament voltage supply.

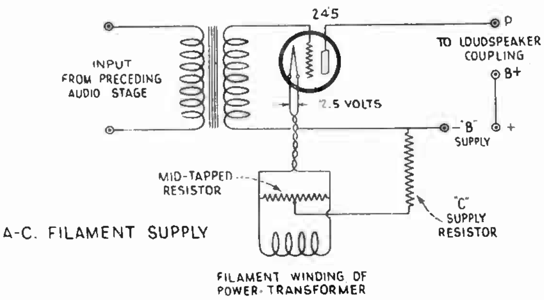


Figure 9

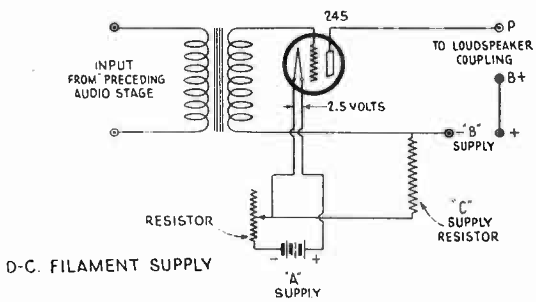


Figure 10

The proper value of a resistor in the plate return lead should be 1550 ohms when 250 volts are used on the plate, or 1350 ohms when 180 volts are used. This method of obtaining the bias must be used in any amplifier circuit where grid leaks are used. In such a circuit a grid leak having a resistance of greater than 1.0 megohm should not be used. When the filament is operated from a d-c source, the grid and plate returns should be made to the negative filament terminals. When a-c is used on the filament, the plate and grid returns should be brought to (1) a mid-tapped resistor of from 20 to 40 ohms across the filament windings, or (2) the mid-tap of the filament winding itself.

Either an output transformer or a choke coil and condenser should be used to keep the high plate current of the 245 from the windings of the loudspeaker driving unit. This was previously referred to in Figure 8.

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POWER AMPLIFIER - TYPE 245

Rating and Data

Filament Voltage		2.5	volts a-c or d-c
Filament Current		1.5	amperes
Plate Voltage	180	250	volts (maximum)
Grid Voltage (C-Bias)	-33	-50	volts
Peak Grid Swing	33	50	volts
Plate Current	26	32	milliamperes
Plate Resistance	1950	1900	ohms
Amplification Constant	3.5	3.5	
Mutual Conductance	1800	1850	micromhos
Undistorted Power Output	780	1600	milliwatts

If it is desired to obtain more power output than one 245 tube will deliver then two 245 tubes may be operated in parallel or push-pull. The parallel connection permits increased power output without any increase in the signal applied to the power stage, while the push-pull connection for maximum power output requires that the input signal to the power stage be doubled, as previously explained.

The value of 250 volts with its negative grid bias of 50 volts need be used only in those cases where there is a sufficient signal to secure the full grid swing and where the maximum power output of a 245 tube is desired. Where maximum output is not essential, the lower value of 180 volts with a negative grid bias of 33 volts, is recommended. As stated before, high plate voltage does not of itself produce appreciably greater volume but it allows the use of a larger negative grid bias and this in turn permits the application of a larger signal to the grid. Consequently, the combined result gives higher volume without distortion when the volume control of a given receiver is advanced.

SCREEN GRID R-F AMPLIFIER - TYPE 222

The 222 vacuum tube is a screen-grid amplifier recommended for use primarily as a radio-frequency amplifier in carefully shielded circuits especially designed for it. It may also be effectively used as a space-charge grid tube or as a double-grid tube in special circuits. This tube is designed for use with the standard UX socket, the socket connections being given in Figure 11. The connection for the control grid is made to the metal cap at the top of the tube.

The voltage applied to the filament terminals of the 222 should not exceed the rated value of 3.3 volts. It may be supplied by either dry-cells so connected as to give 4.5 volts or by a storage battery of 6 volts, depending upon whether 3.3 volt or 5.0 volt filament tubes are used in the other stages of the radio receivers.

When the 222 type is to be used in connection with storage battery tubes, for example tubes such as a 201-A, 112-A, and so on, then each 222 should have a 15 ohm resistor connected in series with its negative filament lead with the resistor tapped at 12 ohms. The resistor and filament may then be connected directly in parallel with the 5 volt filaments of the other tubes and operated from the same common rheostat. This connection is shown in Figure 12.

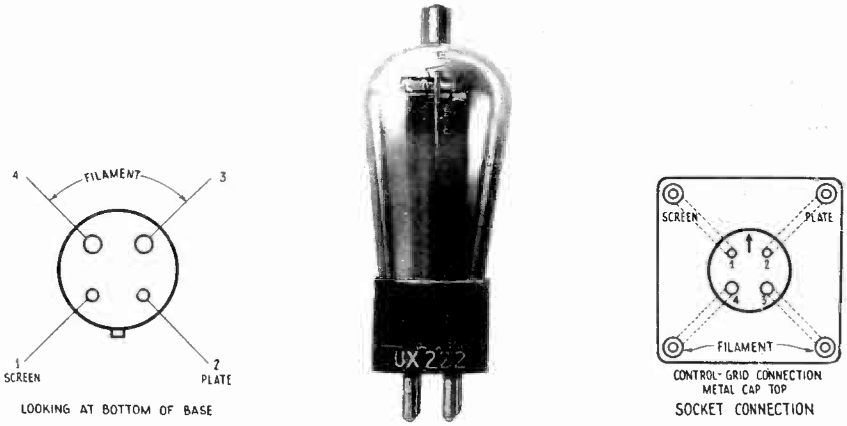

Figure 11

Or, if dry-cell tubes, such as a 199 and 120, are used the filament of the 222 may be connected directly in parallel with the filaments of the other tubes and operated from the same common rheostat. This arrangement is given in Figure 13. It is recommended that both the filament and plate voltage be disconnected before any tube is inserted in or removed from its socket as we suggested before.

HOW TO OBTAIN SCREEN VOLTAGE. The positive voltage for the screen should be obtained from a tap on the plate battery or from a tap so located on the B - supply device, such as a voltage divider for example, as to definitely give the required screen voltage. Never attempt to obtain the screen voltage by connecting the screen through a series resistor to a high plate voltage source, such as that of the power amplifier tube for instance. Such a series resistor connection will not in general be satisfactory for screen voltage supply because of the considerable variation in screen current of different tubes.

The screen voltage obtained from a definite voltage tap on the B - battery or the B - supply device may be made variable between 0 and 45 volts by the use of a potentiometer connected as shown in Figures 12 and 13 which are typical screen grid r-f amplifier circuits. As the voltage applied to the screen is reduced by adjustment of the potentiometer, the mutual conductance of the 222 tube is decreased with consequent reduction in volume. The potentiometer method, therefore, makes a suitable volume control for the receiver in which it is used.

It should be noted that when the potentiometer method of volume control is used with a "B" battery source of screen potential, precautions should be taken to provide for opening the screen grid circuit connection to the "B" battery when the radio set is not in use as indicated at X in Figure 13. If this precaution is not observed, current will continue to flow through the potentiometer and shorten the life of the battery.

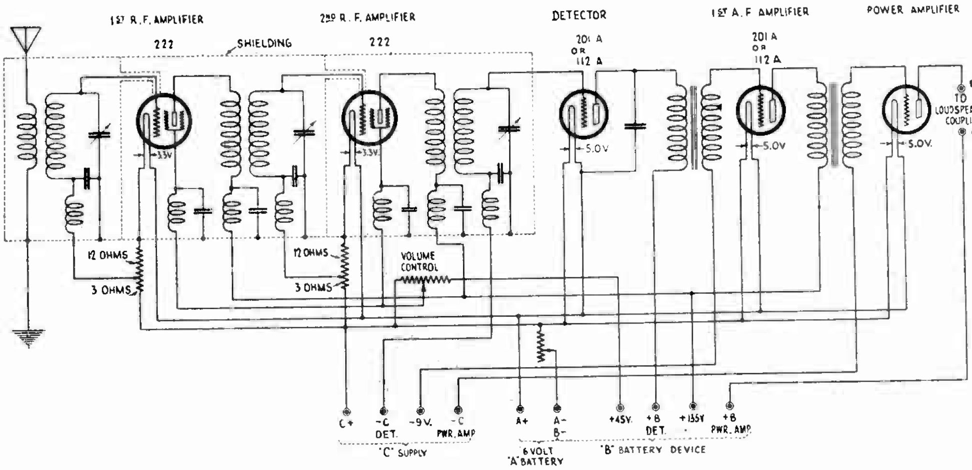

Figure 12

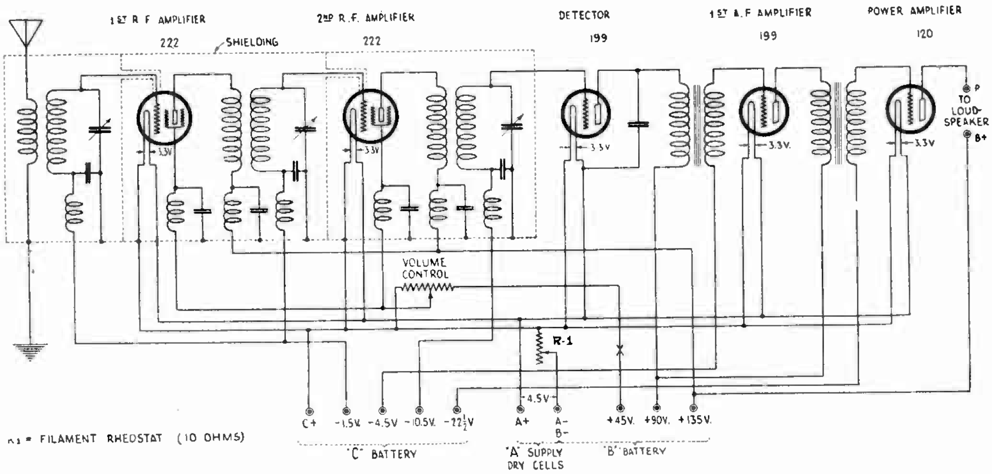

Figure 13

When the 222 type is used as a screen-grid radio-frequency amplifier, neutralization of the inter-electrode capacity between grid and plate to prevent feed-back through the tube is unnecessary because of the internal shielding by the screen. It is necessary, however, to take every precaution to avoid external coupling between the grid and plate circuit elements if stable operation of the 222 is to be obtained in circuits designed to give maximum gain per stage.

In multi-stage amplifier circuits, it is necessary to completely and effectively shield each stage, and to include within the stage

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shield all of the component parts of that stage. You can understand this arrangement by referring to Figures 12 and 13. Unless the coils and condensers of the various stages are shielded from each other, the amplification possibilities of the 222 cannot be fully realized.

If only a single 222 radio-frequency stage is used, it may not be necessary to shield this stage completely for reception of broadcast frequencies. Sufficient shielding will usually be obtained by placing the grid coil and condenser within a grounded metallic shield. In some cases it may be necessary to shield the 222 by a metallic jacket fitting closely over the tube and having an insulated opening at the top for the grid cap. The jacket should extend down at least to the base of the 222 and should be connected to either one of the filament terminals of the socket. The control grid lead should be kept as short as possible and should be spaced from other circuit elements.

The grid and plate circuit returns should be made to the negative filament terminal. The grid bias voltage of - 1.5 volts may be obtained from a "C" battery or from the drop in the 12 ohm portion of the tapped 15 ohm resistor which was previously mentioned. It should be noted that the tapped resistor method of obtaining the control-grid bias is usable only when the filament of the 222 is operated from a 6 volt "A" supply.

As a means of reducing coupling in the circuits external to the tube, the use of radio-frequency filters in all of the leads entering the stage shields as shown in Figures 12 and 13, is recommended. When filters are used the impedance of the circuit from screen to ground is kept as low as possible by the use of by-pass condensers.

In general, properly designed radio-frequency transformers are preferable to impedances for inter-stage coupling, and especially so in cases where a high impedance "B" supply device may cause oscillation below radio frequencies. If, however, impedance coupling is used between stages it is best to employ a blocking condenser having a capacitance of 0.00025 mfd. and a grid lead of from 2 to 5 megohms.

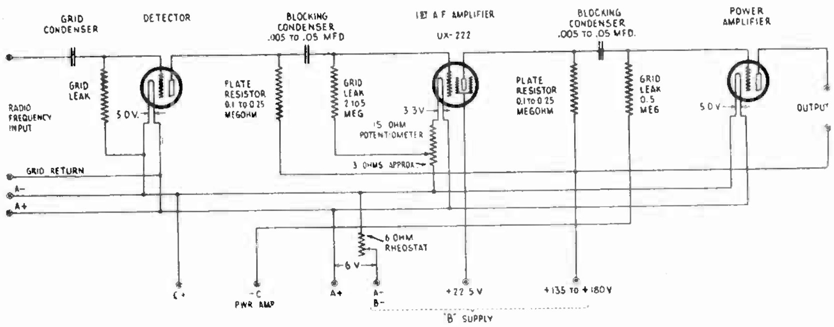

Figure 14

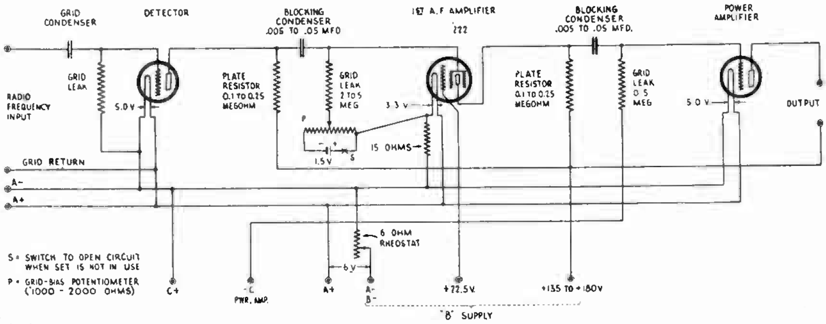

Figure 15

If the 222 type is to be operated as a screen-grid audio-frequency amplifier or as a space charge grid audio-frequency amplifier, resistance coupling should be used in its plate circuit. For either case, the value of the plate coupling resistor should be of the order of from 100,000 to 250,000 ohms. With the value of 250,000 ohms, a voltage amplification of 40 per stage should be obtained from either type of circuit. Suitable values of grid leaks and blocking condensers are shown in Figures 14 and 15. In Figure 14 you see a typical screen grid audio-amplifier circuit while Figure 15 gives a typical space charge grid audio-amplifier circuit.

SCREEN GRID R-F AMPLIFIER - TYPE 222

Rating and Data

Filament Voltage	3.3	volts
Filament Current	.132	ampere
Plate Voltage, Maximum and Recommended	135	volts
Grid Voltage (C-Bias)	-1.5	volts
Screen Voltage, Recommended	+45	volts
Plate Current	1.5	milliamperes
Screen Current	not over 1/3	of plate current
Plate Resistance	850,000	ohms
Amplification Factor	300	
Mutual Conductance	350	micromhos
Direct Inter-Electrode Capacitances		
Effective Grid-Plate	0.0025	mmf. maximum
Input	3.5	mmf. approx.
Output	12	mmf. approx.

In the following paragraphs we discuss about the special considerations concerning operating voltages and characteristics. When the 222 type is employed as a screen-grid radio-frequency amplifier, critical adjustment of the plate or screen voltage is not required. A plate voltage as low as 90 volts may be used but in special cases a screen voltage not exceeding 67.5 volts may be found desirable.

If the 222 is operated as a screen-grid audio-frequency amplifier, a plate supply voltage of from 135 to 180 volts applied through a plate coupling resistor of from 100,000 to 250,000 ohms is recommended. Under these conditions, the screen is operated preferably with + 22.5 volts, and the grid with from - .75 to - 1.5 volts. A

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higher value of screen voltage may be used but because of the greater voltage amplification obtained at the increased voltage, more critical circuit adjustment will be required.

When the 222 is connected as a space charge grid audio-frequency amplifier, the inner or control grid is operated at -22.5 volts to neutralize the electron space charge around the filament. The outer grid then becomes the control-grid and should be biased negatively by from 0 to - 1.5 volts depending upon the conditions of operation. For best results, the use of a variable control-grid bias potentiometer as shown in Figure 15, is recommended.

The screen-grid audio-frequency connection, in comparison with the space charge grid connection, will give somewhat lower maximum amplification but it will permit of better audio-frequency fidelity.

SCREEN GRID R-F AMPLIFIER.....A-C HEATER - TYPE 224

The 224 vacuum tube is a screen-grid amplifier containing a heater element which permits operation from alternating current. It is recommended for use primarily as a radio-frequency amplifier in carefully shielded circuits especially designed for it but it may also be effectively used as a space charge grid tube or as a double grid tube in special circuits as in the case of the 222 type which we just discussed.

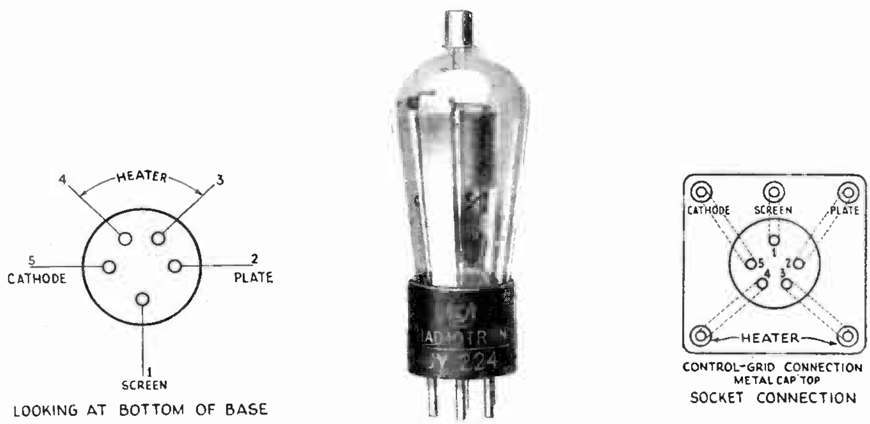

Figure 16

The five-prong base of the 224 type requires the standard UY socket. As with all types of tubes the socket should make firm, large surface contact on the prongs to minimize contact resistance. In Figure 16 we have drawn a sketch showing the socket connections for this tube and keep in mind that the connection for the control grid is made to the metal cap at the top of the tube.

THE HEATER CONNECTION. The heaters of the 224 tube should be connected in parallel, as shown in Figure 17. The transformer winding supplying the heaters should be designed to maintain 2.5 volts across the heaters of the total number of 224 tubes used in the receiver. Due to the high current and low voltage all connections in the heater circuit must be particularly low resistance and all heater circuit leads hould be of high current carrying capacity with all splices well soldered. The heater leads to the different tubes should be as nearly of equal length as is found practicable to make them and all leads carrying alternating current should be of twisted pair.

THE CATHODE CONNECTION. Connection of the cathode to the heater should be made (1) preferably to the movable arm of a potentiometer connected across the heater winding of the power transformer, or (2) to a mid-tapped resistor across the heater winding, or (3) to the mid-point of the heater winding itself. In some circuits, biasing of the heater negative with respect to the cathode by not more than 9 volts may be helpful in reducing hum.

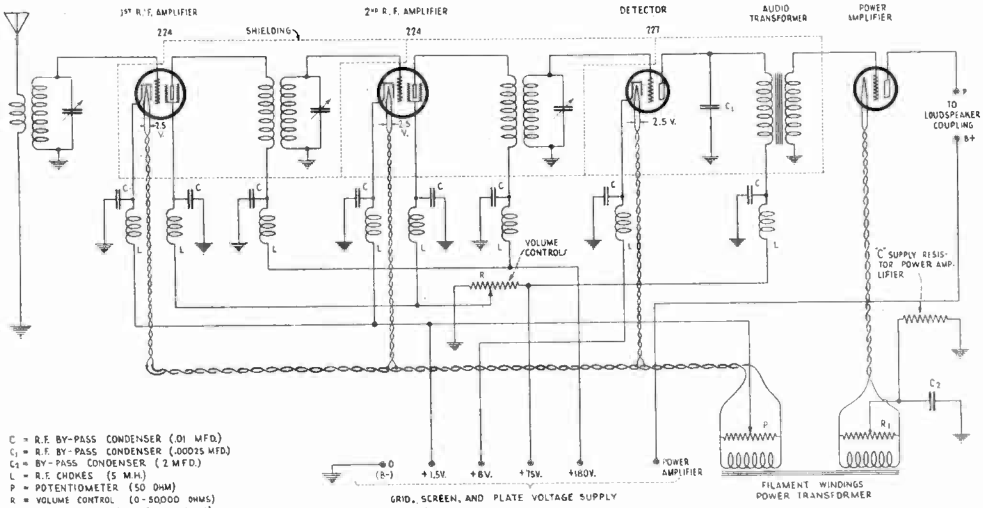

Figure 17

VOLTAGE FOR THE SCREEN GRID. The diagram in Figure 17 illustrates a typical a-c screen grid radio-frequency amplifier circuit. It shows how the screen voltage obtained from the definite voltage tap source may be made variable between 0 and 75 volts by the use of a potentiometer, R, marked "VOLUME CONTROL." Since the voltage applied to the screen is reduced by adjustment of the potentiometer, R, the mutual conductance therefore, of the 224 is decreased with consequent reduction in volume and this action makes a potentiometer a satisfactory volume control for the receiver.

A-C LINE VOLTAGE. The source of power for operating the heaters of the 224 tubes may be one of the secondary windings on the power transformer incorporated in the radio set, or it may be the secondary of a separate transformer. In either case, to obtain from the secondary a heater voltage of 2.5 volts, the transformer primary must be supplied with its rated voltage.

CIRCUIT REQUIREMENTS. When the 224 type is used as a screen-grid amplifier, neutralization of the inter-electrode capacity between grid and plate to prevent feed-back through the tube is unnecessary because of the internal shielding by the screen. It is necessary, however, to take every precaution to avoid external coupling between the grid and plate circuit elements if stable operation of the 224 is to be obtained in circuits designed to give maximum gain per stage.

SCREEN GRID R-F AMPLIFIER.....A-C HEATER - TYPE 224

Rating and Data

Heater Voltage	2.5	volts a-c or d-c
Heater Current	1.75	amperes
Plate Voltage, Maximum and Recommended	180	volts
Grid Voltage (C-Bias)	-1.5	volts
Screen Voltage, Maximum	+75	volts
Plate Current	4	milliamperes
Screen Current	not over 1/3	of plate current
Plate Resistance	400,000	ohms
Amplification Factor	420	
Mutual Conductance	1050	micromhos
Direct Inter-Electrode Capacitances		
Grid-Plate 0.01 mmf. maximum; Input 5 mmf. approx.; Output 10 mmf. approx.		

In multi-stage amplifier circuits, it is necessary to completely and effectively shield each stage, and to include within the stage shield all of the component parts of that stage, as you will understand by referring to Figure 17. Unless the coils and condensers of the various stages are shielded from each other, the amplification possibilities of any screen grid tube cannot be realized.

If the 224 type is to be used as a screen-grid detector for either grid leak detection or grid bias detection, the latter being called power detection, resistance coupling should be used in its plate circuit. A value of from 200,000 to 500,000 ohms is best suited for the plate coupling resistor. All of the voltages, except the 1.5 volts for the heater, may be supplied from taps on the same "B" supply device. Neither the plate nor the screen voltage is critical.

The volume of the receiver may be effectively controlled by means of a potentiometer connected as shown in Figure 17, this arrangement being similar to the connections shown in Figures 12 and 13 or by a variable grid resistor inserted in the cathode circuit through which the plate current must flow.

SCREEN GRID POWER DETECTOR. If the 224 type is used as a screen-grid detector, the grid bias method of detection is recommended because of its ability to handle large input voltages without overloading. For this method the following suitable operating values are suggested: a plate supply voltage of 200 volts applied through a plate coupling resistor of 250,000 ohms, a positive screen voltage of 45 volts, and a negative grid bias (approximately 5 volts) so adjusted that a plate current of 0.1 milliampere is obtained with no a-c input signal. Fig. 18 shows the principle of connecting a screen-grid power detector.

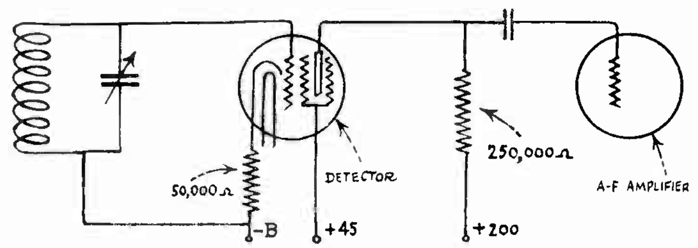

Figure 18

TYPES WD 11 AND WD 12 FOR USE WITH DRY CELLS.

These tubes are among the earliest types of dry cell tube and were designed to be used with one or more #6 dry cells in parallel for filament supply. The -11 type tube has a special arrangement of prongs and so requires a special socket whereas the -12 type was designed to be used in a regular UX type socket. The electrical characteristics of both tubes are the same, hence, in either case the oxide coated filament consumes a quarter of an ampere at 1.1 volts and the plate may be operated with from 40 to 90 volts. Each type is a general purpose tube and can be used either as an r-f or a-f amplifier, or detector.

TYPES WD-11 AND WD-12

Rating and Data

Filament Voltage			1.1	volts
Filament Current			0.25	ampere
Plate Voltage	90	67	45	volts
Grid Voltage (C-Bias)	-4.5	-3	-.5 to 1.5	volts
Amplification Factor			6.6	

For use as a detector the grid return should be connected to the positive side of the filament and for this specific use a 2 megohm grid leak and .00025 mfd. condenser are recommended with 22½ to 45 volts on the plate.

TYPE 199 GENERAL PURPOSE BATTERY-TYPE TUBE.

These tubes are also general purpose battery-type tubes being designed to give more economical battery consumption than the -11 or -12 type. They may be used either as amplifiers or detectors, when used as a detector the grid circuit return should be connected to positive filament and a 3 megohm grid leak and .00025 grid condenser are recommended. Due to the low interelectrode capacity these tubes make good r-f amplifiers and, also, they can be used in the a-f stages to operate small speakers. Care should be taken to use the proper negative bias on the grid of the 199 whenever it is used as an amplifier.

TYPE 199 TUBE

Rating and Data

Filament Voltage	3.3	volts
Filament Current	.063	ampere
Amplification Factor	6.6	
Plate Voltage	90	volts
Grid Voltage (C-Bias)	-4.5	volts

The filament is of the thoriated tungsten type which may be reactivated if desired. Since the normal consumption is .06 ampere at 3.3 volts only three dry cells are necessary to supply the filament current.

TYPE 120 AUDIO OUTPUT AMPLIFIER.

This tube is a power amplifier designed to be used in the last stage of a receiver employing 199 type tubes. It operates with the same filament voltage as the 199 but takes twice as much current to heat the filament.

TYPE 120 AUDIO OUTPUT AMPLIFIER

Rating and Data

Filament Voltage	3.3	volts
Filament Current	0.132	ampere
Amplification Factor	3.3	
Plate Voltage (max.)	135	volts
Grid Voltage (C-Bias)	-22.5	volts

As the characteristic charts indicate, the 120 requires higher plate voltage and greater bias than the 199 and gives more power output without distortion.

TYPE 201-A STORAGE BATTERY TUBE.

For many years the 201-A tube has been the standard general purpose battery type tube. It was at one time the most popular type tube used in radio receivers where the space occupied by the batteries was not of great importance. Although the battery consumption is quite low for a 201-A filament yet a storage battery is recommended instead of dry cells. The plate current is greater than for the 199 and, therefore, higher capacity "B" batteries are recommended.

The filament is of the thoriated tungsten type rated at 5 volts and 0.25 ampere. The UV-type base with short prongs was first used with this tube but now the base has been changed to fit a standard UX socket.

TYPE 201-A TUBE

Rating and Data

Filament Voltage			5	volts
Filament Current			0.25	ampere
Amplification Factor			8	
Plate Voltage	(max.) 135	(recommended)	90	volts
Grid Voltage (C-Bias	-9		-4.5	volts

Detector operation is not critical and, as in the case of other types of tubes just discussed, a 2 megohm grid leak and 0.00025 mfd. condenser are recommended. The tube also makes a good r-f and a-f amplifier and, as mentioned before for other tubes, care should be taken to use the proper C-bias.

TYPE 240 USED WITH RESISTANCE COUPLING.

This tube is designed primarily to be used as a detector or audio-frequency amplifier where resistance coupling is desired. It is similar in appearance to the 201-A but the grid and plate construction differs to secure higher amplification and the plate impedance is also much higher than that of the 201-A.

TYPE 240 TUBE

Rating and Data

Filament Voltage	5	volts
Filament Current	.25	ampere
Amplification Factor	30	

240 USED AS AMPLIFIER

Plate Voltage	135	volts (recommended)	180	volts (max.)
Grid Voltage (C-Bias)	-1.5	volts	-3.0	volts
Plate Coupling Resistance	250,000	ohms	250,000	ohms

240 USED AS DETECTOR

(Grid Leak Detection)

Plate Voltage	135 to 180	volts
Plate Coupling Resistance	250,000	ohms
Grid Leak	2 - 5	megohms

(Grid Bias Detection)

Plate Voltage	135	volts	180	volts
Plate Coupling Resistance	250,000	ohms	250,000	ohms
Grid Voltage (C-Bias)	-3	volts	-4.5	volts

The above chart gives the various ratings for the 240 when used either as an amplifier, or a grid-leak or grid-bias detector. As just stated, this tube may be used for either grid leak or grid bias detection, the first giving higher sensitivity and the latter freedom from distortion on high signal input voltages. When used in a resistance coupled audio amplifier the 240 gives quite uniform amplification from 30 to 10,000 cycles.

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TYPE 112-A AMPLIFIER.

This is an oxide coated storage battery tube, having a lower plate resistance than the 201-A. It may be used as a detector, r-f amplifier or a-f amplifier. For detector use it is recommended to use 45 volts on the plate, a 0.00025 mfd. grid condenser and a 2 to 3 megohm leak. Due to the difference in interelectrode capacity and plate resistance it may be difficult to control if used in a radio-frequency circuit but the low impedance, however, makes this tube most suitable for use in transformer coupled audio amplifiers. It also makes a good power amplifier having a greater output than the 201-A but less than the 171-A.

TYPE 112-A AMPLIFIER

Rating and Data

Filament Voltage			5	volts
Filament Current			.25	ampere
Amplification Factor			8.5	
Plate Voltage	135	volts (recommended)	180	volts (max.)
Grid Voltage	-9	volts	-13.5	volts

TYPE 250 POWER AMPLIFIER TUBE.

This tube is a heavy duty power amplifier intended for use in installations where more undistorted power output is required than for average home use. The 250 is larger in size than the 210 and requires greater bias for the same plate voltage. For this reason it cannot be used in a set formerly using a 210 unless the set is changed to increase the bias. When this is done it will give a greater power output than the 210. This tube has an oxide coated filament rated at 7.5 volts, 1.25 amperes and draws higher plate current and has lower impedance than the 210.

TYPE 250 AMPLIFIER

Rating and Data

Filament Voltage				7.5	volts
Filament Current				1.25	amperes
Amplification Factor				3.8	
Plate Voltage	250	350	400	450	volts
Grid Voltage (C-Bias)	-45	-63	-70	-84	volts
Power Output (milliwatts)	1000	2400	3400	4600	milliwatts

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TYPES 236, 237 and 238 DESIGNED FOR AUTOMOBILE RADIO RECEIVERS

This group of three tubes consists of a screen-grid tube, a general purpose tube and a power output pentode. All three are of the high vacuum type and employ coated cathodes indirectly heated. The cathodes, which are the same for all three types, have been carefully designed to insure uniform heating over as wide a range of heater voltages as possible in order that the tubes will perform satisfactorily under the normal voltage variation of automobile batteries during charge and discharge. This feature together with that of the general freedom from microphonic and battery circuit disturbances of the heater-cathode type, make these new tubes particularly suited for use in automobile receivers.

The 236 Screen-Grid tube is particularly recommended for operation as a radio-frequency amplifier in circuits especially designed for it. It may be employed also as a screen-grid detector.

The 237 general purpose tube is useful either as detector, amplifier or oscillator.

The 238 power amplifier pentode has been designed to give good output volume consistent with the relatively low voltage and limited capacity of the plate supply battery.

The 236 and 237 will also be found especially adaptable to the design of radio receivers for operation from the d-c power line. In such service the heaters of these two types may be connected in series to operate at 0.3 ampere. This is made possible by the uniform heating of the cathode over a wide voltage range to offset normal line voltage variation.

TYPE 236 FOR AUTOMOBILE SETS

This screen-grid tube may be used as either a radio-frequency amplifier, a detector or an intermediate-frequency amplifier in circuits especially designed for it. The 236 employs a coated cathode of the semi-quick-heater type designed for d-c operation only. Owing to the special cathode design, the heater voltage may range between 5.5 and 8.5 volts during the charge and discharge cycles of the battery without appreciably affecting the performance or serviceability of this tube. No resistor in the heater circuit is required for this type operated from a 6-volt battery.

The socket required by the 236 is of the standard UY type and may be mounted to hold the tube in either a vertical or horizontal position. Socket connections are the same as for a UY-224.

Stable operation of the 236 in radio-frequency circuits designed to give maximum gain per stage requires separation of the input and output circuit elements. In general, with multi-stage amplifier circuits, it is necessary to use complete stage shielding enclosing all the components of each stage. Unless this is done, the amplification possibilities of the 236 will not be realized. The use of radio-frequency filters in all leads entering the stage shields is advised to reduce

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coupling in external parts of the circuit. In regard to heater to cathode bias it should not exceed 45 volts.

Since the screen current of individual tubes is subject to variation, the use of a resistance in series with the plate voltage source for the screen voltage supply will result in poor regulation and uncertain operating screen voltages. It is recommended therefore, that the screen voltage be obtained from either a tap on the plate battery, or from a potentiometer or bleeder circuit which maintains the screen voltage approximately constant at the recommended value. If a bleeder circuit or potentiometer is used, its electrical design should be such as to provide adequate screen voltage regulation; otherwise, the effect will be essentially the same as that of a series resistor with resultant poor regulation. The volume of the receiver should be controlled preferably by varying the grid voltage. The control adjustment should be such as to impress not less than - 1.5 volts on the grid when recommended voltages are applied to the screen. The use of some device for reducing the signal input to the first radio-frequency tube will be necessary where strong local signals will cause high values of peak grid voltage.

TYPE 236 FOR AUTOMOBILE SETS

Rating and Data

Heater Voltage			6.3	volts d-c
Heater Current			0.3	ampere
Plate Voltage	90**	135	135*	volts
Screen Voltage	55**	67.5	75*	volts
Grid Voltage	-1.5**	-1.5	-1.5*	volts
Plate Current	1.8	3	3.5	milliamperes
Screen Current		not over 1/3	of plate	current
Plate Resistance	200,000	300,000	250,000	ohms
Amplification Factor	170	315	275	
Mutual Conductance	850	1050	1100	micromhos

The 236 may be employed as a screen-grid detector of either the grid-bias or grid-leak type. For both of these connections resistance coupling may be used with a plate coupling resistor. An equivalent reactor may be substituted for the plate resistor where greater output from low percentage modulated signals is desired. For most sensitive detection with resistance coupling, it will be necessary to reduce the screen voltage to from 20 to 45 volts. For plate detection the bias may be secured either from a fixed voltage source or by automatic biasing from a resistor in the cathode circuit.

TYPE 237 FOR AUTOMOBILE SETS

This three-electrode tube may be used in circuits of conventional design as either an amplifier, a detector or an oscillator. The tube employs a coated cathode of the semi-quick-heater type designed for d-c operation only. Owing to the special cathode design, the heater voltage may range between 5.5 and 8.5 volts during the charge and discharge cycles of the battery without appreciably affecting the performance of serviceability of this tube.

TYPE 237 FOR AUTOMOBILE SETS

Rating and Data

Heater Voltage		6.3 volts d-c
Heater Current		0.3 ampere
Plate Voltage	90**	135* volts
Grid Voltage	-6**	-9 volts
Plate Current	2.7	4.5 milliamperes
Plate Resistance	11,500	10,000 ohms
Amplification Factor	9	9
Mutual Conductance	780	900 micromhos
Load Resistance***	14,000	12,500 ohms
Undistorted Power Output	30	75 milliwatts
Approximate Inter-Electrode Capacitances		
Grid to Plate	2.0 mmf.	
Grid to Cathode	3.3 mmf.	
Plate to Cathode	2.3 mmf.	
Base		small UY
Socket		UY

***Optimum load resistance for maximum undistorted power output as given.
*Recommended values for use in automobile receivers.
**Recommended values for use in receivers designed for 110 volt d-c operation.

In detector service, the 237 may be used either with grid lead and grid condenser or with grid bias. If grid leak detection is used, a condenser of 0.00025 mfd. and a grid leak of from 1 to 5 megohms will give excellent sensitivity. However, more stable operation and better quality will be obtained by using a low value of grid leak. For plate detection the bias may be secured either from a fixed voltage source or by automatic biasing from a resistor in the cathode circuit. The heater to cathode bias should not exceed 45 volts as in the case of type 236, and the socket connections are the same as for a UY-227.

TYPE 238 - POWER PENTODE FOR AUTOMOBILE SETS

The 238 is a screen-grid tube designed primarily for giving large audio power output for relatively small signal voltages impressed on the grid. This is made possible by the addition of a "suppressor" grid between the screen and the plate. The suppressor is connected inside the tube to the cathode and is therefore operated at the same potential as the cathode. When connected and operated in this manner, the suppressor is effective in practically eliminating the secondary emission effects which limit the power output from four-electrode screen-grid types.

Other considerations already mentioned in regard to the special types of automobile tubes are that the heater to cathode bias should not exceed 45 volts and the grid bias for the 238 may be obtained either from a fixed voltage source or by automatic self-biasing from a resistor in the cathode circuit. Also, this tube employs a coated cathode of the semi-quick-heater type designed for d-c operation only and owing to the special cathode design, the heater voltage may range between 5.5 and 8.5 volts during the charge and discharge cycles or the battery without appreciably affecting the performance or serviceability of this tube.

TYPE 238 - POWER PENTODE FOR AUTOMOBILE SETS

Rating and Data

Heater Voltage	6.3	volts
Heater Current	0.3	ampere
Plate Voltage, Recommended	135	volts
Screen Voltage, Recommended	135	volts
Grid Voltage	-13.5	volts
Plate Current	8	milliamperes
Screen Current	2.5	milliamperes
Plate Resistance	110,000	ohms
Amplification Factor	100	
Mutual Conductance	900	micromhos
Load Resistance	15,000	ohms
Undistorted Power Output	375	milliwatts
Base	small	UY
Socket		UY

THE 2-VOLT TYPE TUBES FOR BATTERY OPERATION

2-VOLT TUBE - DETECTOR AND AMPLIFIER - TYPE 230

The 230 is a new general purpose tube of the three electrode, high vacuum type. It employs a strong metallic filament coated with alkaline earth compounds. The filament has been designed to take as little power as possible consistent with satisfactory operating performance. This new tube, therefore, is particularly suited for use either as a detector or amplifier in radio receivers operating from dry-cells or from a storage battery where economy of filament current drain is important.

This 2 volt tube should be mounted in a vertical position and its socket and connections are the same as for the 199 tube. It should be mentioned that although the 230 is very free from microphonic disturbances, cushioning of its socket may be desirable.

The coated filament of the 230 should be operated at its rated value of 2.0 volts. This voltage may be supplied from dry-cells or from a single cell storage battery, but in either case an adjustable filament rheostat must be used together with a permanently installed indicating instrument to secure the proper filament voltage. This instrument should be either a voltmeter to indicate the terminal e.m.f. or a milliammeter to indicate the current drain. This requirement is applicable to all of the three types of 2 volt tubes, namely, the 230, 231 and 232 tubes. Bear in mind that fixed filament resistors will not give sufficient regulation to permit of satisfactory performance.

When this tube is used as a detector with a grid condenser and leak, the 230 tube should preferably be operated with a plate voltage of not more than 45 volts. The grid condenser and leak may be of usual sizes. However, as an amplifier, the 230 should always be used with a negative grid bias and for a plate voltage of 90 volts, it is best to use a grid bias of 4.5 volts.

2-VOLT TUBE - DETECTOR AND AMPLIFIER - TYPE 230

Rating and Data

Filament Voltage	2.0	volts
Filament Current	0.06	amperes
Plate Voltage (Maximum)	90	volts
Grid Voltage (C-Bias)	-4.5	volts
Plate Current	2.0	milliamperes
Plate Resistance	12,500	ohms
Amplification Factor	8.8	
Mutual Conductance	700	micromhos

Further, let us advise you that the 230 tube cannot be substituted for the 199 tube in radio sets designed for the latter, without circuit modifications. Suitable precautions must be taken to limit the filament voltage to 2.0 volts. In addition, the filament circuit must be altered to conform to the requirements of this new tube. If these tubes are used in tuned radio-frequency receivers not especially designed for them it may be necessary to readjust the neutralizing condensers or grid resistors before stable operation is obtained.

2-VOLT TUBE - POWER AMPLIFIER - TYPE 231

The 231 type tube is a new power amplifier tube of the three electrode, high vacuum type. It employs a strong metallic filament of the coated type which has been designed to take as little power as possible consistent with satisfactory operating performance. This new 231 tube, therefore, is particularly suited for use as the power output tube in radio receivers which operate with 230 or 232 type tubes. Both of the latter type may be used in the same receiver in conjunction with the 231, hence, all three types of the new 2 volt tubes may be employed in a single receiver.

2-VOLT TUBE - POWER AMPLIFIER - TYPE 231

Rating and Data

Filament Voltage	2.0	volts
Filament Current	0.130	ampere
Plate Voltage, Maximum and Recommended	135	volts
Grid Voltage (C-Bias)	-22.5	volts
Plate Current	8	milliamperes
Plate Resistance	4,000	ohms
Amplification Factor	3.5	
Mutual Conductance	875	micromhos
Undistorted Power Output	170	milliwatts

The 231 should be mounted in a vertical position and is to be used with a socket having connections the same as for the 199 or 120. It has been found that provision for cushioned sockets to prevent microphonic disturbances will not usually be necessary when this tube feeds directly into the loudspeaker.

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The recommended and maximum plate voltage for the 231 tube is 135 volts while the corresponding grid bias is - 22.5 volts. Under these operating conditions the plate current, which is 8 ma., is not high enough to require the use of a loudspeaker coupling device.

The 231 tube cannot be substituted for the 120 tube unless the filament circuit is altered to conform to the requirements of this new power output tube since the filament voltage must be limited to 2.0 volts.

2-VOLT TUBE - SCREEN GRID R-F AMPLIFIER - TYPE 232

The 232 type tube is a new screen grid tube recommended for use primarily as a radio-frequency amplifier. It employs a strong metallic filament of the coated type, which has been designed to take as little power as possible consistent with satisfactory operating performance. This new tube, therefore, is particularly useful in the radio-frequency stages of specially designed radio receivers operating from dry cells or from a storage battery where economy of filament current drain is important. The control grid is electrostatically shielded from the plate by means of an extra grid placed between plate and control grid and operated at a suitable positive potential. The resultant reduction in plate to control-grid capacity makes high voltage amplification per stage practical without external capacity neutralization circuits. This isolation of plate and grid results in a small change of plate current with a change of plate potential. The plate resistance, therefore, is high and averages about 800,000 ohms.

2-VOLT TUBE - SCREEN GRID R-F AMPLIFIER - TYPE 232

Rating and Data

Filament Voltage	2.0	volts
Filament Current	0.06	ampere
Plate Voltage, Maximum and Recommended	135	volts
Grid Voltage (C-Bias)	-3	volts
Screen Voltage, Maximum	67.5	volts
Plate Current	1.5	milliamperes
Screen Current	not over 1/3	of plate current
Plate Resistance	800,000	ohms
Amplification Factor	440	
Mutual Conductance	550	micromhos
Effective Grid-Plate Capacitances	0.02	mmf. maximum

The 232 tube should be mounted in a vertical position. The socket connections for the 232 are the same as for the 222 type tube. Although the 232 is very free from microphonic disturbances, cushioning of its socket may be desirable.

The connection for the control grid is made to the metal cap at the top of the glass envelope as is the usual procedure after placing screen-grid type tubes in their sockets.

The positive voltage for the screen should be obtained from a tap on the plate battery and, therefore, never attempt to obtain the screen voltage by connecting the screen through a series resistor to a high

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plate voltage source. Such a series resistor connection will not in general be satisfactory for screen voltage supply because of the uncertain drop produced by the considerable differences in screen currents of individual tubes.

Stable operation of the 232 tube in circuits designed to give maximum gain per stage requires separation of the input and output circuit elements. In general, it is necessary to use complete stage shielding including all the components of each stage. The use of filters in all leads entering the stage shields is advisable to reduce coupling in external parts of the circuit.

It is recommended that the operating voltage be applied to the 232 tube as follows: maximum plate voltage to be 135 volts with all corresponding negative grid bias of 3 volts, and a maximum positive screen voltage of 67.5 volts. You will find when using tubes of this type that neither plate nor screen voltage is critical. The control-grid bias for this tube when working on B-battery operated receivers should be obtained from a C-battery. The 232 tube cannot be substituted for the 222 tube in circuits designed for the latter, without circuit modifications, that is, the filament and grid circuits must be altered to conform to the requirements of this new screen-grid tube.

VARIABLE MU TUBE - TYPE 235

This most recent screen-grid tube has been developed primarily for use in radio-frequency and intermediate-frequency amplifier stages. It is effective in reducing cross-modulation, and modulation distortion over the entire range of received signals. Furthermore, its design is such as to permit easy control of a large range of signal voltages without the use of local-distant switches or antenna potentiometers. This feature makes the tube adaptable to automatic volume control design.

VARIABLE MU TUBE - TYPE 235

Tentative Rating and Normal Characteristics

Filament Voltage	2.5	volts
Filament Current	1.75	amperes
Plate Voltage, Recommended	180	volts
Screen Voltage, Recommended	75	volts
Grid Voltage	— 1.5	volts
Plate Current	9	milliamperes
Screen Current	not over 1/3	of plate current
Plate Resistance	200,000	ohms (approx.)
Mutual Conductance	1,100	micromhos
Approximate Inter-Electrode Capacitances		
Grid to Plate	.010	mmf. maximum
Input	5	mmf.
Output	10	mmf.
Base and Socket		UY

The 235 employs a cathode of the quick-heater type. Its heater should be operated at its normal rated voltage of 2.5 volts at the normal design line voltage. It is interesting to note that a recent survey of

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normal socket voltage conditions over the United States has established that 113 volts represents average operating conditions.

This tube has a very long characteristic curve that gradually drops off which indicates that very strong grid biases can be applied to the grid before the plate current reaches zero. In effect the signal voltage resulting from the oscillating current in the antenna system picks out the part of the characteristic curve of the tube it chooses to work upon, this being determined by the carrier voltage of this signal. A strong local signal may place a bias on the grid as low as 30 or more volts, whereas the desired signal which is much weaker in intensity may be working around a point which may be only a few volts or even tenths of volts negative. This tube's long characteristic curve is due to the special design of the tube elements which are made in different forms. For instance, the grid may be tilted, or the spacing between the wires may be greater at one part of the grid structure than at another, or the diameter may be non-uniform, that is, wide at one place and narrow at another and so on. Observe that curves A and B in Figure 19 illustrate the idea of how a variable mu tube combines the features of both a low-mu and high-mu tube which permits this tube to work over a wide range of input signal voltages. Curve A is the characteristic for a low-mu tube and curve B is the characteristic for a high-mu tube while the long curve drawn in solid line illustrates the combined characteristics. The various arrangements of tube structure cause a different, or variable mu-factor in operation for electrons emitted from the various elements of the cathode. When the grid bias is low, or near zero, the electron flow is such that current flows from all of these elements but as the grid bias becomes more negative the current from the elements having the higher mu-factors is cut off gradually at a certain rate.

The cathode should be connected directly to the center-point of the heater circuit. If this arrangement is not practical in some receiver designs, the heater may be made negative with respect to the cathode by a potential difference not exceeding 45 volts.

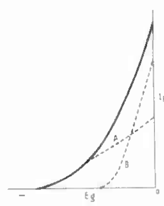

Figure 19

Since the screen current of individual tubes is subject to considerable variation, the use of resistance in series with a high voltage source for the screen voltage supply will result in poor regulation and uncertain operating screen voltages. It is recommended, therefore, that the screen voltage be obtained from a potentiometer or from a bleeder circuit which maintains the screen voltage approximately constant at 75 volts. The electrical design of the potentiometer or bleeder should be such as to draw several times the maximum screen current; otherwise, the effect will be essentially the same as that of a series resistor with resultant poor regulation. Radio-frequency choke filters for screen voltage supply are preferred, due to their low d-c resistance which insures satisfactory screen voltage regulation.

Since the variation in plate current over the operating range of this tube is about 9 milliamperes, the maximum current drain of several tubes may cause a large shift in power pack output voltage. It is, therefore, recommended that the screen voltage be adjusted to average 75 volts between the two extremes of the volume control setting.

Variation of the negative voltage applied to the grid will be found effective in changing the volume of the receiver. In order to utilize the full volume control range of this tube, an available grid bias voltage of approximately 75 volts will be required. This voltage should preferably be obtained from a potentiometer or bleeder circuit. If, however, the receiver is designed so that the required volume control can be obtained without exceeding 45 volts, the cathode resistor method of obtaining the grid bias control voltage is permissible.

The illustration below in Figure 20 shows a diagrammatic circuit for Super-Control R-F Amplifier RCA-235 and Power Amplifier Pentode RCA-247.

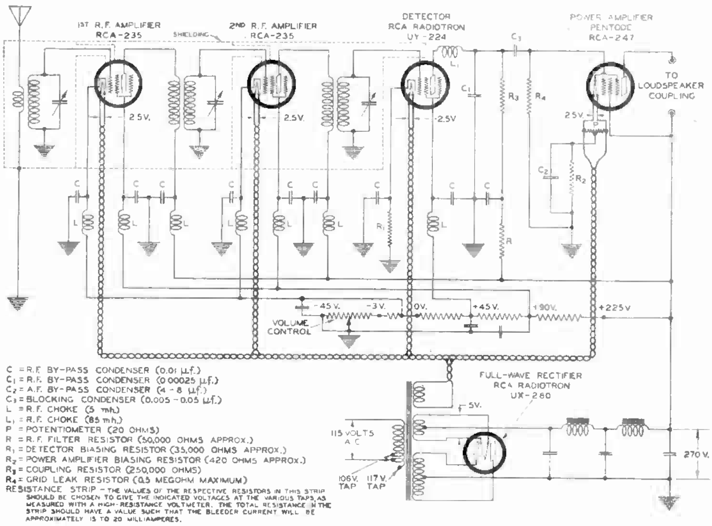

Figure 20

EXAMINATION QUESTIONS (V-13 #1.)

1. Explain the principle on which a pentode tube functions.
2. Calculate the "C" bias resistor for the 245 tube used in Figure 9 with 250 volts plate supply.
3. (a) Under what conditions would you use a 171-A tube with 90 volts applied to the plate and (b) with 180 volts applied?
4. How is screen grid voltage best obtained and how controlled?
5. What is the difference between space charge and screen grid connections?
6. Refer to Question 5. Which makes the better audio amplifier and why?
7. What advantage does the screen-grid type tube have over the 3-element tube as an r-f amplifier?
8. (a) Show by diagram how you would connect a loudspeaker to a 171-A tube, (b) to a 245 tube, and (c) Explain why for each case.
9. A 224 tube used as a detector has 200 volts applied to its plate thru a coupling resistor of 250,000 ohms. Assuming the plate current to be .1 milliampere what voltage is actually impressed on the tube?
10. Give the advantages of the type 235 tube over the type 224 tube.

AVERAGE CHARACTERISTICS CHART

DETECTORS AND AMPLIFIERS

GENERAL								DETECTION			AMPLIFICATION									
Type	Use	Base	Max. Overall Dimensions		Filament Supply	Filament Terminal Volts	Filament Current Amperes	Plate Supply Volts	Plate Current Milliamp.	Grid Return Lead To	Plate Supply Volts	Grid Bias Voltage		Plate Current Milli-amp.	Screen Grid Volts	A. C. Plate Resistance Ohms	Mutual Conductance Micromhos	Voltage Amplification Factor	Ohms Load for Maximum Undistorted Output	Maximum Undistorted Output Milli-watts
			Height	Diam.								D. C. on Fil.	A. C. on Fil.							
WD-11	Detector or Amplifier	WD-11	4 1/8″	1 3/16″	D. C.	1.1	0.25	45	1.5	+F	90 135	4.5 10.5	— —	2.5 3.0	— —	15500 15000	425 440	6.6 6.6	15500 18000	7 35
WX-12	Detector or Amplifier	UX	4 11/16″	1 7/16″	D.C.	1.1	0.25	45	1.5	+F	90 135	4.5 10.5	— —	2.5 3.5	— —	15500 15000	425 440	6.6 6.6	15500 18000	7 35
UX-112-A	Detector or Amplifier	UX	4 11/16″	1 13/16″	D. C.	5.0	0.25	45	4.0	+F	90 135	4.5 9.0	— —	5.2 6.2	— —	5600 5300	1500 1600	8.5 8.5	5600 8700	30 120
UV-199	Detector or Amplifier	UV-199	3 1/2″	1 1/16″	D. C.	3.3	0.063	45	1.0	+F	90	4.5	—	2.5	—	15500	425	6.6	15500	7
UX-199	Detector or Amplifier	Small UX	4 1/8″	1 3/16″	D. C.	3.3	0.063	45	1.0	+F	90	4.5	—	2.5	—	15500	425	6.6	15500	7
UX-200-A	Detector	UX	4 11/16″	1 13/16″	D. C.	5.0	0.25	45	1.5	−F	Following UX-200-A Characteristics Apply Only for Detector Connection					30000	666	20	—	—
UX-201-A	Detector or Amplifier	UX	4 11/16″	1 13/16″	D. C.	5.0	0.25	45	1.5	+F	90 135	4.5 9.0	— —	2.5 3.0	— —	11000 10000	725 800	8.0 8.0	11000 20000	15 55
UX-222	Radio Freq. Amplifier	UX	5 3/8″	1 13/16″	D. C.	3.3	0.132	—	—	—	135 135	1.5 1.5	— —	1.5 3.3	45 67.5	850000 600000	350 480	300 290	— —	— —
UX-222	Audio Freq. Amplifier	UX	5 3/8″	1 13/16″	D. C.	3.3	0.132	—	—	—	180†	1.5	—	0.3	22.5	2000000	175	350	—	—
UY-224	R. F. Amp. or Detector	UY	5 1/4″	1 13/16″	A. C. or D. C.	2.5	1.75	Refer to Technical Bulletin		Cath.	180 180	1.5 3.0	1.5 3.0	4.0 4.0	75 90	400000 400000	1050 1000	420 400	— —	— —
UY-224	Audio Freq. Amplifier	UY	5 1/4″	1 13/16″	A. C. or D. C.	2.5	1.75	—	—	—	250‡	1.0	1.0	0.5	25	2000000	500	1000	—	—
UX-226	Amplifier	UX	4 11/16″	1 13/16″	A. C. or D. C.	1.5	1.05	—	—	—	90 135 180	5.0 8.0 12.5	6.0 9.0 13.5	3.8 6.3 7.4	— — —	8600 7200 7000	955 1135 1170	8.2 8.2 8.2	9800 8800 10500	30 80 180
UY-227	Detector or Amplifier	UY	4 11/16″	1 13/16″	A. C. or D. C.	2.5	1.75	45	3.5	Cath.	90 135 180	6.0 9.0 13.5	6.0 9.0 13.5	2.7 4.5 5.0	— — —	11000 9000 9000	820 1000 1000	9.0 9.0 9.0	14000 13000 18700	30 80 165
RCA-230	Detector or Amplifier	Small UX	4 1/4″	1 3/16″	D. C.	2.0	0.06	45	1.0	+F	90	4.5	—	2.0	—	12500	700	8.8	—	—
RCA-232	Radio Freq. Amplifier	UX	5 1/4″	1 13/16″	D. C.	2.0	0.06	—	—	—	135	3.0	—	1.5	67.5	800000	550	440	—	—
UX-240	Detector or Amplifier	UX	4 11/16″	1 13/16″	D. C.	5.0	0.25	135† 180†	0.3 0.4	+F	135† 180†	1.5 3.0	— —	0.2 0.2	— —	150000 150000	200 200	30 30	— —	— —

*For Grid-Bias Detection, refer to Technical Bulletins. †Applied through plate coupling resistor of 250000 ohms. ‡Applied through plate coupling resistor of 200000 ohms.

POWER AMPLIFIERS

Type	Use	Base	Height	Diam.	Filament Supply	Filament Terminal Volts	Filament Current Amperes	Plate Supply Volts	Plate Current Milliamp.	Grid Return Lead To	Plate Supply Volts	Grid Bias D. C. on Fil.	Grid Bias A. C. on Fil.	Plate Current Milli-amp.	Screen Grid Volts	A. C. Plate Resistance Ohms	Mutual Conductance Micromhos	Voltage Amplification Factor	Ohms Load for Maximum Undistorted Output	Maximum Undistorted Output Milli-watts
UX-112-A	Power Amplifier	UX	4 11/16″	1 13/16″	D. C. or A. C.	5.0	0.25	—	—	—	135 180	9.0 13.5	11.5 15.0	6.2 7.6	— —	5300 5000	1600 1700	8.5 8.5	8700 10800	120 260
UX-120	Power Amplifier	Small UX	4 1/8″	1 3/16″	D. C.	3.3	0.132	—	—	—	135	22.5	—	6.5	—	6300	525	3.3	6500	110
UX-171-A	Power Amplifier	UX	4 11/16″	1 13/16″	A. C. or D. C.	5.0	0.25	—	—	—	90 135 180	16.5 27.0 40.5	19.0 29.5 43.0	12.0 17.5 20.0	— — —	2250 1960 1850	1330 1520 1620	3.0 3.0 3.0	3200 3500 5350	125 370 700
UX-210	Power Amplifier	UX	5 5/8″	2 3/16″	A. C. or D. C.	7.5	1.25	—	—	—	250 350 425	18.0 27.0 35.0	22.0 31.0 39.0	10.0 16.0 18.0	— — —	6000 5150 5000	1330 1550 1600	8.0 8.0 8.0	13000 11000 10000	400 900 1600
RCA-231	Power Amplifier	Small UX	4 1/4″	1 3/16″	D. C.	2.0	0.130	—	—	—	135	22.5	—	8.0	—	4000	875	3.5	—	170
UX-245	Power Amplifier	UX	5 5/8″	2 3/16″	A. C. or D. C.	2.5	1.5	—	—	—	180 250	33.0 48.5	34.5 50.0	25.0 34.0	— —	1900 1750	1850 2000	3.5 3.5	3500 3900	780 1600
UX-250	Power Amplifier	UX	6 1/4″	2 11/16″	A. C. or D. C.	7.5	1.25	—	—	—	250 350 400 450	41.0 59.0 66.0 80.0	45.0 63.0 70.0 84.0	28.0 45.0 55.0 55.0	— — — —	2100 1900 1800 1800	1800 2000 2100 2100	3.8 3.8 3.8 3.8	4300 4100 3670 4350	1000 2400 3400 4600

RECTIFIERS

Type	Use	Base	Height	Diam.	Filament Supply	Filament Terminal Volts	Filament Current Amperes	Ratings	Remarks
UX-280	Full-Wave Rectifier	UX	5 5/8″	2 3/16″	A. C.	5.0	2.0	1 { A. C. Voltage per Plate (Volts RMS) .... 350; D. C. Output Current (Maximum MA.) .... 125 } 2 { A. C. Voltage per Plate (Maximum Volts RMS.) .... 400; D. C. Output Current (Maximum MA.) .... 110 }	For D. C. Output Voltage delivered to filter of typical rectifier circuits, refer to Technical Bulletin.
UX-281	Half-Wave Rectifier	UX	6 1/4″	2 7/16″	A. C.	7.5	1.25	A. C. Plate Voltage (Maximum Volts RMS.) .... 700 D. C. Output Current (Maximum MA.) 85	For D. C. Output Voltage delivered to filter of typical rectifier circuits, refer to Technical Bulletin.

SPECIAL PURPOSE

Type	Use	Base	Height	Diam.	Description	Ratings
UX-874	Voltage Regulator	UX	5 5/8″	2 3/16″	Designed to keep output voltage of B-Eliminators constant when different values of "B" current are supplied.	Operating Voltage .... 90 Volts D. C. Starting Voltage .... 125 Volts D. C. Operating Current .... 10-50 Milliamperes
UV-876	Current Regulator (Ballast Tube)	Mogul	8″	2 1/16″	Designed to insure constant input to power operated radio receivers despite fluctuations in line voltage.	Operating Current .... 1.7 Amperes Voltage Range .... 40-60 Volts
UV-886	Current Regulator (Ballast Tube)	Mogul	8″	2 1/16″	Designed to insure constant input to power operated radio receivers despite fluctuations in line voltage.	Operating Current .... 2.05 Amperes Voltage Range .... 40-60 Volts

FOR AMATEUR AND EXPERIMENTAL TRANSMITTING USE

Type	Use	Base	Maximum Overall Dimensions		Filament Terminal Volts	Filament Current Amperes	Voltage Amp. Factor	Normal Plate Volts	Approx Grid Bias Volts	Approx. Screen Volts	Maximum Plate Current Amperes	Maximum Plate Dissipation Watts	Normal Power Output Watts
			Height	Width									
UX-852	Oscillator or R. F. Amplifier	UX	8 3/4″	6 1/8″	10.0	3.25	12	2000	250	—	0.10	100	75
UX-865	Oscillator or R. F. Amplifier	UX	6 1/4″	2 3/16″	7.5	2.0	150	500	75	125	0.06	15	7.5
UX-866	Half-Wave Rectifier	UX	6 3/8″	2 7/16″	2.5	5.0	Maximum Peak Inverse Voltage .... 5000 Volts Maximum Peak Plate Current .... 0.6 Ampere Approximate Tube Voltage Drop .... 15 Volts						

THE CATHODES ARE CAREFULLY SPRAYED TO GIVE THEM A UNIFORM COATING OF THE ELECTRON EMITTING MATERIAL

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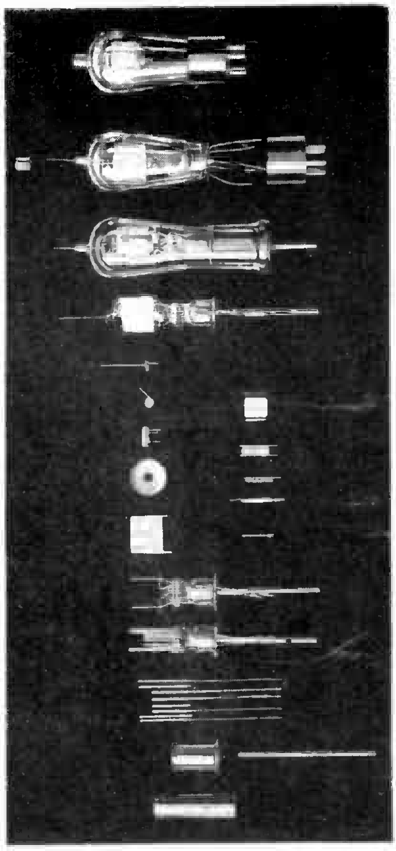
Heater-Cathode Vacuum Tube

VACUUM TUBE THEORY

VOL. 13#3



Parts Assembly of the '24-A Type Tube

VACUUM TUBE THEORY

We now come to the study of the Vacuum Tube, a device which is the very heart of the radio receiver. The student will, at this point, have to give his undivided attention to that which follows and proceed with an open mind and active imagination. In order to understand the action of the vacuum tube we should review the action of the electron in a vacuum. To imagine an electron is one thing, but to follow the actions of electrons is quite another. The study of the electron theory as applied to the vacuum tube is comparatively easy if the student will concentrate, otherwise it is a difficult study and only results in a state of confusion. It is intensely interesting and, when understood, gives a clear idea of the relation between radio circuits and vacuum tubes.

The vacuum tube is not confined to radio alone; it is used in any number of other scientific fields, especially those in which high frequency rays are involved.

Let us consider for the time being that in the vacuum tube we have a device which will not only rectify an alternating current but will also reproduce, in amplified form, the most feeble variations of E.M.F. applied to it regardless of the frequency.

The tube may be employed as a rectifier of alternating currents of any frequency. The term rectifier is sometimes used to indicate the detector action.

It is termed a radio frequency amplifier when it is used to amplify the high frequency currents induced in the antenna by the incoming signal wave.

Further, the tube is used to amplify the output currents of the detector and when so used it is known as an audio frequency amplifier.

When used as a generator of high frequency undamped oscillations in an oscillatory circuit it is called an oscillator.

Before these various functions can be explained it is necessary to have a knowledge of the characteristics of the vacuum tube and to what extent these characteristics can be controlled. Until recent years no satisfactory explanation was offered concerning many phases of electrical phenomena known to science. As the application of electricity developed, however, there was a great amount of data secured which enabled scientists to formulate some of the laws governing the flow of electricity. For example, the relation between electromotive force, current, and resistance was explained by Dr. Ohm and put into the form of a law, the law being known universally as Ohm's Law.

Discoveries were also made regarding the generation of electrical pressure by chemical action between certain liquids and metals. This led to the development of the battery, and then came the evolution of the dynamo. No satisfactory explanation was offered at the time concerning the electrical phenomena of these discoveries yet they were of great practical value in determining from the results obtained, experimentally, many of the present laws of electricity. It also became necessary to settle upon certain arbitrary standard units by which electrical force and energy could be measured and computed, these being known as Universal Electrical Units which were explained in a previous lesson.

It was also found necessary to assume a certain direction in which electricity flowed through a conductor. Scientists decided to call the copper or carbon plate of a primary cell the positive terminal, and the zinc plate the negative terminal, and considered that electricity flowed in an external circuit from the positive electrode to the negative electrode. It must be understood that this direction given to the current flow was entirely an arbitrary one and was agreed upon only as a matter of convenience in understanding certain phenomena.

For many years the atom was regarded as the smallest unit into which matter could be divided and still retain its chemical and physical properties and the phenomenon was then explained by the atomic theory. In recent years many scientists have accepted the general belief that the atom is itself subdivided into many thousands of particles termed electrons and that these electrons carry with them a charge of electricity. It has been found that under certain conditions these electrons or particles of negative electricity can be made to move. Their movement is from a negative to a positive electrode and when in motion they constitute a current flow. This new theory is known as the "Electron theory of matter".

THERMIONIC CURRENTS

Thermionic current is the name given to electricity which is the result of electrons thrown off or emitted from hot bodies. A discovery made by Thomas A. Edison in 1884, known as "The Edison Effect", gave rise to an investigation of thermionic currents which leads up to the vacuum tube of today. Edison, in his work with the electric lamp, found that after a lamp had been in use some time a dark coating formed on the inside of the lamp, becoming in some instances nearly black with long continual use. He became interested in this effect and further research brought out the fact that when a metal plate was placed inside the lamp and connected to one side of a sensitive galvanometer and the other terminal of the galvanometer then connected to the positive terminal of the battery supplying current to the filament of the lamp, the galvanometer would show a deflection when the filament of the lamp was heated.

The effect at the time seemed to indicate that an electric current flowed from the positive side of the filament through the galvanometer to the plate inside the lamp, through the vacuum of the lamp, returning to the filament. Edison also discovered that, when the galvanometer terminal was removed from the positive side of the filament and connected to the negative side, practically no deflection of the galvanometer followed. After the discovery of this phenomenon experiments were carried out by several scientists. J. A Fleming, after considerable experimenting and research on the Edison effect, came to the conclusion that NEGATIVE electricity passed from the filament of the lamp to the plate when the plate was relatively cold with respect to the filament and the plate was charged to a positive potential.

Conclusions of the experiments of J.J. Thompson led to the belief that what is now called the electron existed and that negative electricity consisted of masses of these electrons which were forced away from the filament of an electric lamp when the filament was brought to incandescence. In other words the filament itself consisted of these infinitely small particles called electrons. It has now been generally accepted that it is by means of the electron that electricity is carried through a conductor or through a vacuum.

There are always large numbers of electrons in an atom and normally this quantity amounts to a given number just sufficient to neutralize the effect of the positive nucleus. Generally but one electron can be detached from an atom even though it may have a great many associate electrons. Under normal conditions the atom possesses no electrical charge because a perfect state of neutralization exists between the positive charge and the electrons. When, however, one of the free electrons is forced away by some cause or other this perfect balance is destroyed and the atom predominates in positive charge because it is now deficient in its complement of electrons.

ELECTRON EMISSION

The emission of electrons is dependent upon the temperature of the filament, the size (area) of the filament, the nature of the substance employed as the filament, and the medium in which the filament is heated. The number of electrons emitted will be proportional to the area of the filament. For example, if you have two filament lengths, one twice as long as the other, by heating one filament to a given temperature a certain electron emission occurs. With the same heat applied to the filament of twice the length, double the emission occurs. This happens however only when the same heat is applied to both filaments.

The temperature of the filament is very important in that, with each increase of filament heat, there will be an increase in electron emission. This increase in electron emission increases as the temperature increases until the maximum emission takes place which is just below the melting point of the filament. Heating the filament to excessive temperature is of no advantage as you will later learn.

The composition of the filament, that is, the material employed in its manufacture, will have a bearing upon the electron emission. Some metals, when heated, do not emit as many electrons as others. Carbon, for example will emit a certain quantity of electrons but not nearly in as large quantities as tungsten. Tungsten is materially helped in electronic emission when another metal called thorium is combined with it. It is the Thoriated Tungsten filament that is used in many types of tubes because at low temperatures it has a very high rate of electron emission.

There is still another factor which has a great influence on electron emission and that is the medium in which the emission occurs. In the first place it must be in a vacuum, or at least a partial one. It is quite impossible to obtain a complete vacuum and small traces of gas left in the tube will decrease the electron emission. Most of the gases in the tube, with few exceptions, are inert gases. The presence of gas in the vacuum presents a resistance to the emission of electrons unless ionization takes place. (This particular subject will be taken up later in more detail).

The most important factor in the rate of emission is the temperature of the filament for, upon the rate of emission alone in a certain tube, will depend the number of electrons emitted. It must be understood at this point that the term "Emission" refers only to the emerging of the electrons from the filament and not to the passage of the electron through the vacuum.

Suppose now we attempt to visualize that which takes place in the filament when it is heated. As heat is applied the whole atomic structure is set into a violent agitation and the free electrons about the atoms of the filament are set into rapid vibration. With each increase of heat this vibration increases and the electrons finally gain a velocity in their movements great enough to carry them beyond the positive force of the atom which normally holds them within the filament. As this velocity is attained they emerge from the filament in clouds much as does steam from a pan of boiling water. This happens only after they have acquired a speed which is able to project them beyond the influence of the atom to which they belong.

Once beyond the attractive force of the parent atom they are subject to collisions which are continually occuring as they move about in the filament. Their velocity, on leaving the filament, varies according to the retarding effect these collisions have had upon the electron in its attempt to escape. Once outside the filament they again have difficulty due to the gas molecules which may be present within the vacuum, and with which they continually collide until their energy is exhausted whereupon they are drawn back to the filament.

SPACE CHARGE

The electron constitutes a negative charge of electricity and, on emerging from the filament, leaves the filament positive in respect to the projected electron. The tendency, therefore, is for the electron to be attracted back to the filament. Any gas in the vacuum also presents a resistance to be overcome by the electron. There is also another repelling effect which must be overcome. This is the repelling effect of electrons which are moving at a greater distance from the filament than the newly emitted electrons.

As stated before, the electrons fill the space about the heated filament much as steam fills the space over a pan of boiling water. The electrons, in their countless thousands, may be considered as actual particles of negative electricity, and they constitute in reality an actual negative charge in the space they fill. It is this condition that is called "The Space Charge".

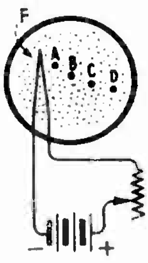


Figure 1

Let us now consider the effect this space charge has upon electrons leaving the filament and, for example, we will consider a single electron. In Figure 1 the filament is shown emitting electrons which are represented by the black dots. The electron A, which is represented by the enlarged dot, is shown a short distance from the filament F and we will assume its velocity carries it to the point shown, first, by overcoming the tendency of the filament to draw it back, second, its velocity carries it against whatever resistance is offered by any gas present and, third, it is carried against the repelling force exercised against it by the electrons which are moving about ahead of it.

At the point shown at "A" the velocity of the electron is spent and it has no further energy to carry it ahead. It is then easily influenced by the repelling action of the electrons beyond it,- also by the attractive force of the filament and it finally returns and is absorbed by the filament.

We will consider Electron "B" as having gained a greater velocity on leaving the filament. It reaches point B before it is drawn back to the filament.

Electron "C" has left the filament at a still greater velocity than either A or B and has reached the point C as shown. This electron has reached a point in the space charge where there is a greater number of electrons behind it than ahead of it and, since like charges repel, electron "C" is actually assisted on its course further away from the filament to point D.

The foregoing will serve to acquaint you with at least a working knowledge of the forces acting upon the electron, this being important because it accounts for certain phenomena which will be encountered later on in our detailed study of the tube.

THE PLATE

In addition to creating a supply of electrons in the vacuum tube it is necessary that we also create some attraction which will cause these electrons to move from their point of origin. This is accomplished by sealing a second element called the plate in the vacuum space. This is shown in Figure 2. It is to be noted that the plate has a connecting lead brought out for a purpose which we will soon explain. For the time being we shall consider the plate as shown in Figure 2 to be sealed in the tube but not connected in any way.

Electrons being emitted will accumulate on the plate and charge it to a negative potential, the negative charge will increase until the plate repels any further electrons moving in its vicinity. Let us now give the plate a positive charge by connecting it to the positive side of a battery, called the "B" battery, as shown in Figure 3. Since this makes the plate positive its natural tendency, in order to restore the state of balance, is to attract any negative charge possible. This it does by drawing to it the electrons being emitted by the filament.

When the plate is connected in the circuit as shown in Figure 3, and is given a positive charge, electro-static lines of force immediately are set up between the plate and terminate at the filament. It is along these lines of force that a positive charge of electricity, as formerly understood, would travel. The electron being a negative charge would move along the same lines of force but from filament to plate which simple means, when expressed differently, that the positive plate will attract to it the negative electrons (unlike charges attract). The attractive force the plate has for the electrons will depend upon the potential of the plate relative to that of the filament

The original tube, known as the Fleming Valve, consisted of only two elements, the filament and plate, as shown in Figure 3.

CHARACTERISTICS OF THE FLEMING VALVE

The phenomenon of a vacuum tube can best be understood by making a preliminary study of the Fleming Valve.

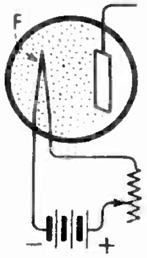


Figure 2

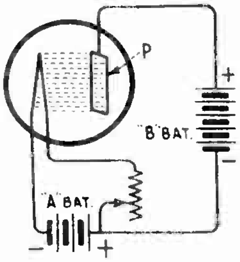


Figure 3

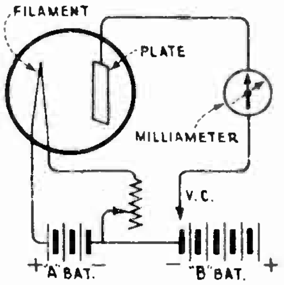


Figure 4

The circuit consists of a source of current, known as the "A" battery to heat the filament. The E.M.F. applied to the filament is made variable. A source of E.M.F., known as the "B" battery, is used to charge the plate and this should also be variable. Such a circuit is shown in Figure 4.

If the plate has a very small positive potential placed on it as shown in Figure 5 a very weak current will flow through the plate circuit, P, M, A, F, because. under these conditions, only a limited number of electrons will reach the plate and the greater majority of them are drawn back into the filament.

It is to be noted here that the plate will have a potential about equal to the filament. Let us, however, connect a battery in the plate circuit as shown in Figure 5A, giving the plate a high positive potential with respect to the filament. Under these conditions nearly all the electrons emitted from the filament will be attracted to the plate resulting in a flow of a comparitively large plate current, as indicated by the milliameter reading. If the B battery is connected as shown in Figure 4 thus placing a negative potential on the plate, the meter will show no deflection because the emitted electrons are negative and they will be repelled by the negative plate. This clearly indicates that electricity cannot flow from the plate to the filament due to the fact that no electrons are passing in the direction of the filament.

As we stated before the rate of emission will depend upon the material of which the filament is made, the size of the filament, and the temperature at which the filament is heated. In the vacuum tube the temperature of the filament is a variable factor. We cannot change the position nor size of any of the elements within the tube, but we can change the filament temperature by a variation of the current passed through it. For a given filament current there will be a corresponding temperature and this temperature will remain constant, providing the current is not varied. At a certain temperature a definite number of electrons will be emitted.

If the circuit as shown in Figure 6 is set up with the filament switch F S open filament current will not flow and no electrons are emitted· hence no plate current will flow, which is indicated by zero reading of the milliameter, M.A. When switch FS is closed current will flow through the filament from battery A. Electrons will then be emitted and as the current increases through the filament its temperature will be increased with a corresponding increase of electron emission.

If the rheostat is set at a point where less than normal filament current flows through the filament and the plate voltage is varied from

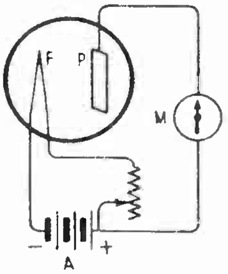


Figure 5

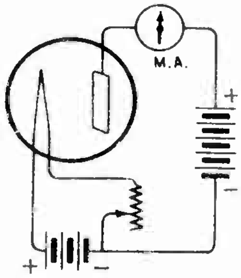


Figure 5A

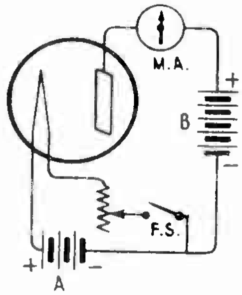


Figure 6

zero upward by changing the taps on the "B" battery a curve as shown in Figure 7, A,B,C,D, is obtained. This shows that plate current increases as the plate voltage is increased. An examination of this curve shows that as the plate voltage is increased at first there is a rapid increase in plate current (A). After a certain value of plate voltage is applied there is no appreciable increase produced in plate current by increasing the plate voltage. This is shown by the horizontal portion D of the curve. If the filament current is now increased and the plate voltage again is varied from zero upward the change in plate current takes place along the curve AEFG. Here the plate current coincides with the lower filament current along part A, but continues to increase above the bend B obtained with the lower filament current. After a certain plate voltage is applied the plate current again fails to increase for further increase in plate potential. This is indicated by the horizontal portion G which however is higher than D, obtained with the lower filament current. If other similar curves are drawn, each corresponding to a definite filament current, the same characteristics would be noted in each, namely a part where the plate current increases as the plate voltage increases. and a part were the plate current is constant even though the plate voltage increases.

From these curves it is evident that with a definite filament current there is a definite plate current that cannot be exceeded. Moreover these curves show that as the filament current increases the maximum value of plate current also increases. This shows that a condition exists in the tube itself which limits the amount of current that can be obtained from the filament. Furthermore it seems certain that this limiting factor depends on the filament temperature which in turn depends on the filament current. Thus we can say that the maximum plate current obtainable depends on the filament. But for each filament temperature there is a definite maximum value of plate current.

A further study shows that the proportion of electrons attracted to the plate depends on the magnitude of the plate potential. When the filament temperature is kept constant and the plate voltage gradually increased the number of electrons attracted to the plate, and therefore the current in the plate circuit, will gradually increase as shown at (A) and (B) of Figure 8. This will continue until a condition is reached where all the electrons are drawn over to the plate as shown at (C). A further increase of plate potential will not result in any increase of plate current. This maximum plate current, beyond which there is no increase for increased plate voltage is known as the saturation current of the tube. For each filament temperature there is a different value of saturation current. Saturation for any definite temperature of the filament occurs when the plate attracts the electrons at the same rate as they are being emitted by the filament. In order to increase the plate current beyond this point it is necessary to increase the filament temperature. The modern tube must be so designed that its filament will be able to emit electrons at a high enough rate so that saturation will not occur at the normal filament current and plate voltage. This means an electron emitter having an ample supply of electrons.

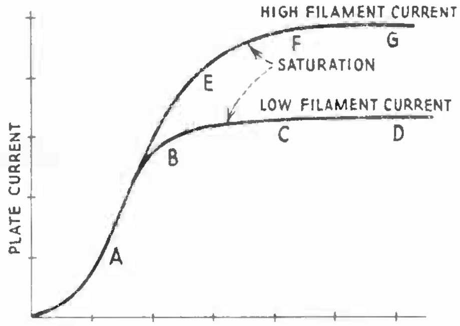


Fig. 7

Characteristic Curves of a Two-Electrode Tube at Two Different Filament Temperatures

GAS EFFECTS

The subject matter just given applies to tubes which are theoretically perfect in vacuum, allowing the electrons to pass in the space between the filament and plate without interference.

When, however, small traces of gas are left in the tube the electron current, which flows when a positive potential is applied to the plate, is increased over that obtained under the same conditions with tubes highly evacuated. The increase in electron current takes place, however, on the condition that ionization takes place.

IONIZATION

Ionization is the effect produced when electrons, on their path from the filament to the plate, collide with the molecules of gas in the tube. The molecule of gas is disrupted by the collision and it frees detachable electrons which then flow with the main body of electrons originating at the filament.

As the "B" voltage is increased the attraction of the plate for the electrons is increased. This, of course, affects the speed of the electrons and when they strike the gas molecules with greater speed the number of electrons freed from the molecules of gas will be increased. It is the liberated electrons from the gas molecules joining the main stream of electrons that increases the plate current.

When the electrons being emitted from the filament have attained a speed great enough they break up the gas molecule into free electrons leaving the gas molecule positively charged. In other words the gas molecule has been ionized and is now what is termed a positive ion. When this takes place in a vacuum tube to any great extent it is made evident by a blue glow which fills the space about the plate because at this point the greatest velocity of the electron occurs. The positive ions thus formed cannot flow to the plate because the plate is positively charged, and like charges repel, and the ions will then move toward the filament. Upon striking the filament they break loose more electrons, which again increases the quantity of electrons available to bombard the plate.

Ionization, therefore, is the splitting or breaking up of gas molecules into free electrons which are always negative and positive charged ions. The freed electrons forming with the main stream of electrons, and the ions shaking more electrons free from the filament which at once start on their journey to the plate, produces increased current in the plate circuit.

THE THREE-ELEMENT VACUUM TUBE

The three-electrode tube differs from the two-element tube only in the introduction of a third element, called the grid.

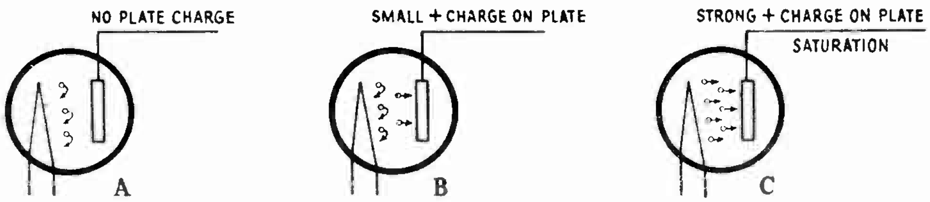


Fig. 8—Action of Electrons in a Two-Element Tube

The introduction of the grid brought about a change in radio that has had a far reaching effect. In fact it was the most important contribution made in the advancement of radio communication since the Fleming Valve was perfected. It greatly increased the sensitiveness of all receiving apparatus used in radio and is directly responsible for all the uses of the modern vacuum tube in transmitting and receiving apparatus.

The grid is capable of controlling the electrons which fill the space between the filament and plate. It exercises a directive power over the cloud of electrons which are racing with tremendous speeds toward the plate. The grid allows certain quantities of the electrons to proceed to the plate or it may prevent them in some cases from striking the plate at all.

By making the grid alternately positive and negative the quantity of electrons flowing from the hot filament to the plate can be increased or decreased. It can thus control large powers of plate current. The amazing feature here is that very small power applied to the grid will exercise this control. How this is accomplished will now be considered

THE USE OF THE GRID

The theory of the two-electrode tube, relative to the electron flow, the space charge, etc., will now be applied while explaining the effects produced by the introduction of the third element, the grid.

The grid is placed in the tube to control the electron flow from filament to plate. For this reason it is often compared to the trigger action of a gun, or the valve control over water, steam lines etc. In the grid, however, we utilize electricity to effect this control. You will remember in our study of the two-electrode tube that the space between the filament and plate was filled with minute negative charges, the electrons. You also know that like charges of electricity will repel and unlike charges will attract.

Now let us refer to the three-electrode tube shown in Figure 9. The grid will then be right in the middle of the cloud of electrons constituting the space charge. If we now connect the negative terminal of a third battery "C" to the grid as shown in Figure 9 we place a negative charge on the grid which will assist the negative space charge.

Since the space charge is already negative an additional negative charge on the grid will repel the greater number of electrons which otherwise would have traveled directly to the plate. As soon as this happens the plate is robbed of electrons and a drop in plate current results. If we have the grid potential battery in Figure 9 arranged so that it is variable, allowing us to gradually increase the negative charge on the grid, a point will finally be reached when the repelling force caused by increasing the negative potential will become great enough to effectually block and turn back all the electrons emitted by the filament.

In this case no current will flow in the plate circuit because electrons are not now reaching the plate. In other words we have made the grid equal in negative force to the positive attraction of the plate and neutralization is the result.

Now let us reverse the battery "C" so the positive terminal is connected to the grid as shown in Figure 10. This will give the grid a positive charge and, since unlike charges attract, the grid will have the effect of attracting the electrons and also conteracting, to a certain extent, the negative space charge. The plate current will be increased because the grid, being made positive, has now added an attractive positive force to that of the plate and consequently assists the plate in attracting electrons to it. By this added positive force in the electron paths the electrons gain a much greater velocity and pass between the fine grid wires striking the plate in greater quantities.

Some of the electrons strike the grid and cause a current to flow therein. This current is usually small and later on methods will be introduced to keep it at a minimum because large grid current is undesirable. If this grid battery C is made variable as in the case of Figure 9, and then gradually changed so that an increasing positive charge is placed on the grid, more and more electrons will be assisted to the plate, but there will be a point reached where further increasing the positive potential of the grid will not draw more electrons from the filament. When the saturation point has been reached further increasing the grid potential will not increase the plate current.

When we consider the repelling effect the space charge has on electrons being emitted it is easily understood how the electron flow is effected when we introduce any element that will either increase or decrease this action of the space charge. The grid has the power to exercise this control as you have observed.

The radio wave is alternating current, rapidly changing from positive to negative. This current is led directly to the grid in the radio receiver and changes the grid rapidly from positive to negative thereby controlling the flow of electrons which, in turn, determine the plate current flow. The plate current flowing through the telephone receivers is made to change in this way. The tube action in the receiving set will bring this explanation out in more detail.

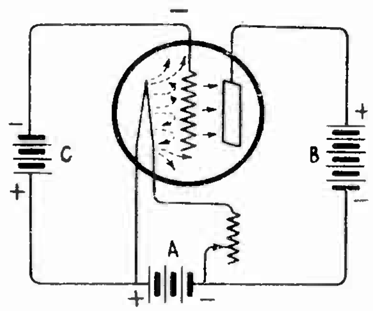


Figure 9

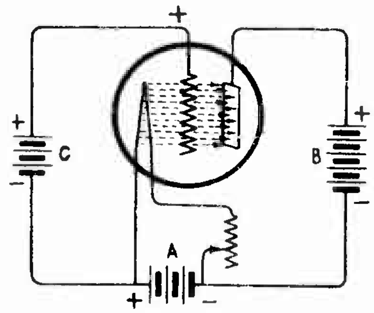


Figure 10

EXAMINATION QUESTIONS

1. What are Thermionic Currents?
2. Of what importance was the discovery of the "Edison Effect"?
3. Does the atom normally possess an electrical charge?
4. Upon what does electron emission depend?
5. Tell what you know about "space charge".
6. (a) In a vacuum tube what is the function of the plate?
   (b) The filament?
7. What is the effect of ionization?
8. How does the three-element tube differ from the Fleming Valve?
9. Of what importance is the grid element?
10. When the heat applied to the filament is increased is there an increase in the electron emission?

DATA SHEET

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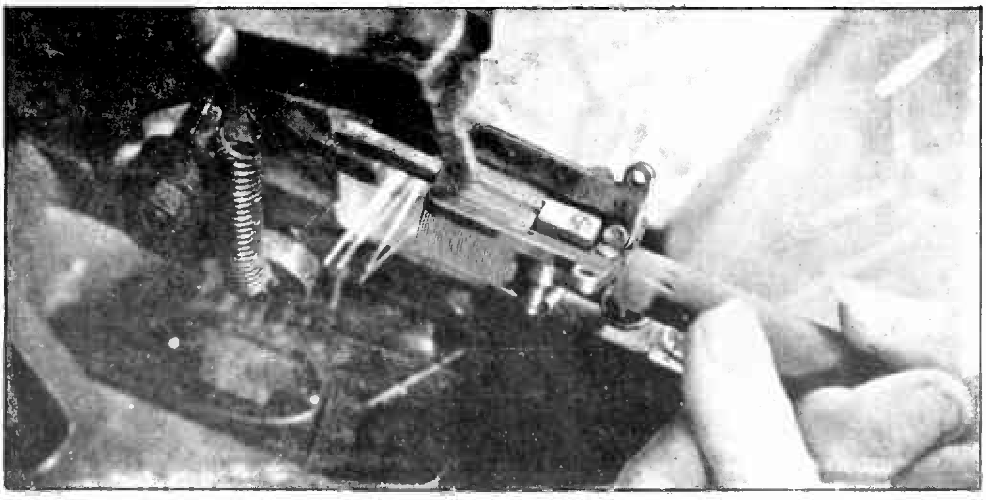

Method of Welding the Screen Grid

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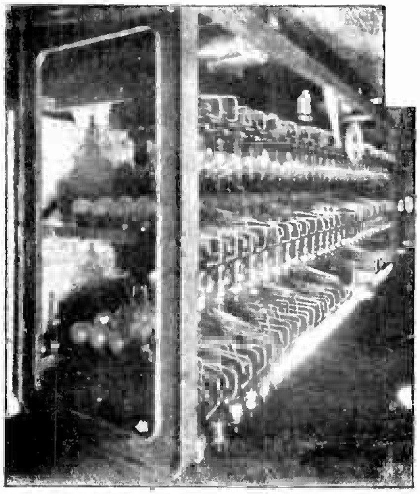

Radiotrons in the
Seasoning and Degassifying
Process

RCA 3301
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Vol.13#3

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Courtesy General Electric Co.

A PHOTOELECTRIC RELAY UNIT SHOWING THE "ELECTRIC EYE" OR PHOTOTUBE AT RIGHT AND AMPLIFIER AND RELAY AT LEFT.

Theory and Uses of Photoelectric Tubes

Dewey Classification 535.3

VOL. 13, No. 5

COMMERCIAL MODEL OF A WESTINGHOUSE PHOTOTUBE RELAY UNIT SHOWING THE LIGHT SENSITIVE TUBE (RIGHT) AND VACUUM TUBE AMPLIFIER (LEFT).

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THEORY AND USES OF PHOTOELECTRIC TUBES

DEFINITION

In its broadest sense photoelectricity covers two phenomena, namely,

(1) The release of radiant energy when electrons strike particles of matter.

(2) The release of electrons when radiant energy falls on particles of matter.

It concerns, therefore, a transfer from electricity to light, or a transfer from light to electricity.

TYPES OF PHOTOELECTRIC PHENOMENA

Under the first type is the ordinary arc lamp, in which an electric current causes gases to become incandescent, producing radiant energy in the form of visible light waves.

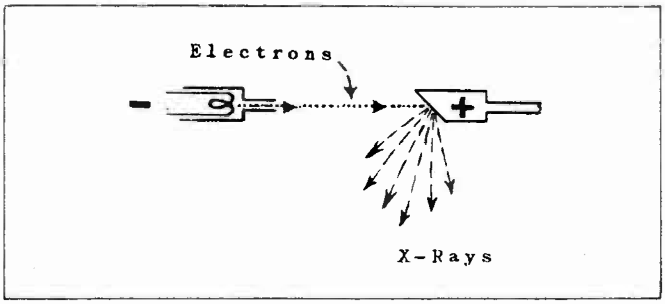

Fig. 1 - PRINCIPLE OF COOLIDGE X-RAY TUBE.

Also under the first type we note the Coolidge X-ray tube, which is simply illustrated in Fig. 1. Here we have a flow of electrons from a filament, the electrons being condensed by a sheath into a fine cathode ray. These electrons attain a tremendous velocity due to the attractive force of the high positive charge on the anode, which is called the "target" for the electron stream. The energy of the electrons in motion is communicated to the molecules of tungsten at the target surface, and these convert the energy into a form of radiation which we call X-rays.

The reverse effect is the emission of electrons from molecules of matter when radiant energy falls on them. This effect was originally discovered by Hallwachs. He found that if a body is negatively charged it will lose that charge when subjected to ultra-violet light. On the other hand, if the body is positively charged it will not be affected by the ultra-violet light. If a negatively charged body loses its charge under the influence of light it follows from the electron theory that we should be able to collect those charges under certain conditions by placing near it a positively charged body. This compares with the ordinary vacuum tube used for radio purposes, in which a positively charged plate is used to collect the electrons given off by the incandescent cathode. In Fig. 2 is shown the energy paths concerned with the Hallwachs effect.

Theoretically at least we could accomplish a double transfer, as shown in Fig. 3. Here we have radiant energy in the form of ultra-violet light directed onto a negatively charged metallic body in a vacuum and which gives up electrons; these would be attracted to the

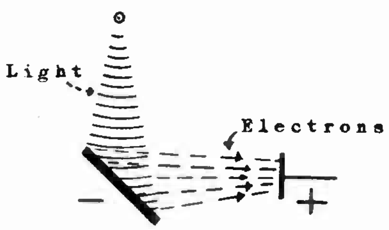

Fig.2 - PRINCIPLE OF THE HALLWACHS EFFECT.

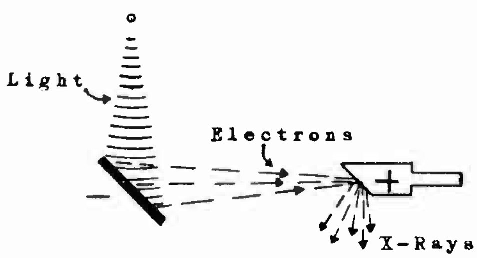

Fig.3 - THEORETICAL IDEA OF A DOUBLE TRANSFER OF ENERGY.

anode or target. If a sufficient number of electrons could be emitted from the cathode in a given time (not practically possible) X-rays might be radiated from the target due to the energy wrapped up in the bombarding electrons. We observe here a difference in the two forms of radiant energy concerned. Ultra-violet light, while invisible, obeys the well-known optical laws of reflection, refraction and polarization. On the other hand X-rays do not. They do have some properties in common, as we shall see.

IONIZATION OF GASES

In various devices in this branch of science we encounter gases, not only of the non-metallic kind such as oxygen, hydrogen, helium, etc. but also those of the metals themselves, of which the most frequently used is the vapor of mercury, which is normally a fluid. You are familiar with the latter in the wide spread use of mercury vapor lamps, and you find it also in mercury vapor rectifiers.

Gas molecules containing two or more atoms may be dissociated into positive and sometimes negative ions by putting the gas in the line of action of any one of the three paths shown in Fig. 3. In like fashion the single-atom molecules which are electrically neutral are usually made over into positive ions.

Ultra-violet light can ionize mercury vapor by causing the release of one or more electrons from the mercury atom.

Electrons in motion at a sufficient speed may "knock off" other electrons from a gas molecule in their path, leaving positively charged atoms or ions, and sometimes negative ions, depending on the molecular construction.

Furthermore, X-rays also have the ionizing power.

SENSITIVITY TO LIGHT. In a foregoing paragraph we mentioned that Hallwachs, in his experiment, used ultra-violet light. There were natural limitations to this early device on account of the nature of the light. It is easy to see that in a practical way it is much

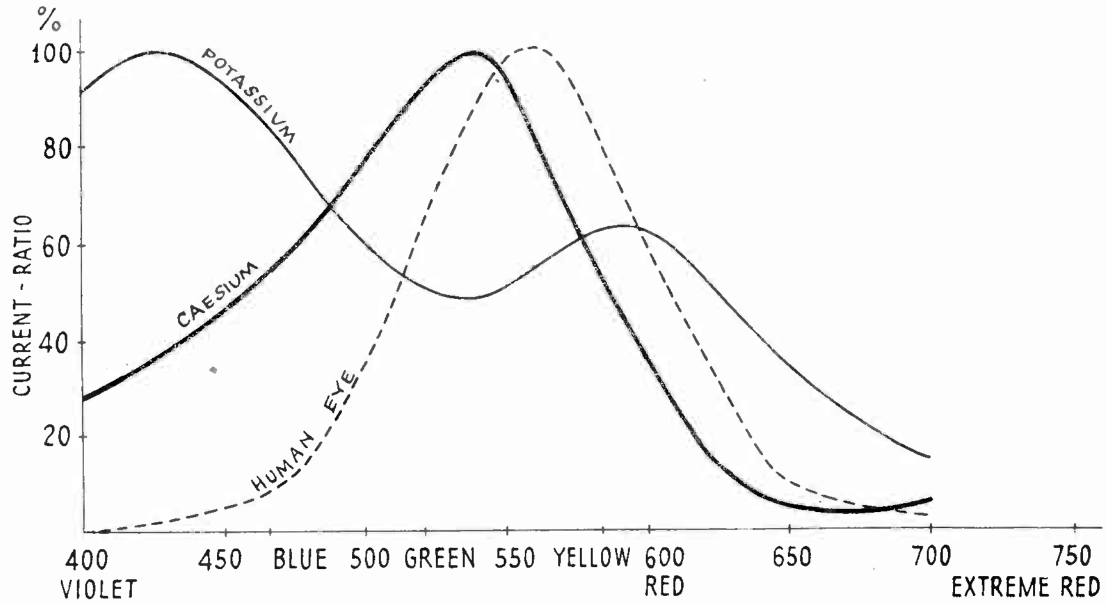

Fig. 4 - CHART SHOWS COMPARATIVE SENSITIVITY OF POTASSIUM, CAESIUM, AND THE HUMAN EYE AT DIFFERENT LIGHT FREQUENCIES.

easier and cheaper to produce and see white or yellow light — which usually contain some ultra-violet, but a much greater percentage of other colors. Thus an ideal material to use would be one that is more sensitive to white light or the same spectrum as the eye.

The discovery that sodium, potassium, caesium and a few other elements were instantly affected by visible light led to intensive development work which brought the photoelectric cell up to its present stage. Although these cells are quite highly developed yet they are not as uniform in performance as the radio tube. Photoelectric cells and radio tubes in general appearance resemble each other and both are classified as "electron discharge devices" although it must be remembered that in the case of the photocell the emission is caused by light while in the thermionic (radio) tube the emission is due to incandescence of the filament or cathode.

An examination of the chart in Fig. 4, which shows the sensitivity of various materials at different light frequencies, indicates that caesium compares favorably with that of the eye. Caesium, however, when used alone is not as sensitive as potassium or copper oxide but it has been found that by coating the caesium on silver oxide its sensitivity is greatly increased and furthermore its frequency characteristic is kept approximately the same as that of the eye.

PRINCIPLES USED IN THE PHOTO-EMISSIVE CELLS

Based on the principles used we have two types of photo-emissive cells or phototubes:

(a) The vacuum type, which consists of a highly evacuated vessel enclosing a positive electrode and a negative electrode, the latter consisting of a surface of such material that it will emit electrons under the influence of radiant energy of the visible or near visible spectrum.

(b) The gas type, which uses the principle of the vacuum type above, with the addition of a certain amount of one or more gases which easily release additional electrons under the forces of collision with electrons emitted from the cathode.

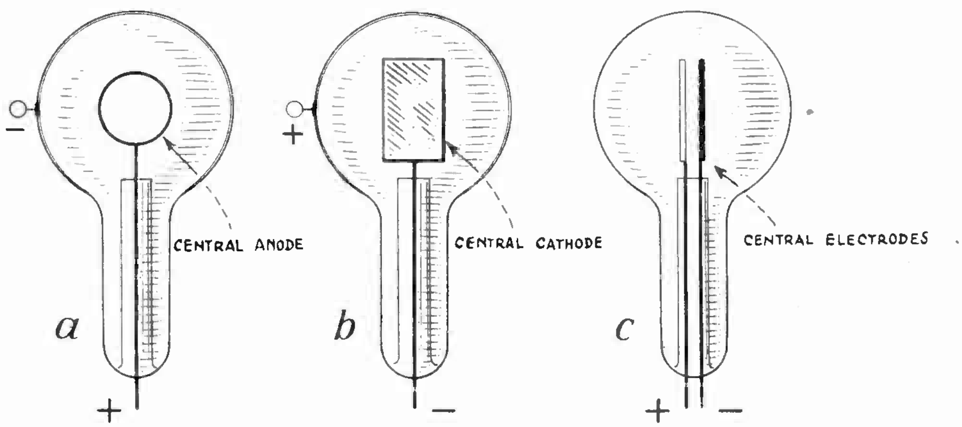

Fig. 5 - PHOTOTUBES ARE CLASSIFIED HERE ACCORDING TO ARRANGEMENT OF THEIR ELECTRODES.

STRUCTURAL FORMS

The three most common forms of phototubes now in use are (a) the central anode, (b) the central cathode, and (c) the central electrodes. In the central anode type the inner surface of the tube is coated with the light sensitive alkali while a rod, used for the anode, is located inside and near the center of the tube. In the central cathode type the inner surface of the tube is coated with a metallic substance and a plate, coated with light sensitive material, is located in the center of the tube. In either case the coating on the inside wall of the tube is connected electrically to a terminal which is brought outside the tube. The third type mentioned or the central electrode tube is now the tube most generally used in sound-on-film movies. It consists of a centrally located rod (anode) with a semicylindrical plate (light sensitized cathode) partially surrounding it. Fig. 5 shows the general arrangement of the electrodes.

VACUUM CELL. When the electrodes of a photocell function in a high vacuum it gives them a much different characteristic than when they work in a gas filled medium. When the cathode of a vacuum type cell is subjected to light a certain number of electrons are released and if a high positive potential is applied to the anode all of these electrons will be attracted to and flow toward the anode. On the other hand, if the anode voltage is comparatively low all of the liberated electrons will not be attracted to the anode, but many will continue to remain on the cathode. This characteristic showing the variation in current (electron flow) for a given fixed light intensity, with changes in anode potential is shown in Fig. 6. When the voltage is sufficient to remove all the electrons released by the light, a further increase of voltage should not produce an increase in electron flow. When this condition is reached the current has

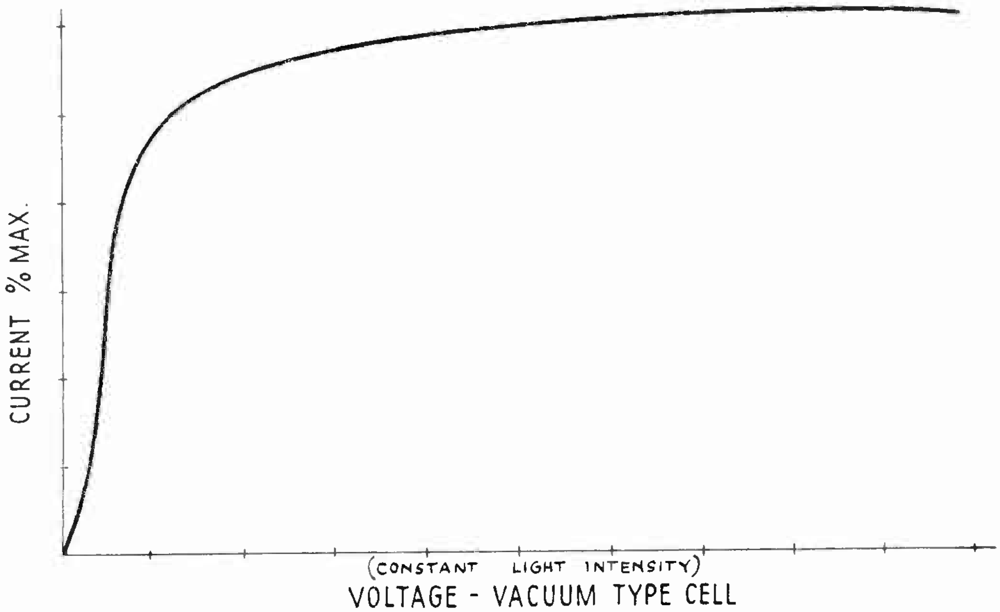

Fig. 6 - CHART SHOWS RELATION BETWEEN CURRENT FLOW AND VOLTAGE CHANGES IN A VACUUM TYPE CELL WITH CONSTANT LIGHT INTENSITY.

reached the saturation value. Of course, if the light intensity is changed the voltage-current curve will be different and the saturation current will increase as the light intensity is increased. Due to imperfect vacuum and rough surfaces on the cathode holding back some electrons there will always be some slight increase in current for an increase in voltage, but this increase becomes so slight that it need not be considered.

EFFECT OF GAS ON CELLS. The action of gas filled cells is much more difficult to understand than the explanation just given for the action of the vacuum type cell. In the first place only gases which do not react chemically with photoelectric material can be used.

Argon, neon and helium answer these qualifications. The normal electron stream in motion will have scattered through it gas molecules which are electrically neutral, and therefore not attracted to either the anode or the cathode. The random motion of the gas molecules through the space of the tube will have no special direction. When an electron collides with a molecule the elastic properties of each may cause them to merely bounce off, their directions and velocities being changed but slightly. If the electron velocity is sufficiently great, however, it may give up some of its energy to the task of freeing another electron from the ties that bound it into the structure of a gas atom. The additional electron joins the stream of electrons originating at the cathode, and more electrons reach the anode than were caused by the light falling on the cathode. The gas atom which was robbed of an electron is no longer neutral, having become a positive ion. This ion is repelled from the anode, and attracted to the cathode, whose charge is of the opposite polarity. During its motion in that direction, it may join another electron and become neutral; or it may approach and reach the cathode at such a velocity that the collision causes an extra agitation of the electrons there, with the consequent increase in the number released. Still another effect occurs when a neutral gas atom combines with an electron to become a negative ion, which is attracted toward the anode.

It all gets very complicated when other variations are considered. Increasing the positive potential on the anode serves to increase the whole effect. It is possible to increase this voltage to a point where the emission from the cathode due to the positive ions present, is as great as or greater than the emission due to the light alone. When this condition is reached the emission of electrons will continue even though the light is cut off. The tube then contains a self-sustaining glow discharge which will continue until the anode potential is lowered appreciably, or until the cathode surface is robbed of its available electrons. In the latter case the tube becomes useless, as it cannot be reactivated like an amplifier tube.

It can be seen that while the gas filled cell is much more sensitive than the vacuum type more care is required to keep it from glowing. The same conditions exist in the gas filled cell as in the vacuum cell insofar as that increasing the light intensity changes the best maximum voltage used. Thus, with greater light intensity a lower voltage must be used to prevent glowing. The graphs of Fig. 7 show this. (The "lumen" is the unit of "luminous flux," which may be defined as the radiant power evaluated according to its visibility). The current sensitivities are graphed for three types of cells made by the Westinghouse E. & M. Co.

Type VA is a vacuum cell having a color-response approximating that of the human eye. Type VB is also a vacuum cell, but having about fifteen times the sensitivity of Type VA, but resembles the latter in that it gives constant output for steady light flux, over a wide range of cell voltages. The gas filled Type GB cell gives increased output up to a limit of about 90 volts. The graph at the right of Fig. 7 shows that the unwanted glow discharge occurs at a voltage which depends on the light flux.

Fig. 8 gives the response per unit energy of the three cells mentioned, with a comparison with the human eye. It will be noted that the GB cell has about five times the response of the VB cell, at the voltages used in taking the data, but that the color response of the two cells is identical.

Referring again to Fig. 7 we see the reason for the greater sensitivity of the gas filled cell. At about 30 volts on the horizontal scale, the VB cell has reached the saturation point for the steady

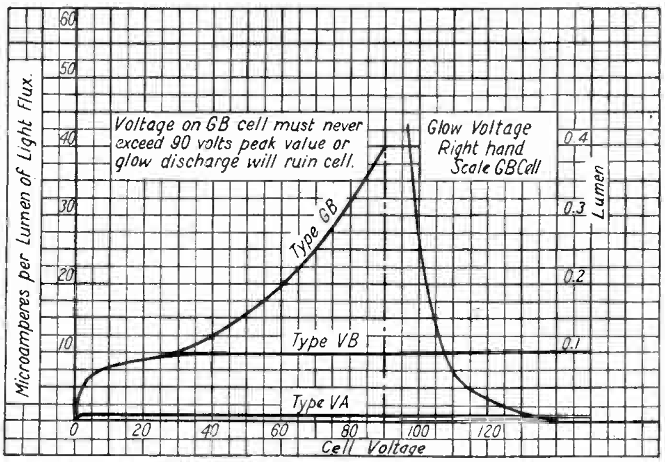

Fig. 7 - TYPICAL CURVES OF AVERAGE CELL OUT-PUT AS A FUNCTION OF APPLIED VOLTAGE AT A LIGHT FLUX OF ONE LUMEN.

light flux condition which determines the electron emission. In the GB cell, however, this voltage is about the point where ionization begins to take effect for that steady light flux, and the current per lumen increases rapidly as the voltage is increased.

In order to limit the cell voltage to a value below that at which glow discharge starts, it is customary to insert a resistor in series with the voltage supply. Its value is such that, as the cell cur-

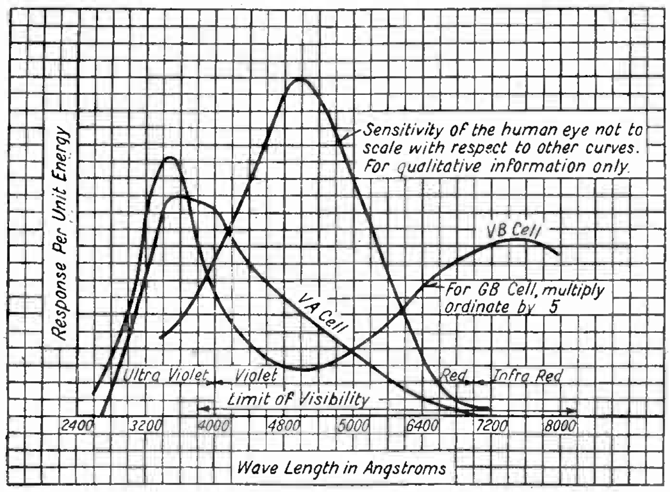

Fig. 8 - COLOR SENSITIVITY OF AVERAGE CELLS OF WESTINGHOUSE TYPES VA, VB AND GB.

rent increases too rapidly near the glow discharge point, the voltage drop across the series resistor will lower the voltage across the cell electrodes. This, of course, reduces the tendency toward a glow discharge. It has a certain disadvantage, in that the average voltage across the electrodes will depend upon the average illumination. What we would like to have is the use of a steady voltage on the electrodes, with the current varying directly as the luminous flux changes. With a resistor in series with the voltage supply, the electrode voltage is no longer constant as the current varies with change in luminous flux. Under this condition there is no longer a nearly linear relation between the illumination and the current, and a slight distortion results.

This disadvantage would not apply to a vacuum type of phototube which is operated above saturation, where a considerable change in electrode voltage makes no appreciable change in current. But then, there is no use in having a protective resistor in the circuit of vacuum phototubes, because the gas in them has been so considerably reduced that no glow discharge could take place except at very extraordinary voltages.

PHOTO-CONDUCTIVE CELLS

The earliest form of photoelectric cell used selenium, but up to very recent times the inherent sluggishness of response limited its usefulness to very few applications. A modern development which is manufactured by the Burgess Battery Company under the name "Radiovisor Bridge" makes use of a unique contact surface and the selenium is carefully treated by a special process. This overcomes much of the slow action of the selenium, and it is claimed to be responsive to variations in light up to a frequency of 10,000 cycles per second. The cell or bridge as it is called consists of two gold electrodes fused into glass. Each electrode is in the shape of a comb, and they are placed with their teeth interlocking, but not touching. The molten selenium is poured over these electrodes in a thin layer and then given a heat treatment to convert it into the chemical form in which it is most sensitive to light. The electrode assembly is then placed in a glass envelope from which air is removed.

The action of this type of cell must not be confused with the photo-emissive cell in which an electronic emission is proportionately caused by light. The property of selenium is such that its resistance to the flow of current is changed by light. The cell resistance decreases when exposed to light, causing more current to flow if the cell is connected across a sufficient voltage. The bridge may be used over a wide range of voltages (10 to 500), the principal difference being that more current flows as the voltage is increased. When dark the resistance is from 1 to 10 megohms. The "bridge" passes appreciably more current than the photo-emissive tubes previously described.

PHOTO-VOLTAIC CELLS

Several oxides of silver and of copper when immersed in solutions of sodium hydroxide become more electropositive when exposed to light. When an electrode having a crystalline cupric oxide surface is associated with an inert electrode of lead, the additional electrochemical potential caused by light makes itself evident as an internal electromotive force which is available for causing current to flow through some external circuit connected across the two electrodes.

The voltage developed in this cell is proportional to the luminous flux to which it is exposed. No external battery is required, which differentiates it from the photo-emissive and the photo-conductive types of cell.

APPLICATION OF PHOTOTUBES IN CIRCUITS

Potassium and caesium cells are very sensitive, but pass such small amount of current that they cannot be used for most commercial purposes unless their output is increased. Since the resistance from

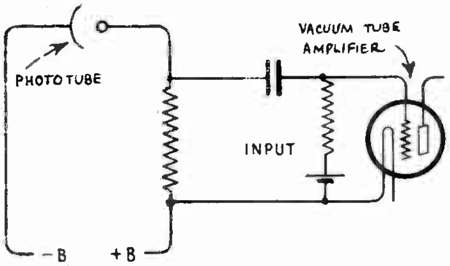

Fig. 9 - ONE METHOD OF COUPLING A PHOTOTUBE TO AN AMPLIFIER TUBE CIRCUIT.

anode to cathode is quite high they are known as high impedance cells. This brings about two requirements. If they are to be used for the production of alternating current of a wide range of frequencies, such as in Sound Pictures and Television, the input impedance of the following amplifier must match that of the phototube. As with any other high impedance circuit, it must be adequately protected by shielding from responding to stray electrostatic and electromagnetic fields which would otherwise introduce random voltages in the signal. These would appear as noise in Sound Pictures, and as flecks of light and shadow in the picture-effect reproduced at a remote Television receiver.

One method of coupling a phototube to an amplifier tube is shown in Fig. 9, where a high resistance is inserted in series with the volt-

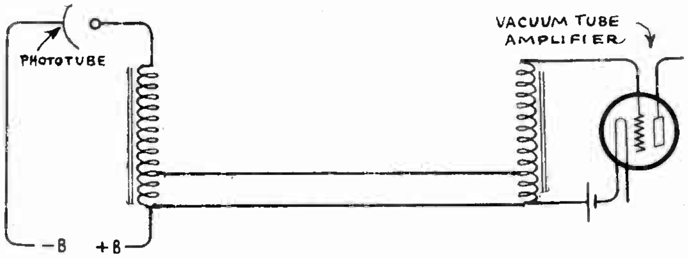

Fig. 10 - AUTOTRANSFORMERS ARE USED HERE TO STEP-DOWN AND STEP-UP THE VOLTAGE.

age supply. As the current changes through this resistor due to light variations on the phototube, the varying voltage-drop is applied to the input of the amplifier tube. This system makes it advisable that the first amplifier tube be placed close to the phototube, not only for noise prevention, but also to prevent the capacity of a long cable acting as a shunt at high frequencies.

These troubles are prevented, and convenience of construction improved, by the circuit of Fig. 10, using an autotransformer close to the phototube to step down the voltage. At the desired location of the first amplifier tube a similar autotransformer steps up the voltage which is applied to the grid of the tube. You will note that this satisfies our requirements because (1) the load on the phototube is a high impedance, (2) the input to the amplifier tube is a high impedance, and (3) the connecting circuit has a low impedance not subject to capacity or magnetic effects to any appreciable degree.

INDUSTRIAL USES OF PHOTOTUBES. The articles entitled "Illumination Control" and "Smoke Density" which follow were written by Messrs. W. R. G. Baker, A. S. FitzGerald and J. I. Cornell of the RCA Victor Company and Mr. C. F. Whitney of the General Electric Company, and are given here with illustrations through the courtesy of the publishers of "ELECTRONICS" in which they originally appeared.

Applications of the photocell in the industrial field are for the control of power through the medium of amplifying systems, thyratrons and relays of the light and heavy duty types and, for indicating smoke density, matching colors, counting articles and so on. These topics will be dealt with in the following pages. Thus many devices that were formerly controlled by hand or by clock-work are now controlled by the photocell. For generations light has been considered

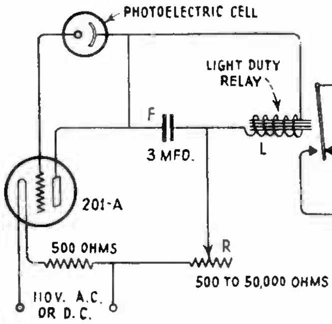

Fig. 11 - A RELAY CIRCUIT WITH PHOTOTUBE AND VACUUM TUBE AMPLIFIER.

only as "something to read by"; of late, however, engineers have begun to realize that beams of light can be put to work. The medium through which light serves for these uses is the surface of an electrode in the phototube which emits electrons under the stimulation of visible or invisible light, as previously explained. These electrons can be used to operate relays and thereby control power of any amount.

A photoelectric cell has the advantage over other devices of being able to operate in periods of unusual darkness during daylight hours which may be caused by a storm for example. Ordinarily during storms apparatus controlled by clock-work would not function. When photocells are used for the switching of incandescent lights used for lighting or for beacons, they are placed in a "window" which faces towards the north so that the direct rays of the sun will not damage the cell. Relays working in conjunction with the light sensitive device make contact when the light shining in the window is less than a certain amount. A typical light-duty relay circuit with photocell and vacuum tube amplifier is shown in Figure 11.

The general scheme for combining several light-duty relays to control many different circuits operated from one light sensitive cell is illustrated in Figure 12. Each relay operates at its own critical current and controls its own heavy duty relay and circuit, although the whole is energized by the same photoelectric cell.

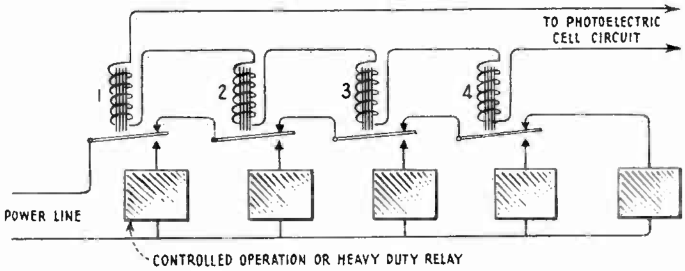

Fig. 12 - AN ARRANGEMENT FOR COMBINING SEVERAL LIGHT-DUTY RELAYS.

A magnetic counting device operated by a photocell is used in many factories at the present time to count the number of articles, such as packages, which pass through a conveyer at a certain point. Any object that is large enough to interrupt a beam of light will operate a photocell, and as a photocell is practically instantaneous in operation, almost any speed may be obtained.

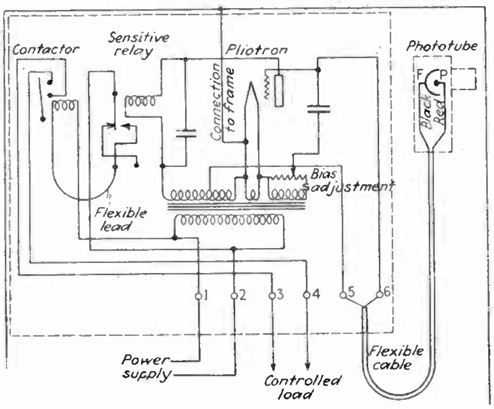

Fig. 13 - CIRCUIT CONNECTIONS OF A LIGHT-OPERATED RELAY.

<u>ILLUMINATION CONTROL.</u> For example, the circuit shown in Figure 13 combines a phototube and triode to form a light-operated relay. The pliotron grid is "biased" negatively by means of a potentiometer across the winding of a transformer and serves to keep the plate current at a low value insufficient to energize a small relay in the plate circuit. A phototube also connects to the grid and a winding of the transformer in such a manner that when light strikes the phototube the grid is made less negative increasing the plate current so that the plate relay is energized. Thus the relay is energized when light strikes the phototube and de-energized when the light is cut off. A contactor capable of controlling usual circuits is operated

by the plate relay contacts. By means of normally closed and normally open contacts on the plate relay the contactor may be either energized or de-energized when the light strikes the phototube. The photograph of a commercial unit of this type, illustrated on the front cover, shows the phototube connected to an amplifier and relay unit by means of a flexible cable, thus allowing the phototube to be

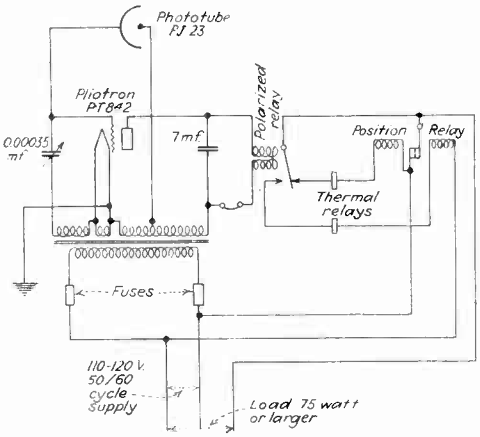

Fig. 14 - THIS CIRCUIT IS ESPECIALLY ADAPTED FOR CONTROL OF ARTIFICIAL ILLUMINATION IN ACCORDANCE WITH DAYLIGHT.

mounted in a variety of positions as required by the application. A modification of the circuit in Figure 13 is shown in Figure 14. Here a phototube and triode are similarly combined, but with special features. The negative bias of the triode is adjusted by means of a variable capacitor which facilitates the setting of the device for operation at a given light intensity. Small thermally operated time-delay relays are interposed between the plate relay and the position

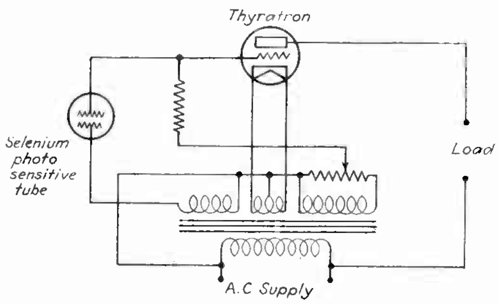

Fig. 15 - A MECHANICAL RELAY IS NOT REQUIRED IN THIS ILLUMINATION CONTROL CIRCUIT.

relay making it necessary for a given change of light to be maintained for several seconds before the position relay is operated. This circuit is particularly adapted for the control of artificial illumination in accordance with daylight. It has been used for street light and sign control. Such apparatus will automatically turn lights "on" and "off."

The circuit in Figure 15 combines a thyratron and a selenium photo-sensitive tube. It provides for illumination control by means of an "on" and "off" relay which is sensitive to light and capable of controlling a large contactor or load directly without the use of a sensitive mechanical relay. When no light falls on the selenium tube the thyratron has positive bias, but when the selenium tube is exposed to sufficient light, this bias is overcome and the thyratron ceases to pass current.

The practicability of the photoelectric cell for regulating traffic lights is being given serious consideration. The Westinghouse Elec-

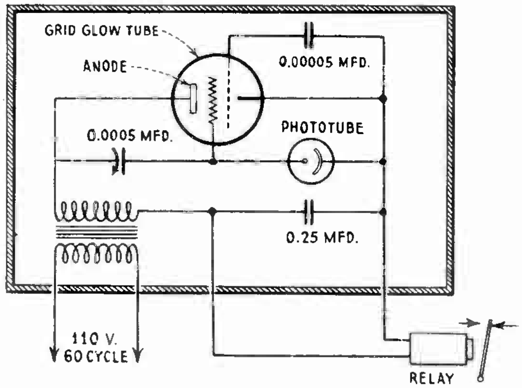

Fig. 16 - PHOTOTUBE SECTION OF A DEVICE WHICH CONTROLS TRAFFIC LIGHTS.

tric and Manufacturing Company has installed traffic lights operated by neon tubes on certain street corners for this purpose. It has long been felt that the stopping of traffic at regular time intervals

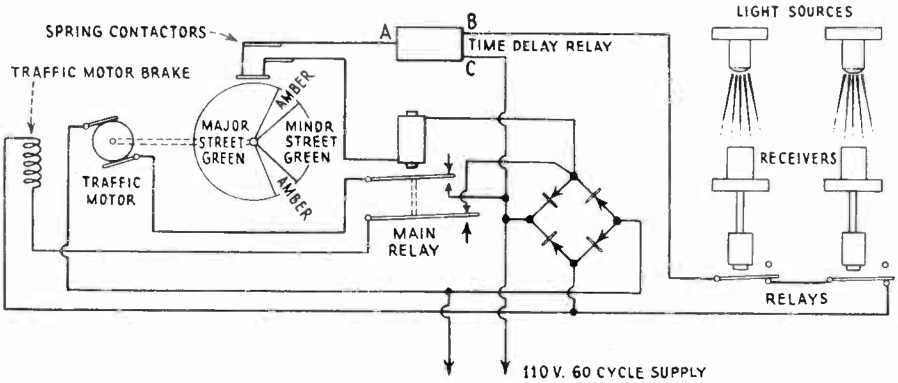

Fig. 17 - THE LIGHT AND RELAY MECHANISM OF A DEVICE USED FOR CONTROLLING TRAFFIC LIGHTS.

on main highways is wasteful of time as very often there are no cars waiting on the intersecting minor street to cross when the main thoroughfare light turns red. The ideal method would be to have a green light on the main thoroughfare at all times giving the right of way to the minor street only when it is needed.

The general arrangement of the phototube circuit and light and relay mechanism are shown respectively in Figures 16 and 17. The function depends primarily upon the interruption of a beam of light by an automobile or any vehicle which comes between the photocell and the light source. In order not to stop traffic on the main highway when cars make a right turn from the highway to the minor street a time delay relay is used which makes it necessary for a car to stop in front of the light beam for a few seconds before the traffic light will change color.

<u>SMOKE DENSITY.</u> Figure 18 shows a schematic diagram of a smoke density recorder which has been built in two units. One box contains a source of light giving a nearly parallel beam, a rectifier-filter system, a photoelectric tube measuring circuit, and a motor-rotated glass dust shield with a wiper to keep the lens system clean. A second box contains a pair of adjustable mirrors set to right angles together with another rotating glass shield with wiper. The shields with cleaning mechanism are important as the smoke to which the whole apparatus is

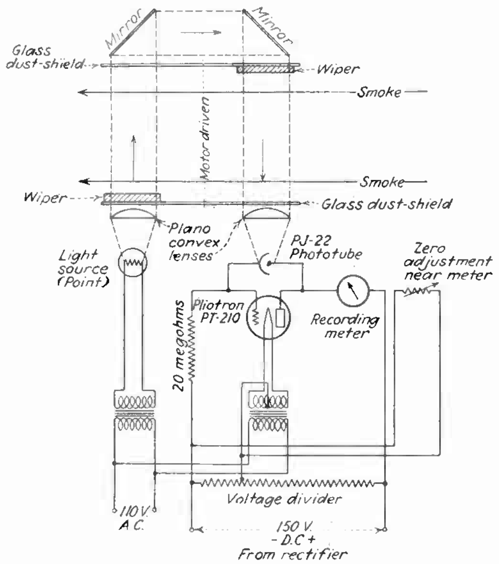

Fig. 18 - SCHEMATIC DIAGRAM OF A SMOKE DENSITY RECORDER.

exposed is heavily laden with carbon, oil, and gasoline fumes. In some cases the units were set about 80 feet apart giving a total beam length of 160 feet.

The system operates as follows: With no smoke interposed between the lens system and mirror system, a fixed amount of light reaches the photoelectric tube which keeps the grid positive with respect to the cathode allowing the plate current to assume a high value. When smoke is carried by the forced draft through the light beam the light is diffused depending upon the density of the smoke. The decreased light on the phototube causes the potential of the grid to become more negative and thus cause a decrease in plate current. This current is brought to the main supervisory control room and a graph is made on a recording milliammeter. A device also made by the Westinghouse Electric and Manufacturing Company for indicating the density of smoke makes use of a combination photocell and amplifier.

The unit is placed in a metal box and is mounted at the end of a small pipe, the end of which opens into one side of a chimney. On the other side of the chimney a lamp is placed so that its rays are directed toward the photocell at the end of the pipe. Thus the rays from the lamp first traverse the smoke in the chimney, then the small pipe, and finally reach the photocell where any change in the smoky medium through which the light rays pass will be recorded and amplified. The output of the amplifier tube is connected to a recorder upon which is kept an accurate record of the smoke density over a period of time. The color of flue gases in a chimney is indicative, to a certain extent, of the quality of combustion in the furnace.

When a chimney emits gases of a dark color it is usually an indication that the fire is poor. A similar device is used in the Holland Automobile Tunnel which connects New York City and Jersey City. The gas fumes given off by automobiles in this tunnel are measured so that the proper ventilation may be maintained to prevent injury to health.

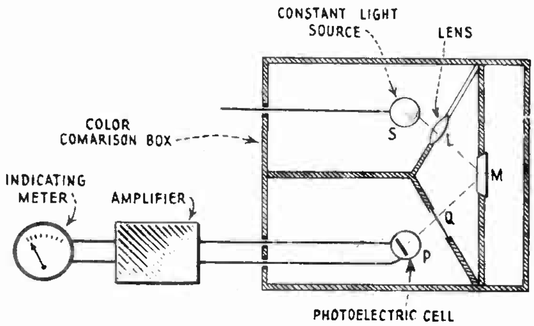

Fig. 19 - ILLUSTRATING THE GENERAL PLAN OF A PHOTOELECTRIC COMPARATOR FOR COLOR MATCHING.

PHOTOELECTRIC CELLS FOR MATCHING COLOR. The photocell may be used in various practical ways for the measurement of different qualities and intensities of light much more accurately than can be accomplished by the eye. This is particularly useful for matching colors.

Figure 19 shows in general how a phototube P, is connected through an amplifier to a meter to indicate any change in color at M. The meter is placed in the plate circuit of the amplifier to provide the indication. A constant source of light S is caused to pass through a lens L and is reflected from any material M whose color is to be compared with that of the standard color glass at Q. If the color of the substance at M is identical with that of the glass at Q no variation will be recorded by the photocell P, and therefore there will be no fluctuation of the indicating meter. The entire unit is made of a light proof material. Color filters may be used to match colors at various points in the spectrum. If, however, the color glass Q is omitted there will be an indication on the meter as the photocell responds to the particular color frequency to which it is sensitive.

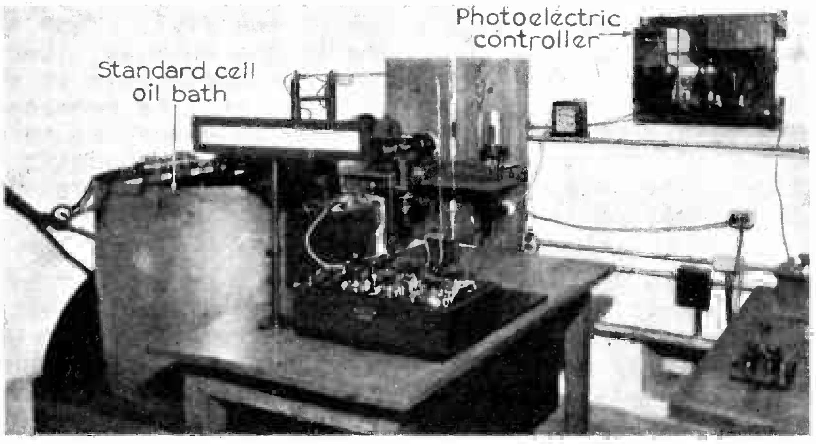

Fig. 20- VIEW OF INSTALLATION USED FOR MAINTAINING CONSTANT TEMPERATURE.

A PRECISION PHOTOELECTRIC CONTROLLER

The rapid strides made in the design and efficiency of electron tubes in the last few years has produced many ultra-sensitive instruments

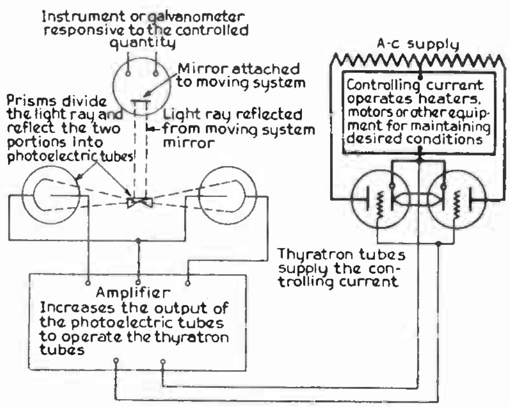

Fig. 21 - DIAGRAM OF CONNECTIONS FOR PHOTOELECTRIC CONTROLLER.

used in the measurement of both electrical and non-electrical quantities. One example is the photoelectric controller, shown in Figure 20, developed by the General Electric Co. for maintaining the standard cell oil bath at constant temperature: the oil bath is in the tank at the left. The schematic diagram of the controller is shown in Figure 21. In brief the equipment operates as follows: The basic instrument is connected across the balance points of a Wheatstone bridge consisting of copper and manganin resistance immersed in the oil bath. The bridge is adjusted to balance at 25° C. and will become unbalanced at other temperatures because of the difference in the temperature coefficient of opposite resistance arms. The illumination on the phototubes will become unbalanced when an unbalance in the bridge deflects the basic instrument. The unbalancing of the illumination on the phototubes sets up a potential which is amplified and applied to the grids of the thyratrons which in turn regulate the value of the heating current passing through resistors placed in the oil bath. The heating effect of the control current is continuously balanced against the cooling effect of water which circulates in the oil bath.

EXAMINATION QUESTIONS

1. What is the principal advantage of the caesium type phototube over the selenium cell?

2. What is the principal disadvantage of any phototube compared to the selenium cell?

3. What is the chief requirement of the load connected to a phototube?

4. What effect on the above is caused by a small capacity in shunt to the load?

5. Describe the structural form of phototubes most used in sound pictures.

6. (a) What is the advantage of a gas filled phototube over the vacuum type?
   (b) What is the disadvantage?

7. How may the gas filled phototube be protected?

8. Why does the photo-voltaic cell not require a battery?

9. Explain simply how a smoke density indicating device works.

10. Name two inventions in which a transfer is accomplished in opposite directions between radiant energy and electrons.

Courtesy General Electric Co.

A PHOTOELECTRIC TUBE OPERATES IN THIS COLOR COMPARATOR USED TO MATCH THE ROAST OF COFFEE BEANS.

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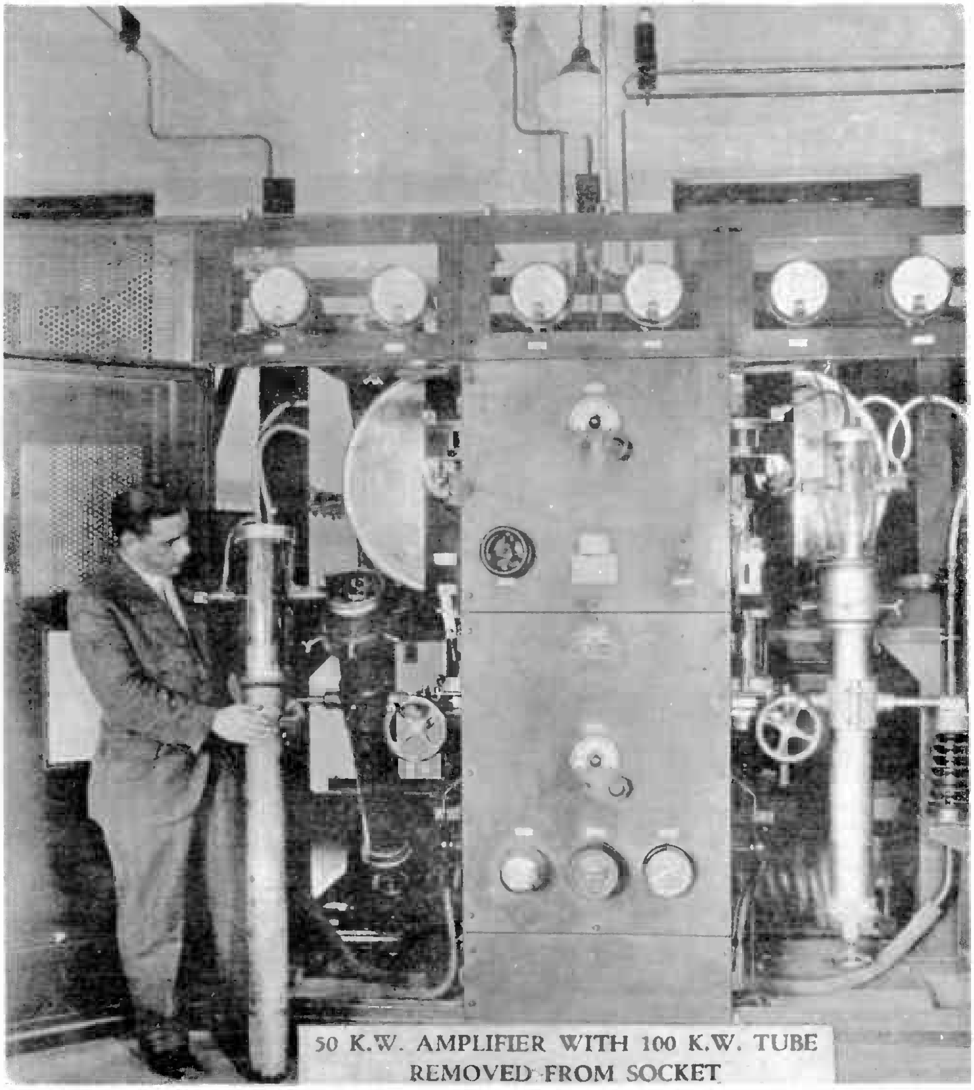

50 K.W. AMPLIFIER WITH 100 K.W. TUBE REMOVED FROM SOCKET

Vacuum Tubes Used in Transmitting

- Class A, B and C Amplifiers -

Dewey Classification R 130

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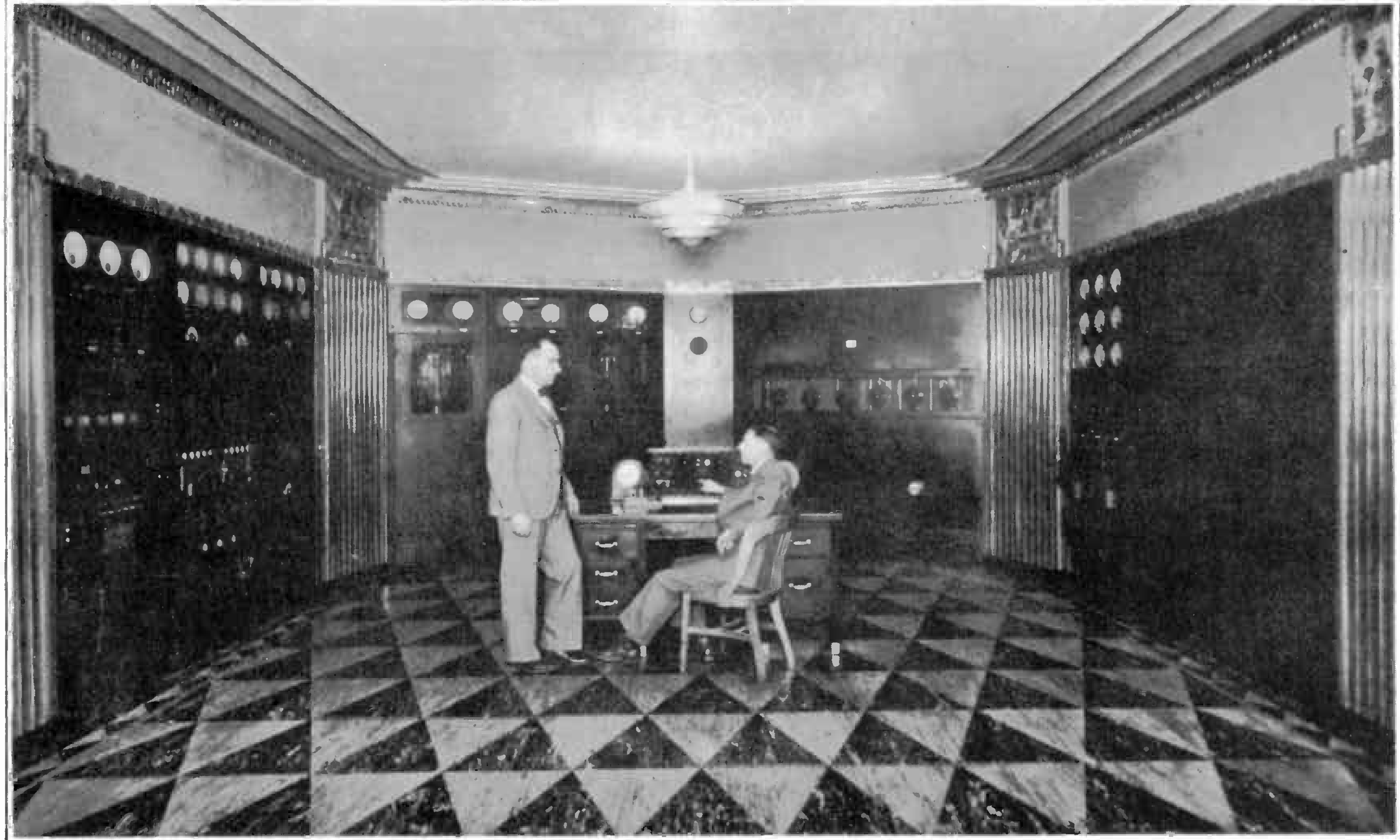

INTERIOR VIEW OF WEAF'S NEW BROADCASTING STATION LOCATED AT BELLMORE, LONG ISLAND.

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VACUUM TUBES USED IN TRANSMITTING
CLASS A, B AND C AMPLIFIERS

The development of power vacuum tubes has kept pace with the demands for a high percentage of efficiency in the operation of all equipment used in radio communication, both in the field of telegraphy and telephony. All power tubes are rated for their power output. In the following paragraphs we will treat on the various tubes from the smallest one which is accorded a place in the power class, the 7.5 watt type, upward and including the water-cooled type rated at 100 kilowatts.

Before dealing with any specific types we will review some important features regarding vacuum tubes in general and especially about power rating. The three circuits associated with the three-electrode tube are the filament, plate and grid.

During the normal operation of a tube the grid and plate become electrically charged bodies and since they are suspended within the glass envelope in a position surrounding and facing the filament both grid and plate necessarily exert their individual influences upon the electrons given off by the filament. Remember that any electron ejected by the filament is actually in clear free space and being a negative charged particle it is subject to the influence of any body with an electric charge upon it, for such bodies set up electrostatic lines of force between themselves and other bodies. It will be noted that the ends of the grid and plate circuits outside of the tube are always attached to some specified point along the filament circuit. These connections are called the grid and plate return leads, and represent the low voltage or low potential side of the vacuum tube circuit. Thus, in tracing out the complete continuity of either the grid or plate circuits, we would find that they embrace part of the filament. Consequently, the current flowing in either the grid or plate must complete its path through the filament and also through the vacuous space within the tube by virtue of the electrons. Considering the filament circuit alone it is easy to see that it is simply a conductive circuit or we may call it a closed metallic circuit through which the heating current flows.

The filament circuit includes, in general, a rheostat or fixed resistor to regulate the voltage at the filament terminals, and there is also the equipment necessary to provide the electromotive force. In many cases this source of e.m.f. consists of a storage battery or d-c generator, or if the filament is heated with alternating current the battery is replaced and the filament is attached to a low voltage coil on a power transformer. The filament, we may then say, is the electron emitting electrode and it is also known as the "cathode".

The plate circuit includes, in general, a high voltage source of supply which may be a "B" battery, or a d-c generator, or a rectifier device to supply plate voltage. The plate is the positively charged electrode in the tube and it is therefore called the "anode". We have mentioned heretofore that the plate functions to attract the emitted electrons and so, when the grid is excited with a fluctuating voltage, the electron flow is varied and thus the plate in our tube serves to supply a fluctuating or a pulsating direct current to operate any device inserted in the plate circuit. The device we refer to may take the form of an inductance, or transformer, or resistor. Such a device constitutes the "load" on the vacuum tube. Power is required to operate the load device in the plate circuit and hence the plate circuit is known as the "output" circuit.

Next we have the grid circuit which is known as the "input" circuit. The grid circuit is so named because the grid receives its excitation voltage from the currents flowing through this circuit which is always connected between grid and filament. The grid circuit consists of either tuning elements, an inductance and condenser for example, or simply the secondary winding of a transformer. In some circuits fixed condensers are inserted in series with the grid and resistors connect the grid to filament. These condensers should have the correct capacity because the input voltages, that is, excitation voltages, must be carried through them without opposition. Bear in mind that the grid is the controlling electrode, because when supplied with electric potentials (called the input voltages) it will act to regulate the quantity of electrons reaching the plate.

The whole action of any vacuum tube is dependent mainly upon the tiny electrons which are liberated or expelled by the hot filament. These electrons are attracted by the positively charged plate and make up and actually constitute the plate current. Thus, when a plate is maintained at a positive potential it will exert a continuous attraction for the electrons emerging from the hot filament.

The value of plate current necessary to insure the normal operation of a tube is governed by the quantity of electrons pulled to the plate. If we are called upon at any time to summarize briefly the various factors which control the amount of the electron energy reaching the plate we could state these factors as follows:

1. The value of the positive d-c voltage supplied to the plate.

2. The operating temperature of the filament.

3. The value of grid bias used and grid excitation voltage.

4. The degree of vacuum existing in the chamber within the glass envelope.

All three-electrode tubes function on the principle that when an alternating or fluctuating voltage is impressed upon the grid the amount of electrons passing through the vacuous space from filament to plate will be made to vary, thus the plate direct current fluctuates constantly and regularly between certain maximum and minimum limits, depending upon the frequencies and intensities of the voltages impressed upon the grid.

While we are relating facts which are more or less general in regard to our vacuum tubes, it may prove both interesting and instructive to point out the similar effects set up in a circuit by either a pulsating direct current or an alternating current.

Although a fluctuating or alternating voltage on the grid causes the plate current to vary in strength from its normal value to either greater or lesser values, yet it must be understood that this plate current can flow only in one direction. The conduction of electrons within the tube is in the direction only from filament to plate. Thus the plate current flow is unidirectional and it should be easy to understand, then, that it cannot be called a pure alternating current. However, we do call the instantaneous variations of the plate current the "a-c component". It can be shown that these variations do produce all of the effects of an alternating current; as, for instance, they set up a changing magnetic field surrounding a coil inserted in the plate circuit and produce a reactance voltage across or between the opposite ends of the coil. Moreover, by the use of a suitable coil (i.e., inductance) and a condenser the changing plate energy is capable of placing an electrostatic charge in the condenser and the latter then can be used to couple the plate circuit with some neighboring circuit. You will recall from your early studies that reactance voltage is the direct result of a coil's opposition voltage (or, as it is called "reactance voltage") which is set up by changing magnetic lines of force cutting back and forth through the same turns of wire which produced these magnetic lines. That is, the magnetic lines react back upon the turns which set up these lines. This effect produced upon a circuit by a coil when it carries a current which is constantly varying in strength is known as "self-induction". The voltage generated is known as the "induced voltage of self-induction".

Now let us consider some facts concerning the metal which is used in the manufacture of the filament wire. A tremendous amount of study and research has been going on steadily in the laboratories of tube manufacturers to find a metal or combination of metals which would give off an abundant supply of electrons for the least expenditure of heating current.

The three materials used to any great extent are tungsten, oxide coated platinum and X-L, or thoriated tungsten. Tungsten was the metal generally used before Dr. Irving Langmuir discovered that the rare metal, thorium, was especially rich in electronic energy. He showed that a thorium-coated tungsten filament heated to a temperature of 2,300 degrees Centigrade provided an electronic emission more than ten thousand times as great as a pure tungsten filament heated to the same temperature. Filament wire may be either coated with an oxide, or the wire is more often treated throughout with the rare material, thorium. So, with a comparatively low heating current, the modern power tube filament gives off a vastly greater supply of electrons than was formerly thought possible. While the fact that the X-L filament requires a much lower power to insure a proper operating temperature than would be the case if other materials of equal practical value were used, yet another quality that this special wire possesses is that the total electron emission for a given power consumption is comparatively long. Thus the expectance of tube life is prolonged many hours. It is agreed that the operating life of a vacuum tube is one of the most important features. Life expectations show up wide variations with respect to operative conditions and to some extent with individual tubes of similar type. These facts outline in general the essential requirements of the filament wire used in power vacuum tubes.

The manufacturer designs the filament of a tube to have the correct length and thickness using a certain material so that when a specified e.m.f. is impressed across the filament terminals the required current will flow and heat the wire to proper operating temperature.

The life of a thorium treated filament is naturally limited for the electron energy is obtained at the expense of the thorium. It is to be expected, then, that during operation of a transmitting set the filaments of the various tubes are constantly evaporating, or being used up, as it were. Electron energy driven off the surface of the wire is replaced by the diffusion of thorium down inside the wire. The thorium apparently boils out and while the actual amount of thorium lost at any given moment is very small to be sure, yet the filament will eventually lose its emission. That is to say, the useful life of the tube will end when the supply of thorium inside the filament is exhausted. Of course, the disintegration and evaporation of the thorium will be very rapid if the filament is operated at too high a temperature. Any power tube is likely to be subjected to a short overload, and in such events the X-I filament type has proven capable of withstanding three times its normal voltage without a burn-out.

Gases are given off by the plate when the tube is overloaded and under such conditions the tube will show considerable color. To reduce the possibility of a hot plate giving off gases during its normal life, the X-L filament type tubes are constructed with molybdenum plates which during the manufacturing process are heated to extremely high temperatures by means of a high-frequency furnace. That is, the eddy currents set up due to high-frequency induction tend to heat the metal parts. Other internal parts of the tube are also brought to high temperatures when the plate undergoes this treatment and thus all metallic parts are heated to a higher point than they ever reach during normal operation. Electron emission is usually lowered temporarily in the event of a severe plate overload, but this condition can often be rectified by the reactivation or rejuvenation process which is explained in the next paragraph. Reactivation cannot be resorted to if an air leak occurs in the tube. A purplish or pink glow can be taken as an indication that an air leak exists, whereas a distinctly blue glow would suggest gases had been released from the metal parts within the tube.

While the tube with a low emission is of no practical use it may still have its relatively inert tungsten wire intact and in this case the wire is capable of carrying sufficient current to heat and light up to its usual degree of incandescence. It is often possible to restore a tube in this condition to give additional hours of service by a very simple process called "rejuvenation." This process consists of forcing metallic thorium from the inner recesses of the filament wire to its surface by heating the wire to a temperature slightly above normal for about 15 minutes with the plate circuit open. Voltage must not be supplied to the plate during this operation. This reactivation of the filament should be carried on with the voltage about 15% above the normal as specified by the manufacturer, and in many instances we have given the exact limit for many types of power tubes in the discussions which are to follow.

CLASS "A", "B", AND "C" AMPLIFIERS

The power rating of vacuum tubes used in transmitting equipment is dependent upon the manner in which they are used. There are three different ways in which vacuum tubes are used in transmitting circuits. In discussing the operation of tubes in a transmitter, it would be necessary to state how each tube was being used. This would entail rather lengthy explanations were it not for the fact that to each method of using a tube a letter has been assigned. These letters are the first three of the alphabet; viz., Class A amplifier, Class B amplifier and Class C amplifier or oscillator.

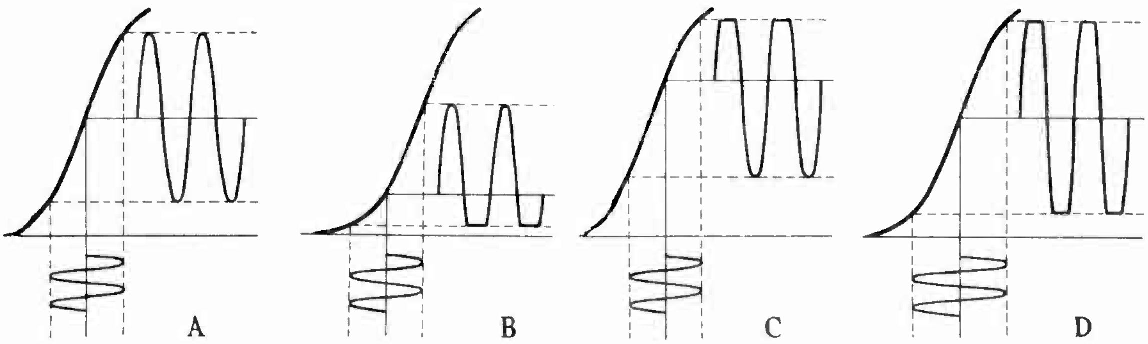


FIG. 1 - (A-B-C-D) CURVES USED TO EXPLAIN CLASS "A" AMPLIFIERS

CLASS "A" AMPLIFIER. The Class A amplifier may be defined as follows: The Class A amplifier is an amplifier which operates in such a manner that the complete output wave form is essentially the same as that of the excited grid voltage. The characteristics of a Class A amplifier are low efficiency and output with a large ratio of power amplification. This type of amplifier is used in most audio-frequency amplifier and modulator circuits.

It is the duty of a Class A amplifier to reproduce in its plate circuit a wave shape which is an exact replica of the wave shape of the impressed grid voltage. In order to accomplish this result it is necessary to operate the tube at that point on the grid voltage-plate current characteristic curve where the change in plate current is directly proportional to the change in grid voltage. In other words, to operate the tube that the entire plate current swing will take place over the straight line portion of the plate current curve. An example of such operation is shown in Figure 1-A. The effect of too high grid bias is shown in Figure 1-B; it will be noticed that in this case the tube operates on the lower curved portion of the characteristic curve introducing distortion.

Another type of distortion is shown in **Figure** 1-C; here the tube is operated with insufficient grid bias resulting in the grid going positive on the positive half of the grid excitation cycle with accompanying distortions.

Too high signal input voltage can also introduce distortion as shown in Figure 1-D. The operation of a tube is the same for a voltage amplifier as for a power amplifier when operating Class A, the only difference being the load in the plate circuit.

<u>CLASS "B" AMPLIFIER.</u> The Class B amplifier is defined as one so adjusted that the power output is proportioned to the square of the grid excitation voltage. This is accomplished by biasing the tube to

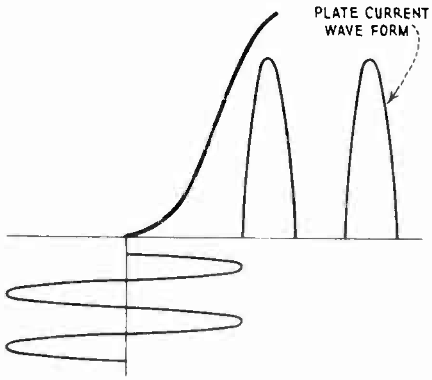


FIG. 2 - CLASS "B" AMPLIFIER CURVES

the cut-off point or nearly so. Plate current then flows only during the most positive half of the grid excitation cycle resulting in half-cycle loops of plate current, each loop representing one-half of the grid excitation cycle, see Fig. 2. During the remaining half of the grid voltage cycle no plate current flows. Since there is no flow of plate current, the plate of the tube is not called upon to dissipate energy. In other words, the tube actually works but one-half the time during the grid voltage cycle.

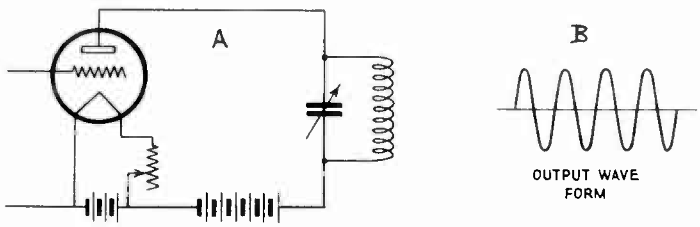


FIG. 3 - ACTION WHEN TUBE OUTPUT IS CONNECTED TO AN OSCILLATORY CIRCUIT

The operation of a tube under these conditions as an audio amplifier would be entirely out of the question as the condition shown in Figure 1-B would be accentuated since as an audio amplifier, the tube would have an aperiodic load in its plate circuit. The wave form of the current through the load would be the same as the tube plate current.

Consider now the circuit shown in Figure 3. The tube is connected in a circuit with an oscillatory circuit as the plate load. The half-wave pulsations of plate current will now be transformed into complete cycles or oscillations through the pendulum effect or fly wheel action of the oscillatory circuits, see Fig. 3-B. The amplitude of these oscillations will depend upon the amplitude of the plate circuit pulsations which in turn depend upon the value of the grid input voltage. It can, therefore, be said that the amplitude of the oscillatory current is proportional to the value of grid input voltage and since doubling the grid voltage would result in twice as much tank current the power output would be quadrupled (I^2R); hence, the definition previously given for the Class B amplifier. The power output of a tube working under Class B conditions is many times that of its Class A rating.

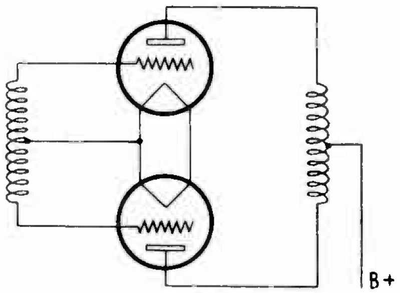


FIG. 4 - TWO TUBES WORKING AS CLASS "B" AMPLIFIERS

Thus far the Class B amplifier has only been considered from the standpoint of a radio-frequency amplifier. It is not restricted to this one use, however, since by special circuits it can also be used as an audio-frequency amplifier.

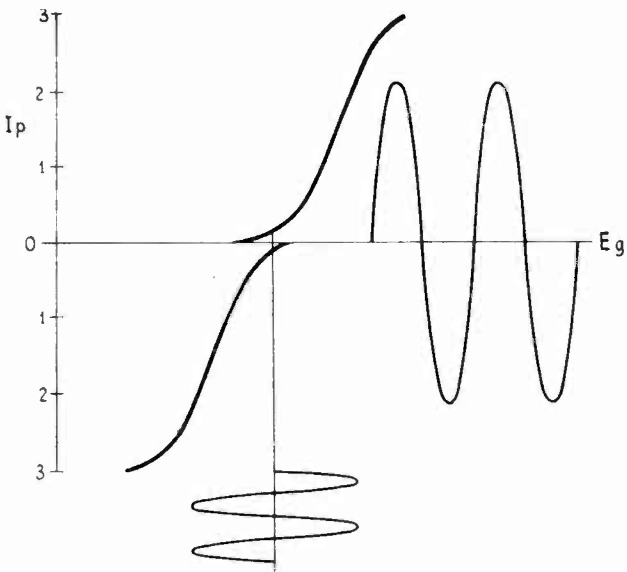


FIG. 5 - CHARACTERISTIC CURVES FOR TWO TUBES IN FIG. 4

Reference to Figure 2 shows that in a Class B amplifier plate current flows during one-half of the grid excitation cycle in the single ended (single tube) amplifier circuit. If a second tube be added and the circuit made as in Fig. 4, the characteristic curves for the two tubes will be as shown in Fig. 5. The curve for tube B is drawn bottom side up since it works on the opposite half of the grid excitation to that of tube A. The double ended Class B amplifier circuit utilizes the complete wave or both halves of the grid excitation cycle; this results in a plate output wave whose shape is a replica of the grid input wave. It should also be noted that the curves at the lower knee bend of the characteristics are opposite to each other and tend to give the effect of a straight line. This fact greatly aids in improving the wave shape in the output circuit. By connecting the two characteristics by a straight line one may think of a double ended Class B amplifier, as a single tube amplifier, Class A, whose characteristic is equal to the combined characteristics of the two tubes working Class B. Such circuits are gaining popularity, as audio output circuits in broadcast receivers, and are in general use to amplify radio-frequency signals after modulation in larger broadcast transmitters. One of the latest types of broadcast transmitters uses a Class B transformer-coupled plate modulator. The double ended Class B amplifier should not be confused with the more common push-pull amplifier. In the latter each tube is biased to work Class A and as the plate current increases in one tube a proportionate decrease takes place in the other and vice-versa; while in the Class B double ended circuit as the plate current increases in one tube no plate current flows in the other. It should also be noted that there is no plate current in either tube when no signal is applied to the grid. This also is contrary to the action of the Class A push-pull amplifier in which an equal amount of plate current flows in each plate circuit when no signal is being received. The efficiency of the Class B amplifier is 30 to 60 percent.

CLASS "C" AMPLIFIER. The Class C amplifier is a vacuum tube amplifier circuit so adjusted that the power output varies as the square of the applied plate voltage.

In order to accomplish this result in practical operation there usually is a biasing voltage applied equal to twice the value required to bring the plate current to the cut-off point.

A sufficient amplitude of grid excitation voltage is then applied to more than drive the plate current to saturation. Such operation gives loops of plate current during the most positive part of the grid excitation cycle.

An efficiency on the order of 60 to 80 percent is obtained under such conditions. Vacuum tubes are operated in this manner when used as oscillators and modulated amplifiers when plate modulation is employed as the output amplifier in radio telegraph equipments.

In Figure 6 is shown an E_gI_p characteristic with a bias equal to twice the cut-off value. From this figure it will be seen that the grid excitation voltage will have reached a certain amplitude on the positive half of the cycle before plate current starts to flow. It is, therefore, evident that this plate current flow exists for less than one-half cycle. The period then during which no plate current exists is greater than one-half cycle. Because of this long period during which the plate is not called upon to dissipate energy it is possible to operate the tube at much higher efficiencies than obtainable with any other type of amplifier.

It is, of course, impossible to utilize such an amplifier for audio-frequency work. When this type of amplifier is used as the modulated amplifier in radio telephone sets, it acts in much the same manner as a pure resistance.

For this use it is customary to vary the plate voltage, the tube responding by increasing or decreasing its plate current in direct proportion to the change in plate voltage. If the plate voltage is doubled the plate current doubles and since, in a resistance the power increases as the square of the current, there will be four

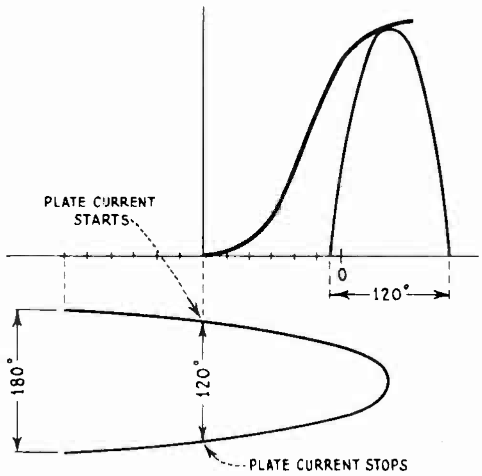


FIG. 6 - CURVES DEPICTING CLASS "C" AMPLIFIERS

times as much power or, in other words, in this type of amplifier the power output varies as the square of the applied plate voltage.

Although the alternating component of plate current may show a comparatively wide departure from sine wave form in such an amplifier, the output voltage will be practically sinusoidal.

HOW VACUUM TUBES USED IN POWER CIRCUITS ARE RATED

The power rating of vacuum tubes used in transmitting equipment is computed by the output energy of the device rather than by the input energy. A considerable part of the power delivered to the plate of a transmitting tube is wasted in heat. Transmitting tubes are used in the capacity of either an oscillator, amplifier, or modulator. A modulator tube is so named because of the specific duty which it is intended to perform, but nevertheless, it is a tube actually working with an amplifier characteristic. Hence, we can consider that transmitting tubes are divided into two general classes according to their function in a circuit; namely, "oscillator" and "amplifier." It should be noted that any type of tube may be used for either of these functions.

The power required to energize the plate of an amplifier or oscillator tube may be furnished by either a "B" battery, a direct-current generator or rectified a.c. depending upon the particular transmitting equipment. To those who study this work it is known that a vacuum tube associated with a circuit containing a suitable amount of inductance and capacity and designed to provide a feed-back of energy from the plate to grid circuits through either magnetic or capacitive coupling will be capable of generating self-sustained oscillations at a predetermined frequency. The tube used in a feed-back circuit is always known as an oscillator. The oscillations are known as continuous oscillations because they are consistent in frequency and their amplitudes are uniform in strength; such energy may be said to have a smooth-topped alternating current wave-form. It is readily seen that a line drawn through all of the amplitude peaks would be a straight line.

From the study of vacuum tube theory we learn how any voltage variation impressed upon the grid of a tube would be reflected in the plate current. Now, in a properly designed oscillator system when a radio-frequency voltage is applied to the grid the plate current continues to rise and fall in strength and, due to the feed-back action, the amplitudes of these plate changes cause further variations in grid voltage which result in corresponding variations in plate current, and so on. A slight change in plate current, as for example when a vacuum tube circuit is first placed in operation, should prove sufficient to set up the initial voltage impulse on the grid to start oscillations. In other words an oscillating current will be maintained so long as the feed-back power supplies grid voltage variations of sufficient amplitude to vary the plate current within limits which will again provide sufficient voltage in the grid circuit for grid excitation. Then in order to generate self-oscillations the amount of plate energy fed back to the grid must be more than that required to supply the losses in the grid circuit.

The point which we desire to set forth is that in any oscillating system there is always a certain amount of plate power dissipated in heat and also loss of power due to the setting up of a current flow in the grid circuit. This means that the actual power which a certain oscillator tube is capable of delivering, called its "output power", must be less than the power input of the plate. We could state this in another way by saying that a certain amount of energy is lost in any oscillatory system through the conversion of direct-current power into alternating-current power.

We must then have some means for determining the efficiency of a vacuum tube oscillator or power amplifier. The measure of the "efficiency" of our power tubes is merely a comparison between the actual power input in watts and the actual power output in watts and the expression of this value in percentage. It is well known that the efficiency of any device in percent is equal to the output divided by the input multiplied by 100. Efficiency expressed in terms of power (watts) may be written in the following way:

$$\frac{\text{WATTS OUTPUT}}{\text{WATTS INPUT}} \times 100 = \text{EFFICIENCY IN \%}$$

In Figure 7 we have the diagram of a vacuum tube radio-frequency oscillator circuit which can be used for transmitting purposes by coupling it to an antenna system in the manner shown. Other methods for keying a circuit of this kind than the one illustrated may be employed for telegraphy; for instance, keying may be accomplished by changing the grid bias from a high- to a low-operating bias. This is done to reduce the key clicks or thumps to a minimum, for when such sounds are reproduced they greatly interfere with the reception of the message. Our aim is merely to show one type of oscillatory circuit in which the plate circuit is directly coupled to the upper end

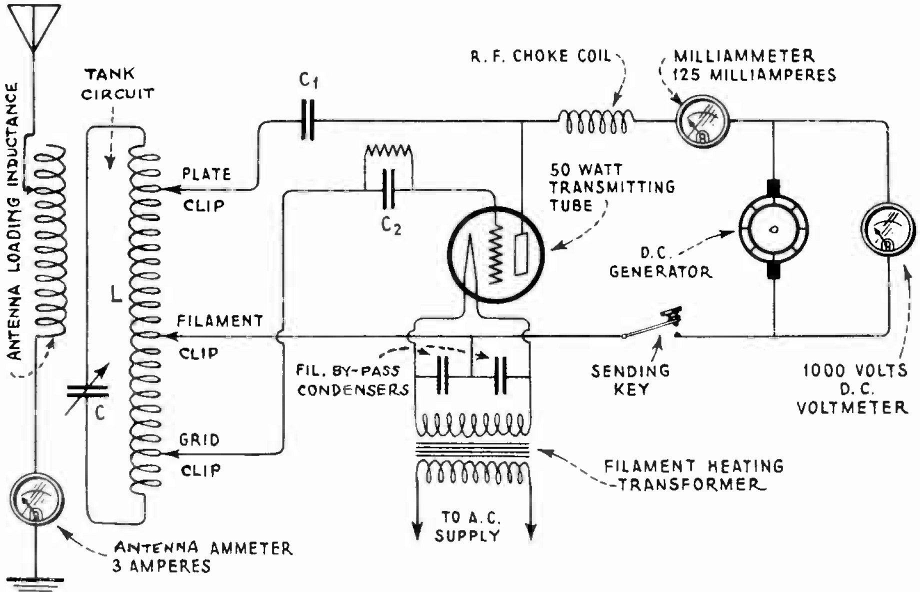


FIG. 7 - ONE TYPE OF TRANSMITTING CIRCUIT

of the oscillatory inductance L by a fixed condenser marked C1, whereas the grid is coupled directly to the lower end of L by the condenser marked C2. Although the frequency of the generated oscillations may be varied by adjusting condenser marked C, the frequency is dependent upon the combined values of L and C. Another

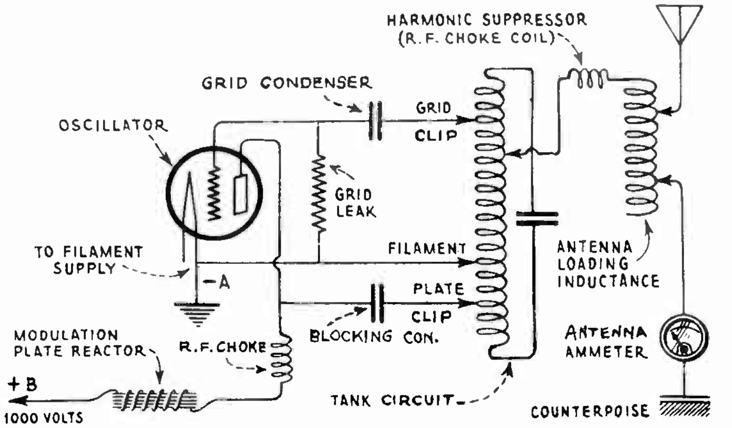


FIG. 8 - ANOTHER METHOD OF COUPLING THE OSCILLATOR OUTPUT TO AN ANTENNA

type of oscillatory circuit and vacuum tube driving an antenna system is shown in Figure 8, this circuit being part of a broadcasting transmitter. These simple circuits are given merely to suggest conventional types to assist in an understanding of the following explanation concerning efficiency and power rating of a power tube. Let us suppose that the power tube in either diagram is rated at

50 watts and, according to the electrical data chart of the manufacturer, the tube draws 125 milliamperes of plate current when the plate is operated with a positive potential of 1000 volts d.c. Then, the power in watts (W) in the plate circuit is equal to the voltage (E) times the current (I), or

$$W = E \times I$$

Note: 125 milliamperes = .125 amperes.

Then W = 1000 x .125; or WATTS INPUT = 125.

It is a simple matter to calculate the watts input. However, to compute the possible power output of this tube working into an antenna system, we find it necessary in our study to assign two arbitrary values; one for the amount of antenna current (I) which would ordinarily be indicated on the antenna ammeter, and the second for the resistance (R) of the antenna circuit. The output power in watts is conveniently expressed as follows:

$$\text{WATTS OUTPUT} = (\text{ANTENNA CURRENT})^2 \times (\text{RESISTANCE OF ANTENNA})$$

or, using the symbols: $\text{WATTS OUTPUT} = I^2 \times R$

Suppose the resistance of the antenna is known to be 10 ohms from previous experimentation, and the current as read on the antenna ammeter is 3 amperes while the 50 watt tube is active and delivering power in the form of an r-f (oscillating) current for antenna excitation. Then substituting these numerical values for the symbols I and E in the formula, we have:

$$\text{WATTS OUTPUT} = (3)^2 \times 10 = 9 \times 10; \text{or WATTS OUTPUT} = 90.$$

Setting down the output and input values in the efficiency formula and solving, we can conclude that the efficiency of this tube is equal to:

$$\frac{\text{WATTS OUTPUT}}{\text{WATTS INPUT}} \times 100 = \frac{90}{125} \times 100 = .72 \times 100 = 72\%$$

It is obvious that the actual power output of the tube itself cannot equal the power input of the plate circuit for reasons already cited. The power lost is equal to the difference between the watts input and the watts output or, in this case, the power lost is equal to 125 minus 90, or 35 watts.

The amount allowed for plate power dissipated in heat, etc., is known as "plate dissipation". This amount should not be exceeded during the normal operation of a tube and a definite limit is set, called the "safe plate dissipation". Since safe plate dissipation is really the power lost it is rated in watts. All power tube characteristics charts list the "safe plate dissipation" in watts for the various types of tubes, and it should now be understood what is meant by this term.

The 50 watt tube in our explanation has a safe-plate dissipation of 100 watts. Thus, at 35 watts dissipation, it is being operated within safe limits. Any power tube worked at such a low efficiency as to permit the plate dissipation to exceed the safe limit would be subjected to considerable abuse and in a very short time its ability to supply electronic emission would cease, hence there is only one conclusion or result, the tube's useful life would be shortened.

The interior of the glass envelope of a power tube often takes on a milky white appearance, which condition may be attributed to operating the plate for long periods at an excessively high temperature. This smoky white color indicates that certain gases have been freed from the metal plate. A plate should never be heated to show more than a cherry red.

The heat energy dissipated by the plate of large power tubes, in the one kilowatt class and upward, is normally so high that water cooling is resorted to in order to obtain a satisfactory output of power. Water cooling increases the efficiency of a power tube because it permits the use of a much smaller plate area than would otherwise be possible. A smaller plate reduces the space charge between the electrodes of the tube. It should be noted that although current is required to heat the filament, that is, energy in watts is consumed, yet it is not taken into consideration in the foregoing work on power rating.

GRID CURRENT AND GRID BIAS

Let us now recount a few facts regarding the grid circuit and the current drawn therein. Only a small grid current should be permitted to flow, and let it be remembered that any current in excess of a certain amount cannot serve any useful purpose. In fact, excessive grid current must be subtracted from the current that would otherwise flow in the plate circuit inasmuch as both the grid and plate currents originate from electrons ejected by the hot filament. Thus it is possible for the grid to consume energy which is a total waste by the excessive flow of grid current. Under such conditions the grid acts as a load on the vacuum tube resulting in a reduction of its output power. Furthermore, a large grid current will introduce distortion in any vacuum tube. Distortion is particularly noticeable in tubes used in transmitting and receiving circuits which handle speech and musical frequencies, as in broadcasting. A large grid current would most likely heat the grid causing it to emit electrons, and if this condition were allowed to occur the grid would cease to be an efficient controlling factor in providing the proper variations in plate current. Bear in mind that the electrons absorbed by the grid flow as conduction current; that is, a direct current through the wires, coils, or resistors contained in the outside circuit connected between grid and filament.

From the foregoing it should be clear why a grid must be operated at some definite negative potential maintained upon it at all times. What really happens when a high fixed negative voltage is applied to the grid is that the grid is prevented from actually becoming positive even at such moments as when a positive voltage is applied to it from the currents circulating in the grid circuit. This is readily explained, for the actual voltage upon the grid at any moment is merely the difference between the value of the negative bias and the amplitude values of the fluctuating voltages delivered to the grid from the grid circuit as just mentioned.

Accordingly, the flow of grid current must be controlled and this is easily accomplished by maintaining a permanent negative voltage upon it as already suggested. The value of this negative voltage or grid bias varies for different types of tubes and depends for one thing upon the amount of plate voltage used. The correct grid bias may be supplied by any one of the following methods:

(1) The bias may be obtained from a "C" battery inserted in the grid return lead.
(2) The grid return wire may be attached to some location on a resistor which supplies the necessary drop in potential when the current flows through the resistor.
(3) The voltage drop obtained across a resistor inserted in the negative lead of the high voltage plate supply may be utilized for this purpose.
(4) A small d-c generator especially built for this purpose is often used to give the requisite bias. The majority of transmitters in radio broadcast work employ either one of the first two methods, whereas commercial telegraph transmitters are more likely to employ one of the latter two methods.

With no negative bias on the grid of a power tube the plate current can run up to exceedingly high values, dissipating so much heat that the plate will become whitehot and cause serious damage to the tube.

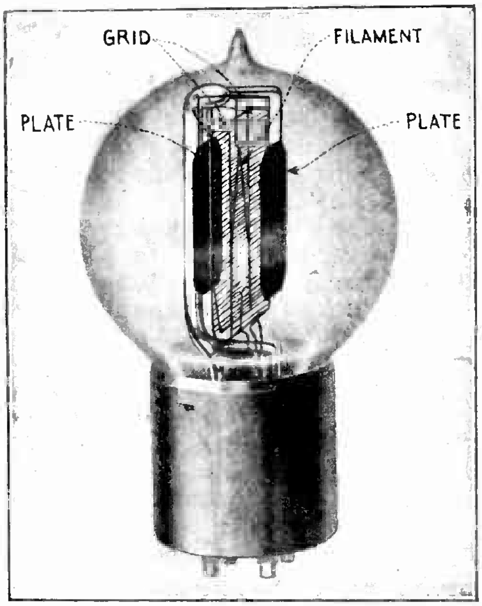


FIG. 9 - WESTERN ELECTRIC TYPE 205-D

7.5 WATT TUBES: { RCA-210, UX-841, UX-842, RCA-843, RCA-844 and RCA-865; WE-205-D and WE-271-A, DeFOREST TYPES 510 and 565.

The 7.5 watt tube is the smallest with a power rating. RCA-210 is particularly suited for transmitting circuits where cost and bulk of the apparatus and power supply are prime considerations. The RCA-210 tube is designed for use as an oscillator, modulator or power amplifier in transmitting equipment. The 7.5 watt tube is used in a large majority of amateur short-wave stations. It is known that under favorable conditions these tubes often supply sufficient antenna excitation to permit messages, carried by the radio waves, to be copied at the opposite ends of the world. These small tubes are also adaptable for use in low powered aeroplane transmitters and for speech amplifiers in broadcasting equipment. When working as a speech amplifier the tube merely functions to step up the necessarily feeble voice and musical frequencies in the output of the microphone to large values before introducing these frequencies into the main modulator-oscillator circuits. The object of amplifying the voice currents is to provide the maximum degree of modulation.

The Western Electric 205-D has similar characteristics except that a lower filament voltage is required. An outline of the 205-D is shown in Figure 9.

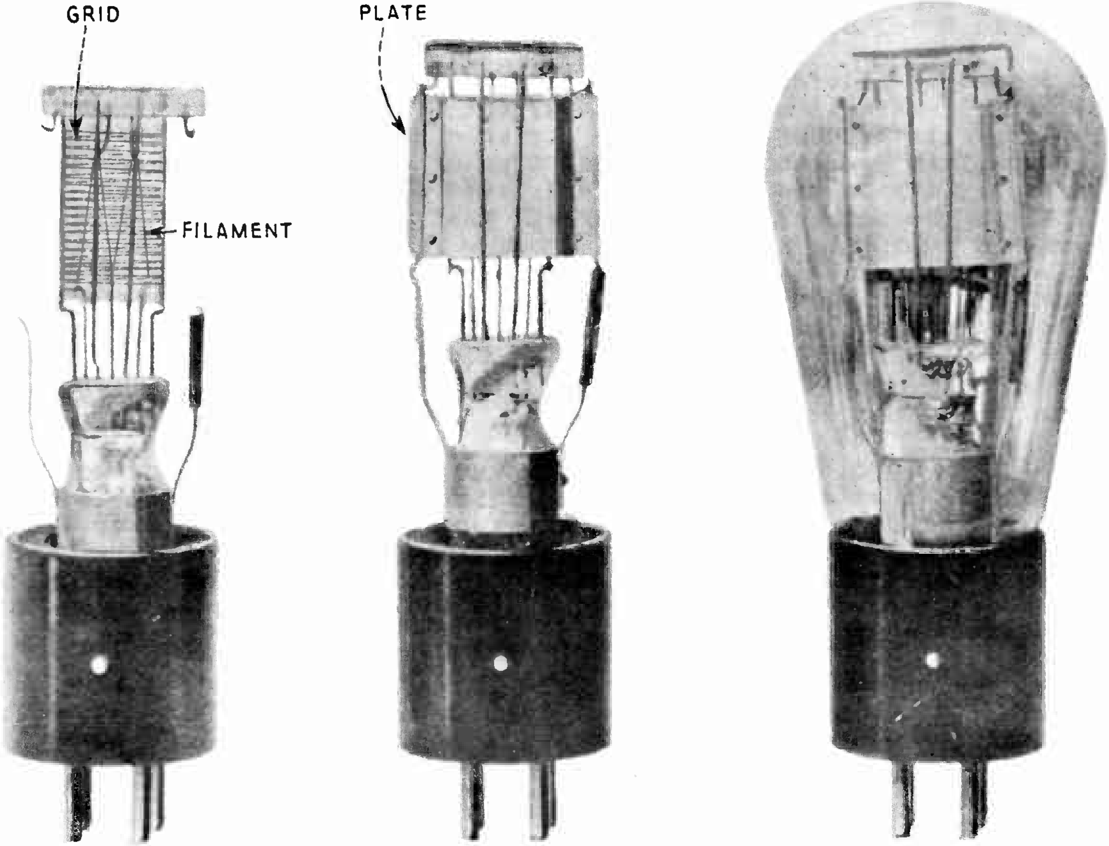


FIG. 10 - SHOWING GRID, PLATE AND FILAMENT OF UX-210 TUBE

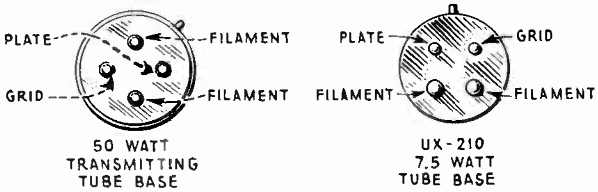


FIG. 11 - IDENTIFICATION OF PRONGS ON TUBE BASES

The views in Figure 10 show the complete tube assembly of the 210, also the grid, filament and plate construction. A sketch in Figure 11, looking at the bottom of the tube base, shows the location of the prongs. The metal shell of the socket must not be connected to ground or any other part of the circuit.

The normal output power of the RCA-210 is rated at 7.5 watts. The filament draws 1.25 amperes when operated at a filament terminal e.m.f. of 7.5 volts. Care should be exercised to operate filaments at constant voltage rather than constant current and always at the rated voltage. A filament voltmeter connected directly to the socket terminals should be used to indicate correct working conditions. It will be noticed that, due to the use of the X-L filament, its brilliancy is much less than that of the older type tungsten filament. A low emission tube caused by a severe overload and consequent overheating may be restored in some cases by operating the filament at its rated voltage with the plate voltage removed. This reactivation process can be accelerated by increasing the filament voltage to 9 volts, but not to exceed this value.

When possible, alternating current should be used to heat the filament, but in certain cases direct current is required, as in radio telephone sets(because of hum)and portable sets for portability of power supply. By using the RCA-843 type of tube, however, a-c filament supply may be used and hum level kept at a very low value. The RCA-843 is the same as a UX-210 except that it has a heater type of cathode requiring 2.5 amperes at 2.5 volts for its operation. The a.c. is, in most all cases, supplied through a step-down transformer and to provide voltage control a rheostat should be included in the primary circuit of the transformer. With a.c. the plate return lead should be connected to the mid-tap of the transformer secondary, whereas with the use of d.c. this plate lead is attached to the positive filament terminal.

Under normal conditions the plate voltage should never be more than 350 volts, the rated value, and with this plate e.m.f. a plate current of 50 or 60 milliamperes may be expected. The plate power dissipation should never be greater than 15 watts. When this tube is used in a non-modulated c.w. telegraph set (usually called straight c.w.) the plate voltage may be raised to 450 volts in order to obtain extreme output.

The amplification constant of the RCA-210 is approximately 7.5 and the mutual conductance value about 2,150 micromhos. Should a tube be required, however, having a higher amplification constant, but retaining the other essential characteristics of the RCA-210, a type UX-841 may be employed which has an amplification constant of 30 and a mutual conductance of 450 to 750 micromhos depending on plate voltage used. This tube is of especial value as a voltage amplifier utilizing resistance coupling and also as a frequency doubler. Let us mention at this time that mutual conductance values are useful for comparison purposes only since the values are computed with the tube operating under zero grid voltage conditions. This does not represent the usual operating condition for we know that in all practical circuits the grid voltage is maintained at some definite negative value and not at zero.

When used as an audio power amplifier or a modulator the value of the negative bias used should be sufficient to limit the plate dissipation, that is, the difference between output and input, to its normal value or 15 watts. For this service, however, it is desirable to use a tube having a lower amplification constant and a higher power output than the RCA-210. It is here that the UX-842 finds a place. This tube has an amplification constant of 3 and an output as a Class A amplifier of 3 watts. While the RCA-210 has an output Class A rating of only 1.6 watts, the UX-842 otherwise has the same operating characteristics as the RCA-210. No less than 15 volts negative should be applied to the grid of the RCA-210 tube with a plate potential of 350 volts. When calibrating a transmitting circuit it will be noticed that with certain adjustments the plate current is greater than the normal amount although the correct grid bias voltage is used. This effect may be traced to an amplifier tube which is oscillating or perhaps a radio-frequency voltage is being picked up from neighboring circuits. This condition is aggravated by the use of a grid leak having an inductive effect in the circuit. A grid leak should be non-inductive, or in other words, its effect should be that of only pure resistance.

It is advisable to insert either a small choke, or a resistance of 10 to 100 ohms, in the grid circuit of each tube when several are operated in multiple in order to prevent the setting up of ultra high-frequency oscillations.

We mentioned previously that the UX-842 is particularly suited for use in conjunction with loudspeakers in receiving circuits. When the 210 is employed in this connection the tube is called a "power audio amplifier" and is capable of delivering a tremendous output without distortion. The characteristic grid voltage-plate current curve of this tube is shown in Figure 12. The so-called "straight part" of this curve indicates that the tube is a typical amplifier, for it is easily seen that the slope of the curve follows almost a straight or linear line.

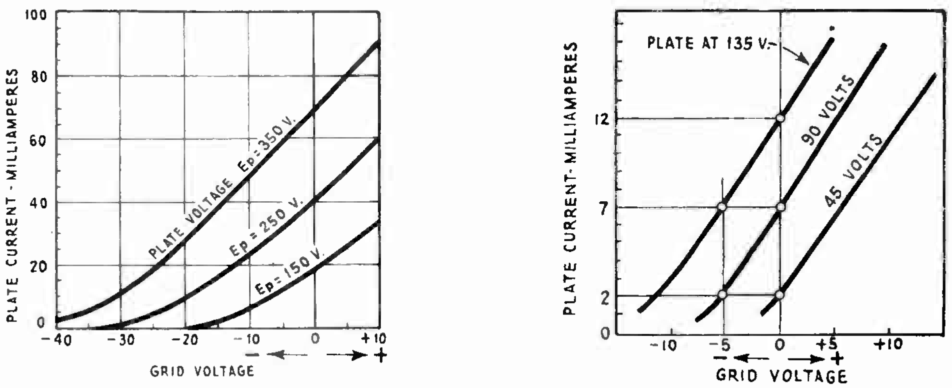


FIG. 12 - CHARACTERISTIC CURVES OF A UX-210

It should be remembered that an efficient amplifier tube provides a greatly enlarged plate current whose pulsations follow in exact accordance and repeat the wave form or modulation frequency of the signal voltages impressed upon the grid. Also, you should fully understand at this part in our course that the only function which the grid is called upon to perform is that of a control member. Any fluctuating voltage, however small, applied to it from any source will cause the electron stream passing from filament to plate (i.e., the plate current) to undergo a corresponding variation. Stated in a few words, this means amplification without distortion. Because of this inherent grid control upon the electron stream we think of the vacuum tube as essentially a voltage operated device.

The straight line variation, as shown by the curves, indicates that the UX-210 can be worked at high or low plate voltages and, with correct grid bias, will deliver the voice and musical frequencies to the loudspeaker with the naturalness of the original rendition in the broadcasting studio. Undistorted amplification is possible in vacuum tubes possessing such characteristics because large grid voltage swings can be delivered to the grid without it actually becoming positive with respect to the filament. A positive grid would attract excessive electron energy causing a large grid current and as we are already aware this undesirable condition would introduce distortion. The grid return lead of the UX-842 when used as an output audio amplifier should be connected to the negative terminal of the "C" battery. The positive terminal post of the "C" battery should be connected to the negative terminal of the filament.

As mentioned heretofore, low power tubes are used extensively in shortwave transmitters. Conservative plate voltages and power inputs should always be maintained in order to be certain that the tube will not be harmed by excessive voltages, currents, or dissipation within the tube. Abnormal conditions are usually experienced at wavelengths less than 50 meters.

The inter-electrode capacity between grid and plate of the tube provides a path of low reactance for currents of high-frequency, or at the short wavelengths. These currents have damaging effects. At long wavelengths, or low frequencies, the capacity reactances are so high that these currents are negligible. For wavelength adjustments below 10 meters great care should be exercised to prevent brush discharges in any part of the tube which are likely to cause breakdown and puncture of the tube. In order to prevent trouble of this kind it is a good rule to reduce plate voltage as the wavelength is reduced. Difficulties in operation of the 3-element 7.5 watt tube on the shorter wavelengths can be easily overcome, however, by the use of 4-element tubes RCA-844 and RCA-865. The difference between these two being that the 844 is provided with a cathode-heater type of filament.

The RCA-865 tube is especially designed for use as a power amplifier in transmitting circuits of the high radio-frequency or short-wave type. The high-frequency transmitters send out continuous wave (c.w.) telegraph signals which cover wavelength ranges as low as 15 to 50 meters, or 20,000 to 6,000 kilocycles. This frequency band may also be expressed as from 20 to 6 megacycles. One megacycle is equal to one million cycles.

This 7.5 watt tube has a plate, filament and two grids, whereas the standard three-element tube has a plate, filament and only one grid. The addition of the extra grid, called the screen or shield grid, minimizes the effects of inter-electrode capacity, that is, it prevents the so-called feed-back from plate to grid. This stabilizes the circuit in which the tube is used. Whistles, howls and other desirable effects are eliminated by the addition of the fourth element.

The theory of operation is that the control grid (the regular grid located adjacent to the filament which is found in all standard tubes) is impressed with the excitation voltages in the manner similar to that for operating any tube, but the screen grid is maintained at a neutral potential with respect to the other electrodes by suitable connection to a source of e.m.f.

The voltage for the screen grid may be obtained either from a potentiometer connected across the plate supply, from the d-c plate supply through a series resistance of approximately 25,000 ohms, or from a separate d-c source. The resistance method, using about 25,000 ohms is the most practical method for maintaining the screen grid voltage at proper value because it provides automatic regulation. When employing the resistance method, the filament supply should not be discontinued for any reason while the plate voltage is on, for this would cause the full plate voltage to be applied to the screen. When the potentiometer method, or separate source method is used the screen grid voltage should not be applied when the plate voltage is off. Under operating conditions the screen grid should never be permitted to reach a temperature which would cause it to show a color more than that of cherry red. When the screen grid is supplied with a suitable positive voltage it acts as an electrostatic screen between the control grid and the plate of the tube. The normal screen grid volts for this tube when operating either as an oscillator or r-f power amplifier is 125 volts. The need for neutralizing the radio-frequency circuits is eliminated by the use of this tube as we have just stated. A photograph of the UX-865 is shown in Figure 13. The UX-865 requires 2 amperes at 7.5 volts for the filament and 500 volts d.c. for the plate. This tube may be employed as a frequency "doubler" and intermediate power amplifier in short-wave commercial transmitters. When used for this purpose the tube's output is fed into a main power amplifier circuit which may also use tubes of the four-element type, but having a greater output power. Tubes especially designed for handling large power at high frequencies are the UV-850, UV-852, UV-860, and UV-861.

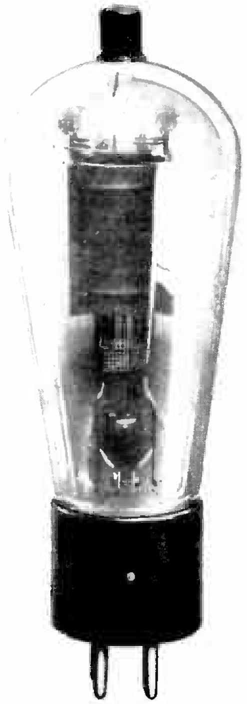


FIG. 13 TYPE UX-865

EXAMINATION QUESTIONS

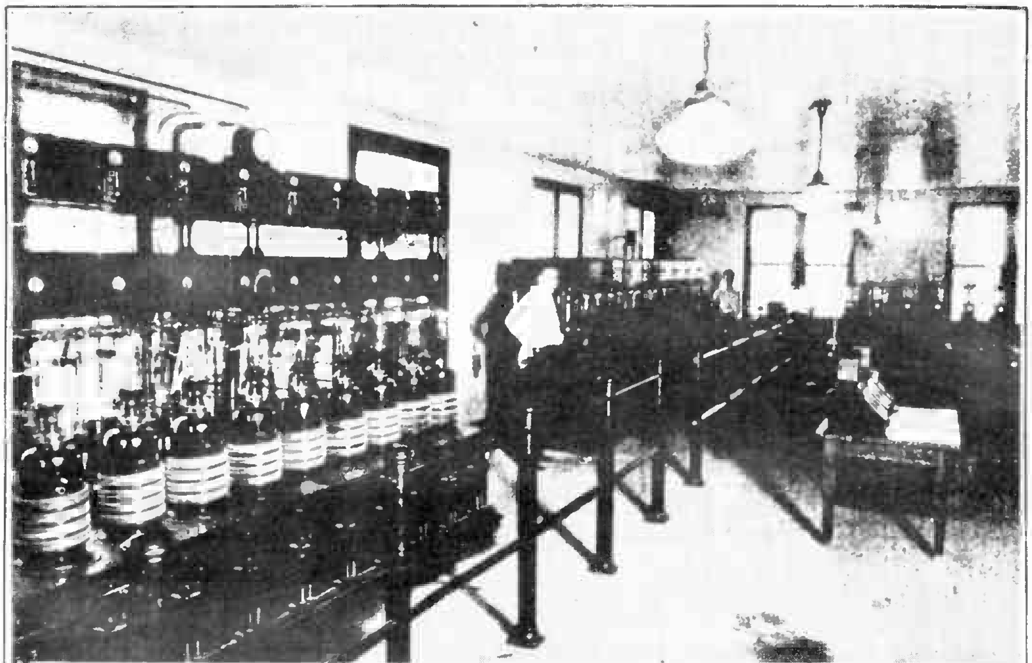
1. Name as many factors as possible which govern the amount of current drawn in the plate circuit of a vacuum tube.
2. What is meant by "safe plate dissipation"?
3. (a) How is a power tube rated?
   (b) Write the formula for efficiency in terms of watts.
   (c) Suppose the output of a tube is 69 watts and the input 115 watts. Find the efficiency of this tube in percent.
4. What material is generally used for filament wire in power tubes?
5. (a) State as many reasons as you can that make the reactivation of a tube necessary.
   (b) In general, what method of procedure would you conform to in order to reactivate a tube?
6. (a) Why should amount of grid current in a power tube be controlled?
   (b) State several ways how this may be accomplished.
7. (a) How are ultra-high frequencies suppressed in coupled circuits consisting of two or more power tubes?
   (b) Of what practical importance is the four-element tube?
   (c) What is the fourth element and in a general way what is its effect within the tube?
8. Define class A, class B and class C amplifiers.
9. Why cannot single tube class B amplifiers be used in a-f amplification?
10. What is the advantage of screen-grid tubes?

TRANSMITTING VACUUM TUBE CHARACTERISTIC CHART

GENERAL INFORMATION										CLASS "A" AMPLIFIER OR MODULATOR							
Type	Filament Volts	Filament Amperes	No. of Electrodes	Average Voltage Amplification Factor	Average Plate Resistance Ohms	Average Mutual Conductance M. Mhos.	Type of Base	Type of Filament	Type of Cooling	Maximum Plate Volts	Maximum Plate Watt Dissipation	Grid Bias (Eg) Negative Volts	Plate Milliamperes	Oscillator Input Watts per Mod. Tube	Peak Grid Swing - Volts	Power Output 5% 2nd Harmonic	Load Resistance
RCA 210	7.5	1.25	3	8	5150	1550	UX	XL	Air	425	12	35	18.0	4	31	1.6	10200
RCA 841	7.5	1.25	3	30	40000	750	UX	XL	Air	425	12	9	2.2		9	(225) (volts)	250000
RCA 842	7.5	1.25	3		2500	1200	UX	XL	Air	425	12	100	28.0	8	96	3.0	8000
RCA 843	2.5	2.5	3		5150	1550	UY	Cathode Heater	Air	425	12	35	18.0	4	31	3.0	10200
RCA 844	2.5	2.5	4	74	125000	600	UY	Cathode Heater	Air								
RCA 865	7.5	2.0	4	150	200000	750		XL	Air								
WE 205D	4 to 5	1.60	3	200 to 300	3000 to 4500		100-M or 115-B		Air	300		10 to 20	15 to 30				
WE 205E	4 to 5	1.60	3	200 to 300	3000 to 4500		100-M or 115-B		Air	350		10 to 30	15 to 30				
WE 271A	5.0	2.0	3	8.5	2850		134-A or 137-A	Cathode Heater	Air	400		25 to 30	39.0				
WE 252A	5.0	2.0	3	5.0	1700		130-B or 131-A		Air	450		65	43.0				
RCA 203A	10.0	3.25	3	25.0	6000	4200		XL	Air								
RCA 211	10.0	3.25	3	12.0	3400	3530		XL	Air	1000	75	52	.072	40	52	10.0	7000
RCA 845	10.0	3.25	3	5.0	1800	3000		XL	Air	1000	75	147	0.075	122	147	23.0	7500
RCA 850	10.0	3.25	4	550	200000	1250		XL	Air								
RCA 852	10.0	3.25	3	12	10000	1200	UX	XL	Air								
RCA 860	10.0	3.25	4	200	180000	1100	UX	XL	Air								
WE 211D	10.0	3.0		11 to 13	3000 to 4000		112-A	Oxide Coated	Air	750 to 1000	100	50 to 60	.005				
WE 242A	10.0	3.25		12.5	3500		112-A	Oxide Coated	Air	1250	100	45	0.150				
WE 276A	10.0	3.0		12	3500		112-A	Oxide Coated	Air	1250	100	50	0.125				
WE 212D	14.0	6.003		15 to 17	2000		113-A	Oxide Coated	Air	2000		30 to 80	.130		55		
RCA 204A	11.0	3.85	3	25	6300	4000		XL									
WE 270A	10.0	9.75		16	1750	9000		Oxide Coated									
RCA 849	11.0	5.0	3	19	3200	6000		XL	Air	3000	300	104	0.110	410	98	81	12000
RCA 861	11.0	10.0	4	300	143000	2100	UX	XL	Air								
WE 251A	10.0	16.0		10.3	2250	4550		Oxide Coated									
RCA 851	11.0	15.5	3	20.0	1400	15000	UV	XL	Air	2000	600	65	0.300	400	60	100	3100
WE 279A	10.0	21.0		10.0	1800	5550	142-A	Oxide Coated	Air								
RCA 1652	14.5	52.0	3	14.0	3000	47000		Tungsten	Water								
RCA 207	22.0	52.0	3	20.0	3500	5700		Tungsten	Water								
RCA 848	22.0	52.0	3	8.0	2400	3300		Tungsten	Water	10000	7500	1040	0.65	7800	1025		
RCA 863	22.0	52.0	3	50.0	7200	7000		Tungsten	Water								
RCA 858	22.0	52.0	3	42.0	8700	4800		Tungsten	Water								
WE 232A	20.0	61.0		40.0	7000	5700	132-A or 133-A	Oxide Coated	Water								
RCA 862	33.0	207.0	3	43.0	2800	17150		Tungsten	Water								

TRANSMITTING VACUUM TUBE CHARACTERISTIC CHART

Type	Max. Screen Dissi- pation	R-F POWER AMPLIFIER: Maximum Operating Plate Voltages: Modulated D-C	Unmodulated D-C	A.C. (rms)	Maximum RF Grid Current (Amperes)	Typical Operation - Class B: E_p	E_c	E_d	Unmodulated DC Pl. Cur. (Amperes)	(Watts) Peak Output	(Watts) Carrier Output	Typical Operation Class C: E_p	E_c	Output
210		350	450	450	5.0	350	50		0.030	7.5	1.9	350	50	7.5
841		350	450	450	5.0	450	8		0.036	16.0	4.0	450	30	13.0
842		350	450	450	5.0							350	150	7.5
843			450		5.0	350			0.030	7.5	1.9			
844	3	500	500	500	5.0				0.020			500	7	5.0
865	3	500	500	500	5.0	500	40	125	0.030	7.5	1.9	125	80	7.5
205D		350	350	350		350			0.015 to 0.030	20.0		350		5.0
205E		350	350	350		350			0.015 to 0.030	20.0		400	110	5.0
271A		400	400	400		400	55		0.039			450	180	
252A		450	450	450		450	90		0.060					
203A		1000	1250	1000	7.5	1000	35		0.130	160.0	40.0	1000	100	100.0
211		1000	1250	1000	7.5	1000	35		0.130	160.0	40.0	1000	200	100.0
845		1000	1250	1000	7.5	1000						1000	250	75.0
850	10	1250	1000	1000	7.5	1000	8	175	0.100	120.0	30.0	1000	150	100.0
852		2000	3000	3000	10.0	2000	150		0.060	120.0	30.0	2000	250	100.0
860	10	2000	3000	3000	10.0	2000	50	300	0.060	120.0	30.0	2000	200	100.0
211D		1750	1000	1000								750		50.0
242A		1250	1250	1250		1000	80		0.150			1000	160	
276A		1250	1250	1250		100	80		0.125			100	160	
212D		1500	2000	2000		1500			0.130	250.0		1500		2000.0
204A		2000	2500	2000	10.0	2000	70		0.143	340.0	85.0	2000	175	350.0
270A		2500	3000	3000		2500	175		0.350	350.0	83.5	3000		350.0
849		2000	2500	2000	10.0	2000	200		0.260	650.0	165.0	2000	200	450.0
861	35	3000	3500		10.0	3000	60	500	0.250	600.0	150.0	3000	200	540.0
251A		2500	3000	3000		2500	260		0.600	1000.0		3000		1000.0
851		2000	2500	2000	10.0	2000	85		0.750	1200.0	300.0	2000	200	1250.0
279A		2500	3000	2500		3000	325		0.800	2000.0		3000		2000.0
1652		6000	75000		10.0	6000	450		0.600	4000.0	1000.0	6000	1200	4000.0
207		12000	15000			12 kv	600		0.900	14000.0	3500.0	12 kv	2200	15000.0
848												12 kv	2600	15000.0
863		12000	15000		30.0	12 kv	250		0.900	14000.0	3500.0	12 kv	2000	15000.0
858		16000	20000		60.0	18 kv	450		0.900	21600.0	5400.0	18 kv	3500	22000.0
232A			20000							35000.0				35000.0
862			20000		60.0	18 kv	380		4.200	100000.0	25000.0	18 kv	4000	100000.0



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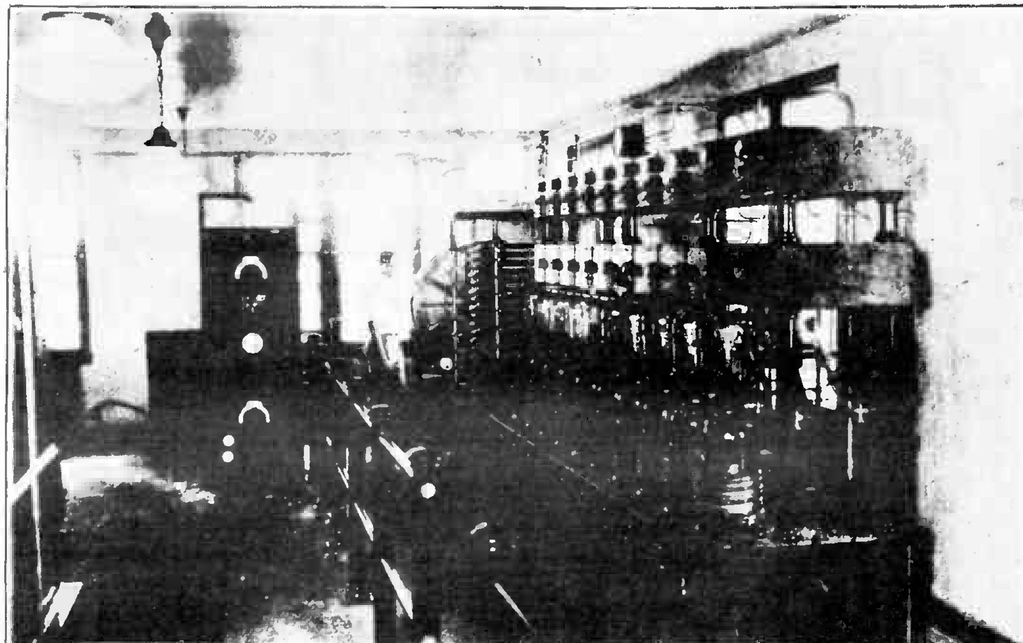

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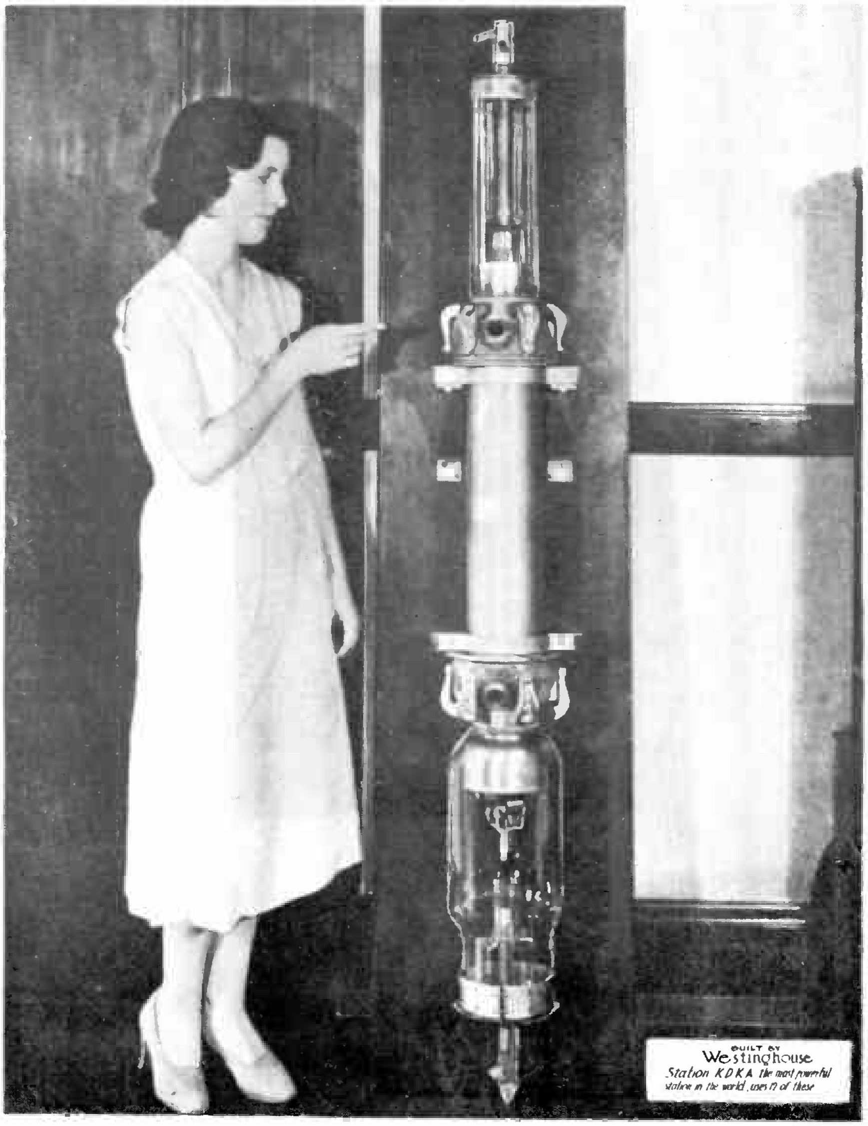
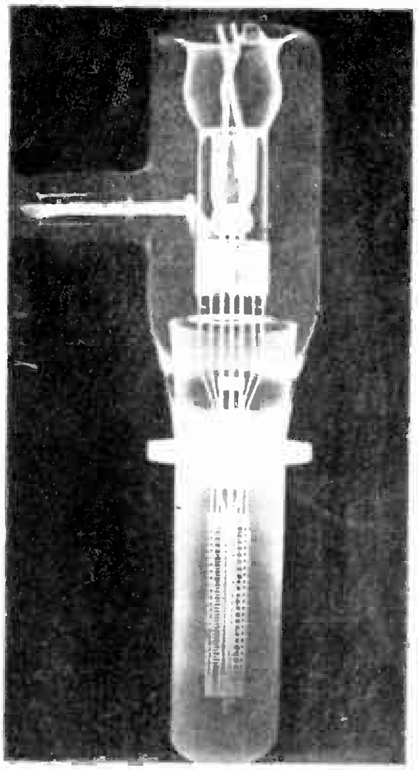


Air-Cooled and Water-Cooled Transmitting Tubes

Measuring Vacuum Tube Characteristics -

Dewey Classification R 130

VOL. 13, No. 7



X-RAY PHOTOGRAPH OF A UV-858
WATER-COOLED TUBE

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AIR-COOLED AND WATER-COOLED TRANSMITTING TUBES

MEASURING VACUUM TUBE CHARACTERISTICS

In this lesson we review standard types of vacuum tubes used in transmitting equipment. Also, we give worked-out examples of the most frequently used constants by which the characteristics of vacuum tubes of the same type may be compared when operating under exactly similar conditions — these are amplification constant, plate impedance and mutual conductance.

100 WATT TUBES: TYPES UV-203-A, UV-211, 845, 850, 852, 860, WE-211-D, 242-A, and 276-A.

The 100 watt tube is manufactured in nine types which differ only in plate impedance and amplification constant or number of electrodes. A photograph of a 100 watt tube is shown in Figure 1 All types are operated at similar filament voltages.

The UV-203-A is intended for amateur and experimental use where voltage amplification is desired. The UV-211 is used extensively in commercial transmitting circuits for oscillators, amplifiers, or modulators. The 845 is better adapted to audio frequency and modulator work than the above mentioned types. An inspection of the characteristic chart shows that the filaments of both tubes normally draw 3.25 amperes at 10 volts, the plate power dissipation being 100 watts when operating either tube as an oscillator at its normal plate potential of 1000 volts.

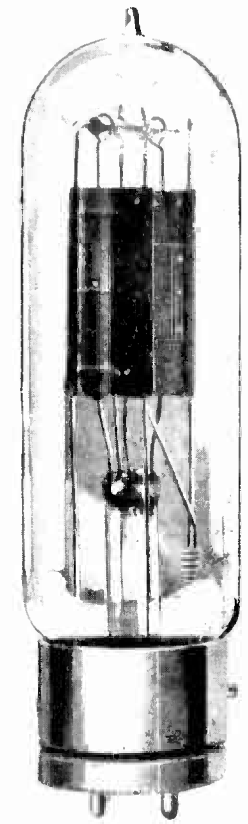


FIG. 1- 100-WATT TUBE

The UV-211 requires a very strong mechanical construction and rigid support of all the electrodes since it is used in many marine tube transmitters.

These transmitters must stand up under severe operating conditions at sea. The plate is mounted on four separate rods imbedded in the glass stem of the tube. Small helical springs attached to the upper end of the supporting rod hold the filament wire and maintain it at the proper tension, thus protecting it from shocks. An elaborate spring suspension for the filaments of small power tubes is unnecessary.

The UV-203-A possesses a very desirable characteristic which protects it from overload. If under any conditions the tube should stop oscillating or lose its negative bias the plate current would not greatly exceed its normal value, as when oscillating. This result is due to the high plate resistance of the tube. On the contrary, however, as in the case of the UV-211 tube, its plate current at zero grid would rise to such excessive values that overheating of the plate would be sure to occur, and in a short time serious damage would result. This inherent plate current characteristic of the UV-211 is due to the low plate resistance of this tube.

Certain types of modern tube transmitters utilize a crystal-controlled master oscillator, several stages of intermediate amplification, and a main power amplifier system. A 50 watt tube is often used with the quartz crystal. The tube supplies power and the crystal controls the frequency at which the continuous oscillations are generated. Experience has proven that for the reliable operation of crystal controlled oscillators, it is essential that low plate voltage be applied to any tube working in conjunction with the crystal. Low voltage permits the transmitter to be operated without fear of subjecting the crystal to excessive voltage which might cause it to crack or shatter. When

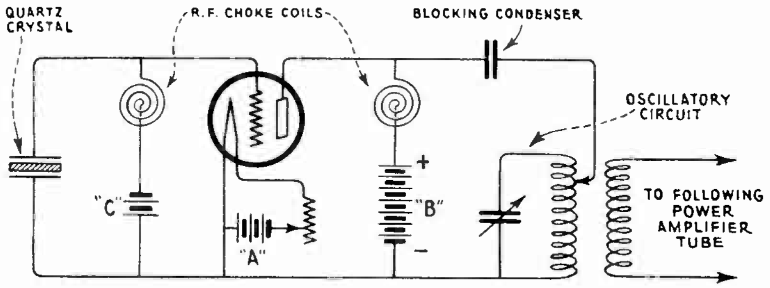


FIG. 2 - 100 WATT TUBE IN A CRYSTAL-CONTROLLED CIRCUIT

used in a crystal circuit the 100 watt tube is usually worked at 500 volts d.c. or at half normal voltage. The schematic diagram in Figure 2 shows a 100 watt tube connected in a crystal-control circuit. It is preferable to use alternating current to heat the filament and in certain commercial sets this a.c. is supplied by means of slip rings on the motor armature connected to a step-down transformer. A center tap on the transformer secondary should be used for plate and grid return leads. Filament voltage is usually controlled through a rheostat placed in the primary side of the heating transformer. When it is necessary to use direct current to energize the filament then it should be remembered to connect the plate return lead to the positive filament terminal. As in the case of all X-L filaments a voltmeter should be provided to check the e.m.f. applied.

If an overload decreases the electron emission in this tube, the activity of the filament may be restored by the reactivation process which simply requires that the filament be heated for a period of ten minutes or longer at the rated filament voltage, but with no plate voltage. If necessary the filament voltage may be raised to 12 volts, but no higher.

A protective fuse which should blow at about .2 to .25 ampere is usually inserted in the plate circuit. Remember that no fuses should ever be placed in a grid circuit since a blown fuse would be equivalent to opening the grid circuit and thus removing the negative bias. A plate voltage rheostat is quite necessary in order that the plate voltage may be lowered so as to protect the tube or other parts in case incorrect adjustments are made, which is likely to happen when first calibrating a new circuit or making regular adjustments in a circuit. The plate voltage may be increased from 1000 volts normal to 1250 volts only when using these tubes in a transmitter circuit in which the tubes are not actually modulating, i.e., when used in a non-modulated c.w. telegraph transmitter.

The UV-203-A and UV-211 are frequently used at wavelengths of less than 100 meters. Precautions should be taken in every case to keep the currents at safe values, but especially is this true in the case of tubes working in short-wave circuits. The 850, 852 and 860 are, however, better adapted to high-frequency work than the 203-A or 211. The RCA-850 is a four-element screen-grid tube, having the same plate voltage and filament characteristics as the 203 or 211 and using the same socket. This makes available a vacuum tube for high-frequency work in the 100 watt class which does not require plate voltages as high as those of the 852 or 860.

100 WATT SPECIAL SHORT-WAVE TRANSMITTING TUBE, TYPE UX-852

The UX-852 tube illustrated in Figure 3 is designed for use as an oscillator or power-amplifier in transmitting circuits operating on 5, 20 and 40 meters. It is also well suited for use as a crystal-controlled oscillator by operating it at less than the rated plate voltage. This tube has a very low inter-electrode capacity made possible by its special construction. Its plate to grid capacity is only 3.3 micromicrofarads as compared to 8.0 mmfd. for the UX-210. Observe in the photograph how the plate and grid electrodes are mounted on separate stems with the connecting leads entering the glass envelope through opposite sides. The filament leads are brought to the prongs on the tube base as in the ordinary tube.

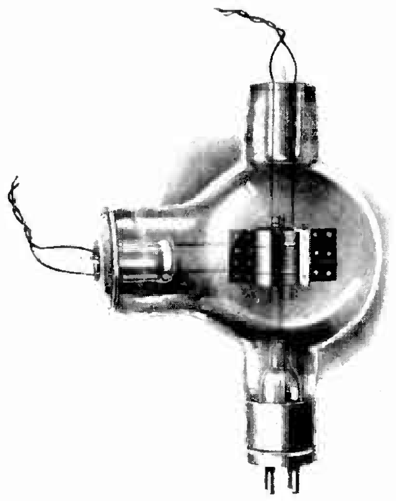


FIG. 3 - TYPE UX-852

On 20 meters, the tube will oscillate with stability and under certain conditions will deliver power on 0.7 of a meter.

The double end or T-shaped glass envelope with leads coming out at safe distances from one another prevents damaging base flashes. Connections to each of the grid and plate electrodes is made through two large stranded leads brought out from each stem as we have just mentioned.

These parallel leads permit large circulating currents to be carried safely at the high frequencies and therefore it is imperative that both leads be always used. The X-L filament used in the tube gives a high electron emission. The filament power is rated at 32.5 watts. The tube base should always be mounted so that the filament wire will occupy a vertical position. Alternating current should be supplied to the filament whenever possible. Plate and grid return leads should be connected to the electrical center (center tap) of the filament heating winding of the power transformer.

Although the normal plate voltage for the tube is 2000 volts, this voltage may be raised to 3000 provided the plate dissipation does not exceed 100 watts. Radiating fins on the plate permit a very large heat dissipation at this point. Because of the impracticability of measuring the output of a tube working on short wavelengths its correct operation may be judged sufficiently accurate by observing the plate. Plate temperature should never be permitted to increase above a certain value that would cause it to become more than cherry red in color. If the plate is heated to a cherry red, this color may be taken as an indication that the energy dissipated in heat is equivalent to 100 watts, resulting from electron bombardment of the anode or plate. Remember that whenever a circuit employing this tube is adjusted, the tube loss, that is, the difference between output and input, must always be kept within the safe limits of 100 watts.

The filament of this tube may be reactivated, like the X-L filaments of tubes previously mentioned, by operating at the normal filament voltage for ten minutes or longer with the plate voltage supply disconnected. The activity of the filament may be accelerated by increasing the filament voltage to 12 volts, but no more. In cases where an overload has liberated a large amount of gas this reactivation process will not be successful.

A fuse of the proper size to blow at 10 amperes should be inserted directly in series with the plate supply lead in order to protect the grid, wiring, etc., from overheating when improper adjustments of the circuit have been made. As we have cautioned before a fuse should never be placed in the grid circuit of any tube, because if it should accidently open or blow it would remove the grid bias from the tube with the result that the plate current would immediately run up to a dangerous value.

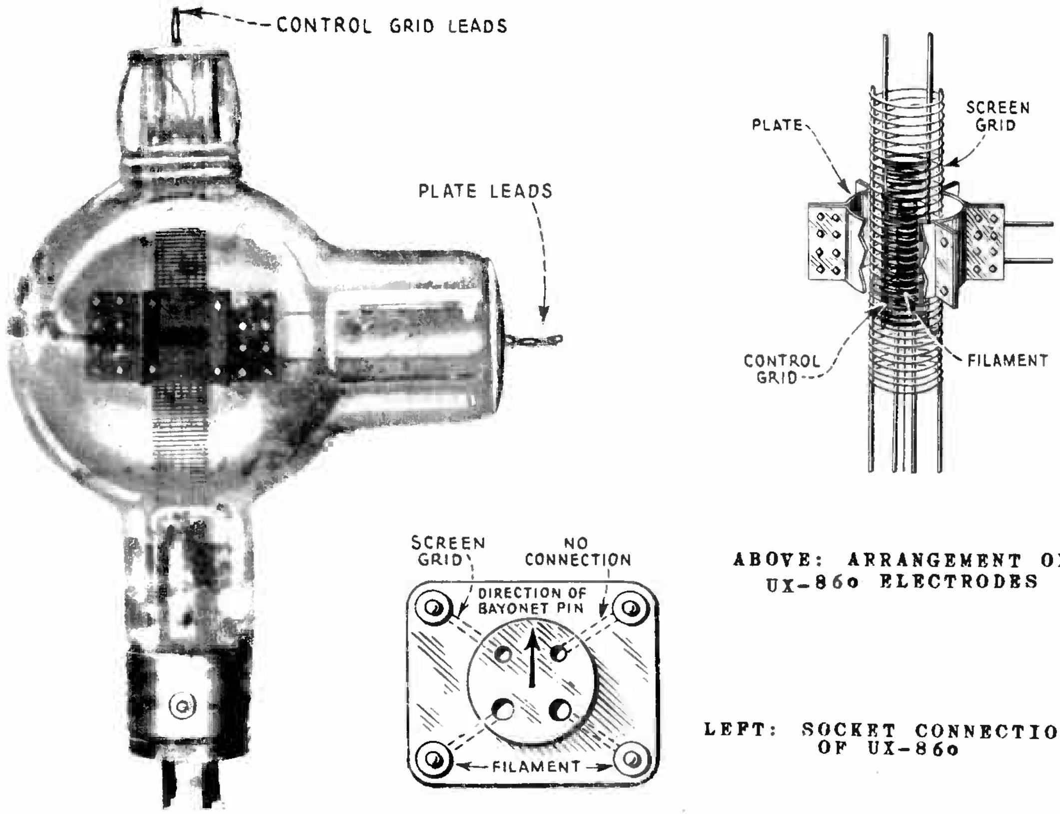
UX-860 FOUR-ELEMENT TUBE,OUTPUT 100 WATTS.

The RCA-860 tube is especially designed for use as a power amplifier in transmitting circuits of the high radio-frequency or short-wave type. The high-frequency transmitters send out continuous wave (c.w.) telegraph signals which cover wavelength ranges as low as 15 to 50 meters, or 20,000 to 6,000 kilocycles. This frequency band may also be expressed as from 20 to 6 megacycles. One megacycle is equal to one million cycles.

This 100 watt tube has a plate, filament and two grids, whereas the standard three-element tube has a plate, filament and only one grid. The addition of the extra grid, called the screen or shield grid, minimizes the effects of inter-electrode capacity, that is, it prevents the so-called feed-back from plate to grid. This stabilizes the circuit in which the tube is used. Whistles, howls and other undesirable effects are eliminated by the addition of the fourth element.

The theory of operation is that the control grid (the regular grid located adjacent to the filament which is found in all standard tubes) is impressed with the excitation voltages in the manner similar to that for operating any tube, but the screen grid is maintained at a neutral potential with respect to the other electrodes by suitable connection to a source of e.m.f.

The voltage for the screen grid may be obtained either from a potentiometer connected across the plate supply, from the d-c plate supply through a series resistance of approximately 70,000 ohms, or from a separate d-c source. The resistance method, using about 70,000 ohms, is the most practical method for maintaining the screen grid voltage at proper value because it provides automatic regulation. When employing the resistance method, the filament supply should not be discontinued for any reason while the plate voltage is on, for



ABOVE: ARRANGEMENT OF UX-860 ELECTRODES

LEFT: SOCKET CONNECTIONS OF UX-860

FIG. 4 - THE 100-WATT UX-860 TRANSMITTING SCREEN-GRID TUBE

this would cause the full plate voltage to be applied to the screen. When the potentiometer method, or separate source method, is used the screen grid voltage should not be applied when the plate voltage is off. Under operating conditions the screen grid should never be permitted to reach a temperature which would cause it to show a color more than that of a cherry red.

When the screen grid is supplied with a suitable positive voltage it acts as an electrostatic screen between the control grid and the plate of the tube. The normal screen grid volts for this tube when operating either as an oscillator or r-f power amplifier is 500 volts. The need for neutralizing the radio-frequency circuits is eliminated by the use of this tube as we have just stated. A photograph of the UX-860 is shown in Figure 4. The UX-860 requires 3.25

amperes at 10 volts for the filament and 2000 volts d.c. for the plate. This tube may be employed as a frequency "doubler" and intermediate power amplifier in short-wave commercial transmitters. When used for this purpose the tube's output is fed into a main power amplifier circuit which may also use tubes of the four-element type, but having a greater output power. Tubes especially designed for handling large power at high frequencies are the UV-861, 858 and WE-251-A.

250 WATT TRANSMITTING TUBE, TYPE UV-204-A.

The large UV-204-A tube illustrated in Figure 5 has an output rating of 250 watts and it also utilizes an X-L filament. The normal plate voltage is 2,000 and the filament is rated at 42.5 watts, drawing 3.85 amperes when supplied with the specified terminal e.m.f. of 11 volts. The maximum safe plate power dissipation is 250 watts. A very high emission is obtained by the use of the thoriated filament; this emission reaches approximately 5 amperes with the filament voltage at 11. The high emission permits the tube to perform very satisfactorily in telephone circuits because the complexities of speech and musical sounds cause large peak values of current.

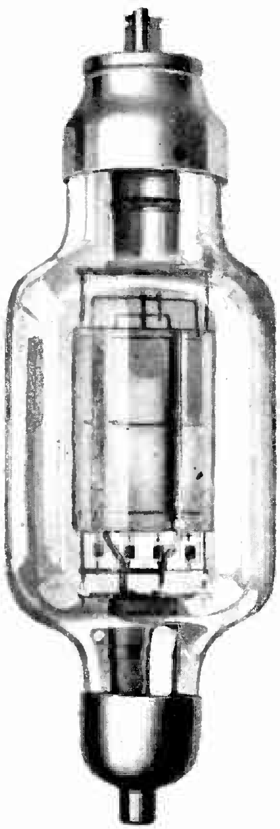


FIG. 5 - TYPE UV-204-A

Two or more 250 watt tubes are sometimes arranged in multiple (parallel) to provide a greater output than that afforded by the use of several smaller tubes. The "Converted P-8" commercial tube transmitter, found on many ships, employs two tubes of this type arranged "back to back" and obtaining their plate excitation from a.c. at 500 cycles supplied from a 500 cycle a-c generator feeding into a step-up power transformer. The note received from a transmitter of this kind whose c.w. is modulated according to the characteristics of a 500 cycle a-c current is somewhat similar to a 500 cycle spark set using a quenched gap. The theory is briefly as follows: The two tubes are connected with their plates to opposite ends of the transformer secondary. Only the positive halves of the alternating current cycles will be utilized. When one plate is positive the other is negative and it is obvious that only that tube which receives a positive half cycle will be active in generating the continuous high-frequency oscillations. Thus each tube alternately generates c.w. energy whose modulation is similar to the wave form of the 500 cycle a.c. This is called "full-wave self-rectification".

Since the positive voltages constantly fluctuate between zero and maximum and zero values according to the wave form of the a-c output of the transformer, then it follows that the resultant modulation produced by rectifying both halves of an alternating current power supply will appear as shown by the curve in Figure 6. There are four completely modulated groups shown in this curve. Each complete modulation produces one click in the receiving head set and since a 500 cycle a.c. is supplied and two tubes are working "back to back", the radiated wave will consist of 1000 completely modulated groups per

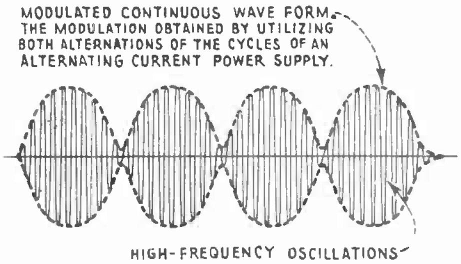


FIG. 6 - MODULATION PRODUCED BY RECTIFYING BOTH HALVES OF AN A-C POWER SUPPLY

second, hence 1000 clicks per second will be heard in the head set. This is known as a 500 cycle note and the tone has somewhat the characteristics of a spark transmitter employing a quenched gap as previously mentioned.

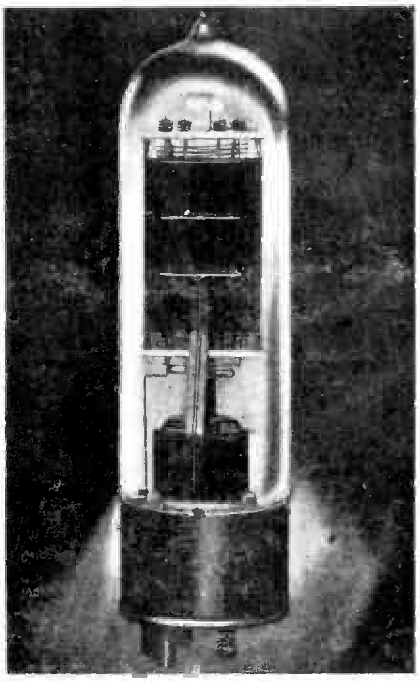


FIG. 7 - WESTERN ELECTRIC 212-D

A tube of similar output rating to the 204-A is manufactured by the Western Electric Company under the number 212-D. In mechanical construction, the tubes are somewhat different in that the 212-D is a single ended tube rather than double ended. The amplification constant of the 212-D is lower and is better adapted to operate as a modulator than the 204-A. A photograph of this tube is shown in Figure 7.

THE UV-849 AND WE-270-A

These two tubes are very similar in their characteristics and both are adapted for use as oscillators, modulators, r-f power amplifiers or audio amplifiers. They are both of the double ended variety, the 849 being shown in Figure 8 and the WE-270-A shown in Figure 9.

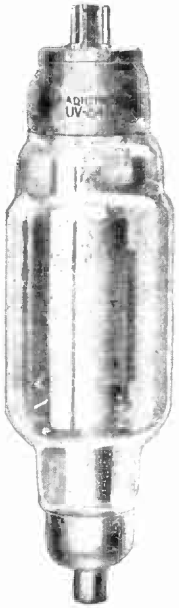


FIG. 8 - TYPE UV-849

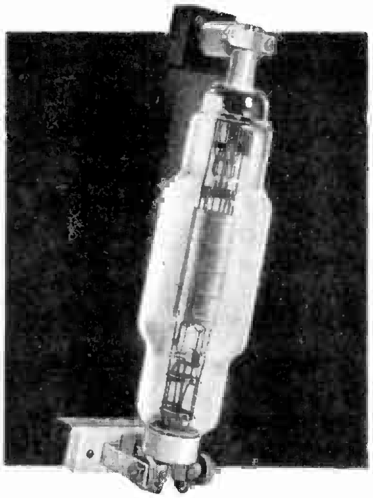


FIG. 9 - WESTERN ELECTRIC 270-A

THE UV-861 FOUR-ELEMENT TUBE, OUTPUT 500 WATTS.

Model UV-861 is a four-element tube of the screen grid type, designed for use as a power amplifier in transmitting circuits. It may also be used as an oscillator and is especially adapted for use in short-wave transmitters. One or more tubes of this type are used in the final power amplifier stage and work directly into the antenna. The

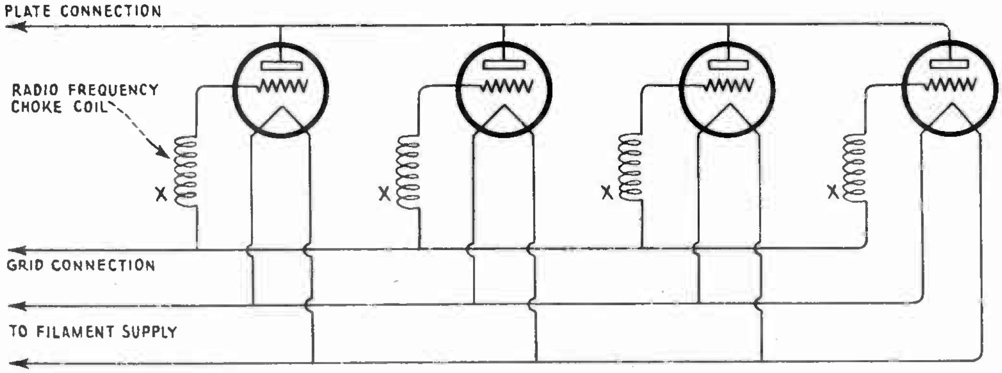


FIG. 10 - WHERE R-F CHOKE COILS MIGHT BE PLACED IN GRID CIRCUITS

input voltages for the UV-861's are supplied by one or more UX-860's located in the intermediate stages. The UV-861 is also constructed with a shield grid, and consequently the use of stabilizing methods in the radio-frequency circuits is likewise unnecessary as in the case of the UX-860. The normal screen-grid volts for this tube is 750 volts. The inter-electrode capacity is reduced to 0.05 mmfd. by the use of the screen grid. In certain types of transmitters the UV-861 plate is energized by a d-c double commutator generator having two 1500 volt windings arranged in series to deliver the normal 3000 volts. A plate current of approximately 0.5 ampere will be drawn at this plate voltage. Power tubes are usually provided with a plate voltage rheostat

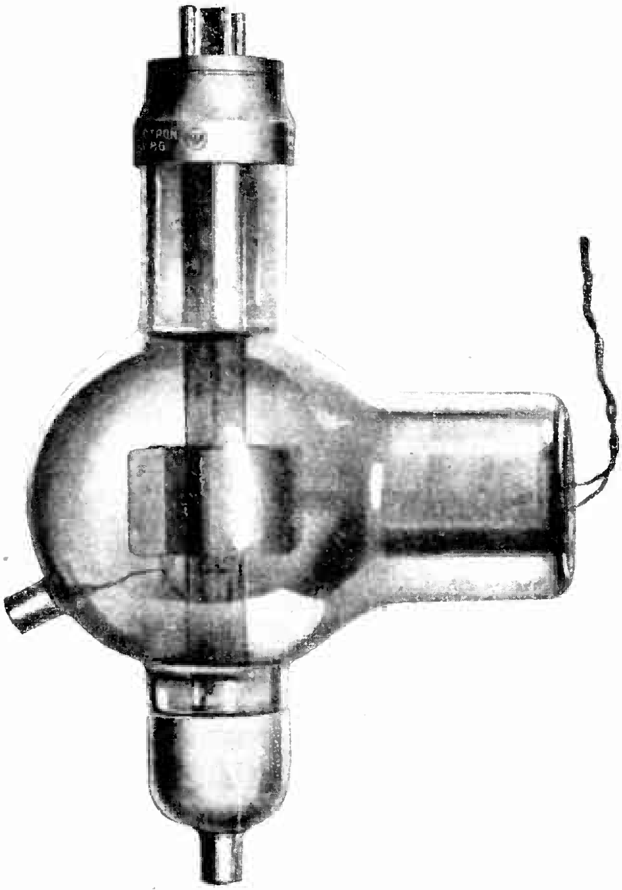


FIG. 11 - PHOTOGRAPH OF A TYPE UV-861 TUBE

so that during the process of tuning the transmitter the plate voltage may first be reduced and then later increased to normal as the various radio-amplifier stages are adjusted for maximum output in the antenna. The normal d-c plate current is 172 milliamperes, but under certain conditions of service this current reaches values as high as 350 ma. The X-L tungsten filament takes 10 amperes at a normal terminal e.m.f. of 11 volts.

In a majority of transmitting circuits, power tubes are connected in parallel, which is also known as multiple arrangement. The actual manner in which tubes are connected in parallel is in itself a simple method of connecting all the grids together and all the plates together. The filaments are energized from the same source of supply. When power tubes are operated in multiple, a small radio-frequency choke coil or a resistance of suitable size, for instance, one with a resistance of from 10 to 100 ohms should be inserted in the grid circuit of each tube as shown in Figure 10. These coils, or resistors (if used) should be placed as close as possible to the grid terminal of the socket for the purpose of suppressing parasitic oscillations. The unwanted oscillations are ultra-high frequencies which would circulate through the circuits and cause undesirable effects if no provision were made to suppress them. They are set up under certain resonant conditions existing between the tubes and the coupled circuits.

An amplifier circuit may consist of six or more tubes connected in multiple in order to supply an antenna system with a large power; the sum total of the watt output of the individual tubes used in the system. Multiple arrangement provides a practical means for dividing the load among several low-powered tubes, and in this way the need for a very large expensive tube and power plant is eliminated. A photograph of the UV-861 is shown in Figure 11.

1000 WATT TRANSMITTING TUBE, TYPE UV-851.

One of the largest sized air-cooled transmitting tubes has an output rating of 1000 watts. This power is obtainable without any increase in plate voltage over the 250 watt tube. The plate of the UV-851 requires 2000 volts d.c. and its plate power dissipation is 750 watts when the tube is worked as an oscillator.

We have already explained about the high efficiency of a thorium filament over a pure tungsten filament. This difference in materials, however, may be better appreciated after reviewing the following facts in regard to the practical operation of the UV-851. The X-L filament of this tube requires a power consumption of 170 watts to give a total electron emission of approximately .20 ampere whereas, on the other hand, a pure tungsten filament requires at least 600 watts to give an equal electron emission. In the latter case, that is, with a tungsten filament, the high emission could be obtained only by considerably overheating the tube; the additional power required would have to be dissipated at the plate. When operated under certain conditions this tube is capable of delivering a radio-frequency output of 1 kilowatt or more.

The mechanical construction of the 1000 watt type tube differs somewhat from that of the ordinary tube. There are four parallel filament wires used, each wire being supported by a helical spring to maintain proper tension at all times. The grid is constructed of a heavy square mesh of molybdenum wire, it being mounted in a frame which is anchored to the plate structure with an insulator for the purpose of holding the grid in correct mechanical relation to the plate. The heat generated by the plate or anode is dissipated with the aid of narrow wings attached to the plate. These thin metal pieces are called "radiating fins". A similar tube is manufactured by the Western Electric Company listed as type 251-A.

20 KILOWATT WATER-COOLED TRANSMITTING TUBES UV-207 AND UV-858.

These tubes are adaptable to either broadcast or telegraph transmitting circuits. Although the 20 kw. tube is one of the largest of the family of vacuum tubes, yet it functions exactly similar to its smaller brothers in the lower power classes. The tube is well suited for use as an oscillator, power-amplifier, or modulator. The enormous power which this water-cooled tube is capable of delivering can be appreciated by noting the magnitude of its various operating voltages. For instance, the plate is energized with 15,000 volts and the current in the plate circuit when the tube is oscillating is 2 amperes or 2000 milliamperes. The radio-frequency current, or oscillations generated by this tube, circulates through the grid circuit and reaches values up to 30 amperes. A grid d-c current of about 100 milliamperes can be safely carried by the grid. The filament e.m.f. is 22 volts which gives a filament current of nearly 52 amperes. A

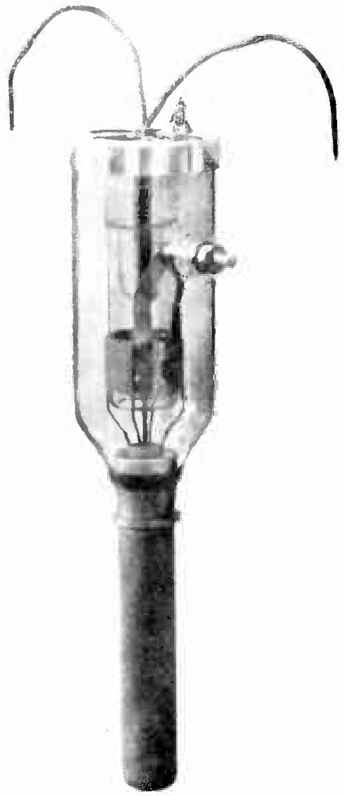


FIG. 12 - A 20 KILOWATT WATER-COOLED TUBE

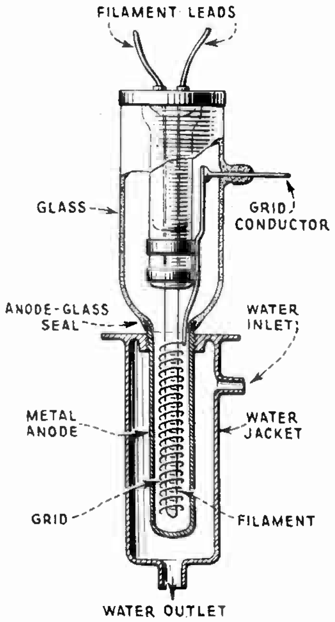


FIG. 13 - TUBE AND WATER-JACKET ASSEMBLY

filament starting resistance is necessary in order to raise the filament temperature gradually, and when the normal operating point is reached the plate voltage is automatically applied.

While the rated output of these tubes is 20 kw. the maximum safe plate dissipation is 10 kw. It will be recalled that lost power is generally dissipated in heat. The long copper cylinder shown at the bottom in the photograph of the tube in Figure 12 is the anode or plate. By inserting the anode in a water-cooled jacket the heat produced at the plate is quickly extracted. The complete water-jacket assembly is so arranged that a flange screwed to the threaded portion of the plate holds the plate in the jacket and special precautions are taken to insure a water tight joint by the use of a suitable gasket of rubber or other material between the flange and jacket. The tube is supported only by the water jacket — see Fig. 13.

There is sufficient space between the inside of the jacket and the copper cylinder or plate to permit a column of water to circulate freely around the plate for the extraction of heat generated at this point. About two or three gallons of water per minute is constantly pumped past the surface of the copper anode and through the system from cooling coils. The water circulation is maintained by electrically driven centrifugal pumps. The temperature of the water is usually measured after it has passed the hot anode. This is known as the outlet temperature, 70 degrees Centigrade generally being set as the limit. It is obvious then that the thermometer is located at the point of highest water temperature. The cooling water is never permitted to boil nor are air pockets allowed to form around the anode which might cause overheating of the water. This condition

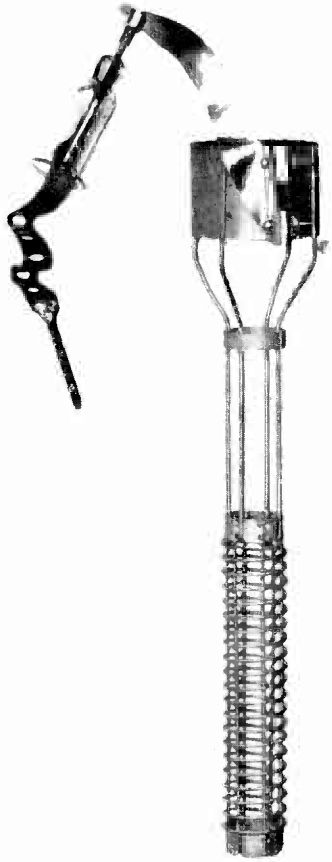


FIG. 14 - GRID CONSTRUCTION

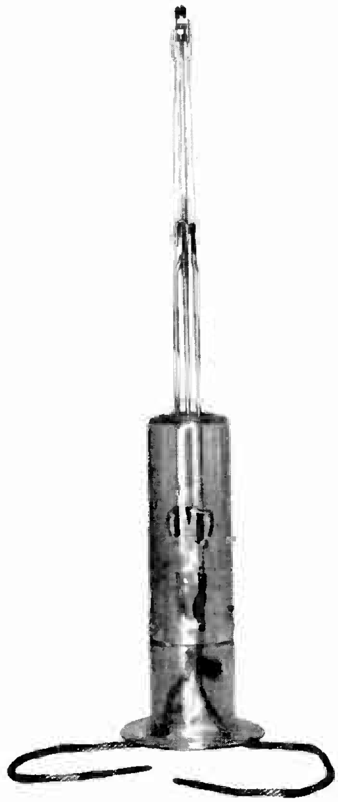


FIG. 15 - CATHODE CONSTRUCTION

would be evidenced by a singing or buzzing noise from the jacket while the power is on, this noise indicating the presence of steam bubbles at the surface of the anode.

Only water surrounds the metal anode and as can be seen in the photograph the other elements are supported by the glass cylinder with the conductors brought out at safe distances from each other. A simple cross-sectional sketch of the water-cooled vacuum tube is shown in Figure 13. The grid and cathode of a 20 kw. tube are shown in Figs. 14 and 15 respectively. It can be seen in Fig. 13 that the plate itself is a hollow cylinder with filament and grid mounted inside. An air-tight seal is made between the copper edge of the cylinder and the glass shell. The tube is very thin and delicate where this union between glass and metal is made.

It may be interesting to note the dimensions of this tube in order that we may compare it with the small receiving tubes which we so frequently handle. However, when we consider the immense amount of d-c power which is converted into radio-frequency power by this tube, its dimensions do not seem unduly large. The maximum overall length of the tube is 19 5/8 inches, the diameter of the glass bulb is $4\frac{1}{4}$ inches, while the weight of the tube alone is 2 pounds and 12 ounces. The dimensions given seem relatively small and are made possible because of the special means of keeping the temperature within safe limits by both water and air cooling. The air cooling is the natural heat radiation which takes place at the outside glass walls and water-jacket while the water cooling is due to direct conduction from the hot cylindrical plate to the water. It will be remembered that it is the electronic bombardment which causes the plate or anode to become the hottest element in the tube outside of the filament which is a normal condition for the latter.

An interlock or circuit breaker between the water circulating system and the electrical circuits is set to open if the water supply fails for any reason or if the tube develops trouble. The filament and plate voltages are instantly disconnected by the opening of the interlock.

Because of the high plate potential of several thousand volts, the plate must accordingly be insulated from the water tank and metal piping which is normally grounded. The use of a fairly long length of rubber hose connecting the water-jacket to the water source and also, by using pure water in the circulatory system, the insulation and resistance is built up to the order of several hundreds of thousands of ohms. This resistance is between the high potential anode, which is in direct contact with the water, and the cooling system and, in turn, the ground.

A tendency for a heavy scale or deposit to form on the outside of the anode (the scale being similar to that collecting on the boiler tubes) may be attributed to the use of water containing a high percentage of mineral matter, especially sulphates and carbonates. The chemical content of the cooling water should be determined by analysis. The water must be pure and have a fairly high specific resistance. A length of about 15 feet of $\frac{1}{2}$ inch rubber hose is all that is required with high resistance water (4000 ohms per centimeter cube) in order to build up the necessary high resistance between the jacket and the inlet and outlet pipes. A length of hose is wound around a cylindrical form with each coil of hose being located under a water-cooled tube in the transmitter.

It can be readily understood that the need of pure water is a very important feature in the operation of large broadcasting stations or any station employing water-cooling for vacuum tubes. The water used in a certain radio station had a specific resistance of only one-tenth that of the water recommended for such purposes.

The table below shows the chemical content held in solution in this water, and we give this list for those of our students who may be interested in work of this kind.

	Per 100,000	Grains Per Gallon
Silica	1.08	.63
Iron oxide alumina	.25	.15
Calcium carbonate	2.16	1.26
Magnesium carbonate	5.00	2.92
Potassium carbonate	3.86	2.25
Sodium sulphate	3.65	2.14
Sodium chloride	14.00	8.17
Total Solids	30.00	17.52

Specific Resistance 359 ohms.

If the composition of cooling water is such that scale cannot be avoided then it is obvious that the tubes must be removed and cleaned at frequent intervals, the frequency of cleaning depending, of course, upon the rate at which the deposit is formed. The danger of accidental breakage is always entailed in the removal of these tubes because they are apt to stick in the water-jacket. A gentle twisting back and forth and at the same time raising the tube carefully will usually loosen it sufficiently to permit its removal.

In order that the glass envelope will not be subjected to an electrostatic strain the external wiring from the transmitter circuits and the leads attached to the electrodes are kept at reasonably safe distances from the glass.

You will recall that glass is a dielectric material, hence, electrostatic strains set up by the relatively large oscillating currents are likely to puncture the comparatively thin walls of the glass. Again observe the photograph of the 20 kw. tube and note how the two filament leads are brought out at the top whereas the grid conductor comes through the center of the glass bulb. If the filament leads swing and strike the glass at any time trouble would arise from corona, resulting in almost certain puncture of the glass.

A transmitter employing tubes of this power may have the oscillating frequency, allocated by the Radio Commission at Washington, maintained within the prescribed limits of 50 cycles by the use of a quartz crystal. A circuit consisting of a quartz crystal, an oscillatory circuit, and a low-power amplifier tube, may be set up to supply the initial oscillating current of the desired frequency. This frequency, after being stepped-up through several stages of intermediate amplification, finally provides a satisfactory amount of radio-frequency voltage for excitation of the grid of the 20 kw. tube

A special tube of the water-cooled variety for use on high frequency has been developed and is known as the UV-858. An x-ray photograph of this tube is shown on the inside front cover page.

MEASURING VACUUM TUBE CHARACTERISTICS

There are several constants by which vacuum tubes of similar type may be compared when operating under exactly similar conditions. We will explain in the following paragraphs how to calculate the amplification constant, plate impedance and the mutual conductance. Although these constants do not enable us to determine exactly how a particular tube will perform in a circuit under certain operating conditions, yet they do provide a very convenient means for us to determine the relative efficiency to be expected from tubes of similar type.

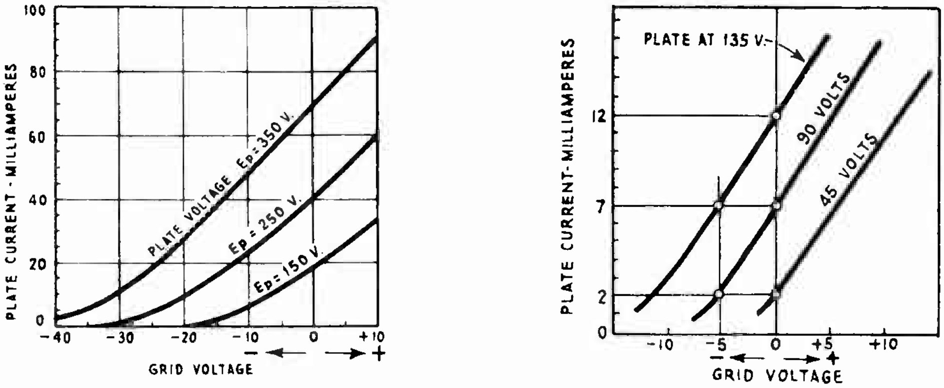


FIG. 16 - CHARACTERISTIC CURVES OF A UX-210 TUBE

AMPLIFICATION FACTOR OR CONSTANT. Mu (μ) is the symbol for this constant. Amplification constant may be defined as the measure of the effect of the grid voltage on the plate voltage, or stated more fully, it is the ratio of the change in plate voltage to a corresponding change in grid voltage which produces the same effect in the plate current. This relation may be expressed as a formula in the following manner:

$$\text{AMPLIFICATION CONSTANT} = \frac{\text{CHANGE IN PLATE VOLTAGE}}{\text{CHANGE IN GRID VOLTAGE}}$$

With the aid of the curves at the right in Figure 16 we will work out an example that will enable anyone to calculate the amplification factor of any tube whose characteristic curve is available. The three curves show the characteristics of the same tube, a UX-210 tube. when worked at three different plate potentials. The first curve is the 135 volt curve, the second 90 volts and the third 45 volts.

In our example let us consider only the 135 and 90 volt curves in order to find the ratio of change in plate voltage to a corresponding change in grid voltage which would give a change in plate current exactly similar for each grid and plate variation. Reference to the curves tells us that when working the tube with the grid at zero potential the flow of plate current is 12 ma. (milliamperes) with the plate at 135 volts. It is readily seen that by reducing the plate voltage from 135 to 90, a difference of 45 volts, we obtained a reduction in plate current of 5 ma.

Let us now locate a point on the 135 volt curve which tells us the value of plate current for a grid bias of negative 5 volts. To do this we follow the vertical line upward from the −5 location on the bottom horizontal line (the line upon which the grid voltages are marked) until the vertical line crosses the curve. Beginning at the point of intersection we follow the horizontal line to the left until it meets the vertical line upon which the plate current values are marked. The plate current value is seen to be 7 ma. However, this same 135 volts, as previously shown with the grid at zero potential, gives a plate current of 12 ma. Hence, it should be clear that with the tube operating under these two different grid voltages, zero and −5, the plate current dropped from 12 to 7 ma. Observe now, that we have the same value of change of plate current, or 5 ma., for two different plate voltages, 135 and 90, corresponding to the two different grid voltages, zero and −5. Briefly, it could be stated that it required only 5 volts change of grid to make the same plate current change that was obtained by a difference of 45 volts on the plate.

Any set of values might be taken from the curve for our example, providing these values are somewhere along the linear or straight portion of the curve. It will be recalled that amplification is obtained by working a tube at some location where the slope of the curve is a straight line.

The numerical values in the preceding paragraphs may now be substituted in the formula and then solving we get:

$$\text{AMPLIFICATION FACTOR} = \frac{135 - 90}{5 - 0} = \frac{45}{5} = 9$$

Then 9 is the amplification constant of this particular 210 type tube.

PLATE IMPEDANCE. This constant is the measure of the change in plate voltage to the resultant change in plate current under conditions of a constant grid potential. The term "constant" means that grid voltage remains unchanged or fixed during the procedure of plotting the characteristic curve. Note that grid voltage will not be varied this time, as for instance, in the case of preceding explanation. In this example we can use the same plate voltages and plate current values as in the foregoing examples, when the plate voltage was lowered from 135 to 90 and it was shown that the plate current decreased from 12 to 7 ma.

After first changing milliamperes to amperes, all of the necessary values can be substituted in the plate impedance formula as follows:

$$\text{PLATE IMPEDANCE} = \frac{135 - 90}{0.012 - 0.007} = \frac{45}{0.005} = 9000 \text{ ohms.}$$

Note: 12 ma. = 0.012 ampere.
7 ma. = 0.007 ampere.

Then 9000 ohms is the plate impedance for this particular tube.

MUTUAL CONDUCTANCE. The mutual conductance value of a tube is a good indication of the efficiency of a tube used as an amplifier, because this value represents the effect of the applied grid voltage upon the plate current. Now then, a certain relationship exists between the plate current and grid voltage which the characteristic curve shows in pictorial form. This relationship is when the quotient of the change in plate current divided by the change in grid voltage produces a certain change in question in plate current, providing the plate voltage is maintained consistent. Or, it can be said that mutual conductance is the ratio of the amplification factor (mu) to plate impedance. This statement may be written:

$$\text{MUTUAL CONDUCTANCE} = \frac{\text{AMPLIFICATION CONSTANT}}{\text{PLATE IMPEDANCE}}$$

We shall again use the curves of the UX-210 tube to obtain our working values. Observe that with the plate at 90 volts the plate current is 7 ma. and with the plate at 45 volts the current is only 2 ma Thus, a 45 volt reduction on the plate causes a 5 ma. reduction in current. It can also be seen from the curve that it requires the grid to be changed 5 volts (that is, from a zero value to −5 volts) in order to effect a similar change of 5 ma. in plate current. Of course, the plate voltage must in this case remain constant or unchanged when the grid voltage is shifted from zero to −5.

To work out this example we must multiply the 5 ma. change in plate current by 1000, or 5 x 1000, and then divide this result (5000) by the required grid voltage change of 5 volts: we then have $\frac{5000}{5} = 1000$.

Then 1000 micromhos is the mutual conductance for this tube when operating at these particular "B" and "C" voltages, that is to say, at 90 volts plate and zero grid.

The unit "micromhos" expresses the conductance value which is the opposite to resistance. Resistance is measured by the unit "ohm", and notice that "ohm" is spelled backwards or "mho" to express conductance. Furthermore, the prefix "micro" indicates a millionth part of the unit "mho".

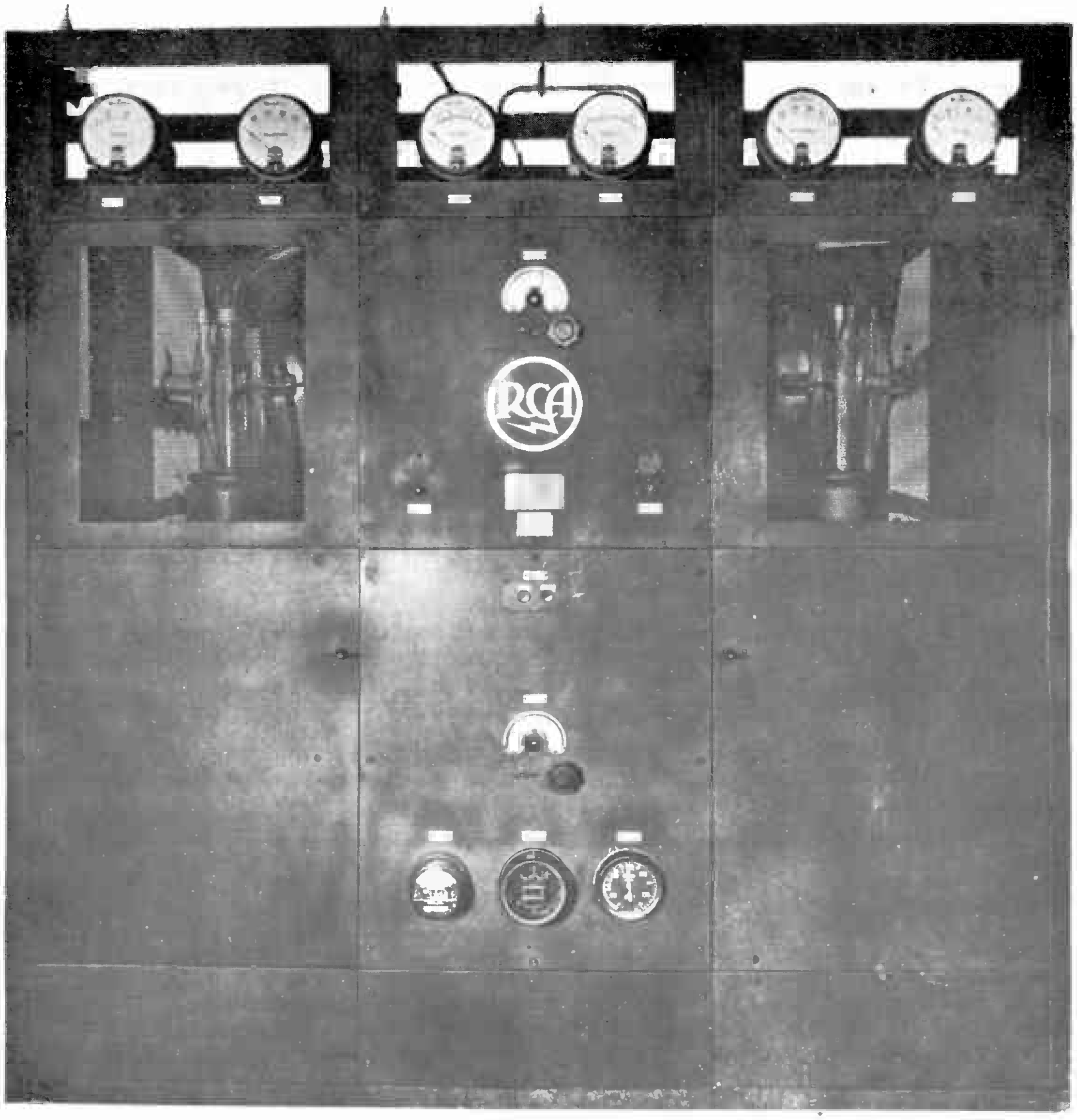
Any change in either plate voltage or grid voltage will cause the mutual conductance to vary, and consequently mutual conductance can be expressed only for one set of conditions, that is, with the tube working at particular "B" and "C" voltages.

At the left in Figure 16 are three curves which show the characteristics of a UX-210 when operated with plate voltages of 150, 200 and 350 volts respectively.

EXAMINATION QUESTIONS

1. What is the advantage of class C amplification over class A?
2. Where is class A amplification generally employed?
3. Why cannot class C amplifiers be used in audio-frequency work?
4. What is the adventage of a single tube of large rating over several small tubes giving the same total rating?
5. How may several power tubes of similar type be connected in order to supply a large output power to an antenna system?
6. Draw a simple sketch showing three tubes connected in the manner suggested by your answer to Question 5 immediately above.
7. Should a fuse be placed in series with the grid of a power tube and why?
8. (a) What practical indication have you that a tube has reached its limit of plate temperature and what limit should never be exceeded?

   (b) What actually causes a plate to become hot and show color?
9. What features make it possible to build and operate a tube of such relatively small dimensions but having the enormous power rating of 20 kilowatts?
10. How is the high voltage plate of a water-cooled tube maintained at a safe operating potential with regard to the water supply tank and other parts which are normally grounded?



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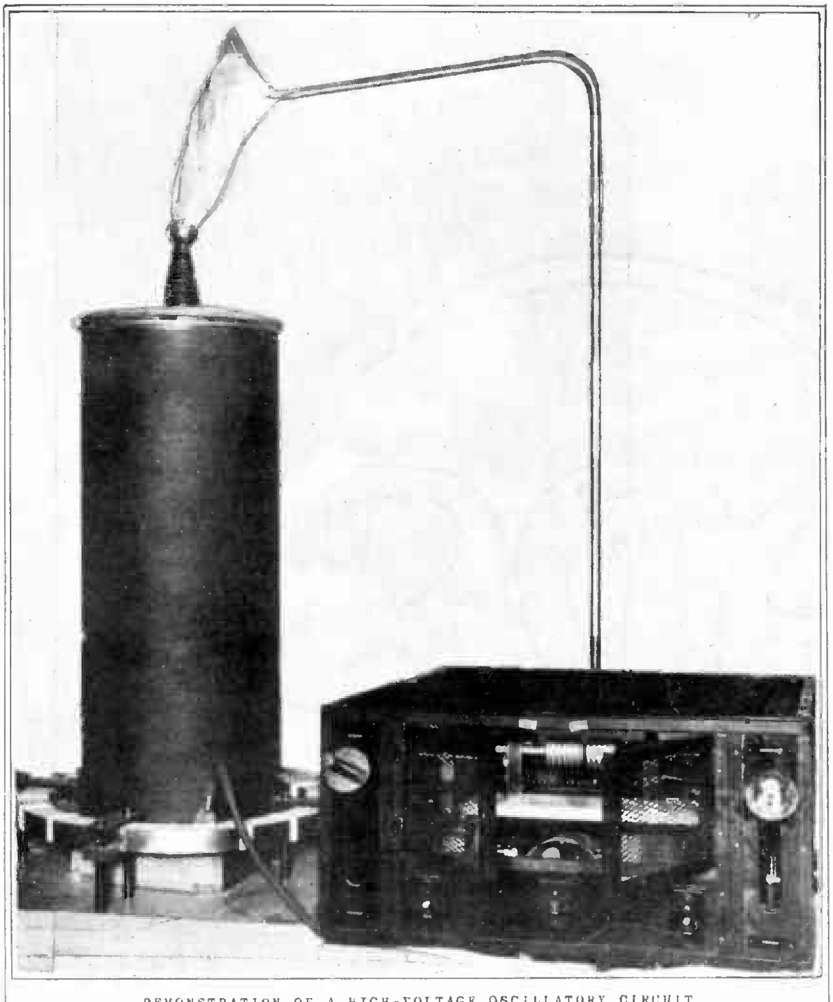

DEMONSTRATION OF A HIGH-VOLTAGE OSCILLATORY CIRCUIT PRODUCING A SPARK DISCHARGE ACROSS AN OPEN GAP.

Resonance and the Oscillatory Circuit

VOL. 14, No. 1

Dewey Classification R 140

THE OPERATOR IN THIS PHOTOGRAPH KEEPS A SHARP WATCH FOR STRAYING FREQUENCIES AND IS SHOWN MANIPULATING MICROMETER TUNING CONTROL IN THE LABORATORY OF R.C.A. COMMUNICATIONS AT RIVERHEAD, LONG ISLAND.

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RESONANCE AND THE OSCILLATORY CIRCUIT

IMPEDANCE

A coil of wire possesses a property called INDUCTANCE, and it may be made of such a wire that it offers a measurable OHMIC RESISTANCE to current flow. A condenser possesses the property called CAPACITY; if the conductivity of the leads and plates is not good, the OHMIC RESISTANCE may be of measurable value.

If we connect a coil of wire, first to a source of direct current and then to a source of alternating current, both of the same voltage, the flow of resulting current measured in amperes is greater when the coil is connected to the direct current source than when connected to the alternating current source. This result is obtained because the counter-electromotive force of self-induction in the direct current circuit is only of momentary duration, the effect being noticed only when the current is turned on or off. The effect produced when the coil is connected to an alternating source, however, is quite different. Since the current intensity is continually changing the effects of self-induction are found to be continuous. This results in a back pressure or counter-electromotive force, which must always be taken into account in determining the net voltage which causes the current to flow.

The flow of steady direct current through the coil is opposed only by its ohmic resistance, ($I = E \div R$). The flow of alternating current is impeded not only by the ohmic resistance, but by an additional obstacle due to self-induction and called REACTANCE. This is measured in equivalent ohms, and is considered positive when due to an inductance coil, and for this we use the term inductive reactance.

When a condenser is connected across a source of direct current, it will charge up to the line voltage, but will not pass any current then unless its dielectric insulation is defective. If the leads to the condenser plates have a measurable resistance, the charging rate will be slower, but the condenser voltage will finally equal the line voltage. When the condenser is connected across a source of alternating current, the flow of current is impeded not only by the ohmic resistance but by the additional obstacle called REACTANCE, which is due to the back pressure or counter e.m.f. caused by the opposition of the condenser to any change in the quantity and polarity of its charge. Since this counter e.m.f. is opposite in direction to the counter e.m.f. which would be developed in an inductance coil at that point, the reactance of the condenser or capacitive reactance. is considered negative with respect to inductive reactance.

Reactance Values. The fundamental formulas for (1) Inductive reactance and (2) Capacitive reactance are as follows:

(1) Coil reactance formula $X_L = 6.28 \times \text{Frequency} \times \text{Inductance}$.

(2) Condenser reactance formula $X_C = \dfrac{1}{6.28 \times \text{Frequency} \times \text{Capacity}}$

Where: Reactance is measured in ohms,
Frequency " " " cycles per second,
Inductance " " " henries,
Capacity " " " farads.

Impedance Values. Any inductance coil will have some value of resistance, though sometimes small, and in effect the coil resistance is in series with the coil inductance. When these two properties are present in the same material, their combined effect is termed IMPEDANCE. The relation between the values of the impedance (Z). reactance (X) and resistance (R) is given in the equation:

$$Z^2 = R^2 + X^2$$

Now this relation may be conveniently shown by what is known as the "impedance triangle", for the equation above represents Z as the hypotenuse of a right-angled triangle having X and R as its other

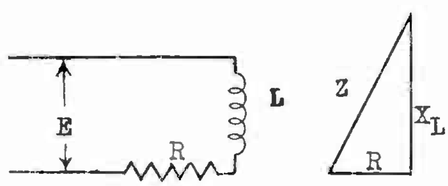


Fig. 1 - SERIES INDUCTANCE AND RESISTANCE

two sides, as shown in Fig. 1. This is for the combination of a resistance with an inductive reactive(X_L) which, as we stated before, is considered positive, and is drawn upwards from the resistance line in the figure.

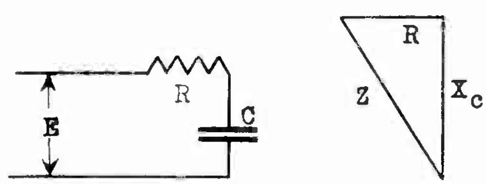


Fig. 2 - SERIES CAPACITY AND RESISTANCE

The same general equations hold good for the condenser having poor conductors, which is in effect a perfect capacity in series with a resistance. The impedance triangle for this condition is shown in Fig. 2, with the capacitive reactance (X_C) graphed downward from the resistance line because capacitive reactance is exactly opposite in effect to inductive reactance.

We have shown the resistance as being part of the coil or condenser construction. Usually the reactance of a choke coil is very high compared to its resistance; likewise the resistance of a condenser is usually low compared to its reactance. Even if they were perfect the rules would still hold for any external resistance in series with the terminals of the pure reactances.

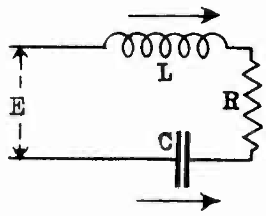


Fig. 3 - SERIES INDUCTANCE, CAPACITANCE AND RESISTANCE

Consider the impedance of a path containing a condenser, a coil and a resistance in series, as in Fig. 3. The equation for this is:

$$Z^2 = R^2 + (X_L - X_C)^2$$

because the net reactance is the difference between the inductive and the capacitive reactances.

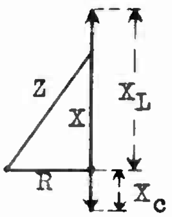


Fig. 4

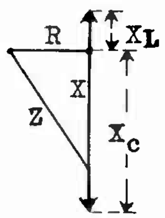


Fig. 5

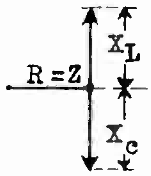


Fig. 6

There will be three conditions possible as follows:

1. X_L is greater than X_C as in Fig. 4.
2. X_L is less than X_C as in Fig. 5.
3. X_L is equal to X_C as in Fig. 6.

An inspection of the foregoing conditions shows that the impedance becomes smallest when it is equal to R, which happens when X_L and X_C have exactly the same numerical value as in Fig. 6; then $(X_L - X_C)$ becomes zero, and

$$Z^2 = R^2$$

$$\text{Whence } Z = R$$

Returning to the paragraph on reactance values, we find that lowering the frequency of an applied alternating current will decrease the inductive reactance of a coil, and increase the capacitive reactance of a condenser. Applying this principle, we can change Fig. 4 into Fig. 6 by merely lowering the frequency of the supply line. We could also change the impedance triangle of Fig. 5 by raising the frequency of the line, which decreases X_C and increases X_L until they are equal and this condition would be as shown in Fig. 6.

SERIES RESONANCE

From the foregoing we see that whenever an alternating voltage is applied to a circuit consisting of a capacitance and inductance in series there will be some frequency at which their reactance values are exactly equal, and being of opposite signs, will balance out. The alternating current flow is then determined only by the ohmic resistance of the path. This condition is called RESONANCE, and the particular frequency at which it occurs for a given circuit is called the "resonant frequency" of that circuit.

To determine this frequency in terms of circuit constants we note that the conditions at resonance may be expressed as follows:

$$X_L = X_C \text{ which is the same as: } 6.28fL = \frac{1}{6.28fC}$$

$$\text{Whence } f = \frac{1}{6.28\sqrt{LC}}$$

For currents of that frequency, the series arrangement is known as an "acceptor circuit."

Voltages in Series Resonant Circuit. If we let E equal the line voltage then line current I equals $E \div Z$. At resonance, I equals $E \div R$.

$$\text{The voltage across the coil: } E_L = IX_L = \frac{X_L E}{R}$$

$$\text{The voltage across the condenser: } E_C = IX_C = \frac{X_C E}{R}$$

From these equations we realize that in a series resonant circuit the voltage across the coil is numerically equal to the voltage across the condenser, and that each may be many times greater than the line voltage, depending on the ratio $X_C \div R$.

PARALLEL RESONANCE. In Fig. 7 we show a diagram of an inductance and a condenser connected in parallel with respect to the applied voltage. This is known as an "anti-resonant" or "rejector circuit" because this combination offers an extremely high impedance to the flow of line current at the frequency at which the inductive and capacitive reactances are numerically equal.

The difference between series and parallel resonance is determined by whether the same current set up by the e.m.f. at the source flows

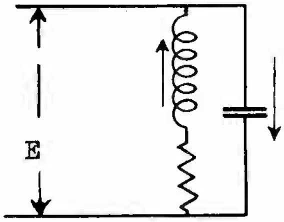


Fig. 7 - PARALLEL RESONANT CIRCUIT

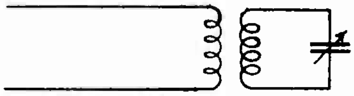


Fig. 8 - SERIES RESONANT CIRCUIT INDUCTIVELY COUPLED TO CURRENT SOURCE

through both the coil and condenser in succession, or whether the current from the source divides into two separate currents, part flowing through the coil and part through the condenser. A comparison of Figs. 7 and 8 will help you to understand this point.

Voltage in Parallel Resonant Circuit. The voltage across the coil, and likewise the voltage across the condenser, is identical with the line voltage. But we find that the current through the coil may be quite high, as shown by an ammeter connected between one side of the coil and one side of the line. In the same fashion we may insert an ammeter between one side of the condenser and the adjacent side of the line, and find a very high current there indicated. This occurs in spite of the fact that an ammeter in the other supply lead will indicate that the net current coming from the source is quite low. This sounds curious, but no more so than the case of the series resonant circuit, in which the voltage across a reactance was appreciably higher than the supply voltage. In the parallel resonant circuit, the currents through the coil and through the condenser are each about 1/4 cycle different in phase from the impressed electromotive force. The coil current lags behind the voltage, and the condenser current leads the voltage. The currents are in an opposite sense to each other, and the net current from the line can be found either by mathematical calculations or by graphing the values in a "vector diagram," of which the impedance triangle is one form.

What causes the high current we mentioned, and where does it flow? The counter-electromotive forces developed by the coil and by the condenser are opposite in direction, or 180 degrees different in phase. This is illustrated on the circuit diagram of Fig. 7 by drawing an arrow pointing up alongside the coil, to indicate the direction of the counter e.m.f. there at a given instant, and drawing an arrow pointing down alongside the condenser, indicating the opposite direction of its counter e.m.f. Forgetting the presence of the supply line, the coil and the condenser form a continuous series path, in which two counter e.m.f.'s are being simultaneously developed, and in the same direction around the coil-and-condenser circuit. This addition of counter-electromotive forces causes the flow of a quite considerable circulating current, which is limited by the resistance of the circuit, since the reactances balance out from the series standpoint. So you see that the circulating current is opposed by very little series impedance, while the line current is opposed by quite a high parallel impedance.

THE OSCILLATORY DISCHARGE — ANALYSIS

Fig. 9 represents a condenser of fairly high capacitance connected to a direct current charging source. After charging in this way, the condenser may be discharged within a reasonable time by making a metallic connection across the two plates of the condenser as shown in Fig. 10.

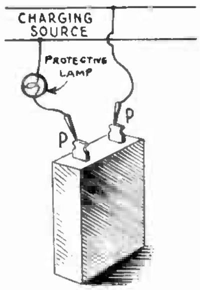


Fig. 9 - CHARGING A CONDENSER

When making the connection at plate A first, and then bringing the free end of the wire to plate B, a spark will be seen to pass between the free end of the wire and plate B just prior to the actual contact being made. This spark is only momentary and upon completion of the spark the condenser will be found to be discharged.

In watching the discharge during the short interval of time the spark is visible, it would seem that there had been but one rush of current. In reality there were many backward and forward rushes of current while the spark was in evidence. Starting with the positive plate this discharge moves through the connecting wire to the opposite plate making it positive. This plate then discharges back into the first plate. This backward and forward rush of current continues, giving up some of its energy at each reversal, which is manifested by light, heat, and sound, until the energy originally stored in the condenser has been dissipated. This back and forward motion of current (or oscillations) finally ceases.

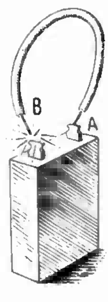


Fig. 10 - DISCHARGING CONDENSER

The number of oscillations taking place with a given charge will in this case depend mainly upon the resistance of the path between the two plates. When this path is of low resistance, there will be several cycles of current with each succeeding cycle becoming smaller in amplitude than the preceding cycle until the current dies out entirely. This gradual dying out of the oscillations is called damping.

A high resistance path will noticeably affect the discharge taking place between the two plates because the initial discharge may produce few or no reversals of current since the energy is dissipated in heat in flowing through the resistance.

For simplifying our explanation again charge the condenser as indicated in Fig. 9 and place it in series with a coiled conductor and a spark gap as in Fig. 11. A spark discharge will occur across the gap if it is properly adjusted for the condenser voltage. This discharge will consist of a series of cycles of alternating current of constantly decreasing amplitude. The events taking place during one complete cycle are explained with the aid of sketches as follows:

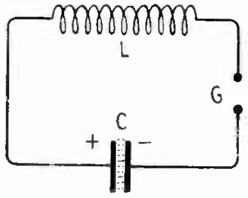


Fig. 11

Fig. 11. Just prior to the first spark, the charge in the condenser takes the form of an electrostatic field stored up between the plates. When the gap breakdown voltage is equal to the condenser terminal voltage, a spark will occur across the gap, causing current to flow through the inductance.

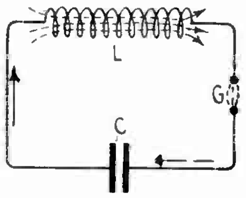


Fig. 12

Fig. 12. The flow of discharge current has set up a strong magnetic field around the inductance. As the electrostatic field reaches zero, the current reaches its maximum, and the magnetic field flux is at its maximum. This field collapses, inducing an e.m.f. which is opposite to its original counter e.m.f. and therefore in the same direction as the original impressed e.m.f.

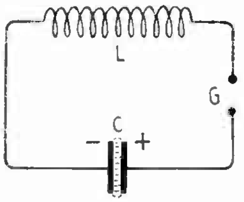


Fig. 13

Fig. 13. The e.m.f. induced in the inductance by the collapse of the magnetic field causes a current to flow in the same direction as the original discharge current. This continued current charges the condenser to the opposite polarity, but with somewhat less than the original charge, due to power losses in resistance, and the creation of sound and light energy at the gap.

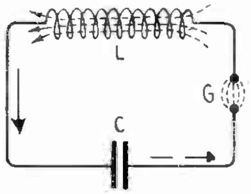


Fig. 14

Fig. 14. The first spark heated the air in the gap, lowering its resistance and lowering the critical breakdown voltage; so the gap will break down under the lessened voltage to which the condenser is now charged. The current flow resulting will be in the opposite direction to its first flow, and will build up a magnetic field again about the inductance coil but opposite in polarity to Fig. 12.

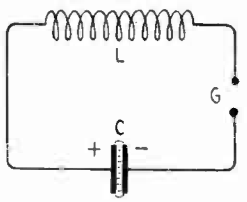


Fig. 15

Fig. 15. When the condenser is completely discharged and the current reaches its maximum, the collapse of the magnetic field will continue this second discharge current in the same direction. This charges the condenser again to its original polarity, but with a somewhat lessened charge.

This action continues, with each reversal of current becoming smaller in amplitude than the preceding one, as shown in Fig. 16.

The foregoing may be summed up by saying that when an isolated charge of electricity is applied to a condenser and the plates are connected together by an external circuit the charges do not completely neutralize at the first instant of discharge but, in fact, several alternations of current take place before a state of equilibrium is restored. When we have an inductance coil connected in series with a charged condenser as shown in Fig. 17, in which the inductance and capacity can be adjusted to various values, we can, by making the proper adjustments, cause the current to oscillate many times before it finally ceases.

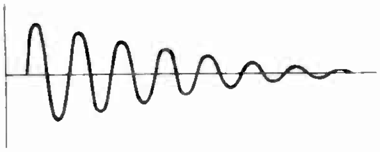


Fig.16 - DAMPED OSCILLATIONS—EACH REVERSAL OF CURRENT IS SMALLER IN AMPLITUDE THAN THE PRECEDING ONE

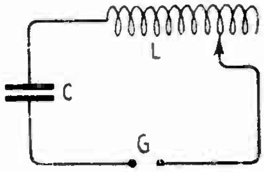


Fig.17 - AN OSCILLATORY CIRCUIT WITH VARIABLE INDUCTANCE

In the circuit just described resistance has a marked effect upon the damping of the oscillating circuit.

EFFECT OF RESISTANCE ON OSCILLATIONS

It is clear that some work is done, with the expenditure of electrical energy, when a charge of electricity moves through a circuit such as Fig. 17. Heat is generated to a certain extent in the condenser plates, leads, and the coil; appreciably more heat is generated in the spark itself. The energy loss in sound and light radiation also represents an effective resistance.

The energy-consuming effect of all these resistances is evidenced in the fact that the current intensity for each successive half-cycle is less than the preceding one, because some of the charge is wasted during each flow from plate to plate. It is simple to see that the greater the resistance of the circuit, the less will be the charge that gets through on each reversal.

Feebly damped oscillations are desired as a general rule, and therefore the resistance of a circuit must be kept low. As the resistance is increased there are fewer and fewer cycles before the charge is so reduced that the condenser voltage becomes less than the voltage required to break down the gap.

When in any given circuit a certain critical value of resistance is exceeded, relative to the other factors of the circuit, the circuit will fail to oscillate. The first discharge of the condenser will be its last, for the charge will leak off the condenser at such a low rate that a negligible magnetic field is built up, and the condenser is not charged at all in the opposite direction.

On page 4 you were given the following formula for the frequency of a typical circuit of this kind:

$$f = \frac{1}{6.28\sqrt{L\,C}}$$

This is sufficiently accurate for most of the circuits you will use, in which the demands of efficiency require low losses in resistance.

In laboratory work, when very close measurements are taken of an oscillatory circuit, the damping factor R/2L is always considered. The formula for frequency then becomes:

$$f = \frac{1}{6.28}\sqrt{\frac{1}{L\,C} - \frac{R^2}{4\,L^2}}$$

This formula is also useful in determining whether the circuit will oscillate. The last term of the above equation is the square of the damping factor. The equation may be worked out to determine just how high a value of resistance may be used and still have an oscillatory condition. If R is greater than $2\sqrt{L/C}$, the circuit will not oscillate.

If the resistance R is barely less than $2\sqrt{L/C}$ the circuit is just oscillatory. When the resistance is appreciably less the circuit will oscillate and it can then be put to practical use.

In the foregoing equations the fundamental units were used, namely, the henry and the farad. Since the oscillatory circuits we are chiefly interested in are for providing radio-frequency currents, it is well to have a formula for frequency in terms of the micro-units generally used, and neglecting the damping factor we have

$$\text{Frequency (in kilocycles)} = \frac{159.2}{\sqrt{L\,C}}$$

where L is in microhenries and C in microfarads.

RESONANCE APPLIED TO AN OSCILLATORY DISCHARGE

In order to bring out the idea of resonance as applied to radio-frequency circuits we will consider three types of systems.

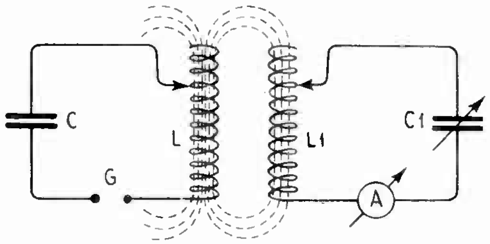


Fig. 18 - AN OSCILLATORY DISCHARGE CIRCUIT COUPLED TO ANOTHER OSCILLATORY CIRCUIT

The first consists of an oscillatory discharge circuit coupled as in Fig. 18 to another circuit having a variable capacitance, a variable inductance and a current indicating meter. The coupling is secured by placing the inductance of the latter circuit in the field of the inductance of the discharge circuit.

Let us assume the circuit LCG is set into oscillation by charging the condenser; the variable capacity C_1 is left set at some convenient value and the inductance L_1 carefully adjusted. A point will be found where the milliammeter will give a maximum deflection. At any other adjustment of the inductance the meter will indicate a lower reading. It can be shown that when the current indication is maximum, the values of L_1 and C_1 are such that their circuit has the same natural frequency as the discharge circuit. It is under such adjustments only that large values of current can be induced in the circuit L_1-C_1-A.

The same reasoning applies to the above when the inductance tap is left fixed at some value, and the condenser C_1 varied through the range of its values. Since a variable condenser provides a better means for obtaining a continuous change of values by small amounts than is afforded by the usual coil, a still more accurate determination can be made of the resonant condition of the circuit by varying C_1. Due to this fact, it may be possible to bring the circuit so closely into resonance that the current will read higher than when the frequency change was made by connecting to different turns of the coil.

The flow of current through the coupled circuit is attended by a certain loss of energy in the resistance of that circuit. This energy, being supplied by the oscillatory discharge circuit, will cause

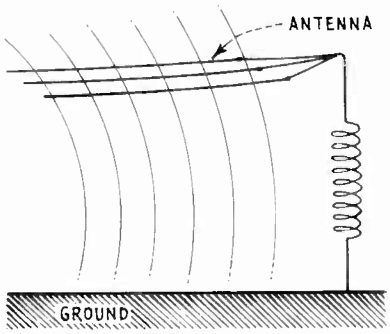


Fig. 19 - A LARGE CONDENSER IS FORMED, IN EFFECT, BETWEEN THE ANTENNA WIRES AND THE GROUND

the energy of each cycle of current in the latter to be decreased by that amount. This means that the damping of the oscillatory discharge will be greater than if the resonant circuit were removed from the influence of the discharge circuit.

The second illustration of resonance at radio frequency is given in the use of an inductance between an antenna and ground. Instead of a small condenser we have, in effect, a large condenser which is formed by the antenna wires as one plate, and the ground as the other plate. The air between constitutes the dielectric. As shown by Fig. 19 the condenser will be charged by the electrostatic field which is one component of the energy sent out into space in the form of radio waves from a transmitting station. In addition, there is an electromagnetic field component of those waves which induces currents in the antenna wires and leads due to their small inductance, even though they are straight wires. If the inductance coil has the proper value for resonating a receiving antenna with the frequency of the incoming waves, a maximum current will flow through the coil.

As a third case, if we inductively couple to the antenna coil L another circuit containing a coil L_1 and a variable condenser C, as shown in Fig. 20, the magnetic field set up about the coil L will cut the coil L_1 and induce therein an e.m.f. This will cause current to flow in the circuit L_1-C. The value of this current will be

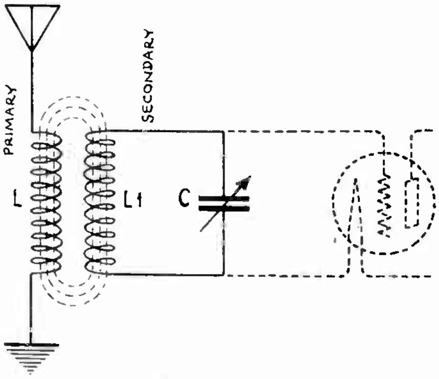


Fig. 20 - MAXIMUM TRANSFER OF SIGNAL ENERGY WILL RESULT IF THE PRIMARY AND SECONDARY CIRCUITS ARE IN RESONANCE

small unless we make use of the principles of resonance again. A value may be found for the variable condenser which will make the natural frequency of its circuit the same as the frequency of the incoming signal. At this point of resonance the maximum current for that signal will flow; at the same time an appreciably high impedance is offered to currents of any other frequency which may exist in the antenna circuit. Tuning can be accomplished by using either a variable inductance or a variable capacitance, or both. Convenience in manufacturing and the fine degree of variation allowed has led most manufacturers to use variable condensers for tuning receivers. When a wide range of frequencies must be received, it is sometimes good practice to have the inductance variable in steps, with the condenser providing the fine variation for accurate tuning.

INDUCTANCES IN SERIES IN AN OSCILLATORY CIRCUIT

In practice we find oscillatory circuits which require more than one inductance coil for their operation. If the inductances have no

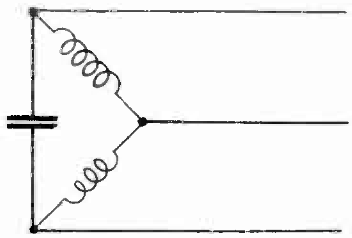


Fig. 21 - DIVIDING INDUCTIVE REACTANCE INTO TWO SECTIONS, AS IN THE ORIGINAL HARTLEY CIRCUIT

mutual field flux (zero coupling between them) the total inductance will be the sum of the separate inductances.

However, dividing the total inductance into separate units permits us to use these units in different ways. In Fig. 21 is shown the resonant circuit used in a particular vacuum tube oscillator known as the "Hartley" oscillator. The resonant voltages across the coils are numerically in direct proportion to their inductances. The usefulness of the circuit consists in the phase difference between the voltages across the coils. Whenever the top condenser plate is positive, the lower plate is negative. The upper lead is then positive with respect to the center lead, and the lower lead is negative with respect to the center lead. Opposition of phase of these voltages holds good throughout all the polarity reversals of the oscillating current.

CAPACITIES IN SERIES IN AN OSCILLATORY CIRCUIT

Just the opposite use of reactances is found in the resonant circuit of the "Colpitts" oscillator, shown in Fig. 22, in which a single inductance is used, but the net capacity for resonance is secured

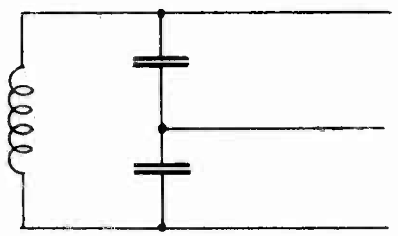


Fig. 22 - DIVIDING CAPACITIVE REACTANCE INTO TWO SECTIONS, AS IN THE COLPITTS CIRCUIT

through the use of two condensers in series. When the charges of the condensers are such that the upper lead is positive with respect to the lower lead, then the upper lead is positive with respect to the center lead, and the lower lead is negative with respect to the center lead. Phase opposition of these two voltages holds good throughout the current reversals of the oscillatory circuit.

The voltages across the condensers are in direct proportion to their capacitive reactances, and therefore in inverse proportion to the capacities of the condensers.

EXAMINATION QUESTIONS

1. What conditions must be met in a series type alternating current circuit, which contains both inductance and capacity, to obtain a maximum current flow?

2. Will a perfect condenser retain its charge over a period of time?

3. When a condenser is discharged is there only one rush of current?

4. How will a high resistance path affect the discharging of a condenser?

5. Explain briefly in your own words the action of the discharging condenser when inductance is in the circuit.

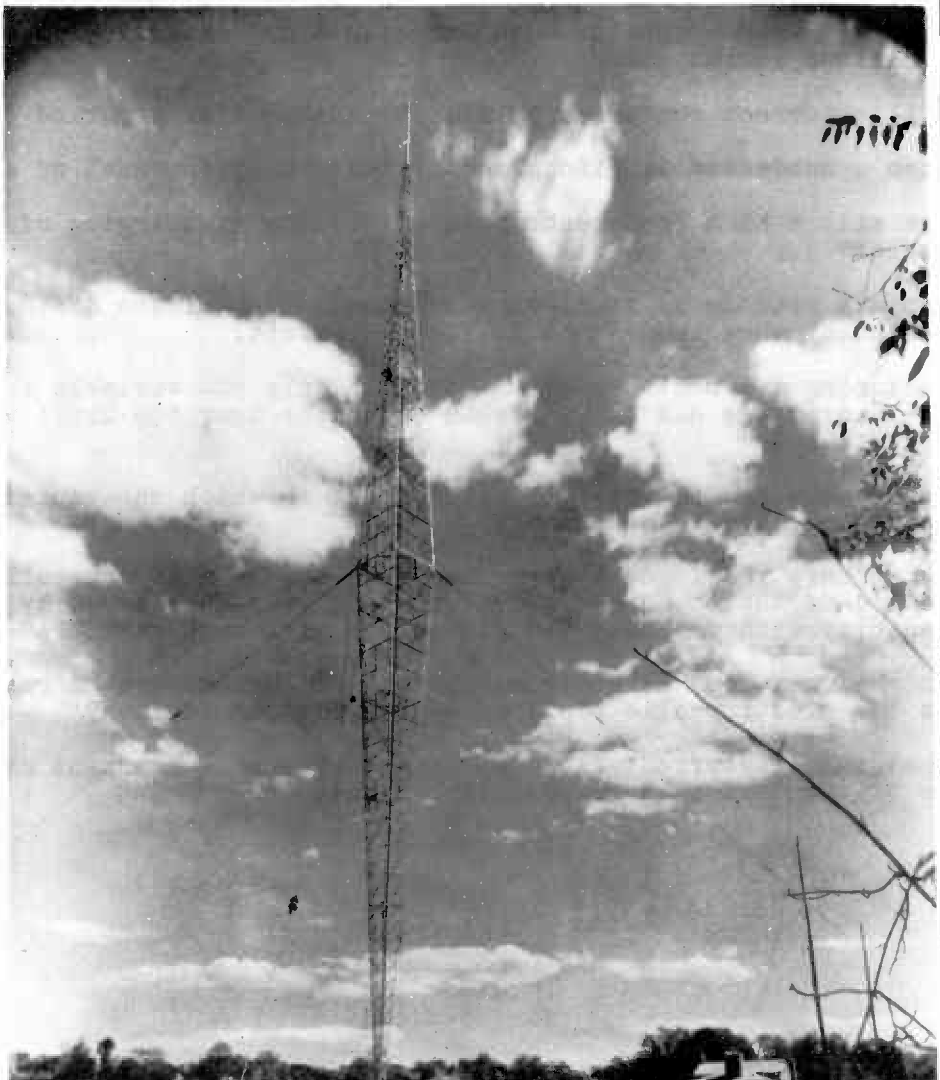
6. In tuning a circuit to resonance with only one variable reactance what advantage has the variable condenser over the usual variable inductance?

7. Is it possible to tune a receiving set in which the capacity and inductance are both variable?

8. Which have you found by experience to be the most generally used method of tuning, fixed inductance with variable capacity, fixed capacity with variable inductance, or with both variable?

9. In what way does a receiving antenna and ground system respond to the electrostatic field of a transmitting station?

10. What rule of current flow determines whether a resonant circuit is of the series or the parallel type?



THE 665-FT. VERTICAL ANTENNA OF STATION WABC AT WAYNE, N. J., IS RESONATED BY MEANS OF INDUCTANCES AND CAPACITORS HOUSED IN THE SMALL BUILDING AT THE FOOT OF THE MAST.

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BOTH THE VOLTAGE AND POWER AMPLIFIERS IN THIS EQUIPMENT ARE BUILT INTO A SINGLE UNIT LOCATED IN THE UPPER COMPARTMENT. TWO UX-112A TUBES (LEFT) AND FOUR UX-200 TUBES (RIGHT) ARE IN PUSH-PULL ARRANGEMENT.

Audio-Frequency Power Amplifiers
Principles of Push-Pull Amplification

VOL. 14, No. 2

Dewey Classification R 140

FOREWORD

This lesson deals with the principles underlying the theory of push-pull audio-frequency amplification. The text, written by members of the instruction staff at R.C.A. Institutes for "Motion Picture Projectionist" and "Radio News", is presented with illustrations by courtesy of these publications.

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AUDIO-FREQUENCY POWER AMPLIFIERS

PRINCIPLES OF PUSH-PULL AMPLIFICATION

Although numerous amplifier circuits have been brought out from time to time which are departures from generally accepted practice, there is one type of circuit that has been accorded a steadily increasing popularity since its invention and introduction to the field. To-day it is more firmly entrenched in technical favor than ever before. We refer to the push-pull circuit.

The characteristic that a push-pull amplifier has of delivering large amounts of undistorted voltage or power output has led to its almost universal adoption in systems where a high-grade quality output is not only desirable, but essential. Such systems, as referred to above, exist in high-quality broadcast transmitters and receivers, talking picture and public address amplifiers, etc.

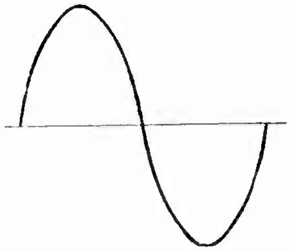


Fig. 1 - THE SCHEMATIC ILLUSTRATION OF A-C SINE WAVE FORM.

Before proceeding with the study of this type of circuit, it will be of great value to the student to review the subject of wave shape and harmonic analysis.

HARMONIC ANALYSIS.

Different shapes of curves have different names, and in the majority of simple curves the names given are obtained from their mathematical derivation. A wave is merely a graph which shows the relation (in a case of a voltage) between the value of the voltage and the particular instant of time at which the voltage has that value. The shape of the wave (voltage or current) existing in a-c work has the familiar shape shown in Fig. 1 and it is called a sine wave.

Just why the curve has the shape shown in Fig. 1 is as follows:

Assume a wire rotating in a magnetic field as shown in Fig. 2A. The upper pole is a north pole and the lower pole is a south pole. Now, a wire cutting a magnetic field at right angles to the field will develop a voltage between the ends of the wire. The amount of this voltage depends on (1) rate of cutting the field, (2) length of wire in the field, and (3) the strength of the magnetic field being cut. If the wire loop is being rotated at constant speed and the length of wire is always the same, then the voltage generated in this wire depends entirely on the angle at which the wire loop cuts the magnetic field. The intensity of the field being constant and from north to south, the voltage generated in the wire then is at maximum when it is moving at right angles to the field and zero when it is moving parallel to the field. The voltage for various positions of the wire is shown in the sketch at the right of Fig. 2C.

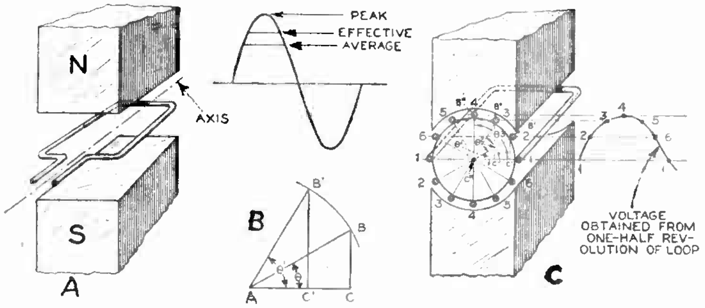


Fig. 2 - THESE FIGURES SHOW THE POSITION OF A WIRE LOOP IN A MAGNETIC FIELD, AND CURVES INDICATING THE VALUE OF VOLTAGE GENERATED AT THE VARIOUS POSITIONS OF THE LOOP.

In mathematics the sine of an angle in a right triangle is defined as the ratio of the length of the side opposite the angle to the length of the hypotenuse of the triangle.

This is indicated by the triangle in Fig. 2B. The ratio of the length of the side, BC, to the length of the hypotenuse, AB, is called the sine of the angle. In symbols:

$$\sin \theta = \frac{BC}{AB}$$

If the size of the angle be increased from θ to θ_1 , and if the length of the hypotenuse remains the same, then the sine of the angle θ_1 is larger than the sine of the angle θ. Or in symbols:

$$\frac{B^1C^1}{AB^1} = \theta_1 \text{ is greater than } \sin \theta.$$

This can be seen from an inspection of Fig. 2B. In this figure $AB = AB^1$, but B^1C^1 is greater than BC. Therefore $\sin \theta_1$ is greater than $\sin \theta$. The larger the angle θ becomes the greater the sin of θ becomes, until $\theta = 90^\circ$. At this point

$$\frac{B^1C^1}{AB^1} = 1 \text{ and } \sin \theta_1 = 1.$$

If θ is made larger than 90°, then the sin of θ decreases from its maximum value to zero.

Consider now the diagram of Fig. 2C. When the ends of the wire are in position 1 no voltage is generated, since the wire is moving parallel to the main field. In position 2 the voltage generated is small, being given by the length B^1C^1. When the wire reaches positions 3 and 4 the magnitude of the voltage generated is given by the lengths B^2C^2 and B^3C^3, respectively. For position 4 the voltage generated is at maximum, the wire cutting the field at right angles. The lengths B^1C^1, B^2C^2, B^3C^3 correspond to the instantaneous values of the voltage generated when the wire reaches positions 2, 3 and 4, which also correspond to angles θ_1, θ_2 and θ_3.

For any position of the loop, the sine of the angle made with respect to the horizontal position (which corresponds to zero voltage in the wire) is given as the ratio of instantaneous value of the voltage to the maximum value. Thus:

$$\text{sine } \theta = \frac{\text{instantaneous value}}{\text{maximum value}}$$

or, in symbols:

$$\text{sine } \theta = \frac{\mathcal{E}}{E_m}$$

where:
$\mathcal{E}$ = instantaneous value
E_m = maximum value

or: $\mathcal{E} = E_m \text{ sine } \theta$

The shape of the curve merely shows the manner in which the instantaneous value of the voltage varies as the loop completes one revolution. It must not be supposed that if it were possible to see the voltage existing between the terminals of the loop, it would have the shape as shown in Fig. 1. The proper viewpoint to assume is that the intensity of the voltage existing would vary from instant to instant in the manner pictorially represented by Fig. 1. The effective (r.m.s.) average and peak values are as indicated in Fig. 2.

By definition any wave is a distorted wave if it does not follow the variations specified by a sine shape. Since all calculations are based on the assumption of a pure sine wave, then, if a distorted wave is present, the proper corrections must be applied to compensate for this irregularity. Distorted waves result from various causes, such as unsymmetrical design of an alternator, overloading of a vacuum tube or by the use of iron-core inductances. The latter two will be discussed more in detail later.

If a distorted wave is present, then formulas which were originally derived on the assumption of the application of a pure sine wave will yield erroneous results if a distorted wave is used. For convenience a distorted wave may be resolved into a pure sine wave of the same frequency as the distorted wave (which pure sine wave is known as the fundamental), plus pure sine waves of frequencies which are multiples of the fundamental frequency. These latter waves are known as harmonics. Any distorted wave is a composite of a fundamental and harmonic frequency. This is illustrated in Fig. 3.

Referring to the figure, the original distorted wave can be completely resolved into a fundamental and a second harmonic, but this is a rare occurrence. Usually not only the second, but the second, third, fourth, fifth, etc., harmonics must be added together with the fundamental to obtain the original distorted wave. However, different types of distortions can be resolved into a fundamental and either even or odd harmonics. By this is meant that if a given distorted wave can be conveniently resolved into a fundamental and, let us say, even harmonics, then it must not be supposed that absolutely no odd harmonics exist, but rather that the maximum amplitude of the odd harmonics that must be added to give the original distorted wave is so small compared to the maximum amplitude of the even harmonics that the odd harmonics may be completely neglected. The reverse, of course, is also true regarding a distorted wave containing a predominance of odd harmonics.

It cannot be stressed too strongly that even though we speak of a distorted wave as containing harmonics, that these harmonics exist as separate waves distinct from the distorted wave, but rather the

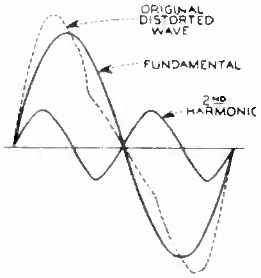


Fig. 3 - ILLUSTRATING THE BREAKING DOWN OF A SINE WAVE.

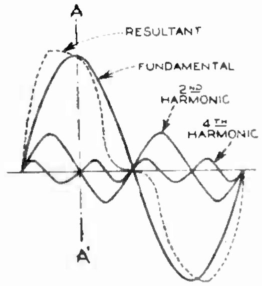


Fig. 4 - SHOWING A DISTORTED WAVE COMPOSED OF THE FUNDAMENTAL, 2ND AND 4TH HARMONIC FREQUENCIES.

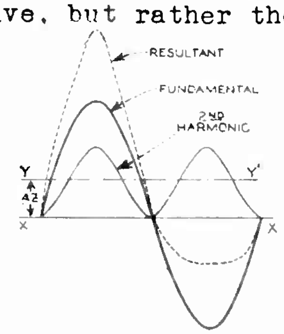


Fig. 5 - CURVES SHOWING THE PRESENCE OF A STRONG 2ND HARMONIC WITH THE FUNDAMENTAL.

reaction of the distorted wave upon the circuit is exactly the same as if the distorted wave were replaced by a fundamental frequency and associated harmonics.

It can be determined from the shape of the distorted wave whether it contains even or odd harmonics or whether it contains both even and odd harmonics.

Distorted waves, as previously stated, result from various causes. Let us first consider the shape of a wave resulting from a vibration originating, let us say, from a violin string. Also let us suppose that this wave contains a predominance of even harmonics. If only the second harmonic is considered, then the shape of the resultant wave is as shown in Fig. 3. If the second and fourth harmonics are great enough to be considered, then the resultant wave will have the shape shown in Fig. 4.

An inspection of the resultant curves of Figs. 3 and 4 reveal that the general shape is exactly the same. Each loop of the wave is unsymmetrical about a line drawn through the center of the loop such as AA^1 in Fig. 4. The left side of the loop has not the same shape as the right side of the loop. This type of resultant curve containing even harmonics is present in outputs of musical instruments and voice. The currents flowing through the primary of a transformer, with the secondary open and no direct current flowing through the primary, has the shape of the curve in Fig. 3, which is due to the hysteresis loop of the iron. It should be noted that the amplitude of the upper loop is equal to the amplitude of the lower loop.

There exists another type of distorted wave which bears a very definite relation to quality of reproduction. This type of wave is the main cause of distortion in amplifiers and is shown in Fig. 5. An analysis of the above shape reveals the presence of a very strong second harmonic. This shape would result if an amplifier tube were worked below the midpoint of the straight portion of the grid voltage-plate current curve. The flux variation in the core of a transformer would have this shape if the core were first saturated by sending d-c through the primary winding and then superimposing the pure sine wave of voltage. The fundamental and second harmonic of this type of distortion is as indicated in Fig. 6. Both Figs. 5 and 6 are similar in shape except that they are 180° out of phase.

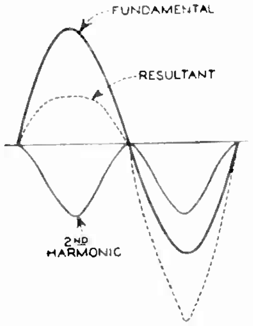
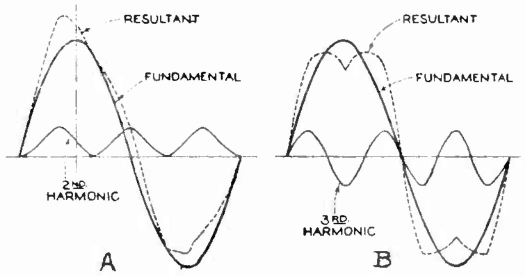


Fig. 6 - DEPICTING THE PRESENCE OF A STRONG 2ND HARMONIC, BUT 180° OUT OF PHASE IN COMPARISON TO FIG. 5.



Figs. 7A and 7B - TWO TYPES OF WAVES CONTAINING ODD HARMONICS WHERE IN ONE CASE (7A) THE ODD HARMONIC LIES ENTIRELY ON ONE SIDE OF THE ZERO AXIS WHILE IN THE OTHER (7B) IT IS SYMMETRICALLY ABOUT THIS AXIS.

It is to be particularly noted that in these types of distortions the second harmonic is entirely above or below the zero axis. This must be so if the amplitude of one loop is greater than the amplitude of the other loop. A physical explanation of this is as follows.

Let the line XX^1 in Fig. 5 represent the normal plate current in a vacuum tube with no signal impressed. Then if a signal now be impressed on the grid of the tube and this tube is worked on the curved portion of its characteristic, the shape of the distorted wave will be as shown in Fig. 5. The average plate current is now raised from the line XX^1 to the line YY^1, an increase of ΔZ. This is evident from the different amplitudes of the wave. The increase in plate current being greater than the decrease, the average value (as read by a d-c meter) will be higher. This is similar to the action which takes place in a detector tube. When a signal is impressed, the average plate current rises (in a linear detector). Incidentally it is a known fact that the detector introduces a strong second harmonic. It is also to be noted that the fundamental does not produce an average increase in plate current, since both loops are equal, but it is the harmonic introduced that is the cause of this increase. The steady increase must rise to the axis of the second harmonic since a line drawn through this axis is the average of the harmonic wave. It therefore follows that if in any wave shape having one loop greater than the other a strong second harmonic exists which lies on the side of the zero line having the greater loop.

The shape of a wave containing harmonics is dependent entirely upon the manner in which the harmonics have been introduced. If these harmonics have been introduced by the device producing the sound, then the resultant wave form, even though it departs from a true sine wave, is not ordinarily spoken of as being distorted, but it is said to be complex, for the reason that the harmonics so introduced are essential for naturalness and intelligibility. It is only the harmonics present that enable one to discriminate between one instrument and another or one voice and another. Since the harmonics introduced by a vacuum tube or any electrical device are of a parasitic nature and were not present in the original sound itself, the waves resulting from these parasitic harmonics are said to be truly distorted.

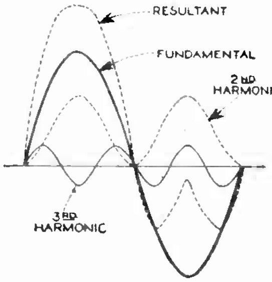


Fig.8 - THE RESULTANT WAVE OBTAINED BY THE COMBINATION OF A FUNDAMENTAL, A THIRD AND SECOND HARMONIC

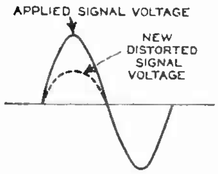


Fig.9 - DISTORTION DUE TO GRID GOING POSITIVE.

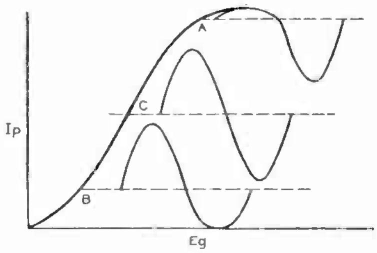


Fig.10 - CURVES TO ILLUSTRATE PLATE CIRCUIT DISTORTION.

A study of waves containing odd harmonics indicates the presence of two general types. One where the odd harmonic lies entirely on one side of the zero axis and one where it is symmetrical about the zero axis. These two types are indicated in Figs. 7A and 7B, respectively. An examination of the resultant distorted wave of Fig. 7A shows that the upper loop is not symmetrical about a line drawn through the center of the loop, the amplitude of the upper loop is greater than the amplitude of the lower loop and that the base width of the upper loop is greater than that of the lower loop.

A study of the resultant wave of Fig. 7B shows that each loop is symmetrical about a line drawn through the center of the loop and the amplitude of both loops are the same.

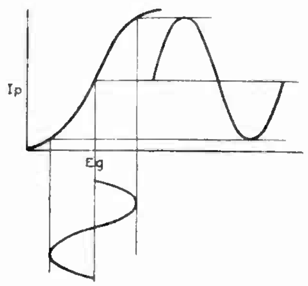
It is extremely difficult to obtain the distorted wave indicated in Fig. 7A, but the shape shown in Fig. 7B is of a more common complex nature and is present in sound produced by voice, musical instruments, etc. The resultant obtained by a combination of a fundamental, a third harmonic symmetrical about the zero axis and a second harmonic which lies entirely above the axis is shown in Fig. 8.

There are, of course, many other types of distorted waves which may result from the addition of even and odd harmonics, but all of them cannot be taken up in a discussion whose scope is somewhat limited. The above types, however, have a direct application in push-pull amplifiers.

Let us consider first the various types of harmonics and the manner in which they may be generated by a vacuum tube. Of this there are two types, grid distortion and plate distortion.

GRID DISTORTION. If a sine wave of alternating voltage be applied to the grid of a tube, and during a portion of the cycle the grid goes positive, the shape of this voltage will be distorted due to the grid going positive, causing grid current to flow, which in turn causes a decrease in the signal voltage by the impedance drop. The shape of the sine wave will be changed to the form shown in Fig. 9.

It is to be noted that the grid only goes positive during the positive half of the cycle. If the grid is positive during both halves of the cycle, then both halves of the wave will be reduced in amplitude. In general, however, the upper loop will be smaller than the lower loop. From a previous analysis of this type of wave, Fig. 5, this distortion signifies an introduction of a second harmonic.



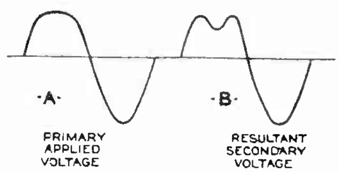


Fig. 12 - CURVE "B" IS THE RESULTANT DUE TO PRESENCE OF A DISTORTED WAVE

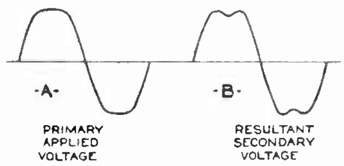


Fig. 13 - THIS TYPE OF WAVE CONTAINS ONLY ODD HARMONICS

Fig. 11 - THIS TYPE OF WAVE CONTAINS A PREDOMINANCE OF ODD HARMONICS

PLATE CIRCUIT DISTORTION. Assume a grid voltage, plate current characteristic as shown in Fig. 10. If for some reason the tube is worked at point A or point B and the form of the grid voltage is sinusoidal, then one-half of the plate current loop will be greater than the other half, as shown in Fig. 10. Such a plate current form also contains a second harmonic; this, as previously pointed out, is what happens in a linear detector.

If the tube now be worked at the center of the curve, point C, which is the proper operating point for an amplifier tube, and a large signal is impressed on the grid so that both the upper and lower bends of the curve being used then the form of the plate current will be as shown in Fig. 11. This type of wave contains a predominance of odd harmonics.

If a pure sine wave of voltage is applied to the primary of a loaded transformer, then the secondary voltage will also be a sine wave. If a distorted wave of the type shown in Fig. 5 is impressed, then the form of the wave of the secondary will be as shown in Fig. 12B. The secondary voltage therefore contains not only a second but a third harmonic, this latter harmonic having been introduced by the transformer. This type of wave is discussed under Fig. 8.

If a distorted wave which has both top and bottom loops flat is applied to the primary of the transformer the form of the secondary voltage will be as shown in Fig. 13. This type of wave contains only odd harmonics. This type of wave is discussed under Fig. 7B.

In any case where the primary voltage is flat-topped the secondary voltage contains a dip. This is evident from the fact that the secondary voltage depends upon the change in primary voltage. During the flat portion of the wave the change in voltage is practically zero, which means that during this flat portion the secondary voltage will drop.

Inductance wire carrying a current generates a magnetic field around it in a direction given by the right-hand rule. If this current be alternating, then the intensity of this magnetic field is in time phase with the current. Since the intensity of the field is measured by the number of magnetic lines per square inch, then the number of magnetic lines per square inch is in time phase with the current. A wire, if it is being cut by a varying magnetic field, has induced in it a varying voltage; and the magnitude of this voltage is dependent upon the length of the wire in the field being cut, the flux density and the frequency of variation of the flux. The generated voltage is given by the formula

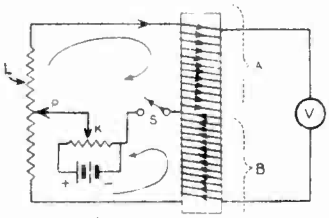


Fig. 14 - VOLTAGE IS APPLIED TO THE COIL BY MEANS OF POTENTIOMETERS.

$$E = B f l$$

where B = flux density
f = frequency
l = length of wire.

If this wire is wound in a coil and if the practical system of potential difference (the volt) is desired, then the formula for generated voltage becomes

$$E = \frac{4.44 \, f \, N \, B}{10}$$

Where: N = Number of turns.
4.44 = Constant based on the assumption of sine wave.
B = Flux density.

Since the current through an inductance lags the impressed voltage by 90°, the voltage generated in the coil is maximum when the current is passing through itz zero value. This also follows from the statement previously made that the generated voltage is always a maximum when the change in current is greatest. No voltage is generated in a coil when the current is not changing in value.

It is important to remember that the direction of the induced voltage is dependent upon the direction of current flow through the coil. If the coil has more than one applied voltage, each one of these voltages being applied to a different section of the coil, then the direction of the induced voltage in each section of the coil not only depends upon the direction of current flow through each section, but also upon the direction in which each section is wound and whether this current be increasing or decreasing.

Consider the coil depicted in Fig. 14. This coil is wound continuously in one direction and is tapped at the exact center of the winding; the end terminals of the potentiometer P are connected across the extreme terminals of the coil. A variable voltage is interposed between the slider on P and the center tap of the winding. The variable voltage is obtained by means of an additional potentiometer K placed across the battery. The voltmeter V is placed across the ends of the coil to indicate the total generated voltage across the coil.

CASE I. Suppose both potentiometer sliders be kept in their center positions and switch S suddenly closed, current will flow through the circuit and through the coil in the directions shown in Fig. 14. Since the coil is wound continously in one direction and the current in section A is flowing in the opposite direction to the current in section B, the voltage generated in section A will be opposed to the voltage generated in section B (these being 180° out of phase) and the voltmeter V which indicates the total voltage generated across the entire coil will not show any indication.

CASE II. Suppose switch S be open and the potentiometer slider be moved to point L, then if switch S be suddenly closed the current through section A of the coil will be greater than the current through section B. The voltage generated across section A will be greater than the voltage generated across section B. The voltmeter V will indicate and its indication will be equal to the difference between the voltages generated in sections A and B.

It should be noted that thus far the circuit is merely a simple bridge affair and the considerations outlined in cases I and II apply when the bridge is balanced and when it is unbalanced.

CASE III. Suppose switch S is now closed and the sliders of both potentiometers be kept at their center positions. A steady current will flow through the windings of the coil. If the slider of potentiometer P now be moved to position L the current through section A increases above its normal value, generating a certain voltage across section A. At the same time the current through section B decreases below its normal value, generating a voltage in section B which adds to the voltage generated in section A, producing a voltage across the entire coil which is the sum of the voltages in each section. The reason for the voltage generated in section B now being additive is that, whereas, in case II the currents in each section were increasing in opposite directions, the voltages generated were 180° out of phase, while in this consideration the current through section B suffered a different type of change. That is, it was decreasing instead of increasing, which resulted in a reversal of the polarity of the voltage generated in section B.

With the above facts in mind, we can now proceed to study the push-pull amplifier, and the reasons for its use.

In the early days of the art, if more power was desired from an amplifier, there were two means of obtaining it. One way was to double up on the number of output tubes used, i.e., connect another tube in parallel with the first. This meant that the two grids and the two plates were connected together respectively. In operation, the pair of tubes functioned practically as one tube of twice the dimensions and hence twice the power output.

The second method was actually to use a larger tube. This, however, is essentially the same as using two tubes in parallel, at least from a theoretical viewpoint.

The push-pull circuit was invented by Colpitts. Basically, the arrangement was such that the grids of the two tubes acted opposite to each other upon their respective plate currents, and the latter were so coupled to the load as to have an additive effect. The net effect was that the two tubes acted as if they were connected in series to the load, much like two locomotives coupled to a freight train.

CIRCUIT EMPLOYED. In order better to understand the operation of this system, let us examine the circuit employed. Refer to Fig. 15.

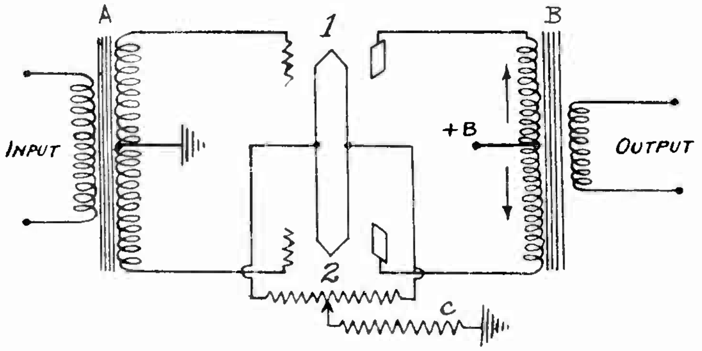


Fig. 15 - PUSH-PULL AMPLIFIER CIRCUIT DIAGRAM.

Two tubes, 1 and 2 are employed, together with an input transformer "A," and an output transformer "B." As can be seen from Fig. 15, the secondary of "A," and the primary of "B" are center-tapped. The signal—from whatever source we desire—is fed into the primary of "A." An alternating voltage is induced in the secondary. If we ground the mid-point, as shown, then at one instant, the end connected to the grid of tube 1 will be positive with respect to ground, and simultaneously, the other end, connected to the grid of tube 2, will be negative with respect to ground. A half cycle later, conditions will be reversed. The grid of 1 will be negative, and the grid of 2 will be positive with respect to ground.

Let us suppose for the moment, that the filaments are connected in parallel and grounded at the mid-tap of their supply. Then, when one grid is positive with respect to the filaments, the other will be negative, since these are their potentials with respect to ground, and both filaments are grounded.

The plate current of the tube whose grid at that moment is positive with respect to the filament, will increase; the plate current of the other tube will decrease, because its grid at that moment is negative with respect to its filament.

It will be noted that the plate current is fed to the primary of the output transformer "B" through its center tap. The two arrows show the direction of the current to the plates of the two tubes. It can be seen from the arrows that the two currents are opposite. As long as the currents are steady (direct current), the flux produced by either will be steady. However, if the two currents are equal, the flux produced will be zero, since the currents flow in opposite directions through the primary windings, and nullify each other magnetically.

EFFECTS ADDITIVE. If the current to tube 1 increases for instance, its flux increases. This change in flux induces a voltage in the secondary of "B" in the direction, let us say, toward the top of the drawing. Now if the current to tube 2 decreases, it will not "buck" the current going to tube 1 as much as before, so that the latter current can produce more flux than it otherwise could. The result is that the flux change will be greater than before, and the voltage in the secondary of "B" will be increased. Thus, an increase in the current to tube 1, or a decrease in the current to tube 2, will each induce a voltage in the same direction in the secondary of "B," i.e., the current changes are additive in effect, and one current change is just as effective as the other in inducing voltage in the secondary. Thus, the two tubes act in series, as far as the secondary is concerned, since their voltage inducing effects in the secondary are in the same direction and hence additive.

When the grids of the two tubes assume polarities opposite to those assumed above, the current in tube 1 decreases, and that in tube 2 increases, and a voltage is induced in the secondary in the opposite direction but, nevertheless, the two tubes are still additive in their effects.

In this way twice the alternating voltage is induced in the secondary by the two tubes as compared to that which one tube alone could produce, so that the two tubes at all times act in series. By a similar method of reasoning it can be seen that the internal plate resistances of the two tubes are in series, so that we have twice the plate voltage of one tube acting through twice the plate resistance of one tube to feed current into the output transformer and load.

APPLICATION OF BIAS. So far we have considered the circuit as operating without any grid bias, i.e., if no signal is impressed upon the grids, they are at ground potential, and hence at the same potential as the filaments. By inserting resistor "C" between the center tap of the filament supply (here obtained by means of a potentiometer and ground) the plate currents, in flowing back to the filaments, have to pass through "C," and cause a voltage drop in it of such direction as to make the filaments positive with respect to ground. Since the grids are normally at ground potential, they are now negative with respect to the filaments, that is, have a negative bias with respect to the filaments. Resistor "C" is thus the well-known grid biasing resistor, only a by-pass condenser is not usually connected in parallel with it, as will be explained later.

In this arrangement, if one grid receives a positive voltage from the incoming signal, its negative bias is reduced. The other grid simultaneously receives a negative voltage from the incoming signal, so that its negative bias is increased. The signal must be below the value that would make the first-mentioned grid go actually positive with respect to the filaments, or the other grid go so negative that the plate current is reduced to zero before the grid has reached its lowest negative value. These limitations to signal strength are exactly the same as those for a single tube amplifier operating without distortion. In short, a push-pull amplifier does not work the tubes any more completely than an ordinary amplifier, so that each tube delivers the same output in either case. Hence the output of the two tubes in push-pull arrangement is approximately twice that in a single tube amplifier, and not three to four times as much, as is so often claimed.

OUTPUT POWER. So far it would appear we have gained nothing by putting the tubes in push-pull arrangement instead of in parallel. It is seen that the transformers used require center taps, and hence are apparently more expensive to manufacture than those used in the ordinary cascade amplifier. Now suppose there is greater capacity between the turns of one-half the secondary of "A" than the other, the phase between the voltages applied to the two grids will not be the same, i.e., the voltages applied to the two grids will not go through their maximum values simultaneously.

A similar effect may be obtained if the leakage reactance between one-half of the primary of "B" with respect to the secondary is not the same as that of the other half. In either case the output will not be twice that of one tube, but somewhat less, depending upon the phase angle between the two voltages, so that the full benefit of the two tubes is not realized.

ADVANTAGES OF THE CIRCUIT. Nevertheless, this circuit has so many important advantages that the above consideration is of little comparative consequence. In the first place, examination of Fig. 15 shows that the steady or average value of the d-c current of either tube (as measured by a d-c milliammeter), flows in a direction through its half of the primary of "B" opposite to that of the plate current of the other tube. Thus, if the tubes have nearly equal plate currents, they practically balance each other magnetically, and produce little or no steady (d-c) flux in the core of "B." Thus, the core can be made smaller without any danger arising of its becoming saturated, and the importance of this may be appreciated when it is realized that the plate current of either power tube is quite large and would saturate even a larger core if present there by itself. Of course, on the other hand, care must be taken in operation to see that the plate currents are nearly balanced, otherwise saturation will occur. As an example in a certain output transformer designed for use with two UX-245 tubes, the difference between the two plate currents must not exceed five milliamperes. In the case of large tubes, they are arranged so that the grid bias of each may be adjusted independently, so that the plate currents can be matched.

The second advantage--that of cancellation of the second harmonic, is more generally appreciated. To demonstrate this effect, we shall refer to Figs. 16, 17 and 18. In Fig. 16 we have plotted the variation in plate current Ip with that of grid voltage Eg for an ideal tube. In such a tube the plate current (measured along the vertical axis) is strictly proportional to the grid voltage (measured along the horizontal axis), and the graph is a straight line, because only in the case of a straight line is the rise in proportion to the distance along the horizontal direction. In particular, if the voltage applied to the grid were of sine wave in shape, the variation in the plate current would be sine wave in shape.

In practice, however, tubes do not have such ideal characteristics. Instead, the graph is that shown in Fig. 17 (solid line). Here, as the grid voltage is increased from a negative direction, as it reaches the value at point "A," the plate current begins to rise rapidly, but still not as abruptly and sharply as in Fig. 16 "A." Thereafter, it increases up to the value "B" at a rate faster than the increase (in a positive direction) of the grid voltage. From "B" to "C" the plate current begins to taper off until finally it ceases to increase, and may even decrease.

The reason is that all the electrons emitted by the filament are now all drawn to the plate, and the current can increase no further, as the quantity of electrons are limited by the filament. Furthermore, if the grid potential be increased to a value greater than that of the plate, it will rob the plate of electrons, so that the plate current will then decrease.

NORMAL OPERATING RANGE. We are interested, however, in the values of plate current between points "A" and "B," as this represents the normal operating range of the tube. An ideal tube would have the characteristic or graph shown by the dotted straight line in Fig. 17.

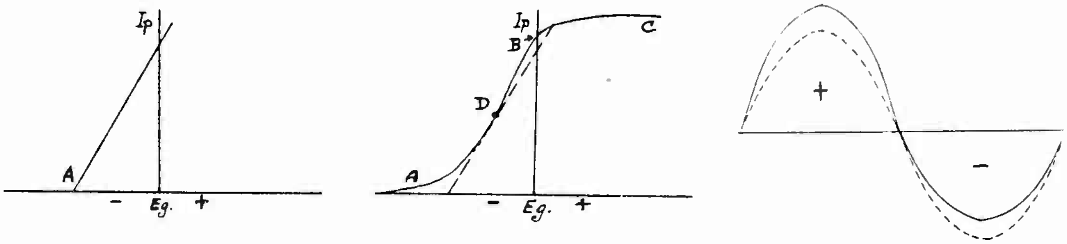


Fig. 16 - PLATE CURRENT IDEAL CONDITION. Fig. 17 - PLATE CURRENT ACTUAL CONDITION. Fig. 18 - ACTUAL AND IDEAL WAVE SHAPE.

From this we can see that if the normal value of plate current in the actual tube is "DA," then if the grid increases positively, the plate current is greater than that proportionately as the graph is above the dotted ideal line at "B."

On the other hand, if the grid becomes more negative, the plate current does not decrease as rapidly as it should for strict proportionality, that is, its graph is here too, at "A," above the dotted line. Hence, if a sine wave of voltage is impressed upon the grid, the plate current will not be sine wave in shape, but the positive half cycles, or alternations, will be peaked, and the negative alternations will be flat-topped. This is shown in Fig. 18. The solid line gives the actual wave shape of the plate current, and the dotted line the ideal, sine wave shape desired.

Now, referring to a push-pull amplifier, the plate current of one tube is going through a positive alternation when that of the other tube is going through a negative alternation. Since the currents in the two tubes are additive in their effect of inducing voltage in the secondary of the output transformer, it is evident that since one current is peaked, and the other flat-topped, the excess of one is balanced by the deficiency of the other, and their combined effect is to induce more nearly a sine wave of voltage in the secondary.

This can be checked by shifting the negative alternation under the positive one in Fig. 18 so that their ends coincide, and adding together corresponding vertical distances. The result will be a curve of approximately twice the height of either, and practically sine wave in shape.

Thus, by causing the plate currents of the two tubes to vary oppositely to each other, the distorting effect of one is balanced by the oppositely distorting effect of the other, and the net result is more faithful amplification. The distortion of either tube consists mainly of the second harmonic of the sine wave to be amplified, and it is this harmonic that is practically eliminated by a push-pull amplifier. Note that if the two tubes were in parallel, their plate currents would both simultaneously increase and decrease, so that no cancellation of the second harmonic could occur. Also, it is to be noted that both plate currents would flow through the same primary in the same direction, so that the d-c or steady flux would be doubled instead of cancelled, as is the case in the push-pull amplifier.

PLATE CURRENT. Since when the plate current of one tube is increasing, that in the other is decreasing, the sum of the two is practically constant, so that there is no audio component flowing into the center tap of the output transformer—"B," Fig. 15. This means that the last condenser in the plate supply filter circuit does not have to be so large, since it does not have to by-pass a large audio component coming from the power tubes. Also high regulation of the plate supply voltage has no bad effects, as it would on a single power tube, or two connected in parallel. Furthermore, since there is no appreciable audio component flowing through the grid biasing resistor, it does not have to be by-passed with a condenser, and this, too, represents a considerable saving, since for power tubes the plate current is large, the grid biasing resistor is low, and therefore otherwise has to be by-passed with a large condenser.

EQUALIZING EFFECT OF GRID BIAS RESISTOR. It was stated in the preceding paragraph that the increase in plate current in one tube was balanced by the decrease in the other, so that the total plate current is constant. This is, however, not strictly so, for it will be remembered that due to the curvature of the tube characteristic, as shown in Fig. 17, the increase in plate current is greater than the decrease for equal and opposite grid voltages. Consequently, there is a second harmonic current of small magnitude—flowing in the circuit, and in particular, through the grid biasing resistor.

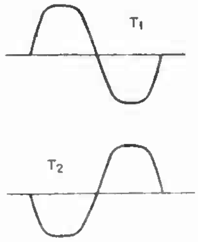
Now, in general, an increase in plate current tends to increase the grid bias, and thus depress the grid voltage, and consequently decrease the plate current. In other words, as the grid tends to increase the plate current, the latter tends to prevent this through its action on the grid biasing resistor. This is known as degeneration, and is the reason for the large by-pass condenser across the resistor in single tube amplifiers.

In a push-pull amplifier, however, this opposing effect of the plate current of the tube on its own grid potential is an aiding effect upon the grid of the other tube, since that grid is swinging in potential in the opposite direction. Hence, each tube has a degenerating effect upon itself, and a regenerating effect upon the other tube.

The net consequence of all this is that the second harmonic current mentioned above, in flowing through the grid biasing resistor, tends to reduce the peak of the positive alternation of the one tube, and to peak the flat-topped wave shape of the negative alternation, and so tends to destroy itself. As a result, the second harmonic is even further wiped out, in addition to the cancelling effects of the two tubes, as described previously.

There is another beneficial effect due to this action. If one tube is stronger than the other, i.e., if the change in its plate current is greater than that in the other tube for the same grid swing, then the excess current will flow through the grid bias resistor, and cut down the excess current of the stronger tube, and raise that of the weaker tube, thus equalizing their outputs. Thus the grid bias resistor tends to make the mutual conductances of the two tubes more nearly equal.

It is evident that if the plate supply current, coming in through the center tap of the output transformer, increases, it increases in both halves of the primary. The two halves therefore induce equal and opposite voltages in the secondary, or no net voltage at all. The same argument holds for a decrease in plate supply current. Hence, if the voltage supply is not very perfectly filtered, no hum



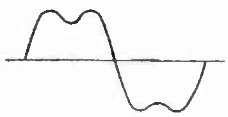
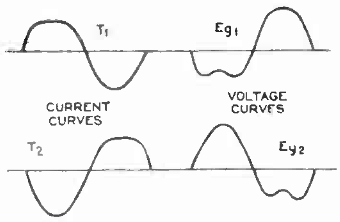


Fig. 20 - THIS IS THE FORM WHEN THE VOLTAGES OF EACH HALF ARE ADDITIVE.



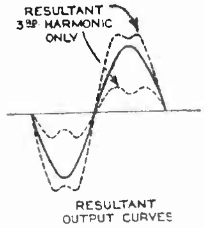


Fig. 19 - THE PLATE CURRENT IN EACH TUBE IS ABOVE SATURATION POINT.

Fig. 21 - THE TUBES ARE BEING WORKED OFF THE CENTER OF THE STRAIGHT PORTION OF THE CURVE.

Fig. 22 - DEPICTING TOTAL VOLTAGE GENERATED ACROSS PRIMARY OF OUTPUT TRANSFORMER.

will be heard in the loud speaker anyway. A similar argument holds if there is a ripple in the grid bias voltage, or even filament supply, so that the push-pull amplifier is much more free from hum than the single tube or parallel tube type of amplifier.

Now that we understand the normal action of the push-pull amplifier, let us examine its action under abnormal conditions, such as excessively large signal applied to the grids of the tubes.

If a large signal voltage be applied to the grids of both tubes such that the plate current of each tube rises above the saturation point and down below the lower end of the curve, the form of the plate currents in each tube is as shown in Fig. 19.

The voltages generated by each half are additive and have the form shown in Fig. 20.

The dips in this curve are due, as previously explained, to the flat-top form of current. This voltage curve contains a large third harmonic which is passed on to the speaker.

If, however, the tubes are worked off the center of the straight portion of the curve, such as point A or B in Fig. 10, then the form of the plate current in each tube will be as shown in Fig. 21. The form of the total generated voltage across the primary of the output transformer is as shown in Fig. 22.

The form of the voltage curves depicted in Fig. 21 shows the presence of a second and third harmonic as was previously analyzed. The resultant of the two voltages shown in Fig. 22 indicates the presence of only the third harmonic, the second harmonic having been eliminated. The magnitude of the third harmonic that is usually present is small enough to be neglected.

It was previously mentioned that the current is about 90° out of phase with the voltage. This is true only in a simple inductance; but in a transformer under load the phase relation between primary current and the applied voltage depends upon the power factor of the load on the transformer, neglecting the magnetizing current. It is assumed in this discussion that the load on the secondary of an

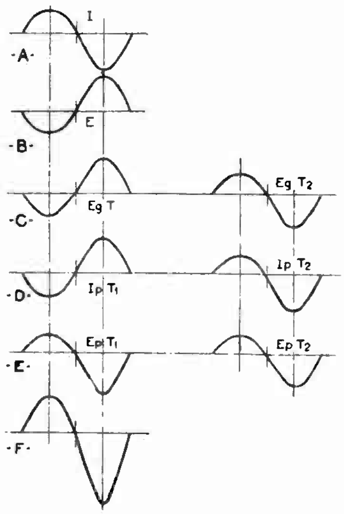


Fig. 23 - CURVES ILLUSTRATING VOLTAGES ACROSS VARIOUS TRANSFORMER WINDINGS.

interstage transformer is resistive due to loading resistors usually connected across it, hence, the primary current is practically in phase with the voltage. With this in mind it can be seen how the dip voltage wave is obtained from a flat-top current wave.

Suppose the form of the plate current of a stage of amplification previous to the push-pull stage is as indicated in Fig. 23A. The voltage generated across the primary is as indicated in Fig. 23B. The voltage across the secondary is shown in Fig. 23C, which is the voltage on each grid with respect to the mid point of the winding. The plate current of each tube is shown in Fig. 23D. The voltages generated in each half of the secondary is as shown in Fig. 23E and the resultant voltage across the primary of the output transformer is as depicted in Fig. 23F. An inspection of this final wave shape will reveal the presence of a second harmonic which existed in the wave impressed on the primary of the input push-pull transformer. The push-pull amplifier therefore does not eliminate harmonics originating in previous stages.

By a similar reasoning it is found that harmonics existing in a sound wave are not eliminated.

The sweeping conclusion is that the only even harmonics that are eliminated are those that would be present if push-pull amplification were not used.

Maximum power output is obtained from a tube when the load impedance equals the impedance of the tube. If the load impedance is made equal to the tube impedance in a straight amplifier, maximum output will be obtained, but the percentage of the second harmonic present due to the curvature of the characteristic prohibits the use of this one-to-one ratio. The ratio of load impedance to tube impedance is usually two to one, in order to minimize distortion. In a push-pull amplifier in which the second harmonics due to overloading are eliminated the load impedance may be equal to the tube impedance and so a greater output may be realized. Usually about 12½ per cent more undistorted output is obtained with two tubes in push-pull than with two tubes in parallel.

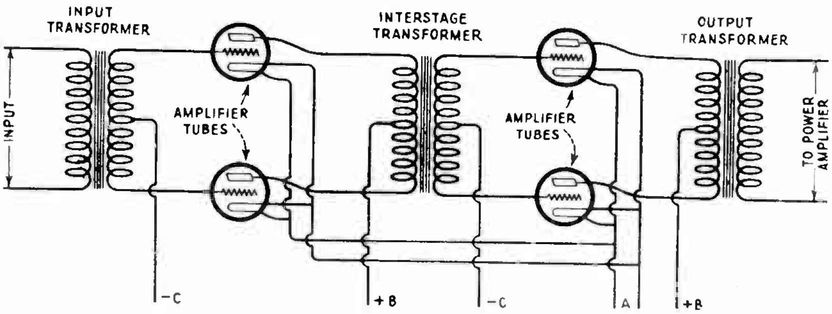


Fig. 24 - SCHEMATIC DIAGRAM SHOWING TWO STAGES OF PUSH-PULL AMPLIFICATION.

The formula for power output of two tubes in push-pull is

$$P = \frac{\mu^2 Eg^2}{2Rp}$$

where Rp is the tube impedance and is equal to the load impedance.

<u>OUTPUT TRANSFORMERS.</u> Output transformers for push-pull amplifiers are usually designed on the assumption that the d-c component of the flux in the core is zero. If the plate current of each tube is different a d-c component will be present which will tend to saturate the core. In a well-designed transformer a slight amount of d-c component of flux will not seriously impair the operation of the amplifier.

The location of input and output push-pull transformers and amplifier tube sockets in typical commercial power amplifier equipment is shown in the views on the cover pages of this lesson. In Figs. 24 and 25 are shown schematic diagrams of two types of push-pull amplifiers, one consisting of two stages of push-pull amplification and the other a stage of push-pull parallel amplification.

SUMMARY OF ADVANTAGES. We may now summarize the advantages of the push-pull amplifier:

(1) Saturation of the core of the output transformer is minimized.

(2) The second harmonic component in the output wave shape, due to the curvature of the tube characteristic, is practically eliminated.

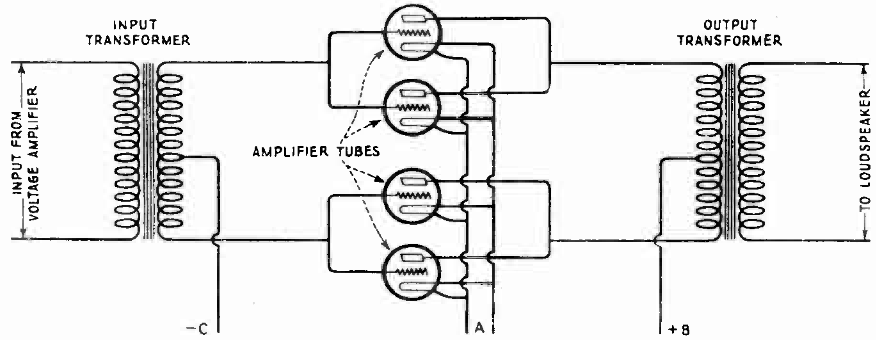


Fig. 25 - SCHEMATIC DIAGRAM SHOWING A STAGE OF PUSH-PULL PARALLEL AMPLIFICATION.

(3) When no by-pass condenser is shunted across the grid bias resistor, further cancellation of the second harmonic component is obtained, as well as equalization of the tube outputs.

(4) Ripples in the power supply tend to cancel out in the push-pull circuit, so that it is quieter in operation, or, for the same hum level, requires less filtering of the power supply.

EXAMINATION QUESTIONS

1. Name at least two advantages of a push-pull audio-frequency amplifier over other types.

2. If the d-c plate current is greater through one tube than the other in a push-pull circuit what is the resultant effect upon the output transformer when a signal voltage is applied?

3. Give a brief explanation of the operation of a push-pull a-f amplifier with the aid of a simple schematic diagram.

4. What is the comparative difference in the effect of the d-c plate currents which flow in two tubes when connected in parallel and when connected in push-pull?

5. (a) What causes the presence of a second harmonic in a distorted wave?
   (b) Is a second harmonic usually comparatively strong or weak?
   (c) If present, is a third harmonic usually strong or weak?

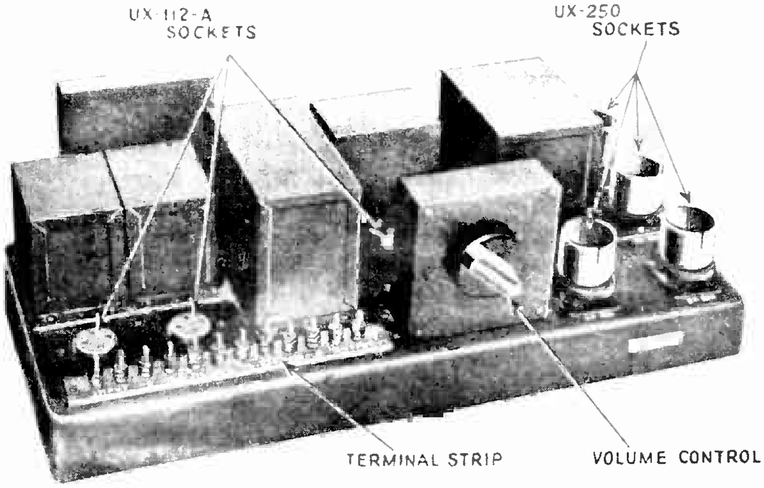
6. What means are employed to reduce the magnitude of a second harmonic?

7. Explain what is meant when it is said that the current changes are additive in effect in a push-pull amplifier.

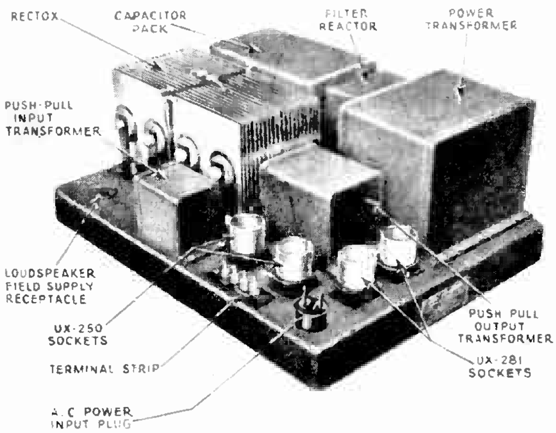
8. Is it possible to obtain from two tubes in a push-pull amplifier much more than approximately twice the output provided by one of the tubes when operated in a single tube amplifier? Explain.

9. What is the effect on grid potential when plate current varies through the grid biasing resistor in a single tube amplifier?

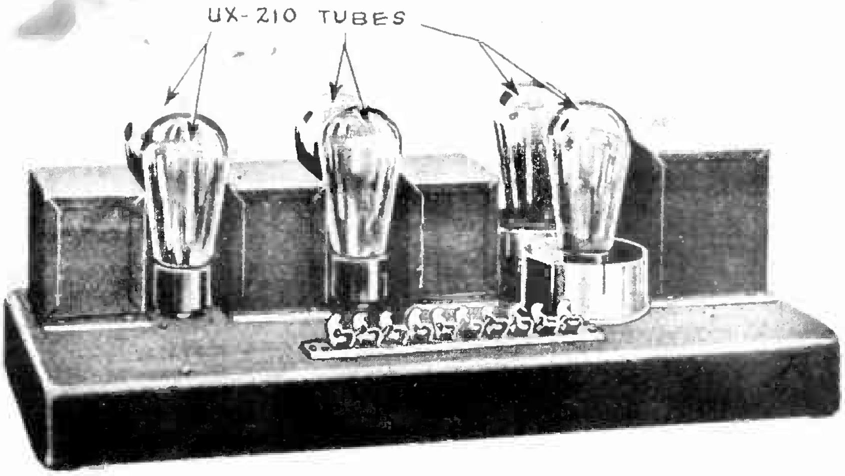
10. In a push-pull amplifier what is the effect produced on the respective grids due to increases and decreases in plate current through each tube?



FRONT VIEW OF A POWER AMPLIFIER UNIT SHOWING ARRANGEMENT OF INPUT, INTERSTAGE, AND OUTPUT PUSH-PULL TRANSFORMERS AND TUBE SOCKETS.



TWO UX-250 TUBES ARE IN PUSH-PULL
IN THIS POWER AMPLIFIER UNIT
USED IN SOUND PICTURE EQUIPMENTS.



A COMMERCIAL THREE-STAGE PUSH-PULL AMPLIFIER EMPLOYING SIX TUBES. SHIELDS (NOT SHOWN) ARE PLACED OVER THE FIRST STAGE TUBES TO PREVENT MICROPHONIC COUPLING.

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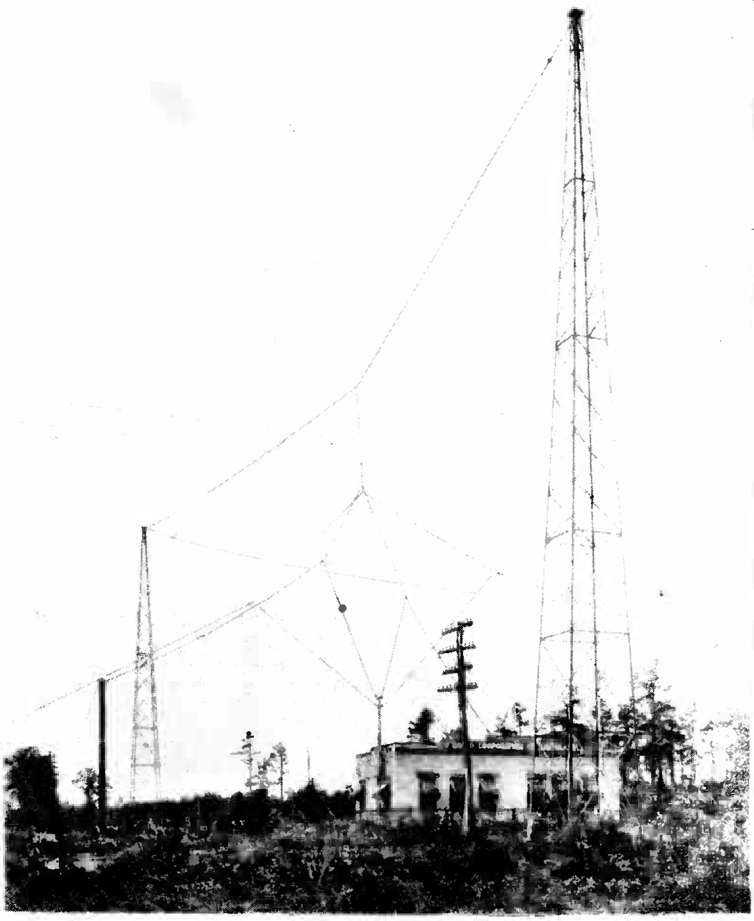

THE DIAMOND SHAPED ANTENNA AT THE TUCKERTON N. J. RECEIVING STATION IS A BELLINI-TOSI SYSTEM WHICH IS USED FOR DIRECTIVE RECEPTION IN THE 500-KC BAND

Fundamentals of Radio Reception

VOL. 16, No. 1

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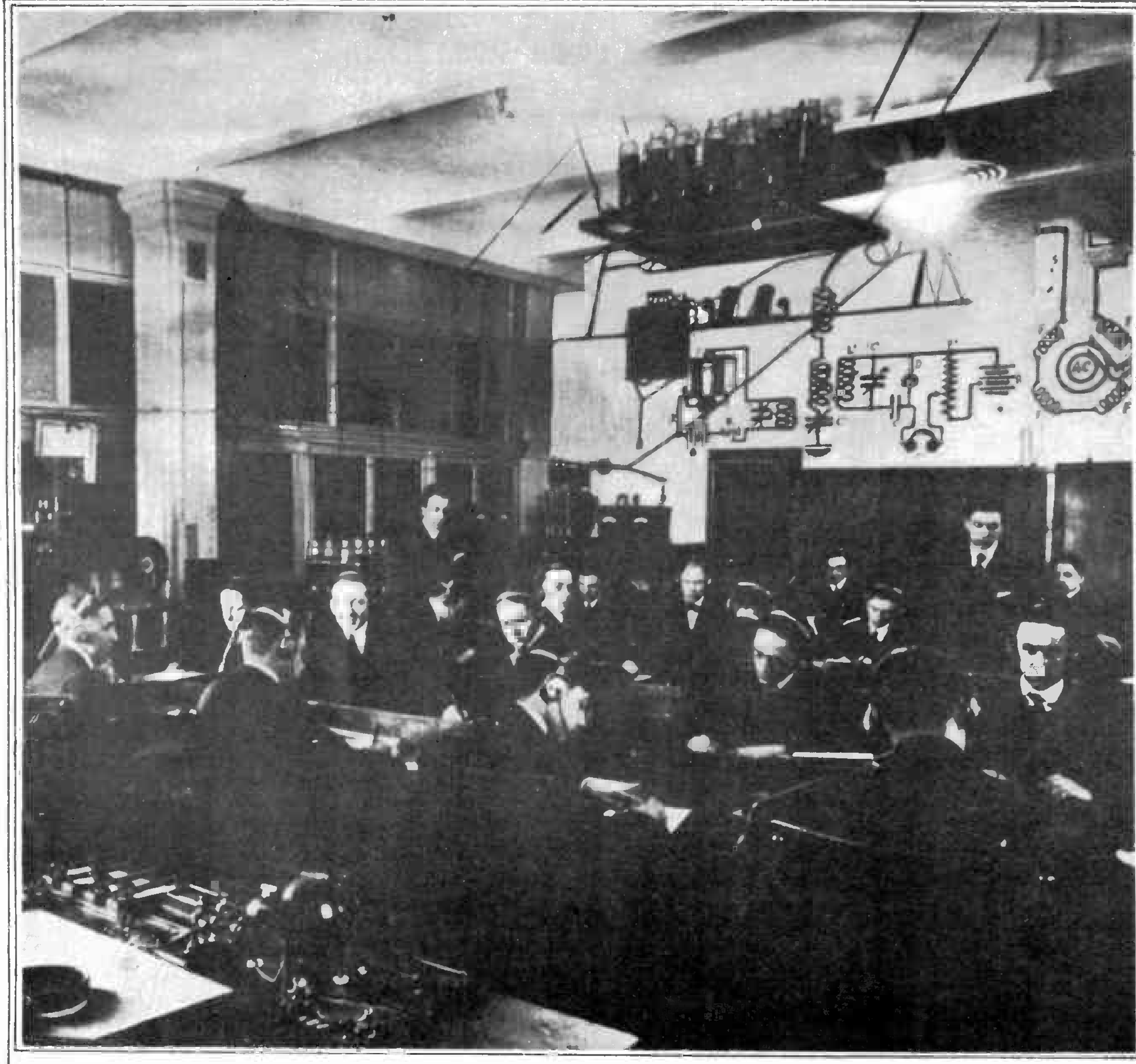

A CLASSROOM PHOTOGRAPH OF THE MARCONI SCHOOL TAKEN IN 1917— THIS SCHOOL WAS THE FORE-RUNNER OF THE R.C.A. INSTITUTES. OF PARTICULAR INTEREST IS THE DIAGRAM DRAWN ON THE WALL SHOWING THE CIRCUITS OF A TYPICAL RECEIVER USED AT THAT TIME; NOTE THE CRYSTAL DETECTOR, TUNING CONDENSERS AND THE USE OF INDUCTIVE COUPLING TO TRANSFER THE SIGNAL ENERGY FROM THE PRIMARY TO SECONDARY CIRCUITS.

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FUNDAMENTALS OF RADIO RECEPTION

HIGH-FREQUENCY WAVES

A transmitting station sends out electromagnetic waves and as these waves pass or cut across a receiving antenna they induce therein an electromotive force which will, if the antenna circuit is complete, cause a current to flow in the antenna. From the principles of electromagnetic induction it can be understood how a current is caused to flow in the receiving antenna system by the phenomenon of induction. This current will be of the same frequency as that of the electromagnetic wave which caused it.

In radio telephone work the transmitter supplies the antenna with a high-frequency current having constant amplitude or strength during program silences and this current produces what is called a continuous wave, or carrier wave. The sound waves directed before the microphone modify this continuous wave. Suppose, for example, a key of a piano is struck; the sound waves thus produced impinge upon the diaphragm of the microphone, setting it into vibration. By means of suitable electric circuits the sound vibrations are made to change the amplitudes of the continuous or carrier waves to a form somewhat as shown in Figure 1 which is the result of superimposing audio-frequency current variations upon a radio-frequency carrier wave.

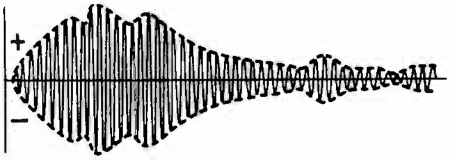


Fig. 1 - DEPICTING MODULATED HIGH-FREQUENCY CURRENT WHICH MIGHT FLOW IN THE RECEIVING ANTENNA

The alternations of the radio wave are shown by the full lines in Figure 1 while the dotted outline shows how the amplitude of the radio wave has been caused to vary in accordance with the wave produced by the piano string. This resultant typical radio wave, upon striking the receiving antenna, will induce therein a current which will alternate as shown in Figure 1.

THE TELEPHONE RECEIVER

Now let us consider for a moment the construction and operation of the telephone receiver. Figure 2 is an open view of the receiver showing two electromagnets so supported that there is a small separation between the ends of their pole pieces and the diaphragm. There is a certain amount of residual magnetism in the iron core of these magnets so that a constant pull is exerted on the diaphragm at all times. When current flows through the magnet windings in a certain direction it strengthens the magnetic field and the thin iron diaphragm is attracted to the pole pieces causing it to bowl in at the center. If you wish to experiment and determine if the receiver coils are in perfect condition you may do so by touching the receiver terminals to a dry cell; you will hear a distinct click when touching the terminal P of the cell with the lead L and, upon removing L, you will hear a second click.

The attraction on the diaphragm is very strong when the current through the magnets is increased, and correspondingly less when the current decreases. If the lead L is alternately placed on and removed from contact with the terminal P of the dry cell, thus making and breaking the circuit very rapidly, the diaphragm will be attracted and released as rapidly and a succession of clicks will be heard. The speed of making and breaking the connection can be increased by using a vibrator and it may be regulated so that the diaphragm will vibrate with such rapidity as to cause practically a continuous

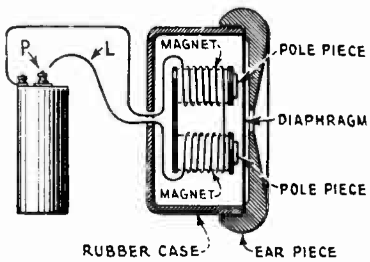


Fig.2 - GENERAL CONSTRUCTION OF A TELEPHONE RECEIVER, OR ONE UNIT OF A HEADSET

sound. When the vibrations of a diaphragm have a frequency of between 15 and about 10,000 vibrations each second the air waves resulting therefrom will produce the sensation of sound. If, however, the diaphragm could be attracted and released at such a rate that the resulting air vibrations would be greater than perhaps 10,000 per second no sound would be heard because the average human ear will not respond to a frequency much greater than that. Remember there is no exact limit defined as to just where audio frequencies end and inaudible frequencies begin.

In order to include all of the possible frequencies, it might be stated that "frequencies above 15,000 are INAUDIBLE and frequencies between 15 and 15,000 are AUDIBLE to many human ears."

The magnet coils of the ordinary wire telephone receivers have a resistance of 75 ohms and are not suited for radio reception. The receivers employed for radio reception, however, are wound with many turns of fine wire and have a resistance of from 1,200 to 3,000 ohms. A very small current in radio receivers will produce a large volume of sound. The high number of turns is required by the fact that the detector circuit provides power at a relatively low current compared to the voltage, and the sound intensity from the telephones depends on the ampere-turns.

ANTENNA CURRENTS WILL NOT OPERATE A TELEPHONE RECEIVER

The e.m.f. induced in the antenna by the electromagnetic wave is alternating and of very high frequency, so high in fact that if a receiver were placed in the antenna circuit no sound would be heard even though the e.m.f. produced by the radio wave were impressed on the magnet windings of the receiver.

In the first place the high-frequency alternating current is changing direction so rapidly that although the positive half cycles of current might tend to move the diaphragm in one direction and the negative half cycles might tend to move it in the opposite direction, yet no vibratory motion could be imparted to it because of its inertia; the diaphragm having a certain weight, mass and rigidity, depending upon its material and dimensions. The average pull or attraction on the diaphragm caused by the opposing positive and negative half cycles is zero.

In the second place, suppose the diaphragm could follow such rapid alternations of current; we still would hear no sound because the diaphragm would be moving at the same rate as the frequency of the radio wave and, since this frequency is above from 15,000 to several million cycles per second, it is inaudible.

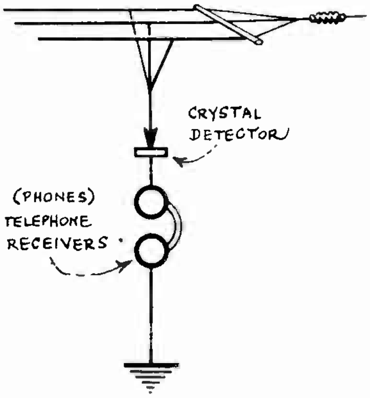


Fig. 3 - THE ANTENNA, CRYSTAL DETECTOR, TELEPHONE RECEIVERS AND GROUND FORM A SIMPLE RECEIVING CIRCUIT

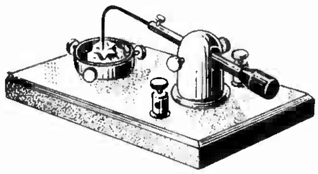


Fig. 4 - THE CRYSTAL IS MOUNTED IN A METAL HOLDER. THE FINE WIRE THROUGH WHICH THE CURRENT FLOWS RESTS ON THE SURFACE OF THE CRYSTAL AT ITS MOST SENSITIVE POINT

THE CRYSTAL DETECTOR

Since the receivers in Figure 2 will not produce the effects of this high-frequency alternating current it is evident that we must introduce some device which will allow the radio current to pass through the receiver in only one direction, to make the pull on one side greater than the other. When we have accomplished this the diaphragm will then respond and vibrate at some frequency less than the radio frequencies because one half of the wave will not be exerting an equal force to act against the other half. This can be done by the circuit of Figure 3, where a crystal detector is inserted in the antenna circuit with headphone receivers connected in series with the crystal. This hook up is one of the simplest circuits for radio reception, but it is not efficient. The action of this receiving set is as follows: An electromagnetic wave radiated by the transmitting antenna cuts across the receiving antenna and thereby produces an alternating current in the receiving circuit which will flow more readily through the crystal in one direction than in the opposite direction. The crystal almost eliminates half of the radio-frequency wave because it presents a very high resistance to half of the wave, and a low resistance to the opposite half.

The crystal is a mineral. Galena which is often used for this purpose is a silver grey or lead colored crystal, obtained in small squares with smooth glistening mirror-like surfaces. These small pieces of galena are mounted in a metal cup in such a way that a fine piece of wire can be brought to bear on the exposed surface of the crystal. A holder for such a detector is shown in Figure 4. All places on the surface of such crystals are not as sensitive as others, and it is therefore necessary to shift the wire until a sufficiently sensitive spot is located. Due to vibration the contact may be jarred loose, and also a strong signal will sometimes cause the sensitivity of the crystal to change.

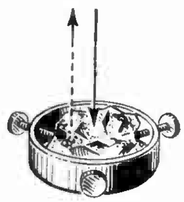


Fig. 5 - THE ARROWS HERE ARE USED TO INDICATE THE UNI-DIRECTIONAL PROPERTY OF THE CRYSTAL

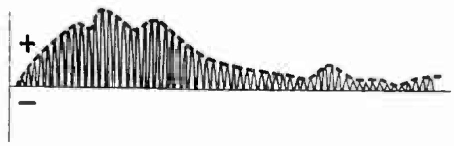


Fig. 6 - A CURVE DEPICTING THE ACTION WHEN THE NEGATIVE HALF OF A WAVE IS SUPPRESSED

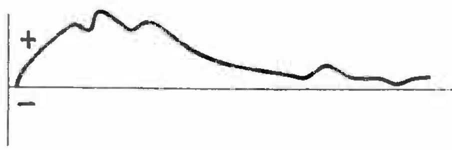


Fig. 7 - THE DIAPHRAGM MOVEMENT OF THE TELEPHONE RECEIVER IS INDICATED BY THIS CURVE

There are other minerals besides galena which will act as detectors and which come under the crystal classification; some of the more common are silicon, zincite, bornite and Carborundum. There have been used at various times detectors in which the rectifying contact is established between two different minerals instead of between one mineral and a metal point.

It is known that the crystal will allow one half of a current wave to easily pass, but will more or less effectively block the other half of the same wave. For example, we will assume that the positive half of this wave flows in the direction as shown by the full line arrow in Figure 5 and is effectively conducted through the crystal. The negative half of the current wave tends to flow through the crystal as shown by the dotted line arrow, but, due to the resistance of the crystal to current in this direction, very little current passes. Therefore the negative half of the wave of Figure 1 is suppressed as shown in Figure 6.

The crystal thus acts as a rectifier, that is, it conducts electric currents readily in one direction, but offers great resistance to currents of opposite polarity. The current flowing in one direction through the telephone receiver magnet coils varies the magnetic field and the diaphragm is moved corresponding to this change in field strength; the curve in Fig. 7 indicates this movement.

PRINCIPLES OF TUNING

Radio waves from any particular transmitting station have, in general, only one wavelength. The frequency of the antenna current at the receiving station will be the same as that of the transmitted radio waves and unless the antenna system is tuned to this same frequency the radio current will not be maximum in strength. This means that the receiving circuit must be so arranged that it will respond to the frequency of the radio waves coming from the transmitting circuit.

An idea of this principle of tuning may be explained by employing two tuning forks having the same pitch or frequency of vibration. When the first fork is caused to vibrate the second will vibrate also, producing a note having the same pitch as that of the first fork. The second fork was set into vibration by the sound waves produced by the first fork because it is an exact duplicate of the first fork and

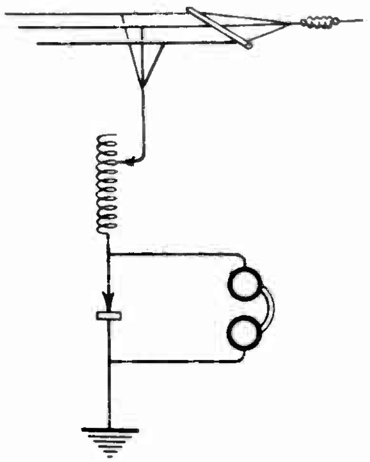


Fig. 8 - A SIMPLE RECEIVING CIRCUIT WHICH PERMITS TUNING TO A LIMITED DEGREE BY THE ADDITION OF THE VARIABLE INDUCTANCE

is, therefore subject to the same vibratory laws as the first one. Suppose we detune the second fork by attaching some wax to it, this will change its weight and it will consequently have a different fundamental vibratory frequency. If we again set the first fork into vibration, the second one will not respond as it previously did because it is out of tune.

A radio receiving circuit must be so constructed that it can be tuned to the different frequencies assigned to broadcast transmitters. When a receiver is so constructed it will be possible to tune or select any desired radio wave and, at the same time, reject all other waves (within certain limits) having a different frequency. It is also possible to obtain the greatest strength from the selected wave by utilizing another phenomenon of electrical circuits known as coupling.

In Figure 8 is shown a variation on Figure 3. In the first place, the detector has been moved to a position across the telephone receivers; here the action is the same in effectiveness. Positive half-waves will pass through the crystal in preference to the phones. Negative half-waves are effectively blocked by the crystal and seek the other path, through the phones. This could be illustrated by turning the curves of Figures 6 and 7 down from the zero axis, indicating the use of the negative half-waves.

The other and most important difference from Figure 3 is the addition of an inductance, with a movable tap, between the antenna and the detector. This permits the selection of a value of inductance which, combined with the inductance and capacity of the antenna-ground system alone, determines at what radio frequency the system will possess the quality of series resonance. Under this condition the maximum radio-frequency current will flow between antenna and ground, producing the maximum rectified current and therefore the greatest telephone response.

The resistance of the crystal prevents, to some extent, the free flow of oscillations and tends to destroy the tuning qualities of the antenna circuit. The tuning properties of the antenna system can be improved by removing the crystal from the simple circuit of Figure 2 and connecting it in a second circuit which is called the detector circuit. This will be taken up next.

FUNDAMENTAL IDEAS OF COUPLING

When two circuits are associated in such a way that power may be transferred from one to the other they are said to be coupled. This involves the use of impedance which is common or mutual to the two circuits. The impedance may be an inductance, capacitance, or resistance. The latter is seldom used except in vacuum tube amplifier circuits.

Inductive coupling applies to the association of two circuits by means of inductance which is mutual or common to both circuits, and generally refers to the use of mutual inductance. When an inductance is common to both circuits, the coupling is generally called direct inductive, and sometimes conductive to distinguish it from the inductive coupling which does not necessarily have any direct connection between the two circuits.

Capacitive coupling applies to the association of two circuits by means of capacitance which is mutual or common to both circuits. When the capacitance is common to the two circuits, the coupling may be referred to as direct capacitive.

The two circuits we are interested in here are the antenna-ground system and the detector-phones system. Brief descriptions will be given of the use of the fundamental coupling methods above in transferring power from the first system to the second.

DIRECT INDUCTIVE OR CONDUCTIVE COUPLING

VARIOMETER. One method of using a common inductance employs a device called the variometer, shown in Figure 9. The variometer has two split coils; one fixed and the other movable. A shaft extends through and supports the movable coil on the end of which is attached a graduated dial. The winding on these coils is made continuous by connecting the stationary coil to the movable coil through a pigtail, or flexible lead. This makes one continuous series winding from the beginning of the fixed coil to the end of the movable coil.

The graduated dial is generally fitted to the shaft of the movable coil in such a way that when the graduated mark 100 is up, it indicates that the movable coil is then in such a position with respect to the fixed coil that current flows through both coils in the same direction. The inductance and wavelength are then maximum. When the coil dial is rotated toward zero the movable and fixed coils are then so related that current will flow in an opposite direction through each. This reduces the inductance and lowers the wavelength. Fine adjustment is obtained by slowly moving one coil with respect to the other in this manner.

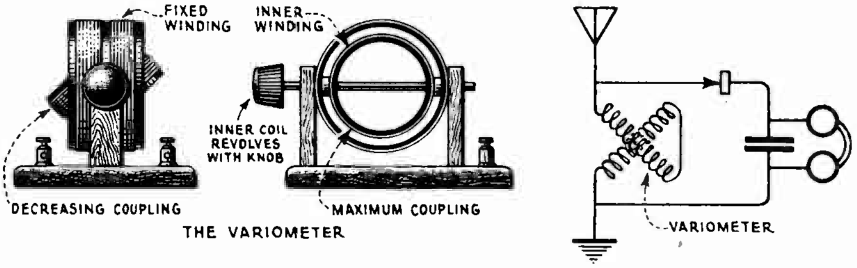


Fig.9 - THE VARIOMETER AND ITS CONNECTION IN THE ANTENNA CIRCUIT

It is seen that the variometer has a double function. Since it is part of the primary circuit of which the other elements are the antenna and ground, the tuning of that circuit depends on the value of inductance in the variometer. It also serves as an autotransformer transferring power to the secondary circuit which includes the detector and telephones. The latter is shunted by a small fixed capacitance which increases the signal amplitude by passing on to the detector the full radio-frequency current available in the circuit, which would otherwise have been impeded by the high inductive reactance of the telephones. The condenser serves the additional purpose of acting as a temporary storage for the single-polarity charges produced by rectification at the detector.

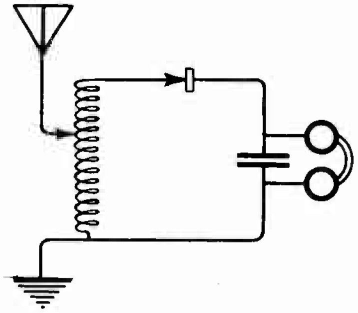


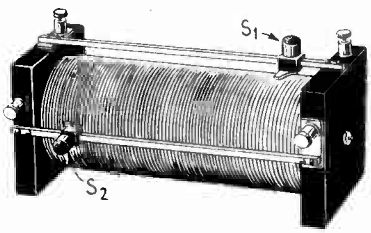
Fig.10 - ILLUSTRATING THE CONNECTIONS OF A SINGLE-SLIDE TUNER IN A SIMPLE CIRCUIT

SINGLE-SLIDE TUNER. The variometer in Figure 9 may be replaced by a variable inductance consisting of a number of turns of insulated wire wound on a tubular form, variation being secured by means of a sliding contactor which can be moved along a strip of coil surface which has been scraped bare of insulation on top of the wire, but not between turns. One end of the coil would be connected in the place of one end of the variometer, and the sliding contactor in the place of the other end of the variometer.

An improvement in the use of a single-slide tuner is shown in Figure 10. It is seen that the antenna alone goes to the slider, permitting the antenna-ground system to be resonated with the desired radio signal, while the entire coil is used in the secondary or detector circuit. This provides a greater voltage than the arrangement of the preceding paragraph. The reason for this is that in the latter arrangement not only is there a direct coupling due to the coil section between the slider and the lower end of the coil, but that section acts as a primary having a mutual inductance with the coil turns above the tap in the diagram, these turns providing an additional voltage in series with the voltage across the lower section.

This circuit will produce loud signals, but it is not selective and therefore considerable interference results with its use.

DOUBLE-SLIDE TUNER. In Figure 11 is shown a tuner equipped with two separate sliders, one method of using them being shown in the schematic diagram. The primary or antenna-tuning section is that portion of the coil which is between the two sliding contactors. The secondary section extends from the right-hand slider to the upper end of the coil. The coupling is then by both common and mutual inductance. However, if the left-hand slider is moved down below the right-hand slider, there will be no coil-turns in common in the two circuits,



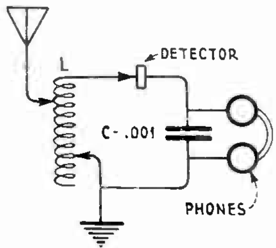


Fig. 11 - SHOWING THE CONSTRUCTION OF A DOUBLE-SLIDE TUNER AND ITS CONNECTION IN A SIMPLE RECEIVING CIRCUIT

though interconnected, and the coupling will be only by mutual inductance. This gives some improvement in selectivity, but tuning coils with sliding contactors have long since gone out of use in reception, not only because of the poor selectivity afforded, but because of the poor and intermittent contact provided by the slider.

INDUCTIVE COUPLING

The inductive coupling shown in Figure 12 utilizes the magnetic field which springs up about the primary in the antenna circuit to transfer the energy to the secondary circuit. As these magnetic lines of force, shown as dotted lines, expand from the primary circuit they cut the secondary coil and an e.m.f. is set up in the secondary which causes a current to flow in this circuit. When the primary and secondary coils are so placed that practically all the lines of force from the primary cut the secondary, they are said to be closely coupled. When only a comparatively few lines of force cut the secondary the circuits are said to be loosely coupled.

As stated previously the detector is usually placed in a separate circuit called the local detector circuit which is provided for by the inductively coupled arrangement. Figure 13 is an inductively coupled receiver. In this receiver we have two separate windings; the one called the primary is connected directly in the antenna-ground circuit and the value of inductance used is made variable by means of the slider which can be moved along the winding, thus turns are cut in or out as desired.

The secondary is entirely separated from the primary, that is, no physical connection exists between them. This winding has taps taken off and connected to switch contacts as shown. By use of the switch "S" the number of turns in the secondary circuit may be varied.

A form of tuner which was popular more than a decade ago is shown in Figure 14. It is one type of "loose coupler" and is so arranged that the secondary may be moved in and out of the primary at will, thus increasing or decreasing the coupling between the two circuits. The purpose of the tuning arrangement in the two methods of coupling

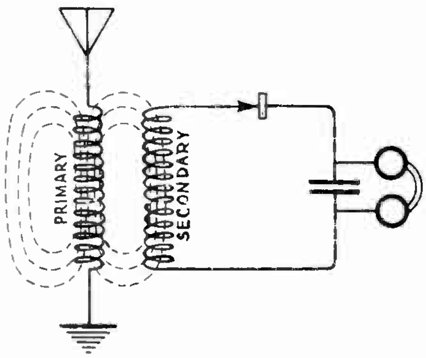


Fig. 12 - ILLUSTRATING THE PRINCIPLE OF INDUCTIVE COUPLING

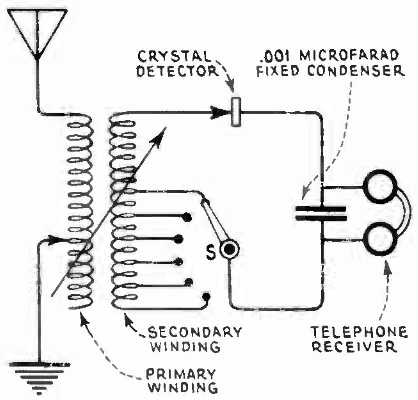


Fig. 13 - IN THIS CIRCUIT THE INDUCTANCE OF PRIMARY AND SECONDARY CAN BE VARIED AS INDICATED

just discussed is to adjust the frequency of the primary and secondary circuits and also to provide an adjustment which will produce the proper transformer action in order that the greatest possible energy will be transferred to the secondary circuit.

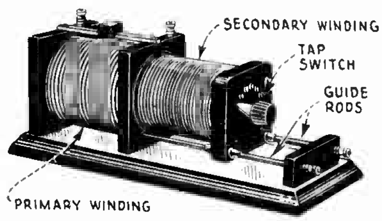


Fig. 14 - THIS "LOOSE COUPLER" WAS POPULAR AS A TUNER IN THE EARLY TYPES OF RECEIVERS OVER A DECADE AGO

EFFECT OF DISTRIBUTED CAPACITY. Every turn of a coil has small capacities between it and every other turn. The greatest capacity, of course, is between turns lying next to each other. Just as every conductor has the properties of both inductance and resistance to some extent, whether coiled up or not, so we find the presence of a condenser effect which must be taken into account in determining the resonating effect of the coiled conductor.

In the variometer shown in Figure 9 the distributed capacity will be fairly low and would probably not make a resonant secondary circuit anywhere near the setting at which the variometer makes the primary circuit resonant to a given frequency. This is because the antenna-ground capacity would be in parallel with the distributed capacity of the variometer and of a higher value.

In Figure 10 we have a different condition. Here the distributed capacity and inductance of the whole coil will make the secondary circuit broadly resonant at some frequency. It may be possible to secure resonance to that frequency in the primary circuit by including only a few turns whose inductance and capacity are combined with the inductance and capacity of the antenna. It would only be an accident if a resonant frequency of the circuits were obtained that might be useful for receiving some station. The primary resonant frequency may be varied by the slider, but not the secondary.

In Figure 11 the use of two sliders corrects that defect. The right-hand slider allows the selection of that length of winding whose inductance and distributed capacity determine a desired resonant frequency.

In Figure 13 the antenna circuit is finely tuned by the primary of relatively large wire, the number of turns, and therefore the inductance, being varied by means of the slider. The secondary circuit is approximately tuned by the selection of the tapped section in circuit. The secondary is usually of fine wire having a large inductance and appreciable distributed capacity due to close spacing of the wire. By moving the secondary coil in or out of the primary the mutual inductance is increased or decreased. This alters the effective separate inductances of the two coils as well as the coupling. Hence the secondary resonant frequency is changed somewhat, and the results obtained are about as satisfactory as could be expected with the use of many more taps on the coil to provide a finer selection of inductance values.

SECONDARY TUNING WITH A VARIABLE CONDENSER. In Figure 15 is shown a double circuit receiver in which the coupling is changed by varying the distance between the primary and secondary coils. This circuit can be very closely coupled. A good degree of selectivity is secured by connecting a variable condenser across the secondary coil as shown. When the resonant frequency of the primary and secondary circuits is made the same by a proper selection of inductance in the primary circuit and of capacity in the secondary circuit, the current flowing through the telephone receivers will be a maximum, thus giving a loud signal.

As the secondary is moved away from the primary the mutual inductance is decreased. This changes the effective separate inductances of the primary and secondary coils, and each circuit will have to be retuned slightly to secure resonant conditions. The signal voltage in the secondary is of course decreased, but there is an advantage in getting better selectivity, because the voltage of a signal at the resonant frequency will be cut down much less than the voltage of an undesired signal at some other frequency.

In general the desired results of high signal voltage and good selectivity can be secured best when the ratio of inductance to capacity in a resonant circuit is great. Because of this fact, when a wide range of resonant frequencies must be provided in a receiver then selective tuning of the secondary circuit is not left to a variable condenser alone. The condenser can be small in capacity range if the total inductance of the secondary circuit can be increased by the addition of one or more coils in series with the transformer secondary winding and the condenser. These added coils need not be coupled

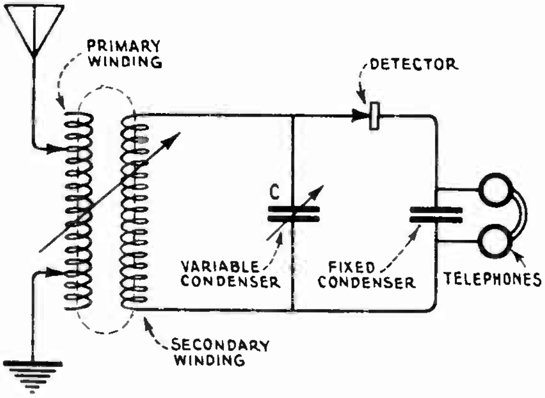


Fig. 15 - THE ARROW THROUGH THE PRIMARY AND SECONDARY WINDINGS INDICATES THAT THE COUPLING IS VARIABLE

inductively at all to the primary circuit, if the transformer secondary provides sufficient coupling to the primary circuit to accomplish the desired transfer of power.

CAPACITIVE COUPLING

The method known as "capacitive coupling" is shown in Figure 16. The coils designated by L_1 and L_2 are not in inductive relation; in fact they are usually placed in a receiver with their axes at right angles in order to prevent inductive coupling. The only tuning control

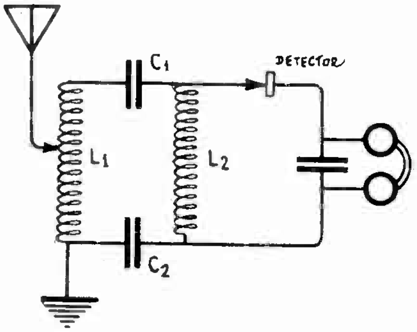


Fig. 16 - A CAPACITIVE COUPLED CIRCUIT WITH ONLY ONE TUNING CONTROL

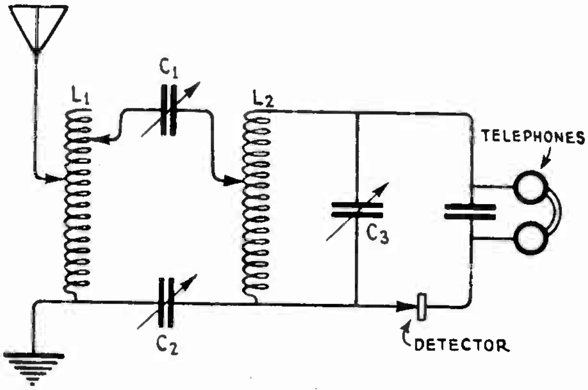


Fig. 17 - A CAPACITIVE COUPLED CIRCUIT UTILIZING VARIABLE INDUCTIVE COUPLING AND VARIABLE CAPACITIVE COUPLING

shown is the tap or slider permitting variation of the inductance in the primary or antenna circuit. The secondary circuit consists of the two coils and condensers C_1 and C_2 in series. The detector is in a third or tertiary circuit composed of L_2 and the telephone receivers with their by-pass condenser.

In Figure 17 improvement has been secured by introducing variable inductive coupling in the autotransformer L_1 and in the autotransformer L_2. Variable capacitive coupling is secured by making both

C_1 and C_2 variable. By a proper selection of their capacities and the number of turns of the coils used in the secondary circuit, this can be made resonant at the desired frequency. The tertiary circuit composed of all of L_2 and the variable condenser C_3 can, of course, be resonated. More coupling controls are shown in Figure 17 than would be useful in a practical receiver.

It is also apparent that the two coupling condensers could be replaced by a single condenser having a maximum capacity less than C_1 or C_2. If the secondary circuit is kept far from resonance the transfer of energy will vary directly with the coupling capacity.

RESONATING THE ANTENNA FOR HIGH AND LOW RADIO FREQUENCIES

When it is desired to receive a radio signal whose frequency is higher than the frequency to which the antenna circuit (antenna and ground plus a necessary few primary coil turns for coupling) will respond, it is necessary to employ a variable condenser in series. This reduces the capacity of the antenna circuit. This condenser is usually placed in the circuit with the rotor plates connected to the ground side. When the capacity of the condenser is decreased the net capacity of the system is decreased and the resonant frequency

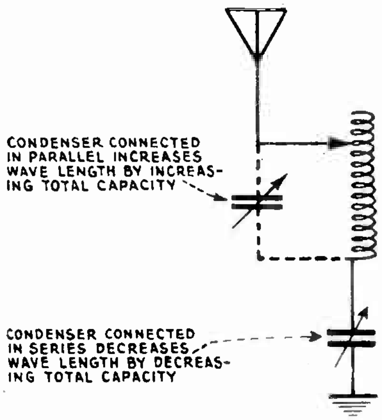


Fig. 18 - INDICATING HOW A VARIABLE CONDENSER IN DIFFERENT POSITIONS EITHER INCREASES OR DECREASES THE NET CAPACITY OF AN ANTENNA SYSTEM

increased. This arrangement is shown in Figure 18 and is employed when the antenna is so long that the natural frequency of the antenna-ground system is lower than the frequency of desired stations. It is sometimes used even when the station could be tuned in with the primary inductance alone. By inserting a series condenser, resonance will be secured with an increase in the primary inductance used. This increases the ratio of inductance to capacity which increases the selectivity of the antenna circuit.

When an antenna circuit is tuned only by an inductance the maximum value of the latter may not be great enough to tune in stations of relatively low radio frequency. In this case a variable condenser connected in parallel with the primary inductance will increase the total capacity of the antenna circuit. This is shown by the dotted lines of Figure 18. Increasing the capacity of the condenser will lower the resonant frequency of the circuit.

For convenience a single condenser may be used for either purpose, by the use of a double-pole, double-throw switch which transfers the condenser from the series to the parallel arrangement. The student should keep in mind the fact that the antenna constitutes one plate of a condenser of which the other plate is the ground, the dielectric being the air and any more solid objects intervening between them. Now when an additional condenser is connected in parallel to the antenna-ground system its capacity is increased; when connected in series the capacity is decreased.

EXAMINATION QUESTIONS

1. What is the function of the diaphragm of a telephone receiver?

2. Are air vibrations audible if they have a frequency above 15,000 cycles?

3. Could they be produced by the diaphragm of a telephone receiver?

4. (a) Explain the action of a crystal when used as a detector.
   (b) Name a few minerals that may be used as detectors.

5. Tell in your own words what you can about the principle of tuning.

6. What is the difference between plain inductive coupling and the so-called conductive coupling?

7. How are the windings of a variometer arranged?

8. Where are variable condensers used to advantage in a receiving circuit?

9. Draw a diagram of an inductively coupled receiver in which both circuits can be resonated.

10. Name some disadvantages of a crystal detector.

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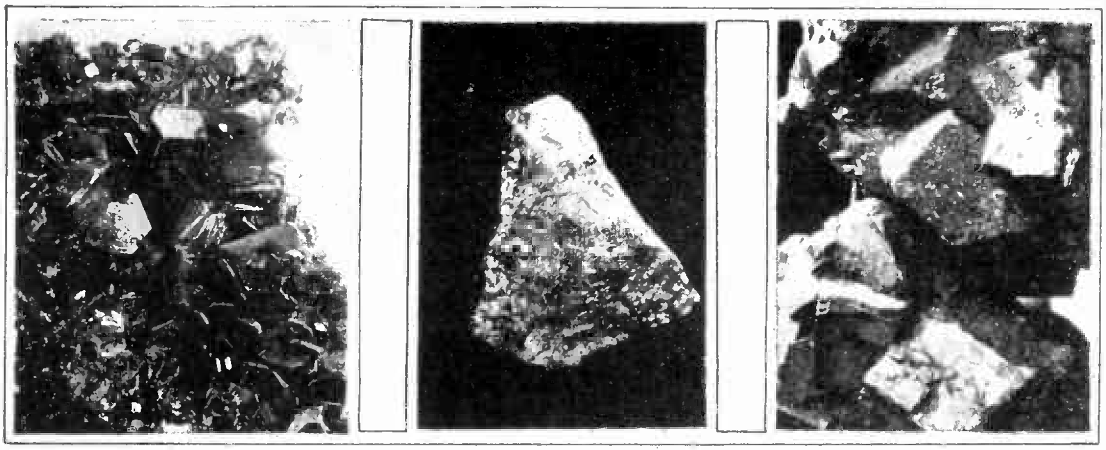

BEFORE THE UNIVERSAL ADOPTION OF THE VACUUM TUBE THESE MINERALS WERE IN WIDESPREAD USE AS CRYSTAL DETECTORS IN RADIO RECEPTION

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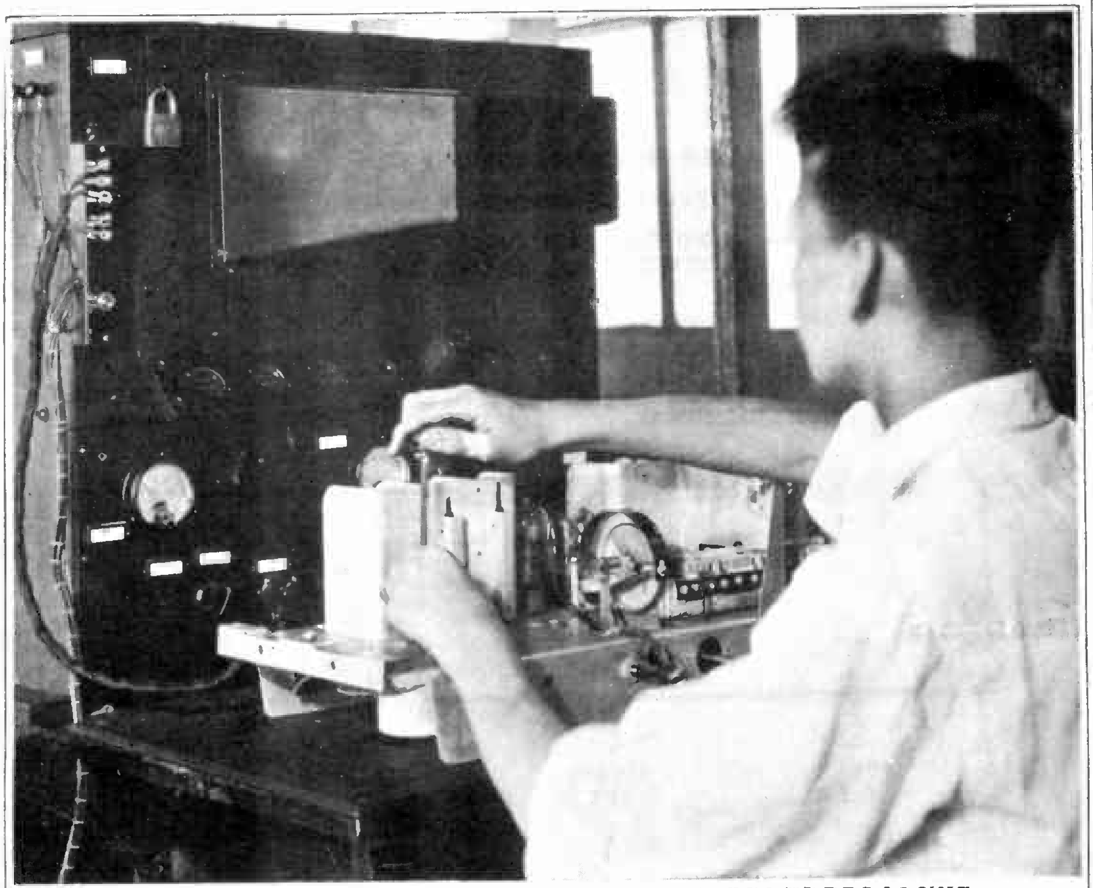

THE CORRECT FUNCTIONING OF A SUPERHETERODYNE RECEIVER IS DEPENDENT ON PROPER ALIGNMENT OF ITS I-F STAGES. AN OSCILLOGRAPH IS USED HERE TO VISUALLY CHECK ACCURACY OF I-F CONDENSER ADJUSTMENTS.

The Development of the Superheterodyne

VOL. 16, No. 2

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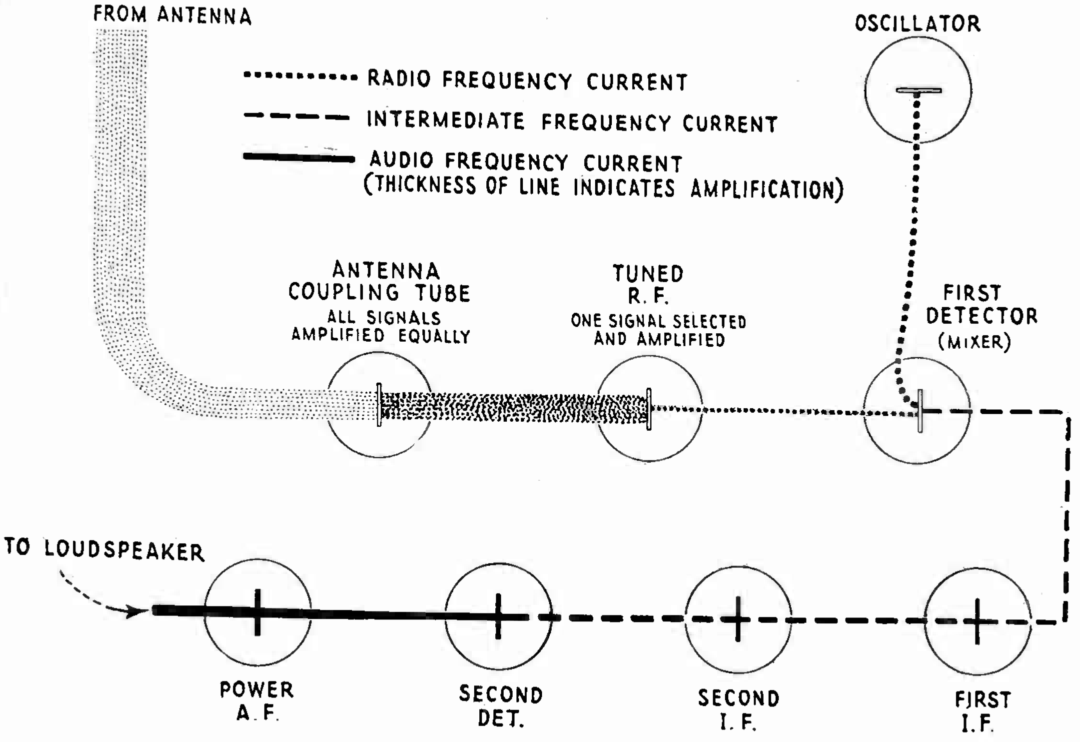

Fig. 1 - ILLUSTRATING THE PATH OF A SIGNAL THROUGH THE CIRCUITS OF A SUPERHETERODYNE RECEIVER.

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THE DEVELOPMENT OF THE SUPERHETERODYNE

At the very beginning of your study dealing with the development of the superheterodyne it is best to obtain a perspective of this subject by reading over the definitions of terms which apply specifically to this work. Therefore, in the paragraphs immediately following we have given the definitions of the three systems which employ the heterodyne principle for the reception of radio signals, namely; heterodyne reception, autodyne reception and superheterodyne reception.

These definitions, from the standards of the Institute of Radio Engineers, are as follows:

(1) Heterodyne reception is the process of receiving radio waves by combining in a detector a received voltage with a locally generated voltage. The frequency of the locally generated voltage is commonly different from that of the received voltage.

(2) Autodyne reception is a system of heterodyne reception through use of a device which is both an oscillator and a detector.

(3) Superheterodyne reception is a method of reception in which the received voltage is combined with the voltage from a local oscillator and converted into voltage of an intermediate frequency which is usually amplified and then detected to reproduce the original signal wave.

THE PHENOMENON OF "BEATS".

Sound. A perfect demonstration of the principle of beats can be made with three tuning forks whose frequencies are 400, 500 and 600 cycles per second. If all three forks were made to sound simultaneously, a good musician could pick out the three separate frequencies. Any person of normal hearing would also be able to distinguish sound components of other frequencies in addition to those being actually produced. The other frequencies would not actually be present in the air, but would seem to be due to a non-linear response characteristic of the human ear. The presence of the 400 cycle and 500 cycle frequencies in the ear would produce an impression of 100 cycles also being present, this being the arithmetical difference between 500 and 400; likewise the arithmetical difference between 600 and 500 cycles would represent the same effect. The difference between the 600 and the 400 cycle tones would cause the impression of a 200 cycle note being present.

The apparent presence of all these frequencies, 100, 200, 400, 500 and 600 gives a sense of pitch to the average individual corresponding to the production of a fundamental frequency of 100 cycles plus the 2nd, 4th, 5th, and 6th harmonics of that note, as represented by the other apparent and real frequencies. There are also quite a number of other frequency-impressions that may be computed by taking the various arithmetical sums of real tuning fork frequencies, such as 900, 1000, 1100 and so on.

The principle of "beats" on which this is based covers the particular effect produced when two wave-motions of different frequency exist in a common medium, and some interpreting or translating device is used whose response does not vary linearly with the amplitude of the wave-motion. The human ear is an example.

No doubt you are by this time quite familiar with the annoying squeal produced by a regenerative radio receiver when its feed-back control is advanced too far, thus causing it to set up oscillation and in this way become a miniature transmitter of radio waves. In other words this regenerative receiver, when in an oscillating condition becomes a radio station operating on a certain frequency and its received energy is applied to the input side of the detector. If the detector tube happens to be in an oscillating condition, it may produce another current of such frequency that an audible beat-note would be produced in the headphones or loudspeaker. Furthermore, the same effect can be produced, even without a non-oscillatory detector, by one of the radio-frequency amplifier stages if it is sufficiently far from being neutralized to produce the separate oscillating current required before the beat can be produced.

Another way in which a beat effect may be produced is when some radio station is transmitting at a frequency appreciably different from its assigned carrier frequency. The carrier frequencies of radio stations are allocated so that the frequency of a given station should be 10 kc. away from the stations in the adjacent bands. However, suppose a certain station is off frequency, so that it is 18 kc. from the station on one side, and only 2 kc. from the station on the other side. If you were listening-in it would be found that this 2 kc. difference in carrier frequencies would produce a 2000 cycle beat-note in your phones or speaker.

The interesting thing about this beat effect is that you could place the headphones in series with the plate-voltage supply to any of the radio-frequency amplifier tubes, and not get the beat-note, providing, of course, the r-f tubes were perfectly linear in their grid-voltage plate current characteristic. Actually, tubes are not so perfect in this respect, and there might be a very weak beat-frequency produced. However, such a beat-frequency would not be nearly as strong as it would be if you appreciably increased the grid bias voltage on the tube in whose plate circuit the phones had been inserted. This tube would then have the non-linear response characteristic which determines the evidence of beats. From these facts it is seen that a detector of some kind is required.

It must not be assumed that beats can occur only at audio frequencies. To the contrary, we will be particularly concerned later with producing a resultant frequency which is quite above the audible range, for use in the superheterodyne reception method.

TWO METHODS OF AMPLIFYING RADIO SIGNALS.

Radio amplification is used before the demodulating detector is reached in order to amplify weak signals that would not otherwise actuate the detector at all. At the same time it allows the insertion of successive tuned circuits designed to select a desired signal and reject others not wanted.

Audio-frequency amplification finds its use in amplifying the signal after it has been rectified by the detector, thus building up the signal to the strength necessary to operate the electrically-driven air pump which we know as a loudspeaker. This is generally accomplished with from one to three stages of voice-frequency amplification. More than this is not generally successful due to tube noises and reaction effects which destroy the quality of the signal thus amplified.

DIFFICULTIES ENCOUNTERED IN R-F AMPLIFICATION.

Before the advent of neutralizing of grid-plate capacity in a vacuum tube, considerable difficulty was experienced in amplifying radio-frequencies above 300 kc., due to the tendency to oscillate. Another source of trouble was in the stray inductive couplings between parts of the grid and plate circuits of tubes, and even between circuit parts which were remote from each other in the amplification line, but all too closely spaced by the requirements of convenient handling.

At a frequency of 1000 kc. a tube capacity of 8 micromicrofarads is equivalent to approximately 20,000 ohms impedance. At 50 kc., the same capacity would present an impedance of about 400,000 ohms. It is apparent then that an amplifier could be so efficiently designed at 50 kc. that its voltage gain would be considerably greater than could be achieved (with the three-electrode tube) at 1000 kc.

It was on this principle that Major E. H. Armstrong worked when he developed the superheterodyne for use in listening posts behind the lines during the World War, when a great deal depended on the interception of secret code messages passing between various units of the opposing forces.

THEORY OF THE SUPERHETERODYNE.

We now come to a principle used to obtain far greater amplification together with extreme selectivity and sensitivity and, while there is a similarity in some parts of the circuit to the methods just described, it will be seen that improvements are incorporated to obtain the desired results. This principle is embodied in the superheterodyne receiver.

When first developed, the receiver had about as many controls as a radio-frequency receiver of the same number of stages, but with a far greater sensitivity. In later years, the number of controls was considerably reduced because, as we shall see, certain selective circuits of the superheterodyne can be left in a tuned condition which does not vary for changes in the signal radio-frequency which it is desired to receive.

The superheterodyne receiver fundamentally consists of five main parts:

1. A radio-frequency amplifying system.
2. A frequency changing system.
3. An intermediate-frequency amplifying system.
4. A demodulator-detector.
5. An audio-frequency amplifying system.

The 1st, 4th and 5th parts are exactly the same as found in any ordinary tuned radio-frequency receiver, which uses only two frequency ranges, namely, radio and audio. The superheterodyne uses a third frequency range, which is intermediate in value between the radio and audio, and is therefore termed the "intermediate frequency".

The production of this third frequency is a local matter in the receiver itself, the frequency changing system consisting of an oscillator which provides the heterodyning frequency, and a mixer or detector which makes available the beats which constitute the intermediate frequency. This frequency is subsequently amplified selectively by means of one or more tubes associated with tuned circuits whose capacity and inductance are made fixed and resonant at the intermediate frequency which it is desired to use.

TRACING A RADIO SIGNAL THROUGH A SUPERHETERODYNE.

As a means of illustrating the path of a radio signal and the changes that it undergoes in passing through a superheterodyne, what may be called a current flow chart has been prepared as shown in Figure 1. It shows the path of the various current frequencies through the tubes in the set. Radio-frequency current is represented by dotted lines, intermediate-frequency current by dash lines, and audio-frequency current by a solid continuous line. Amplification is indicated by the increase in the thickness of the various lines.

The incoming signals of high frequency are the dotted lines on the extreme left. These currents come in directly from the antenna and are all amplified equally in the first stage. This amplification is indicated by an enlargement of the dots. You will note that each one has been increased by the same amount. The input to the first tube for this chart is the signal voltage developed across an untuned impedance, such as a resistance, connected between antenna and ground.

Connected to the first tube or coupling stage is the second tube or tuned radio-frequency stage which will permit current of approximately only one frequency to pass. This frequency may be selected at will. In the second stage this signal is amplified still further before being passed on. The third stage or detector is also tuned to the incoming signal.

At this detector stage the signal from the local oscillator is introduced. As you see, it is dotted, meaning high frequency. The oscillator is adjusted so that it will oscillate at a certain frequency difference from the incoming signal. These two currents of different frequency enter the detector and are mixed in such a manner that the output is of a frequency equal to the difference between them. It is important to remember that this detector is called the first detector in superheterodyne circuits.

This frequency, known as the intermediate frequency, is shown in dash lines. The audio signal, originally superimposed on the incoming radio-frequency current, is now superimposed on the intermediate-frequency current.

This combination is allowed to pass through two stages of amplification before it passes to the next tube circuit where it is detected, or demodulated. This detector, which functions to demodulate the signal, is called the <u>second detector</u> in superheterodyne circuits. From the second detector we get an output current of an audible frequency, indicated by a heavy solid line. This audio current is similar in characteristics to the audio current used to modulate the carrier wave sent out from the transmitter. In order that this current may be of sufficient intensity, it is put through a stage of power amplification—indicated by an increased thickness of the solid line—before going to the speaker. Thus, we have followed the three frequencies through the tubes of the set. Before leaving this chart it may be well to point out that the regulation of the flow of current at three different radio frequencies may be controlled by one dial in most receivers, thus eliminating the difficulty of trying to perform three tuning operations at one time.

FREQUENCY CHANGING SYSTEM.

Since this is the most important part of the superheterodyne, and the thing that distinguishes it from other forms of receivers, we will commence our explanation with a circuit shown in Figure 2, where the radio-frequency signals are picked up by a loop antenna and fed directly into the first detector. For the present we will pass over the review of the radio-frequency amplifying system that may also be embodied in such a receiver because this subject, in general, is common to other types of receivers.

The loop pickup circuit and 1st detector in Figure 2 are shown in simplified form in Figure 3. It will be reasoned that such a circuit will serve to demodulate the radio-frequency carrier and make the audio frequencies of the received broadcast program energy available in the plate circuit. This would be true, if headphones were inserted in that circuit. However, we are not interested in listening to the program sounds as yet, because the simplicity of the single tuned circuit is such that it is both insensitive and highly unselective for our needs.

Let us leave this circuit for a moment and consider the circuit in Figure 4, which shows a simple Hartley oscillator.

This circuit consists of an inductance coil in the grid circuit and one in the plate circuit. These coils are so arranged that energy from the plate circuit coil will be inductively supplied to the grid circuit coil.

A variable condenser placed between the grid and plate sides of the two coils makes possible the tuning of the total inductance provided by these coils and also enables one to tune the system so that it will oscillate at a frequency which will permit the circuit to be used for practical reception.

Depending upon the inductance of the coils and the capacity of the condenser, the frequency can be made anything within the range of the value of these units.

With such a system capable of producing radio-frequency oscillations, we will couple it to the circuit of Figure 2 by means of a small pickup coil marked L_3. We now have three coils in the coupled oscillator, L_1 in the plate circuit, L_2 in the grid circuit and L_3 in the grid circuit of the frequency changer or first detector. We also have two variable condensers, C_1 in the first detector circuit to tune the loop, and C_2 in the oscillator circuit. These are the only tuning controls necessary in the superheterodyne.

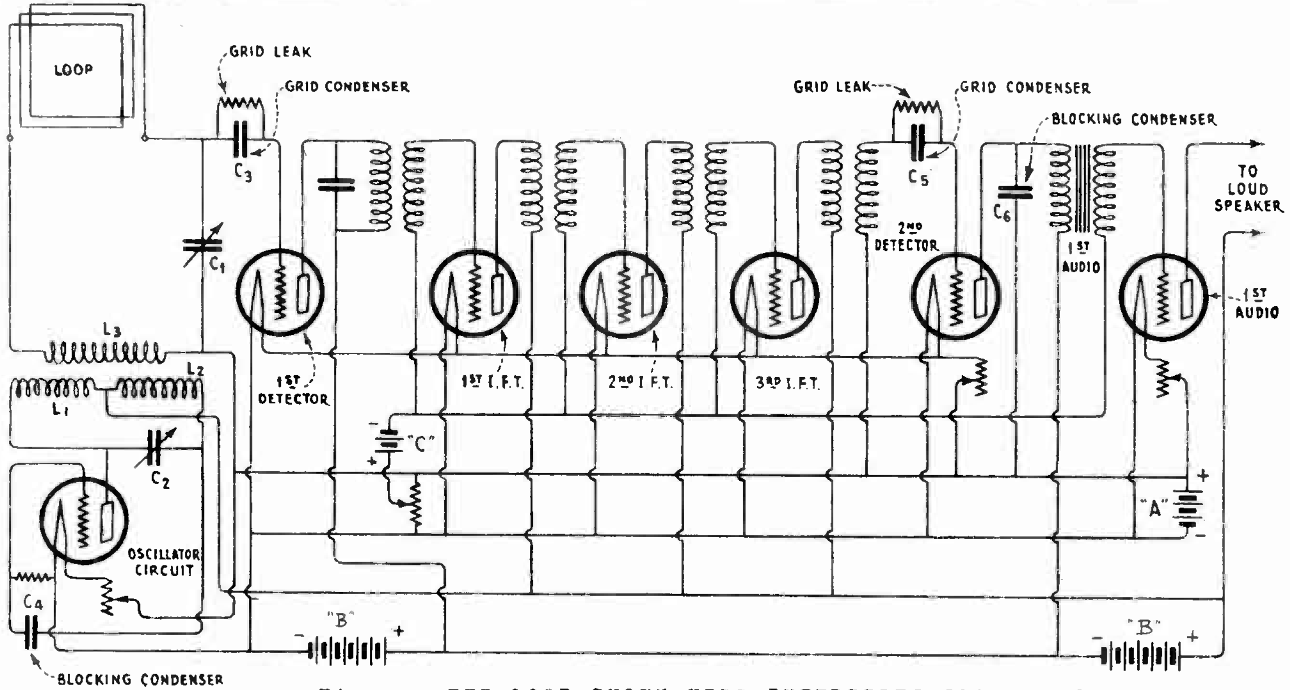


Fig. 2 – THE LOOP SHOWN HERE INTERCEPTS THE RADIO SIGNAL AND DELIVERS ENERGY DIRECTLY TO THE FIRST DETECTOR.

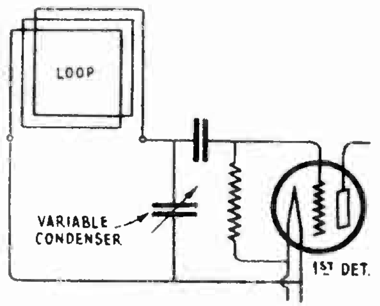
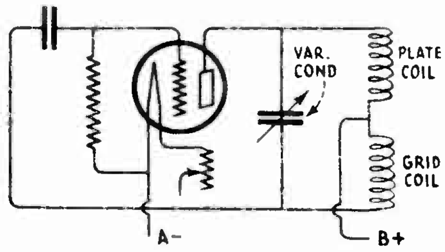


Fig. 3 (LEFT) SIMPLIFIED CIRCUIT OF A LOOP CONNECTED TO THE FIRST DETECTOR.

Fig. 4 (RIGHT) SCHEMATIC DIAGRAM OF A SIMPLE HARTLEY OSCILLATOR.



Now by adjusting C_1, we may have the frequency of any desired signal in the loop circuit; and the oscillator circuit may be made to produce any desired frequency independent of external signals or forces.

Let us assume that the incoming frequency oscillation picked up when tuning the loop by means of a condenser and impressed on the grid of the first detector or frequency changer is 1,000,000 cycles per second, which would be the signal from a station transmitting on a wavelength of 300 meters. The oscillator is now adjusted by means of the variable condenser C_2 to a frequency of 1,180,000 per second; this frequency being impressed likewise on the grid of the first detector through pick-up coil L_3.

We now have two different frequencies being impressed on a common circuit, that is, impressed upon the grid of the first detector. When two different frequencies are thus impressed on a common circuit, they produce a third, or beat frequency, and the frequency of this beat will be the difference between the two impressed frequencies. Since the incoming frequency is 1000 kc. and the oscillator frequency 1180 kc., the difference between these two frequencies will be 180 kc. We now have a frequency which is lower than the incoming frequency of 1000 kc. to work with, namely, 180 kc., or in terms of wavelength it is higher, being equivalent to 1606 meters. This beat frequency is called the intermediate frequency, and is passed to the first intermediate frequency transformer and vacuum tube , where it is amplified and then passed on to the second and third intermediate transformers. Note that amplification can be carried on for more than two stages if desired. After passing through the intermediate-frequency amplifiers, it is impressed on the grid of the second detector.

The second detector performs the demodulating function with which you are familiar in any tuned radio-frequency amplifier system. The output of this detector is an audio-frequency voltage capable of operating headphones, or of being amplified through an audio-frequency system to provide the power level necessary to operate a loudspeaker.

DIFFICULTIES IN STATION SELECTION.

It will be observed that the loop antenna circuit of Figure 2 is a system used for input to the first detector. In the following paragraphs we will show that there are three undesirable features to an input system of this kind.

FIRST. An oscillator is a miniature form of transmitter. Therefore, if the loop circuit is tuned to a frequency not very far from that of the oscillator, the loop becomes a very good radiator of the energy produced by the oscillator. Since this radiation is at a frequency which is usually in the broadcast band it causes interference by the production of heterodyne whistles in nearby receivers.

SECOND. The selectivity of the single tuned circuit (loop and condenser) to incoming radio frequencies is not very good. It may be desired to receive a certain station which is transmitting on its assigned carrier frequency at a time when a nearby station of greater power but of another carrier frequency is transmitting. In this case the undesired signal will override the desired one, causing what is termed "cross-modulation" which spoils the program. Another interference results from the fact that there are two signal radio frequencies which will combine with an oscillator frequency to produce the same beat frequency. For instance, if an oscillator at 650,000 cycles beats with radio station frequencies of either 600,000 or 700,000 cycles a beat frequency of 50,000 cycles will result in both cases. Two stations can be received at the same time if the selectivity of the system is poor between the antenna and the first detector. In this type of interference the term "image frequency" is applied to the undesired signal frequency. A further interference type occurs when two stations, whose frequencies differ by the value of the intermediate frequency, reach the first detector and by heterodyning with each other form the intermediate frequency which passes through to produce a badly garbled combined program. This can happen with the local oscillator completely removed.

THIRD. The inductive coupling between the loop circuit and the oscillator circuit causes a reaction between them when changing the constants of either one while tuning.

After exhaustive experiments a means was evolved whereby the first detector was made to function both as the oscillator and first detector, thus eliminating one tube. This was not a simple solution but one which required considerable research and time. There was finally developed a simple and effective arrangement which solved the problem completely. It consisted of connecting two tuned circuits to the oscillator; one a simple circuit which could be tuned to the frequency of the incoming signal, and the other a regenerative circuit which could be adjusted to oscillate at some particular frequency, the second harmonic of which, beating with the incoming signal frequency, would produce the frequency desired for intermediate amplification.

ELIMINATING RADIATION, CROSS-MODULATION AND IMAGE RESPONSE.

The use of tuned radio-frequency stages of proper design between the antenna system and the first detector will eliminate all three of the troubles just mentioned.

By the use of screen-grid tubes in r-f amplifier circuits or by properly neutralized triode amplifier circuits it is possible to prevent the antenna from radiating the energy generated by the local oscillator.

Cross-modulation in the first detector is prevented by the selective amplification of sharply tuned stages which precede this detector. The super-control tubes eliminate cross-modulation in the r-f stages. Image response is prevented by the same selectivity afforded.

The use of an intermediate frequency of the order of 180 kc. also helps, as the difference between the desired and the undesired station frequencies is 360 kc., as compared to a station frequency difference of only 80 kc. when the intermediate frequency is but 40 kc.

CONSIDERATION OF THE FREQUENCY BANDS CONCERNED.

In order to understand just what frequencies are involved in the intermediate-frequency amplifier, let us start at the radio transmitter, and review what happens when a carrier frequency of 800 kc. is modulated simultaneously by two musical notes which are at the opposite extremes in the range. These notes are, namely, the low note of the bass viol, or 40 cycles, and the highest note of the piccolo, which is about 4100 cycles. According to the side-band theory, the radio transmission would consist of the following radio frequencies:

Upper side-band due to high piccolo note.........804,100
" " " " " low bass viol note........800,040
Carrier frequency.............................800,000
Lower side-band due to low bass viol note........799,960
" " " " " high piccolo note.........795,900

Subtracting the lowest from the highest frequency, it is seen that a radio-frequency band 8200 cycles wide is required to transmit the highest note played as well as other lower musical frequencies created by the bass viol as fundamental and overtones, in which it is rich.

For this explanation let us assume the local oscillator provides a single radio frequency which is 980,000 cycles. When this frequency is combined with the various frequencies representing the radio program just outlined the beat frequencies will be produced as follows:

Oscillator Frequency	Transmitted Signal Frequencies	Intermediate Frequencies by Heterodyne	Original Cause
980,000	804,100	175,900	Piccolo
980,000	800,040	179,960	Bass Viol
980,000	800,000	180,000	Carrier
980,000	799,960	180,040	Bass Viol
980,000	795,900	184,100	Piccolo

It might be well for you to prove these figures by the indicated subtractions.

By subtracting the lowest from the highest intermediate frequency produced, you see that a band 8200 cycles wide is required to transmit through the intermediate-frequency amplifier all the frequencies which are necessary to produce at the output of the second detector the range of musical frequencies set up by the instruments listed above.

From the fact that radio stations are allotted a channel width of 10 kc. in the broadcast band it is evident that the intermediate-frequency amplifier must be capable of passing this band of frequencies if successful reception of broadcast programs is to be accomplished.

It is important that we should continue this reasoning into the field of television transmission and reception. Considerably more information must be passed over a television channel than over a sound broadcast channel as the following comparison indicates; a very ordinary television program will use signal frequencies up to 50,000 cycles, whereas 5,000 cycles is sufficient for sound programs. Hence, the width of the television frequency band required is 100 kc. instead of 10 kc. This extremely wide band demands that a television transmission be on some high carrier frequency in order to economize in the use of radio channels. On this account the Federal Radio Commission has licensed experimental stations between 2000 and 3000 kc., which provide a range for 10 stations to operate nearby simultaneously, each on a separate channel 100 kc. wide.

In a superheterodyne receiver for such a signal, the use of a 180 kc. intermediate frequency would be impractical, because the i-f amplifier would have to pass frequencies from 130 to 230 kc. However, we can use a higher intermediate frequency, such as 600, 800, or 1000 kc., and get good amplification of the entire band width of 100 kc.

Note that in this particular design the intermediate-frequency amplifier may pick up considerable interference from the broadcast stations unless special care is taken to exclude such signals.

Selection of the Intermediate Frequency. To return to the problem of broadcast reception, we are concerned with the selection of some value for the intermediate frequency which will not complicate our problem of amplification without interference. Early superheterodyne receivers used between 30 and 45 kc. as the intermediate frequency, but later use was made of 180 kc. It was found that in the case of an intermediate frequency of 180 kc. it was practically inevitable that harmonics of this frequency would exist in some of the circuits. For example, of these harmonics the second would be 360 kc.; the third, 540 kc.; the fourth, 720 kc.; the fifth, 900 kc., and so on. The difficulty encountered here is that the i-f harmonics might combine on the second detector grid with stray radio-frequency signal voltages and due to the heterodyning action undesirable whistles would be heard through the loudspeaker.

The most offending harmonics of the intermediate frequency are the second and third, because they are comparatively strong. From the range of the harmonics just mentioned and the fact that the broadcast band extends from 550 to 1500 kc. it is apparent that the third harmonic of all intermediate frequencies between 183 and 500 kc. and the second harmonic of all intermediate frequencies between 275 and 750 kc. will fall in the broadcast band. Hence, it is difficult to use intermediate frequencies greater than 265 kc. for broadcast reception.

Band Tuning of Selector Circuits in Intermediate-Frequency Amplifier.

If every tuned circuit in the i-f amplifying system is tuned exactly to the nominal intermediate frequency, 180 kc. for instance, the sharpness of tuning in so many stages may result in the loss of the side bands representing the high musical notes. Therefore to obtain uniform efficiency from an i-f amplifier it required special care in design which permitted the adjustments required to get a flat-topped i-f resonance curve. This can be accomplished as follows: The operation consists in tuning one i-f selector circuit to a frequency several kilocycles lower than the nominal intermediate frequency, and tuning another of its selector circuits to a frequency several kilocycles higher. Then with one or more other selector circuits tuned accurately to the intermediate frequency, an over-all resonance curve for the amplifier shows an approximately flat top 10 kc. wide with steep sides.

As just explained a flat-topped i-f resonance curve indicates the desirable condition for uniform efficiency in reproducing all the musical frequencies transmitted, and yet have the proper degree of selectivity against radio programs in the adjacent radio-frequency channels, that is, only 10 kc. above or below the desired station.

VOLUME CONTROL.

Whatever methods of volume control are suitable for a straight radio-frequency receiver are also applicable to the radio-frequency amplifying system of the superheterodyne receiver. In addition, the same change in amplifier grid bias voltage which may be used in the radio-frequency section can be applied to the grid bias of tubes in the i-f amplifier. Although the grid bias of i-f tubes can be controlled as just stated it is not good practice to have any wide range of volume control in the i-f amplifier system alone. The reason is because a very strong radio frequency may reach the first detector and cause distortion there, without the second detector being anywhere near overloading, due to the protective effect of the lowered amplification of the i-f system. Therefore, when a single knob is provided to control the grid bias voltages in both the r-f and i-f systems, then a voltage divider system may be used which applies a much greater bias change to the r-f amplifier tubes than to the i-f tubes.

Automatic volume control (AVC) by various methods is extensively used in superheterodyne receivers. In brief the AVC functions by making use of the direct current produced by the rectification of the intermediate frequency in either the second detector or in some auxiliary tube which is added especially for this purpose and, therefore, has no other function. Such a rectified current depends in value, of course, on the amplitude of the intermediate-frequency current. The rectified current, when passed through a fixed resistor, provides a voltage drop which becomes available for volume control just as though the voltage were provided by a manually-operated volume control using a variable resistor and a fixed current.

A fine degree of engineering design in the various constants of the bias control circuits has made this action so automatic that very little change in loudspeaker volume is noticed as the tuning control is varied to bring in stations on different channels and of widely different field strengths at the antenna. A hand control located on the receiver panel allows the listener to adjust the sound volume to whatever general level is pleasing at the moment.

In some receivers a "local-distant" switch is included in the design. In one form of circuit, two resistances are arranged for connecting to the first i-f transformer. At the "local" position the switch connects a 40,000 ohm resistor directly across the primary of this transformer and a 500 ohm resistor in series with the secondary and one side of its tuning condenser. The effect of these resistors is to decrease the sensitivity, broaden the selectivity and thus improve the fidelity of the receiver. At the "distant" position the resistance is out of both circuits and the original sensitivity and selectivity is obtained.

RADIOTELEGRAPH RECEPTION BY SUPERHETERODYNE.

Radiotelegraph or code signals of the damped or otherwise modulated type may be received on any superheterodyne whose radio-frequency selector circuits can be adjusted to pick up the station.

Continuous waves from a code transmitting station require the production of an audible beat note by some method of heterodyning which is independent of the superheterodyne principle. It may be accomplished by either the separate heterodyne or the autodyne methods.

Separate Heterodyne. A second local oscillator consisting of a vacuum tube and tuned circuit may be used to provide a frequency which differs from the intermediate frequency by only a few hundred cycles so that when coupled to the input of the second detector, an audio tone is produced whenever the transmitter is keyed on. This second local oscillator may be made to function at a frequency a few hundred cycles removed from either the original radio frequency or the first local oscillator frequency; the coupling is then into the first detector. Either heterodyne action produces an intermediate frequency which is the same few hundred cycles removed from that produced by the incoming signal and the first local oscillator. These two intermediate frequencies are amplified together, and when they reach the second detector, the audible beat note of a few hundred cycles is extracted.

Autodyne. Either the first detector or the second detector can be made self-oscillatory by ordinary feed-back methods to provide the additional local oscillation required for the audible tone.

Complete Autodyne. This method completely eliminates the necessity for any separate oscillator in a superheterodyne, even for CW reception. The first detector is made self-oscillatory at radio frequency of such a value that the autodyne action results in an intermediate frequency. This is amplified before reaching the second detector which is self-oscillatory at near the intermediate frequency, the autodyne action here producing an audible frequency for translating dots and dashes.

PRACTICAL APPLICATIONS OF SUPERHETERODYNE PRINCIPLE

ELECTRICAL DESCRIPTION OF A TYPICAL SUPERHETERODYNE CIRCUIT.

The schematic diagram of a typical superheterodyne receiver for broadcast reception is shown in Figure 5. Starting from the antenna circuit, we find the following action taking place in the various stages.

The antenna is coupled to the grid coil of the r-f stage by means of a high inductance coil connected from antenna to ground. This in-

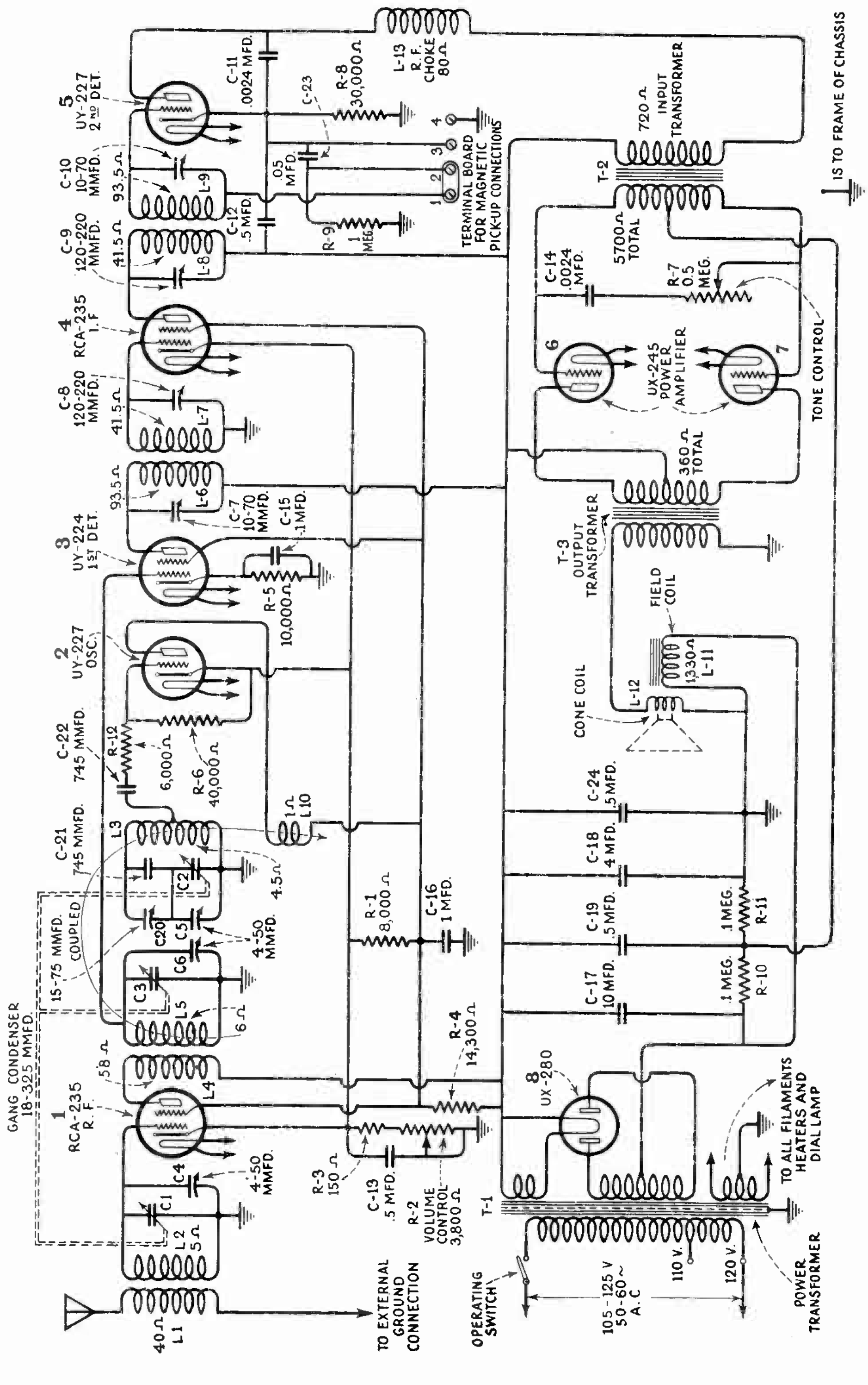


Fig. 5 - COMPLETE CIRCUIT DIAGRAM OF AN 8-TUBE SUPERHETERODYNE RECEIVER.

ductance has a sufficiently high value so that variations in the antenna system have but little effect on the tuning of the adjacent circuit.

The first tube is a tuned r-f stage. This is the super control screen-grid tube type RCA-235, which has a grid potential-plate current curve that has no pronounced "knee". This characteristic reduces the tendency of the tube to become a detector when the control grid voltage is raised by the volume control. Such a characteristic means that secondary modulation effects will not be obtained and distortion due to high signal intensities will not develop. Also, improved volume control action and elimination of the local-distant switch is obtained through the use of this tube. The gain and other characteristics are approximately the same as those of a UY-224. The output of this circuit is inductively coupled to the grid coil of the first detector.

At this point the oscillator should be considered as its output is also coupled inductively to the grid coil of the first detector. This is a tuned grid circuit oscillator using a UY-227, and having a closely coupled plate coil that gives sufficient feed-back to provide stable operation. The grid circuit is so designed that by means of a correct combination of capacity and inductance a constant frequency difference between the oscillator and the tuned r-f circuits throughout the tuning range of the receiver is obtained.

The next circuit to examine is the first detector. The circuit is tuned by means of one of the gang condensers to the frequency of the incoming signal. In the grid circuit there is present the incoming signal and the oscillator signal, the latter being at a 175 kc. difference from the former. The first detector is biased so as to operate as a plate rectification detector and its purpose is to extract the difference or beat frequency, produced by combining the signal and oscillator frequencies. The beat frequency—175 kc.—appears in the plate circuit of the first detector which is accurately tuned to 175 kc. The tube used as a first detector is a UY-224.

The next stage is that of the i-f amplifier. A single stage is used. This requires two i-f transformers consisting of four tuned circuits. The plate circuit of the first detector, the grid and plate circuits of the i-f amplifier and the grid circuit of the second detector are all tuned to 175 kc. The transformers are peaked, no attempt being made for flat top tuning. An RCA-235 tube is used in this stage and its control grid voltage is also varied by means of the volume control.

The second detector is a high-plate voltage, grid-biased type using a UY-227, which gives sufficient output to drive two UX-245's connected in push-pull without an intermediate audio stage. The purpose of the second detector is to extract the audio-frequency component of the r-f signal which represents the voice or musical modulations produced in the studio of the broadcasting station. The audio component is extracted and used to drive the power tubes while the r-f current is by-passed and not used further.

A filter circuit consisting of a 0.05 mfd. condenser and 1 megohm resistor is used in the second detector grid circuit. This further reduces the small a-c hum voltages present in the detector stage.

The power a-f stage consists of two UX-245's connected in push-pull. Transformer coupling is used between the detector and the grids of the UX-245 tubes as well as from the plates to the cone coil of the reproducer unit.

A tone control, consisting of a 0.0024 mfd. condenser in series with a 500,000 ohm variable resistor connected across the two grids of the UX-245 tubes is incorporated in this stage. The tone control functions to reduce the high-frequency output as the resistance is reduced. At the extremely low position, the condenser and secondary of the a-f transformer resonate at a low frequency and thereby further accentuate the bass response, thus partially compensating for the lack of a large speaker baffle surface.

The direct plate and grid voltages used by all the tubes are supplied from high voltage alternating current which is rectified by means of a UX-280. The filter used is of the "brute force" type using the field of the reproducer unit as the reactor. Electrolytic type condensers of 10 and 4 mfd. capacity respectively are used before and after the reactor. Two 0.5 mfd. condensers in the filter circuit function to by-pass any r-f current that may be present. The bias voltage (45 volts) for the UX-245 tubes is obtained by using half the voltage drop (90 volts) across the field coil of the reproducer unit. Two 100,000 resistors shunted across the field act as the voltage dividing resistor for this bias voltage.

CIRCUIT DESCRIPTION OF A PORTABLE TYPE SUPERHETERODYNE.

Another practical application of the superheterodyne principle is illustrated in the portable superheterodyne receiver designed for dry-battery operation. Figure 6 shows a schematic diagram of this portable type receiver. The r-f pentode tube, type RCA-234, is employed in the r-f and i-f amplification and second detector stages.

As in other pentodes, this tube utilizes an additional grid or suppressor which is located between the screen grid and the plate and serves to minimize the effects of secondary emission. The added element is connected inside the tube to the filament. As an amplifier, this pentode is effective in the reduction of cross-modulation and of modulation distortion throughout the entire broadcast-frequency band and permits easy control of a moderate range of signal voltages without the use of a local-distant switch.

The second detector serves to furnish grid bias voltage variation to the r-f and i-f amplifiers with incoming fluctuations of signal strength. The second detector thereby provides an automatic volume control feature in addition to its primary function and thus permits the elimination of the additional "control" tube.

In this system, the entire i-f signal input in series with a large fixed resistance is impressed between the plate and filament of the second detector. These elements function as a diode rectifier. The low-potential end of the i-f transformer secondary winding thus assumes a negative polarity with respect to ground which is applied to the grids of the r-f and i-f amplifiers. The audio-frequency modulation also appears across two resistors in the rectifier circuit and is capacitance-coupled to the control grid of the second detector. The screen grid of that tube functions as the customary plate and is impedance coupled to the grid of the first audio-amplifier. The

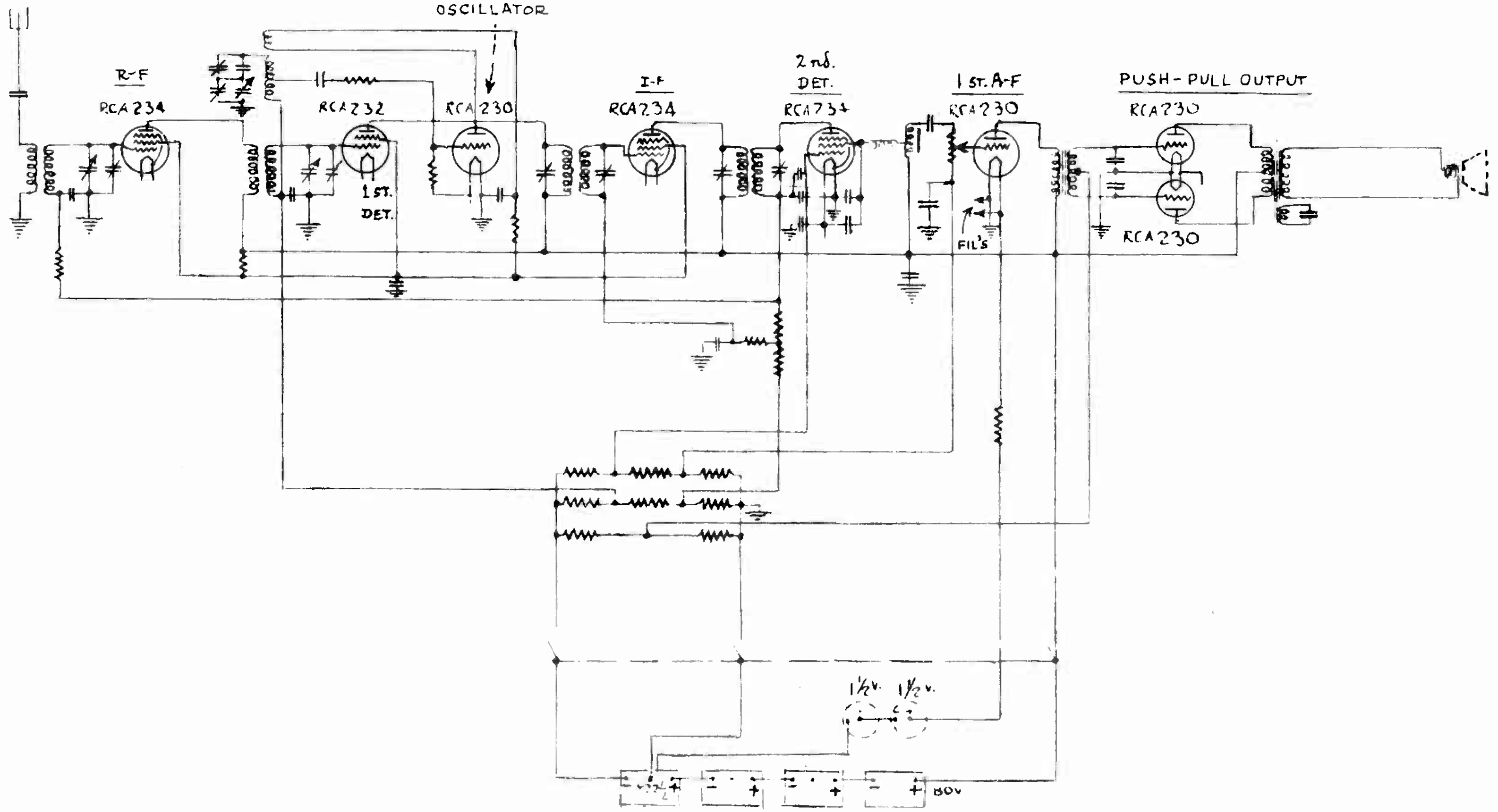


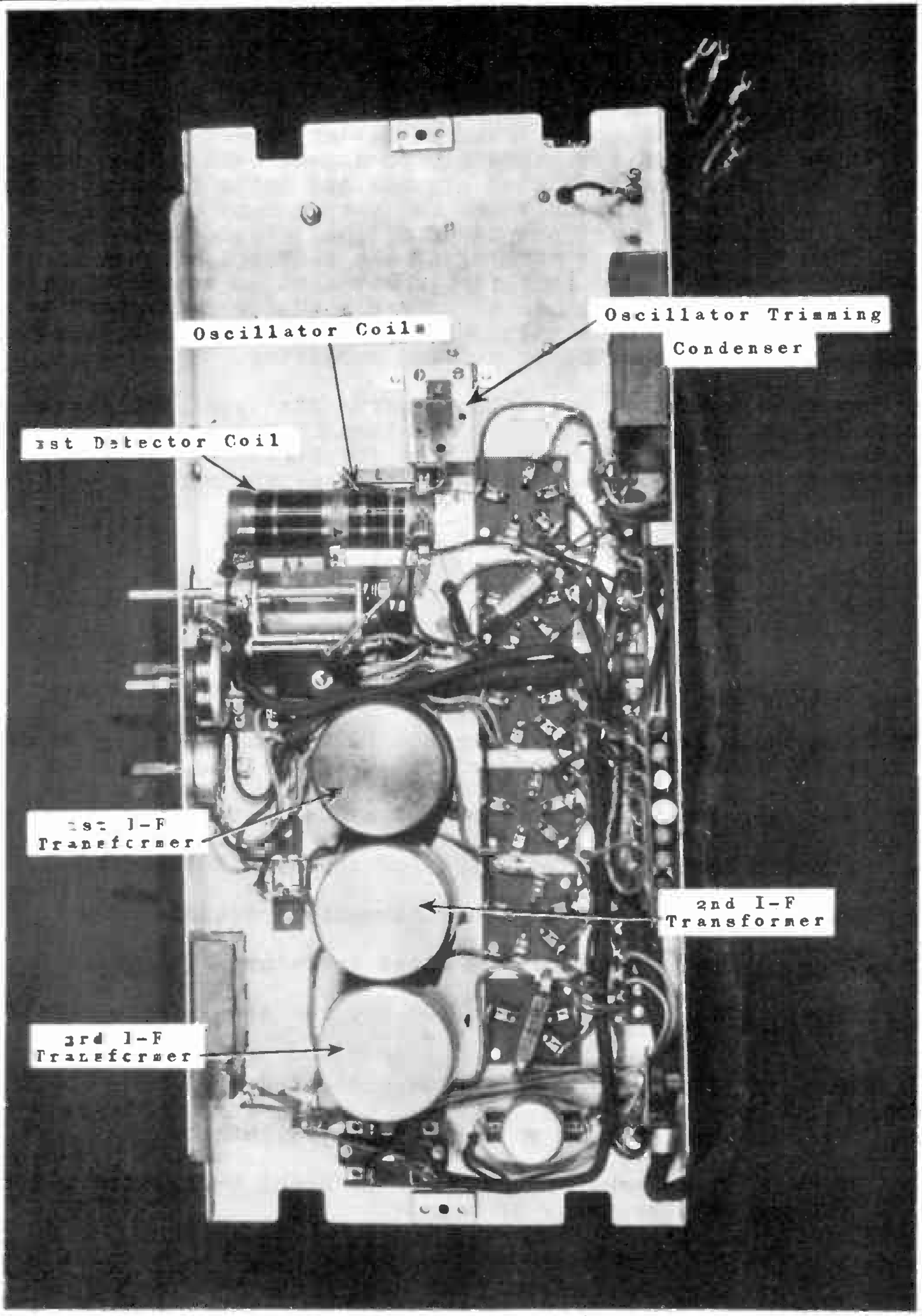
Fig. 6 - THE CONNECTIONS OF THE COILS IN THE OSCILLATOR TUNED CIRCUIT AND THE LOCATION OF THE INTERMEDIATE AMPLIFIER ARE EASILY FOLLOWED IN THIS SCHEMATIC DIAGRAM OF A PORTABLE SUPERHETERODYNE, DRY-BATTERY OPERATED.

manual volume control serves, as a potentiometer, to vary the audio-voltage impressed on the latter tube and thus permits adjustment of the audio output to the desired level. The audio-amplification system consists of a single driver stage transformer-coupled to a class "B" operated power output stage. The use of class "B" amplification permits of extremely economical "B" battery operation since the output tubes are biased approximately to cut-off and normal plate current flows only when modulated signals are being received. The plate current is at all times only the audio-component of the signal which feature provides a power output of at least four times that obtainable from the same tubes working at the same voltage but in the conventional manner. Note in this circuit that objectionable high-frequencies generated within the power stage are minimized by means of a filter circuit consisting of an additional output transformer secondary winding shunted by a fixed capacitor.

In regard to practical operation observe that bias voltages for all tubes except the oscillator are obtained from three voltage-divider systems connected in parallel across the first 22.5 volt section of the "B" battery. The oscillator in this arrangement is self-biased

EXAMINATION QUESTIONS

1. What is an advantage of radio-frequency amplification?
2. Can radio frequencies above 300 kc. be amplified as successfully as at lower frequencies?
3. What are the principal parts of a superheterodyne circuit?
4. Explain briefly the principle of the superheterodyne.
5. What is the function of an intermediate transformer?
6. What is the purpose of the first detector?
7. Why is 175 kc. better than 190 kc. for the intermediate frequency?
8. What is the function of the second detector?
9. What is the function of the local oscillator?
10. How would the program sound if the local oscillator suddenly changed its frequency by 5 kc.?



SUB-CHASSIS VIEW OF A TYPICAL SUPERHETERODYNE RECEIVER ASSEMBLY SHOWING LOCATION OF OSCILLATOR AND 1ST DETECTOR COILS, AND SHIELDED INTERMEDIATE-FREQUENCY TRANSFORMERS.

3302

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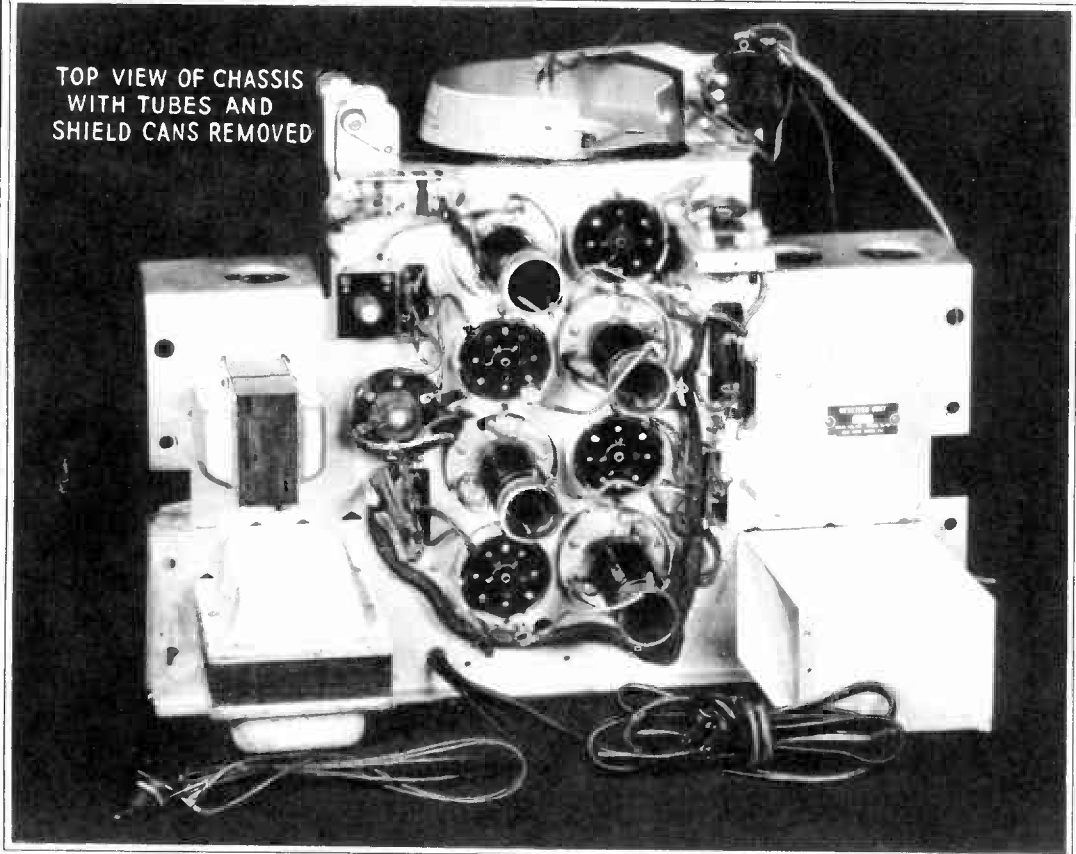
Assortment of parts used in a typical A.C. screen-grid receiver with pentode output.

General Review of Screen-Grid Pentode Receivers

VOL. 16, No. 12

Dewey Classification R 161



Top view of chassis showing general layout of the coils.

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GENERAL REVIEW OF SCREEN-GRID PENTODE RECEIVERS.

The popularity achieved by electrically operated screen-grid receivers is a tribute to those who are responsible for the production of the a-c screen-grid vacuum tube and later the variable-mu and pentode tubes. When the wonderful characteristics of a screen-grid tube became known the interest of radio set manufacturers centered chiefly around the development of an electric set that could utilize one or more of these tubes and obtain from them every advantage to the fullest extent.

Although the screen-grid tube was originally designed to reduce inter-electrode capacity to a negligible amount and thus make it possible to build radio-frequency circuits without requiring the use of neutralizing devices of any kind, yet it was soon noticed that the tube had extraordinary amplifying qualities. To think that the amplification constant of an a-c screen-grid tube is 420 as compared to 9 for the three-electrode tube is nothing less than remarkable. With screen-grid tubes in the r-f circuit of a receiver weak signals or signals from distant stations are amplified many fold to be reproduced by the loudspeaker with ample volume, and the signals from nearby local stations usually come in with such large amounts of power that a volume control is required ahead of the detector so that the signal voltage applied to the detector grid may be lowered to a suitable value to prevent detector overloading. An overloaded detector produces distortion no matter what efforts are made to overcome this condition through careful designing of the audio amplifier circuits.

The extra high gain of signal level in a receiver using two stages of tuned radio-frequency amplification and a-c screen-grid tubes requires that some method of lowering this level be incorporated in the receiver. Thus, in certain types of receivers which do not have a volume control tube it is the general custom to employ a "LOCAL-DISTANT" switch. This switch is sometimes inserted in the antenna input circuit and is brought into operation under extreme conditions, that is, where a strong local signal would cause detector overloading. Although the use of the "LOCAL-DISTANT" switch and the volume control both have the same ultimate effect of controlling volume by permitting more or less signal energy to be applied to the detector grid, yet the principles upon which they operate are by no means identical as we will explain further in our lesson. While on this subject of screen-grid receivers attention should be called to the fact that previous models of receivers employing three-electrode tubes (for instance, the 227 or 226 type) as radio-frequency amplifiers, and with the r-f stages properly neutralized, give results which compare favorably with those obtained from screen-grid sets. The set which does not use screen-grid tubes, however, will invariably be supplied with an additional radio-frequency tube thus permitting it to reach the higher degree of sensitivity. What we wish to point out is that the type of tube, or the number of stages of radio-frequency amplification incorporated in the design of a receiver is not a basis for estimating the performance of the set. We must realize that although the figures mentioned in the foregoing paragraph comparing the amplification constant of two different types of tubes are at such a wide variance these figures do not express in any sense the relative gain in radio-frequency amplification to be expected between the two tubes under consideration when operating in particular receiving circuits. The true gain in signal energy from any receiving circuit can be found only by measuring the performance under practical conditions and not by computing the gain from figures based on tube characteristics.

Whether one type of tube or another is more effective as an amplifier depends as much upon the circuit design and quality of the parts as upon the tube itself. Up to the present time not anything near the gain of which a screen-grid tube is theoretically capable has ever been fulfilled. For example, the advent of the screen-grid tube has brought about special considerations in the matter of coil design to reduce capacity effects and give the plate circuit a high impedance at resonance, and even with the best designing the impedance of the load circuit, due principally to the coils, is still far below the tube's plate impedance which is several hundred thousand ohms.

These and other factors which govern the maximum gain possible from screen-grid amplifiers (referred to usually as sensitivity) and also the degree of sharpness of tuning that permits a receiver to cut through a strong local station and pick up a distant station when both are working on closely adjoining frequencies (referred to as selectivity) are discussed in the following paragraphs.

Also, in the latter part of this lesson explanations are given which tell how the performance of a radio set is measured and shown by the use of curves called "performance" curves. The four important tests which indicate the merits of a particular radio set are sensitivity, selectivity, fidelity and power output.

The various important features in a-c screen-grid receivers with pentode output are, briefly:

1. High sensitivity with less tubes.
2. Selectivity greater than that obtainable from a similar number of tuned stages when tubes not of the screen-grid type are used.
3. Ease of control. Screen-grid tubes lend themselves to a very simple means of volume control and due to the fewer number of tuned r-f stages the gang condenser construction is greatly simplified.
4. Freedom from noise. The reduced number of tuned stages permits receivers of the screen-grid type to have a minimum signal to noise ratio.

5. Maximum gain of power. With 247 pentode tubes in the output feeble input signals are amplified to a greater extent than is possible with other types of power tubes.

Reference to the schematic diagram of any electric set will clearly show that the receiver is divided into two main sections, namely, the "receiver proper" and the "power unit," the latter often being called the "power pack" and "socket power unit." In turn we can subdivide these sections into their principal circuits according to the classified list below. These circuits can be easily identified by referring to the diagram in Figure 1 which shows a typical seven-tube a-c tuned r-f receiver employing three screen grid type RCA-224 tubes, one type 227, two type 245 power amplifiers and one type 280 full-wave rectifier. The latter part of our lesson is devoted to a general discussion of a similar type of receiving circuit with 247 pentode tubes operating in push-pull in the output stage and also explanations about the various curves used to indicate the performance of a radio receiver.

(A) The principal circuits of the receiver proper are -

1. Radio-frequency amplifier stages.
2. Detector.
3. Audio-amplifier stages.

(B) The principal circuits of the power pack are -

4. A-C input and power transformer.
5. Full-wave rectifier.
6. Filter, consisting of reactors (choke coils) and capacitors (condensers).
7. Voltage distribution system, consisting of several resistors.

It is suggested that you study this lesson with the idea of keeping the above seven principal circuits separated clearly in your mind.

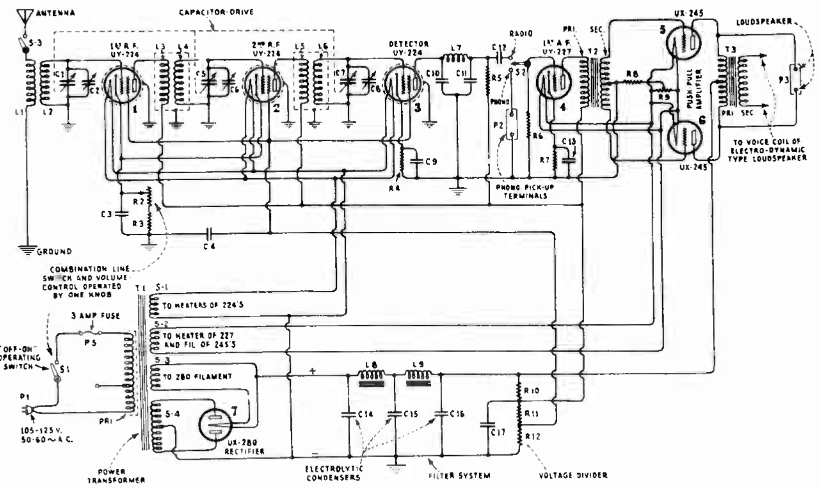

Figure 1

It is suggested that you study this lesson with the idea of keeping the above seven principal circuits separated clearly in your mind.

The schematic diagram in Figure 1 shows a typical tuned r-f receiver using a-c screen-grid tubes in the r-f and detector stages, an a-c three-electrode 227 in the first stage audio and two 245's in the push-pull output. The schematic in Figure 2 shows the use of variable-mu tubes in the r-f stages and by comparison with the diagram in Figure 1 it can be easily seen that only a slight alteration is necessary to provide for the use of pentode tubes in the audio output.

RADIO-FREQUENCY AMPLIFIER

The part of the radio receiver using screen-grid vacuum tubes that differs from the conventional type tuned r-f receiver is the radio-frequency amplifier. The r-f amplifier in Figure 1 employs two screen-grid tubes, and a tube of similar type is used for the power detector. This arrangement provides three tuned r-f circuits which requires a three-gang condenser. Each section of the gang condenser is provided with a small trimmer or balancing condenser built in the unit so that a trimmer is shunted across each tuning condenser as the diagram indicates. The stator plates of the tuning condensers connect respectively to the grids of the 1st and 2nd r-f amplifiers and detector, whereas, the rotor plates are mechanically and electrically connected together and are grounded. This arrangement permits the use of a single dial for simultaneously tuning the r-f circuits.

The three r-f transformer coils are wound to give them the best transformer characteristics, two being completely enclosed in aluminum cans which act as electrostatic shields to eliminate coupling effects between the coils themselves, or between the coils and other parts of the circuit.

From the diagram in Figure 1 each tuned circuit is seen to be a conventional one consisting of an r-f transformer,a variable tuning condenser and a trimmer condenser. The transformers are used as coupling devices to introduce the signal voltages to the input, or grids of the tubes in the case of the secondaries and to receive the output, or plate current in the case of the primaries. The primary of the first r-f transformer, of course, obtains its signal energy directly from the antenna to which it is connected.

The variable tuning condensers are used to resonate the r-f circuits to a particular station's frequency while the function of the trimmer condensers, which are easily adjusted, is to compensate for slight variations in the tuning circuits which may be caused by wiring or discrepancies in coils or condensers which is apt to occur when parts are manufactured in large quantities.

The "LOCAL-DISTANT" switch inserted in the antenna circuit should be used if strong local signals are picked up which would tend to cause detector overloading. By opening the switch according to the position shown in the diagram, the amount of signal energy transferred from the primary coil to the secondary is reduced and, thereafter, the desired signal level can be obtained by regulating the volume control. The next circuit to examine is the one that supplies positive voltage to the screen grids in Figure 1. This circuit operates

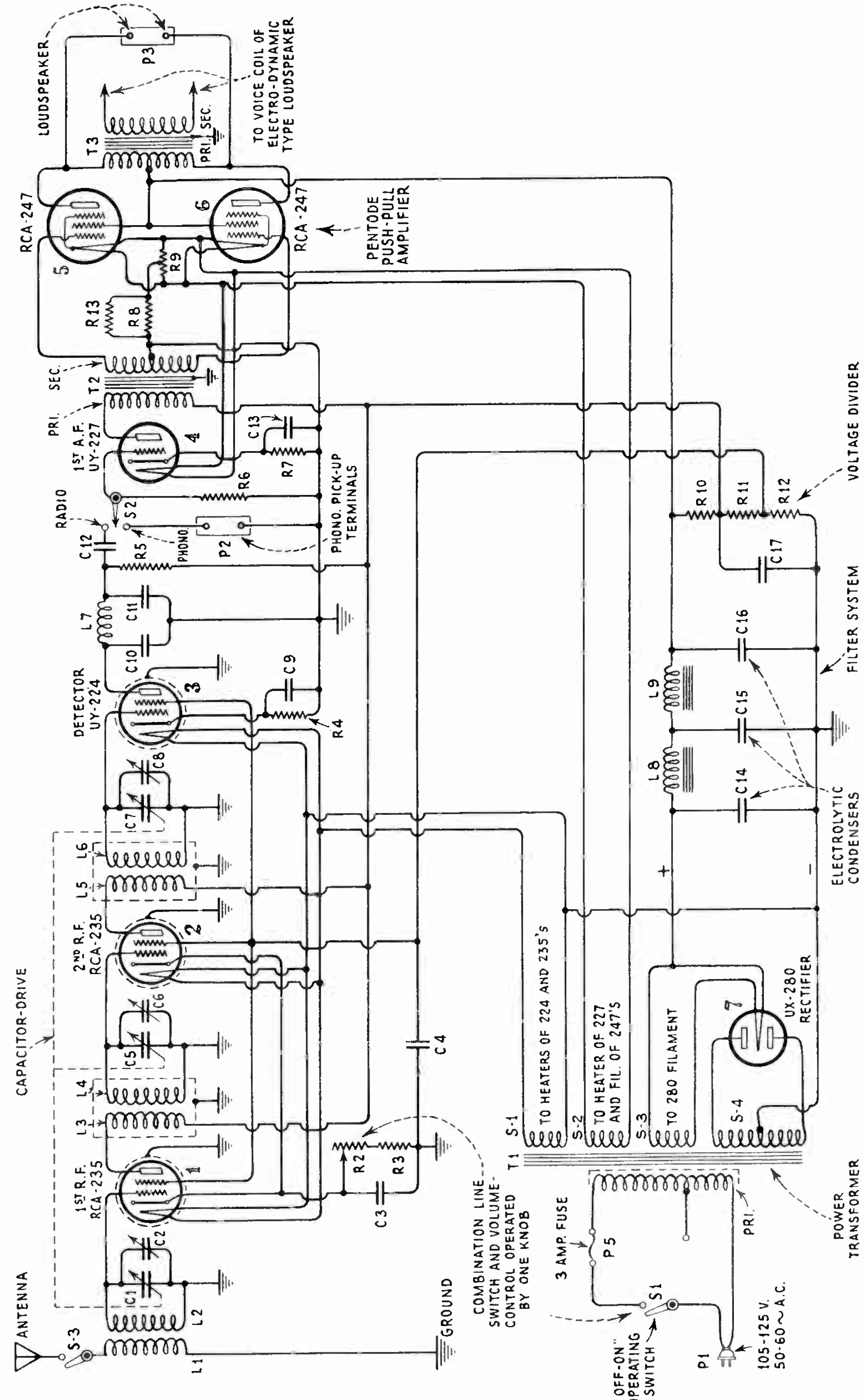
LOUDSPEAKER
P3
TO VOICE COIL OF ELECTRO-DYNAMIC TYPE LOUDSPEAKER
T3
PRI.
SEC.
RCA-247
5
6
RCA-247
PENTODE PUSH-PULL AMPLIFIER
R13
R8
R9
SEC.
T2
PRI.
1ST A.F. UY-227
4
C13
R6
R7
RADIO
S2
PHONO
C12
R5
P2
PHONO. PICK-UP TERMINALS
L7
C11
C10
DETECTOR UY-224
3
C9
R4
C8
C7
L6
L5
2ND R.F. RCA-235
2
C6
C5
CAPACITOR-DRIVE
L4
L3
1ST R.F. RCA-235
1
C4
C3
R2
R3
C2
C1
L2
L1
ANTENNA
S-3
GROUND
COMBINATION LINE SWITCH AND VOLUME-CONTROL OPERATED BY ONE KNOB
T1
S-1
TO HEATERS OF 224 AND 235'S
S-2
TO HEATER OF 227 AND FIL. OF 247'S
S-3
TO 280 FILAMENT
S-4
UX-280 RECTIFIER
7
3 AMP. FUSE
P5
PRI.
POWER TRANSFORMER
"OFF-ON" OPERATING SWITCH
S1
P1
105-125 V. 50-60 ~ A.C.
R10
R11
R12
VOLTAGE DIVIDER
C17
C16
FILTER SYSTEM
L9
C15
L8
C14
ELECTROLYTIC CONDENSERS
+
-

Figure 2

according to the principles as explained by Ohm's law which states that a certain relation exists between current, resistance and voltage as you already know. Observe how the resistors of the voltage divider are placed in series and in turn connected across the d-c power supply. Hence, the required voltage may be obtained from the resistor as determined by the amount of resistance included between the lower, or grounded end of the wire and the point where the screen grid wire is connected.

The purpose of the by-pass condensers shunted around the grid bias resistors is to furnish a path of low reactance which permits the r-f signal currents to pass through and thus prevent losses which would surely occur if this energy were forced to take a route through any resistor. The main purpose behind this design is to provide a radio-frequency circuit in which the signal current will circulate with highest efficiency to be impressed as an alternating voltage between the control grid and cathode of the tube. In Figure 2 the positive voltage for the screen grids of the 235 variable-mu tubes is obtained from a connection taken at one of the resistors comprising the voltage divider. Again we have another application of Ohm's law since the amount of this screen-grid voltage is determined by the voltage drop across the resistor which in turn is governed by the resistance value of the resistor and the intensity of the current flowing through it.

<u>Points About Tubes Used in R-F Circuits</u>, Types 235, 224, and 227. Reference should be made to Figures 3 and 4 which clearly show the general construction of a-c tubes of the three and four-element types. The 235 and 224 type tubes consist of four electrodes, namely, a plate, a control grid, a screen grid and the cathode with a-c heater, the four-electrode type being known as a "tetrode." The 227 type tube has only three electrodes, namely, a plate, a control grid and the cathode and heater unit, and is technically known as a "triode."

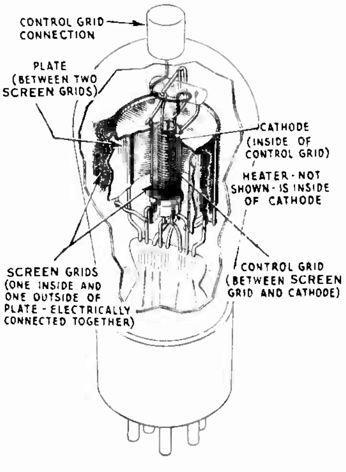

Figure 3

Both tubes have a cathode and heater which are quite similar physically, thus making it possible for a manufacturer to utilize certain parts interchangeably in the construction of their tubes. A small wire, called the heater, is imbedded inside of a special insulating material which is cylindrically shaped and around which is placed a metallic thimble, or sheath, previously covered with an oxide coating. It is this metal sheath of oxide, the cathode, which gives off electrons when the small heater wire is raised in temperature by the alternating current passing through it. The alternating current of proper voltage is obtained from one of the windings of the power transformer. Thus we see that the heater wire, which cannot be shown in the illustration because it is encased in the insulator, serves only to conduct the current and indirectly heat the electron emitting oxide material, or cathode. Remember, the coated cathode around the insulator of a heater-cathode type tube is the source of electron emission. It will be recalled that the source of electrons in tubes such as the 245 or 201-A type is the hot filament wire itself. The filament wire in the latter type tubes is treated with an oxide similar to the coating on the metal thimble in the heater type tube.

Both the 235 and 224 tubes are equipped with 5 pins in the base and a metal cap located on the top of the glass envelope to which the control grid clip may be connected. A point to be mentioned in regard to the sockets used with these tubes is that the heater terminals in some sockets are marked "H" and "H" and in others "FIL." The plate and cathode pins are in the same positions in the bases of the 227, 224 and 235, but the screen grid of either the 224 or 235 connects to the pin which in the 227 would make connection to the regular control grid.

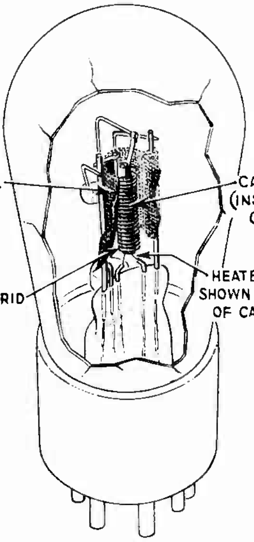

Figure 4

The screen grid is made up in two separate parts which are connected together electrically. One part of the screen, in the form of a spiral coil, is placed between the plate and the control grid, this being called the "inner screen." The other part, in the form of a metal screen of meshlike construction, is located outside of the plate, this part being known as the "outer screen." There is a thin metal cover mounted over the outer screen which acts as an electrostatic shield between the plate and the control grid lead which goes to the metal cap on the top of the tube. The principal difference between a 235 tube and a 224 screen-grid tube is that the control grid of the 235 is made with a non-uniform spacing of the mesh which gives it variable-mu characteristics as explained in a lesson on this subject titled - "Receiving Vacuum Tubes."

The internal capacity between grid (control grid) and plate of either a 235 or 224 is greatly reduced by the presence of the screen (screen grid) to a value which may be considered negligible. This arrangement effectively shields the control grid from effects caused by plate voltage variations through the inter-electrode capacity (grid to plate). If allowed to exist this capacity would permit troublesome feedback of r-f energy from the plate to grid circuits with the result that unwanted oscillations would be set up in the circuits. Due to the open spiral coil construction of the inner screen grid and the lower positive potential applied to it in comparison to the higher positive potential on the plate accounts for the fact that the electron stream is not obstructed as it passes through the vacuous space in the tube from cathode to plate. However, if an exceedingly high positive potential on the screen is permitted it would cause the screen to act like a miniature plate with the result that electrons would be prevented from going through the grid to plate. The latter situation must not prevail because it would reduce the effectiveness of the tube as an amplifier, as it would naturally lessen the current flow in the plate circuit.

The screen-grid tube fulfills two important functions: First, it practically eliminates inter-electrode capacity and thus makes the use of external neutralizing, or stabilizing devices unnecessary. Second, it provides an unusually high degree of radio amplification, or signal gain per stage. The high amplification makes it necessary to provide shielding between the r-f coils or in some assemblies shield cans are placed over coils and screen-grid tubes. In some cases further shielding on the control grid leads is required to prevent external capacitive coupling between the grid and plate circuits. Let us mention further that the screen grid, due to its high positive electric field, acts to speed up the movement of electrons toward the plate and thus the screen grid may be thought of as an accelerating device.

General Remarks About Amplification Factor, Mutual Conductance and So On. In the following paragraphs we have analyzed the comparative qualities of the three-element and four-element type tubes and other features pertaining to their use in r-f receiving circuits. To be specific let us consider the 224 and 227 types in our discussion.

The heater voltage of the 224 and 235 is the same as that of the 227 and, therefore, a common winding on the power transformer may be used to supply heater current for tubes of both types when used in the same receiver. This is a distinct advantage in simplifying transformer construction.

Since the plate voltage and current requirements of these tubes are moderate, the use of a 280 rectifier will prove ample for supplying all plate voltages.

The grid bias of the 224 and 235 is lower than that required for the 227. A low grid bias allows a tube to respond effectively to a low input voltage, hence, giving maximum output, but the disadvantage here is that a large grid swing may cause overloading.

In regard to the amplification factor of either a 224 or 235, it is considerably higher than for the 227. In practice it is impossible to get the full amplification constant from these tubes. However, the amplification obtainable from a 224, for instance, when used in a well-designed stage is several times greater than from the 227. A fair idea of the greater r-f gain possible from the screen-grid tube may be had by estimating that the average radio circuit employing a three-electrode tube, for instance, the 227 type, has a gain per stage of approximately 8, whereas, when a four-electrode or screen-grid tube is worked in a similar circuit, but designed expressly for the latter tube, the gain in signal level possible is from 30 to 40 per stage. So it is safe to assume that a 224 tube is about four or five times more effective as an amplifier. Placing the control grid close to the cathode and relatively far from the plate increases the amplification factor enormously while the insertion of the screen-grid increases the plate resistance. The advantages of high plate resistance are obtained from this tube without sacrificing the additional advantages of high mutual conductance. Since the distance between the grid and cathode is much less than the distance between plate and cathode then a positive potential impressed on the screen grid will cause a flow of plate current to be accelerated. In fact, the screen grid (because of its position in the tube) produces a greater acceleration of plate current than does the higher voltage impressed on the plate. The mechanical construction of the screen does not permit it to collect many of the electrons which would ordinarily go to the plate, hence, the majority of electrons which constitute the tube current pass on through the screen grid to the plate; only a limited quantity flow in the screen-grid circuits as direct current.

The mutual conductance is slightly lower in the 227 than in either a 224 or 235. Mutual conductance is a direct function of amplification constant and plate resistance, and is a measure of a tube's general performance. However, the mutual conductance of an r-f amplifier does not assume the importance that it does in other stages. Inasmuch as the amplification constant of a screen grid tube is high, its mutual conductance is very high. The positive potential on the screen grid in relation to the cathode is necessary for operation as the mutual conductance of the tube is a direct function of the value of this voltage. Therefore, it follows that with a very low voltage the mutual conductance will be low and with maximum voltage the mutual conductance will be maximum. This action is utilized in some types of receivers since if we vary this voltage we can easily control the sensitivity of the r-f amplifier and this will act as a volume control for the receiver. In sets which use this method the screen-grid voltage is varied from 0 volts at minimum volume to about 40 volts positive, or more at maximum volume.

The plate resistance of a screen-grid tube is many times greater than that of a three-element tube. For the different broadcast frequencies that are used in operation it is known that the resistance of the load circuit into which the tube works should be as great, or greater than the impedance of the tube. On this account the 224 or 235 tube requires an output circuit different from that used with other tubes, such as the 227 for example. In practice the high resistance is gained by concentrated inductance in the coil windings.

Because of the fact that the self-capacity of a screen-grid tube is practically negligible the r-f circuits can be constructed without stabilizing or neutralizing devices of any kind providing, of course, all circuits external to this tube are properly shielded and, also, the tube itself is shielded where required, as previously mentioned. The low internal capacity of the tube is accomplished through the insertion of the screen grid between the control grid and the plate. The values in the vacuum tube characteristic tables show that grid-plate capacity is 0.01 mmfd. for the 224 and 3.3 mmfd. for the 227, thus indicating that self-capacity is lowered about 1/300th through the use of the screen grid. Again refer to Figure 3 which shows the screen-grid construction in the four-element tube and its absence in the three-element tube in Figure 4.

High amplification gain which a screen-grid tube provides is an advantage because it permits the use of resistance coupling between the detector and the 1st audio-amplifier stage which is usually followed by the final stage consisting of a transformer coupled amplifier using two power tubes in push-pull relation. It is generally agreed that resistance coupling in the intermediate a-f stage provides pleasing and satisfactory reproduction.

The 235 has a special characteristic which is advantageous when the tube is used as an r-f amplifier, but this makes it unsuitable for use as a detector. This is called the variable-mu characteristic and is caused by the arrangements of the tube structure as explained in a lesson on vacuum tubes. Let us repeat that the amplification factor of a variable-mu tube changes for different values of potential on the control grid, and high negative potential is required on the grid before plate current reaches zero.

FACTORS WHICH GOVERN A SCREEN-GRID RADIO-FREQUENCY SYSTEM

Now let us continue our discussion concerning screen-grid r-f amplifier circuits. Although one or more of the items may have been mentioned earlier in the lesson they will bear repetition. Subjects such as grid swing of radio amplifiers and grid biases are explained in the following paragraphs.

Shielding is required in order to prevent oscillation due to plate to grid feedback of r-f energy through wiring, or coils. This shielding, which is in the form of aluminum or copper compartments or cans, should extend over the coils and tubes and in some cases the control grid leads are shielded. Shielding over the tuning condensers is not necessary as the radio-frequency field surrounding such parts is not particularly strong.

A power unit must provide suitable a-c voltages for the heaters of the 235, 224 or 227 tubes depending upon the type used in any particular receiver. This voltage is 2.5 volts with a current requirement of 1.75 amperes for each tube used. Also, direct current which has been properly filtered, or smoothed out, must be provided for supplying the control grid in certain sets with about 1.5 volts negative bias, and the screen grid with about 75 volts positive potential, and the plate with positive 180 volts. This power unit also supplies the detector and audio stages with operating voltages at specified values.

Due to the high sensitivity of the screen-grid circuits it is desirable to reduce the amount of signal energy when receiving strong local broadcast programs. In certain circuits this is accomplished by disconnecting the antenna from the input r-f coil by means of a switch, called a "LOCAL-DISTANT" switch as shown in Figure 1. In some receivers a small fixed condenser (for example, one with a capacitance of .00C23 mmfd.) is automatically shunted across the antenna coil by the switch. Shunting the condenser around the transformer primary provides an oscillatory circuit on which the signal energy may be picked up. Then again, in other types of circuits we find such a switch so arranged that on the "LOCAL" position the antenna is connected to the ground through a small resistor, the value of the resistor being of the order of 15 ohms. The purpose of such a switch, as heretofore explained, is to prevent the strong carrier of a local station from overloading the detector, thereby causing distortion.

Radio-frequency by-pass condensers are placed in different circuits to act as a radio-frequency by-pass to ground, as otherwise oscillation will be set up and one of the most desirable properties of the screen-grid tubes would be lost.

A schematic diagram of one type of screen-grid amplifier using 224 tubes is pictured in Figure 5. In this circuit all of the d-c plate current flows through the grid bias resistor. It also shows how the screen grids are made positive with respect to the negative cathode, and how the positive voltage on the screens can be regulated between the limits of 0 and about 40 volts by simply varying the amount of resistance on the volume control included between the sliding contact, or positive potential point, and the left-hand end, or negative potential point of this resistor. This is one way of regulating volume; another method by which control grid bias may be regulated is explained later.

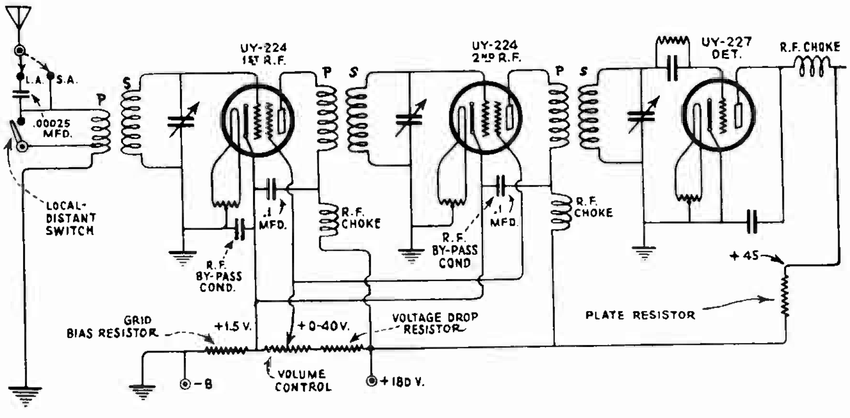

Figure 5

Next we will consider how the negative bias is obtained for the control grids of the 224 tubes in Figure 5. Referring to this diagram we notice that a resistor, marked "grid bias resistor," is connected in the circuit in such a manner that all of the plate current of both amplifier tubes must flow through it. The path of the plate current, considering only one tube and starting from the point marked +180 v. (this being the positive side of the d-c power supply) is through the r-f choke, through the primary of the r-f transformer to the plate of the tube, then to the cathode and down through the bias resistor and thence to the ground, (the ground being the negative side of the d-c supply). We know that there is a certain difference of potential (voltage drop) across such a resistor when current flows, the voltage depending upon the current strength and the number of ohms of resistance. Actually this resistor is connected in series between cathode and ground, and we also find that the grid return lead of the tube is connected to ground, the grid circuit being completed through the secondary of the r-f transformer. By this arrangement the flow of plate current through the grid bias resistor causes the cathode to become positive in potential with respect to the grid, or expressed the other way around and meaning exactly the same thing, the grid is made negative with respect to the cathode, which is the reference point of all potentials of the tube.

Let us now discuss the relation of positive grid swing from a signal voltage to the amount of permanent bias supplied to the control grids of the 224 tubes in Figure 5. If a radio set is located close to a broadcasting station the signal might come in so strong that the radio-frequency voltage applied to the control grid of the tube would cause the grid potential to actually swing over and become positive with respect to the cathode. You can well imagine from your previous knowledge of the control action which the grid exercises over the stream of negative electrons in the tube what the resulting effect would be if the grid ever assumes a positive electric charge. Supposing that this happened, then the grid would naturally act in a manner similar to a miniature plate and, hence, attract electrons in great numbers. Since the flow of electrons between cathode and grid is nothing more than what is known as grid current then the presence of this grid current makes the intervening space between cathode and grid act as though a high resistance were connected between these electrodes. In actual effect this is like placing a high resistance across the tuned r-f circuit, inasmuch as this circuit is always connected across the grid and cathode of an amplifier tube.

Therefore, it should now be clear that if an r-f amplifier grid were not supplied with a permanent negative bias, or if the bias were so low as to be overpowered by strong positive impulses from a local signal, the space between these two elements would exhibit all of the characteristics of a high resistance shunted across the r-f tuned circuit. This condition is undesirable. What we would like to have is a grid which never becomes positive but is always working at greater or lesser negative values with respect to the cathode. The condition should be such that the grid to cathode path remains at all times practically like a small condenser, the electrodes acting as plates and the space as the dielectric. If this is fulfilled in practice the grid is left free to act efficiently as an electrically charged body whose potential is constantly varying in accordance with the characteristics of the signal wave, and the changing grid potential will cause a corresponding variation in plate current.

We know this to be the case because the control of the plate current is due to the effect which the electrically charged grid has over the electron stream as it moves through the vacuous path in the tube from cathode to plate.

What we have just said in regard to the radio-frequency grid swing has some bearing on the tuning qualities of the receiver referred to as "Broadness, or Sharpness" of tuning. The introduction of even a small amount of resistance in a circuit of this kind causes the resonance curve to become less sharp or less peaked, or to flatten out as it were. If this condition exists in a receiver it results in what is known as "broad tuning." In other words the receiver then cannot discriminate between broadcast frequencies when they are 10 kilocycles apart, but will respond with almost equal sensitiveness to the frequencies of more than one station, thus causing serious interference.

This extreme sensitivity of the control grid of either a 235 or 224 tube is responsible for the easy manner in which remote and distant stations are brought in on a modern screen-grid receiver. Moreover, it has the distinct advantage of permitting the use of shorter antennas than have heretofore been required to pick up signals from distant stations. An antenna not exceeding 50 feet in length often gives the best results.

PENTODE TUBES FOR R-F AND A-F CIRCUITS

We have discussed the use of three-and four-element tubes for r-f circuits and the use of three-element tubes for a-f amplification. Five-element tubes, called pentodes, are now available for use. They are of two types, the r-f pentode and the a-f pentode.

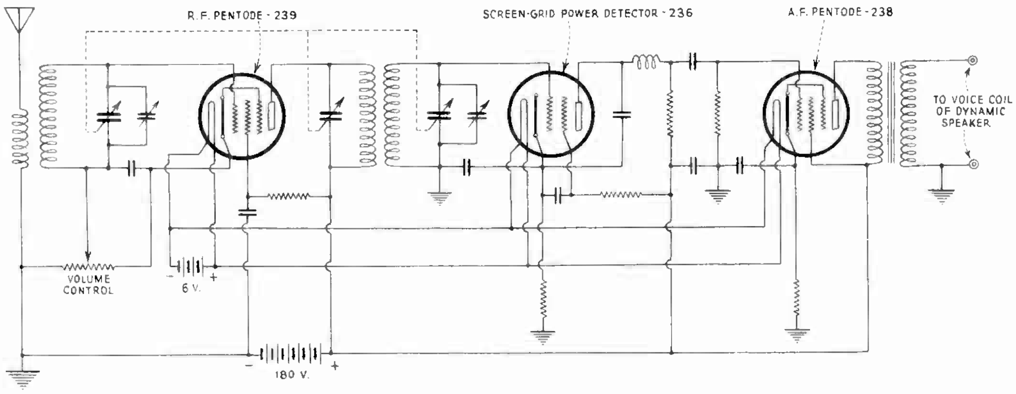

Figure 6

Like the screen-grid variable mu tube, or 235, the r-f pentode, or 239, is free from cross talk and gives high amplification. At present r-f pentodes are made with 6.3 volt filaments for automobile use only. A schematic diagram of a 239 r-f pentode, a 236 screen-grid detector and a 238 a-f pentode is shown in Figure 6. In the sketch in Figure 7-A the electrodes are identified as follows: F represents the filament; G1 is a conventional control grid; G2 is a grid or screen which is maintained at a high positive potential and serves to reduce the affects of "space charge" around the filament and increases the plate resistance of the tube; and G3 is a grid or screen which is usually connected internally to the filament or cathode of the tube and is therefore maintained at essentially ground

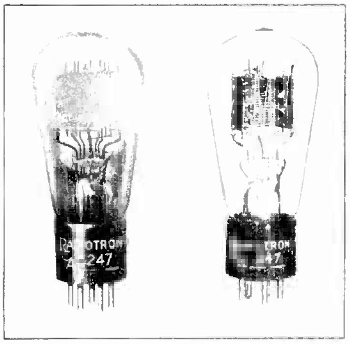

Figure 7

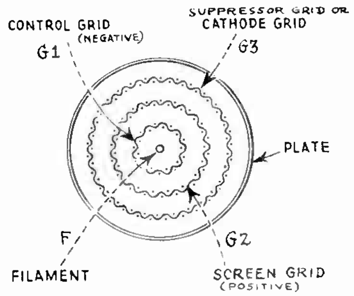

Figure 7-A

potential. The a-f pentode or 247 is shown in Figure 7. Two pentodes connected as push-pull amplifiers are shown in Figure 2. The first grid from the left is known as the control grid and it receives the energy from the previous stages. The next grid is known as the screen grid or high voltage grid. It corresponds to the screen grid of the 224 or 235 tubes. The third or suppressor grid connects to the midpoint of the filament and its function is to attract the space charge or loose electrons which gather around the plate. A comparison of 245 and 247 tubes as audio amplifiers is taken up under the heading "Final Audio Stage or Output".

DISCUSSION OF SCREEN-GRID RECEIVER CIRCUIT WITH PENTODE OUTPUT. REFER TO FIGURE 2.

REQUIREMENTS. Present standards make it necessary for a receiving set to provide a high degree of sensitivity without sacrificing selectivity and also to provide a maximum of undistorted power which is free from any interfering noise such as hum for example. The receiver which is described in the following paragraphs was designed to meet present day conditions. The following general discussion should be studied with reference made to the schematic diagram in Figure 2 showing a typical a-c screen-grid receiver with a pentode output.

SELECTIVITY. An examination of the schematic diagram in Figure 2 shows that the antenna circuit includes a switch designated as S-3. When this switch is open only nearby stations may be heard because coil L-1 becomes the only interceptor of the electromagnetic waves radiated by the broadcasting station. This switch need be opened

Figure 8

only when the selectivity is poor, or the tuning is broad, which is another way of saying that a given station covers too many divisions on the tuning dial.

When tuning in the desired station by means of the single dial located on the panel there are actually three r-f circuits being resonated simultaneously through the variation in capacitance of the respective variable condensers in these circuits, that is, in the two radio-frequency and detector circuits. Vernier, or fine adjustments are provided on the outer rotary condenser plates by bending the split plates to compensate for any difference in capacitance between the tuning condensers or slight discrepancy in the coils or wiring of these circuits. Additional adjustments can be made to bring the r-f circuits into proper resonance by turning a nut which moves the single plate of the midget condenser found on the top of each variable tuning condenser.

Figure 8 is a photograph taken in RCA Institutes' Laboratory showing how the r-f circuits are resonated using a pocket type insulated socket wrench made for this purpose. An ordinary metal tool cannot be used as it introduces hand capacity into the circuit. The instrument on the right is a modulated oscillator which provides a steady signal of uniform frequency.

R-F AMPLIFIERS. The intensity of the received signal is controlled by means of the volume control R2 which is a variable resistance controlling the negative bias potential on the control grids of the two r-f tubes. This device is smooth and noiseless in its regulation of the amplification of the screen grid tubes. Due to their high amplification factor, or mu (μ), the 235 and 224 tubes make excellent r-f amplifiers and power detectors but since they distort when voltages in excess of 1.5 are applied to their grids they do not make good audio power amplifiers. The signal energy in the r-f and detector grid circuits is quite small but when the energy reaches the audio system it may be in excess of 1.5 volts so that 235 or 224 tubes cannot be used. The 227 does not distort until 9 volts are applied to the grid if the plate potential used is 135 volts. For this reason a 227 may be employed in the first audio stage where it is effective in amplifying the signal sufficiently to swing the grids of the two tubes in a push-pull amplifier regardless of whether they are 245 or 247 type tubes.

The r-f and detector coil secondaries which comprise the other parts of the tuning units are connected to their respective condensers. The second r-f and detector coils are shielded from capacity effects to other instruments and wires to prevent interaction between circuits which might cause oscillation. The shields are made of aluminum and are separated from the coil windings, or have a clearance of at least 3/4 of an inch on all sides, in order to reduce losses. It has been found experimentally that the first r-f coil need not be shielded as it does not have a tendency to oscillate as have the other circuits when the shields are removed from them. All shielding is connected to the ground.

IMPEDANCE MATCHING. In order to realize the maximum power transfer from one circuit to another the impedances of the two circuits must be identical. A water analogy will serve to illustrate this point. If we have a large pipe connected to a pipe of smaller diameter the flow of water from the large pipe to the smaller one will be impeded by the restriction of the smaller orifice. If, however, the large pipe is connected to one of like dimensions there will be no impedance to the flow of water due to this cause and the maximum transfer will be accomplished. Bearing this in mind this particular circuit was designed with a 500,000 ohm resistor coupling the high impedance detector plate circuit to the audio input or grid circuit.

PHONOGRAPH PICK-UP CIRCUIT. The audio-frequency amplifying system containing two stages of powerful amplification is capable of amplifying feeble voltages for loudspeaker reception. It is, therefore, a simple matter to introduce a phonograph pick-up into the grid circuit of the first audio stage where any variations in signal energy will be amplified. The phonograph connection is made through the tip jack P2, the switch S2 being used to disconnect the radio-frequency system from the audio and to introduce the phonograph connection at the same time. There are many types of phonograph pickups but in general the principle of operation is the same for each type.

Briefly, the operation is as follows: A voltage is induced in a coil by the cutting of lines of force by a magnet which is moved by means of its connection to a needle that travels in unison with the variations in the groove of the phonograph record. The lighter the pressure of the needle upon the record the less harm will be done to its groove and the more authentic will be the reproduction of the recorded sounds. Since the point of a needle has a very small area a weight of about one pound from the pickup may exert a pressure of several tons upon the record. To alleviate this condition of needle pressure as much as possible the most efficient types of pickups employ a finely balanced arm and are oil damped. The volume is controlled by means of a variable resistor provided with the pickup.

FINAL AUDIO STAGE OR OUTPUT. Modern practice requires that the final output of an audio amplifier must provide high undistorted output to the speaker. To obtain this result large tubes must be used which require adequate excitation from the preceeding stages. As was previously mentioned the 227 in the first audio stage will swing the grids of at least two tubes of the 245 or 247 types. A maximum potential of 16.5 volts is required to swing the grid of the 247 tube whereas 50 volts is the maximum voltage allowed on the grid of the 245 assuming that 250 volts is applied to the plate of either tube. The undistorted power output of the 247 is 2.5 watts whereas for the 245 it is only 1.6 watts. Moreover, the 247 is more sensitive to small variations in grid voltage which means that it is more sensitive to weak signals than the 245. The 247 however will overload when voltages in excess of 16.5 are obtained from the signal input which will cause distortion. For very loud signals the volume control R2 should be kept at a medium position or the antenna switch S3 should be opened. For ordinary use the 247 will give excellent results and will amplify weak signals better than the 245.

The push-pull amplifier has strongly entrenched itself in present day receivers. Wherever the utmost fidelity of tone and the greatest undistorted power are desired a push-pull amplifier is used because objectional harmonic distortion is reduced and also the power output is greater than that of a single tube. Both the 245 and the 247 tubes give excellent results when used in the final stage of this receiver, and it requires only a few simple changes in wiring and sockets and bias voltage to interchange from one type of tube to the other.

When 247 tubes are used the cores of transformers T2 and T3 should be grounded to prevent oscillation.

Either magnetic or dynamic type speakers may be employed but as the average dynamic speaker voice coil has an impedance of about 16 ohms and as the impedance of a magnetic speaker is about 8,500 ohms at 60 cycles it is obvious that an output device designed for one will not be suitable for the other. As previously stated maximum transfer of power takes place when the impedance of the source and the impedance of the circuit to be energized are equal. In view of this fact the output transformer T3 was designed with a primary resistance of 8,500 and a secondary resistance of 16 ohms. By connecting a magnetic speaker to the tip jacks P3, a maximum transfer of power will take place from the tubes to the speaker. Likewise, connecting the secondary of P3 to the low impedance voice coil of a dynamic speaker will give maximum transfer of power.

Magnetic speakers are usually of a type not designed for handling a great deal of power and are generally used when the output is of the order of about 1.5 watts. If the plate current greatly exceeds 10 milliamperes the windings of most magnetic speakers are liable to be damaged. The primary of transformer T3 however is in parallel with the magnetic loudspeaker windings which divides the current so that the speaker is not unduly loaded. The direct current flowing through the windings of the average magnetic speaker connected in this manner to the receiver is usually less than one milliampere. The alternating current flow however will vary from zero to over 30 milliamperes. When peak signals are received voltages in excess of 150 are delivered to the speaker and 30 milliamperes of alternating current often flow through the speaker windings. The maximum undistorted power that can be obtained from two 247 tubes in push-pull is 5 watts, while the maximum from two 245's in push-pull is 3.2 watts. As the ear is only slightly sensitive to the 1.8 watt difference in power as far as volume is concerned it is immaterial which type is used. The choice of tubes should be governed somewhat by the requirements of the locality. If the set is far from most powerful stations the 247 tubes will give better results as the signal energy will have a better chance to excite the grids of these tubes. If the receiver is in an area which contains many powerful stations the 245 combination will be less apt to overload and distort the signal than the 247's. Both the 247 and 245 push-pull amplifiers will operate to best advantage when a dynamic speaker is used.

POWER SUPPLY. Transformer T1 which receives its energy from the 110 volt - 60 cycle alternating current line through plug P1 is the source of power for the entire receiver. The secondary contains three low voltage windings and one high potential winding. Winding S-1 delivers 2.5 volts of alternating current for the heaters of the 224 and the two 235 tubes. Winding S-2 supplies 2.5 volts for the heater of the 227 first audio stage tube and the filaments of the tubes in the push-pull second audio stage. The third winding S-3 delivers 5 volts to heat the filament of the 280 rectifier tube, the plates of this tube being supplied by the potential developed in winding S-4. Due to the fact that a vacuum tube conducts current only in one direction, that is, the electrons flow only from filament to plate, the 280 delivers a unidirectional pulsating direct current.

The insertion of chokes L-8 and L-9 in the positive lead and the connecting of capacitors C-14, C-15, and C-16 between the terminals of the chokes and the negative side of the line, filters or changes the pulsating current to a direct current. Capacitors C-14, C-15 and C-16 used for filters, may be of the paper or electrolytic types, either type being used in modern receivers. By means of the voltage divider the proper bias voltages for the grids and the proper voltages for the plates are obtained for all tubes.

PERFORMANCE CURVES OF BROADCAST RECEIVERS

How to interpret typical performance curves which are plotted from measurements taken in tests on broadcast receivers is explained in the following paragraphs. These curves are taken according to the specifications of the Institute of Radio Engineers which are fully outlined in the section following this explanation of typical curves. In general, it may be difficult to duplicate the absolute values given in the curves unless the same tubes and measuring apparatus are used. The curve form will be approximately the same in any case, however, for receivers of a given type.

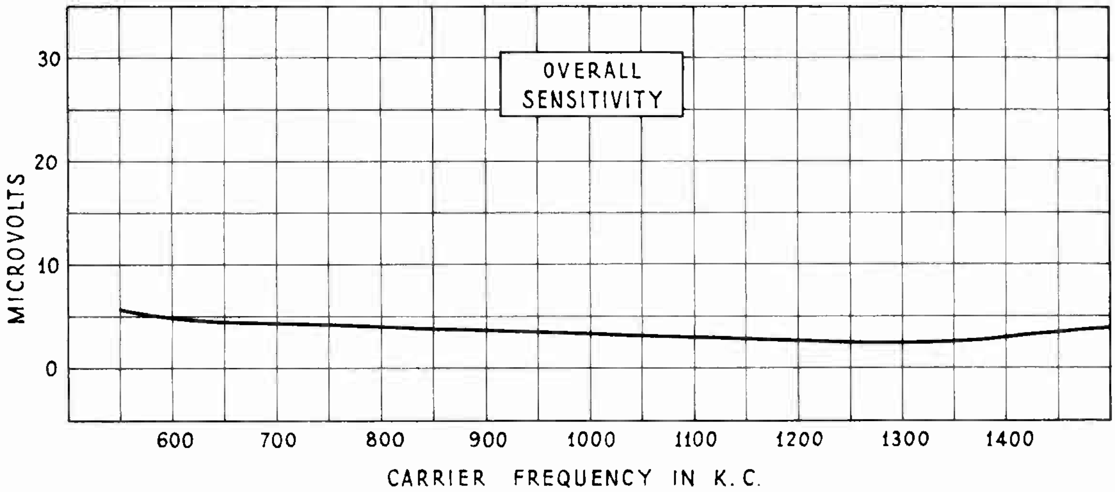

Figure 9

Sensitivity. The sensitivity of a receiver is the determination of how weak a signal the receiver will respond to, and is measured in terms of the amount of input voltage necessary to obtain a standard output. A typical sensitivity chart in which signals of various different frequencies corresponding to broadcasting stations are plotted against input voltages is shown in Figure 9. Looking at the graph we find that at a frequency of 550 kilocycles 5.5 microvolts are necessary to produce a given output whereas at 1300 kc. a potential of only 2.5 microvolts is needed to give the same output. Other points on the curve represent similar relationships. The normal output is taken as 0.05 watts, dissipated thru a load of 8000 ohms connected in parallel with the primary of the output transformer, with the voice coil of the speaker open circuited.

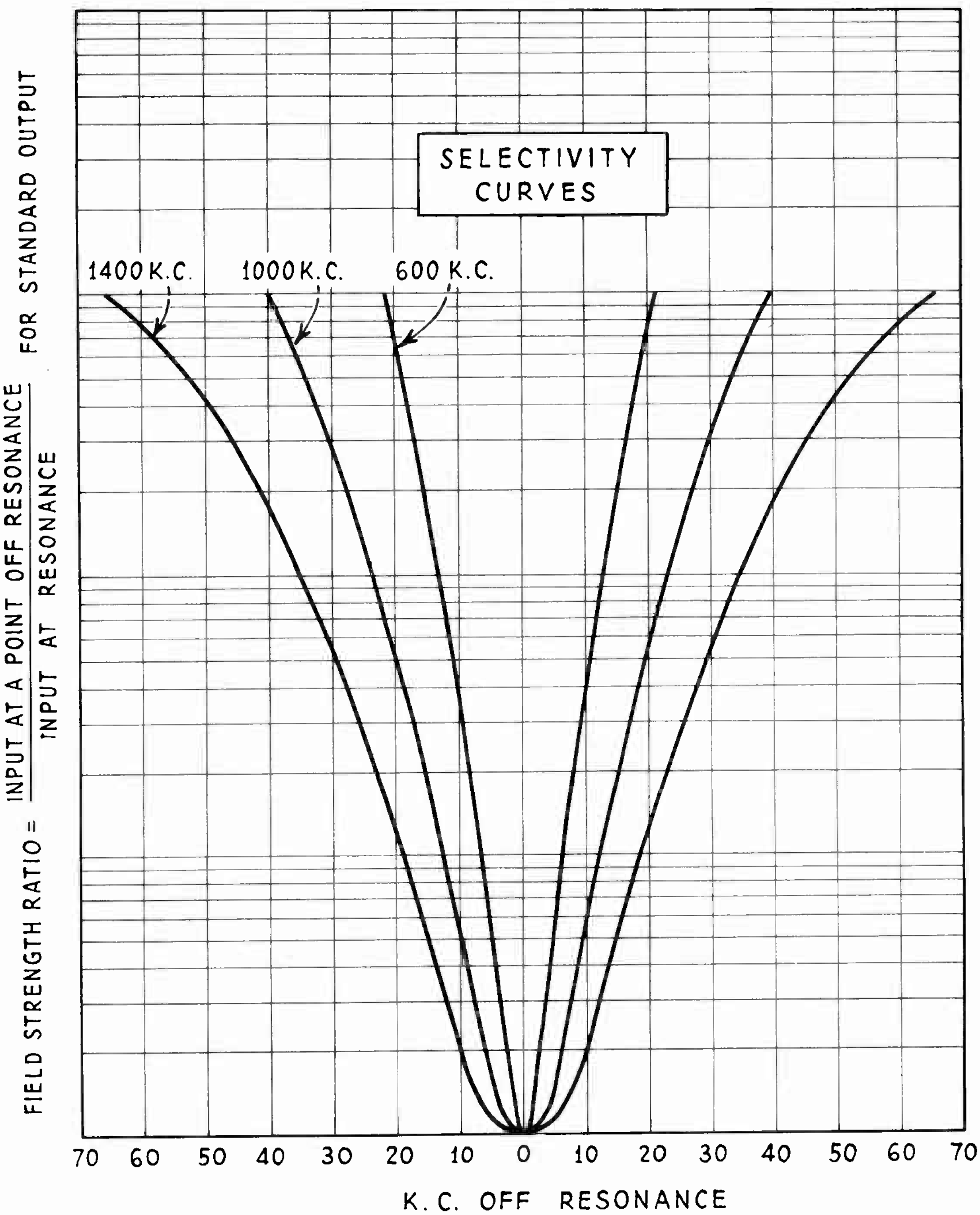
SELECTIVITY CURVES
1400 K.C.
1000 K.C.
600 K.C.
FIELD STRENGTH RATIO = INPUT AT A POINT OFF RESONANCE / INPUT AT RESONANCE FOR STANDARD OUTPUT
70 60 50 40 30 20 10 0 10 20 30 40 50 60 70
K.C. OFF RESONANCE

Figure 10

Selectivity. The ability of a receiver to select a single station and exclude all others is its selectivity. In Figure 10 the straight vertical line or zero axis midway between the two curves represents the exact location of the received signal, or the point of resonance. The width of the band of frequencies to which the receiver responds is indicated by the distance between the two curved lines. The lines join each other at zero field strength but as the received energy increases the curves diverge, the higher frequency curves being further removed from the zero axis than the lower frequency curves because the r-f resistance increases with the frequency. As the signal energy of the broadcast transmitter is reduced by the use of the volume control the signal seldom covers more than 30 kc. in modern broadcast receivers.

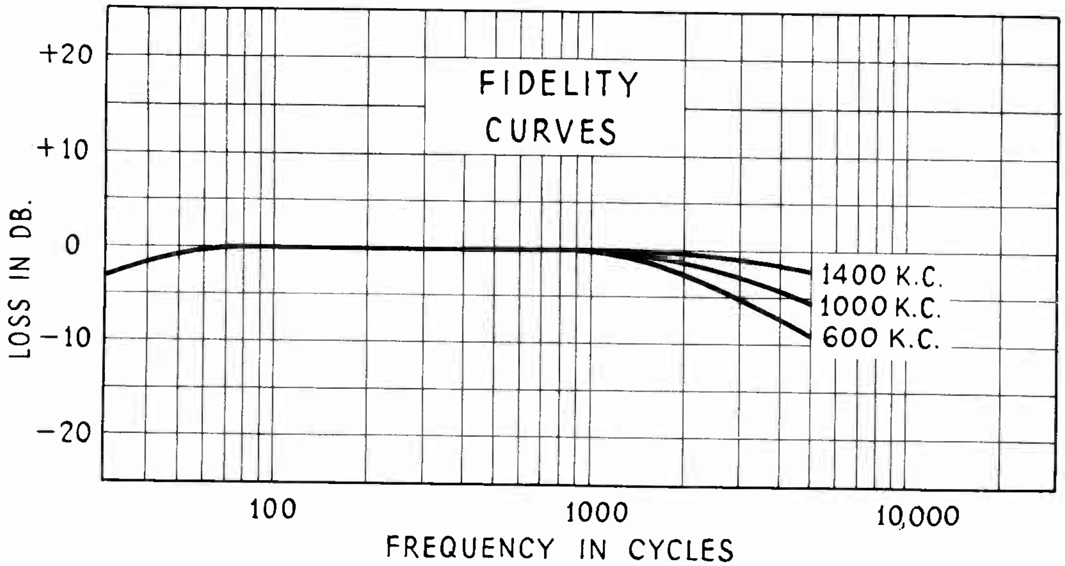

Figure 11

Fidelity. The degree to which a receiver accurately reproduces the modulated wave of the broadcasting station is its fidelity. An ideal receiver would be one which would have a flat horizontal line from the lowest to the highest frequency of sound or roughly from 16 to 10,000 cycles. Figure 11 shows a typical fidelity curve where sound frequencies are plotted against various power outputs measured in decibels. Looking at the curve marked 600 kc. we find that its gain of power output at a frequency of about 16 cycles, or the lower limit of sound, is -3 db. whereas at the audible frequency of 1000 cycles the gain of power is 0 db. The loss increases greatly as the frequency increases above 1000 cycles.

Power Output. Figure 12 shows the relation between input voltage and output power, the abscissae representing the input potential and the ordinate showing the power output. All potentials over 100 microvolts are seen to give a power output of about 7 watts.

An ideal composite curve is shown in Figure 13. It is given to enable one to make comparisons between curves taken under test con-

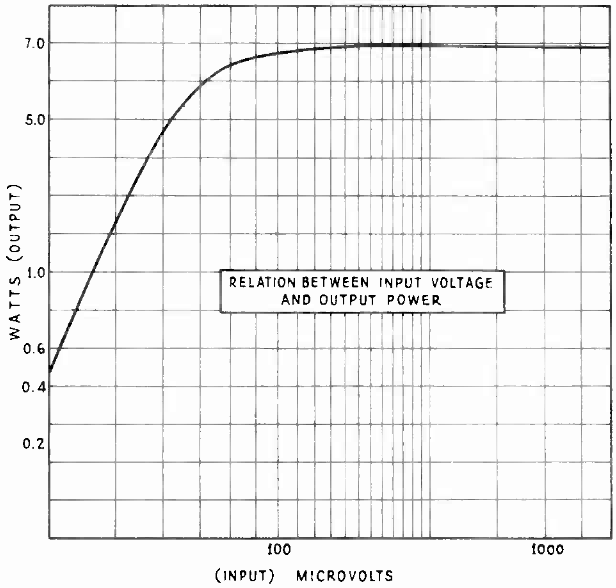

Figure 12

ditions and the ideal condition. As shown on the graph in Figure 13, an ideal fidelity curve is represented by the almost flat horizontal line which covers a frequency band between 60 and 5000 cycles. It is to be understood that this band is an arbitrary one and the frequency range may extend to either side of these limits. In the case of an ideal condition of sensitivity of a receiver a curve which indicates this particular quality would fall between the two horizontal lines ranging from 10 to 5 microvolts as also shown on the graph. The third curve, drawn on the graph paper, whose two sides are vertical practically all the way up and 10 kilocycles apart shows the best condition possible for selectivity.

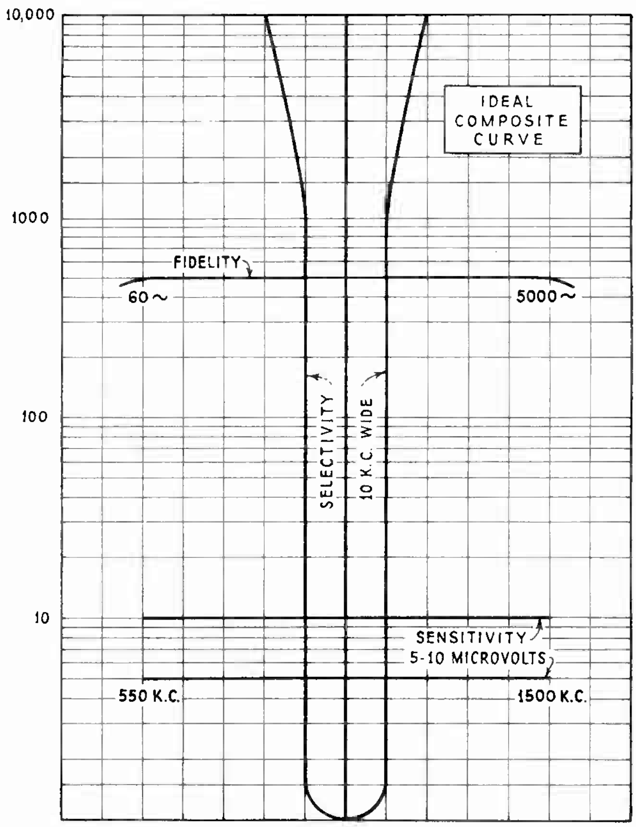

Figure 13

SELECTIVITY, SENSITIVITY AND FIDELITY MEASUREMENTS

The standard tests by which the performance of a broadcast receiver is determined are performed according to specifications proposed by the Institute of Radio Engineers. They are given in the following pages through the courtesy of this engineering society.

I. GENERAL

The purpose of the standard tests here proposed is to provide by general agreement a basis upon which the complete normal performance of any broadcast radio receiver may be reasonably predicted. It is believed that no simple "figure of merit" can properly be derived that will by itself give an index of complete performance. This follows from the varying weights that may be applied at different times and in different services, to the fundamental properties of sensitivity, selectivity, and fidelity. Consequently it is believed to be essential to define and to provide for the separate measurement of each of these fundamental properties. Such information is of somewhat too highly technical a nature to appeal directly to the average user of broadcast radio receivers, but is thought to be useful to radio distributors and dealers in guiding their selection of apparatus for specific service conditions, and to engineers and manufacturers in aiding the comparison and improvement of their products.

It is recognized that the tests do not comprehend the entire range of service conditions that may be met in practice, and that peculiarities of design not reflected in the test data may in special cases affect the deductions to be made properly from the test results. It is also recognized that the three basic properties of sensitivity, selectivity, and fidelity are in some radio receivers dependent upon adjustments that will change the relative prominence of each, and consequently the three factors should be invariably measured at the same settings of the radio receiver adjustments. Nevertheless, it is thought that acceptance of the procedure outlined, together with proper interpretation and correlation of the results obtained by the tests, will serve to permit a standard comparison of normal radio receiver performance.

II. DEFINITION OF TERMS

(A) Sensitivity. Sensitivity of a radio receiver is that characteristic of the radio receiver which determines to how weak a signal it is capable of responding. It is measured quantitatively in terms of the input voltage required to give a standard output.

(B) Selectivity. The selectivity of a radio receiver is the degree to which the radio receiver is capable of differentiating between the desired signal and signals of other carrier frequencies. This characteristic is not expressible by a single numerical value, but requires one or more graphs for its expression.

(C) Band Width. As applied to selectivity, the band width of a radio receiver is the total width of a selectivity curve at a specified point on the scale of ordinates. The specified points are usually two, ten, and successive powers of ten.

(D) Fidelity. The fidelity of a radio receiver is the degree to which the radio receiver accurately reproduces at its output the form of the signal which is impressed upon it. The fidelity of a radio receiver is measured by the accuracy of reproduction, at the output terminals, of the modulation of the received wave.

(E) Normal Test Output. As applied to the testing of a broadcast radio receiver, the term represents an audio-frequency power of 0.05 watt in a noninductive resistor arranged to carry alternating current only and connected across the output terminals of the radio receiver (usually the loud speaker terminals), the resistance of the resistor having been adjusted to that value recommended by the tube manufacturers to give maximum undistorted output power for the type of vacuum tube intended to be used in the output of the radio receiver, with normal adjustments of this vacuum tube. If the radio receiver is not arranged to filter out direct current from its output circuit, then an external filter system shall be employed, of such character as to introduce negligible resistance to direct current, to have negligible loss and to have negligible shunt admittance and negligible series impedance relative to the output resistor.

(F) Normal Radio Input Voltage. As applied to the testing of a broadcast radio receiver, this term represents the root-mean-square voltage of a received signal, modulated 30 per cent at 400 cycles per second, which results in normal test output at resonance. If the radio receiver does not include a self-contained antenna, then the signal is to be impressed on a real or artificial standard antenna.

The method of measuring the percentage modulation involves calculation of the percentage modulation from measured values of the peak voltage of the radio-frequency oscillator output under modulated and unmodulated conditions. The voltage measurements are made with a vacuum tube peak voltmeter.

(G) Standard Antenna (Real or Artificial). As applied to the testing of a broadcast radio receiver not having a self-contained antenna, this term represents an antenna having in series a capacity of 200 micromicrofarads, a self-inductance of 20 microhenries, and a resistance of 25 ohms.

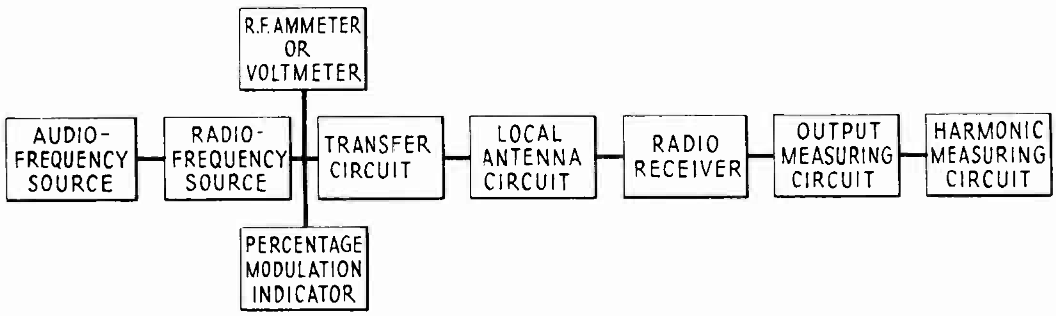

Figure 14

(H) Standard Test Frequencies. In the testing of a broadcasting radio receiver, the five standard carrier frequencies are 600, 800, 1000, 1200, and 1400 kilocycles per second. When tests are required at only three carrier frequencies, the values 600, 1000, and 1400 kilocycles per second are recommended.

III. REQUIREMENTS AND CHARACTERISTICS OF TESTING APPARATUS.

The apparatus employed in testing radio receivers should be as simple as is consistent with accurate performance of the necessary functions. As far as possible, the same apparatus should be used in the different tests. The values of the electrical quantities and calibrations should not change with time, or if some change is unavoidable, means for checking should be provided.

The required apparatus for tests of sensitivity, selectivity, and fidelity, is indicated in block diagram form in Figure 14. Both frequency sources should be calibrated so that a separate measurement of frequency is not needed. The requirements of the separate elements are stated in the following paragraphs.

(A) Audio-Frequency Source. For sensitivity and selectivity tests this may be a mechanical oscillator of fixed frequency (400 cycles per second), but a vacuum tube oscillator having a frequency range at least from 40 to 10,000 cycles per second is preferred and for the fidelity test is necessary. The total harmonic content in the output of this oscillator should not exceed five per cent. The audio-frequency oscillator is arranged to modulate the radio-frequency oscillator by a known amount and preferably should furnish the same degree of modulation without readjustment at all carrier frequencies and all modulation frequencies. Means should be provided for adjusting the degree of modulation for at least the normal value of 30 per cent.

(B) Radio-Frequency Source. This consists of a vacuum tube oscillator supplied preferably from batteries, either fully shielded in itself or so shielded from the radio receiver under test that there is no direct radiation to the receiver. If the power supply is external to the shielding system which encloses the oscillator all ungrounded leads to the oscillator should pass through shielded low-pass filters. The frequency should be adjustable by an external control to any desired value between 500 and 1500 kilocycles per second, and the frequency should not be affected by changes in output power. Means should be provided for varying the frequency in small steps immediately on each side of any specified frequency. A second external control should be provided for varying the modulated radio-frequency output supplied to the transfer circuit, and an instrument should be provided which indicates the effective value of this output. The oscillator in conjunction with the transfer system used (see "Transfer Circuit") should be capable of supplying in series with the receiving antenna system at least 200,000 microvolts at all carrier frequencies.

(C) Transfer Circuit. The radio receiver under test is provided with a local antenna circuit consisting of either a loop antenna (which may be self-contained) or an artificial antenna. In determining the significant characteristics, as outlined in the preceding sections, modulated radio-frequency voltages of known value are impressed in the local antenna circuit through the transfer circuit which should assume one of two forms as follows:

1. A coupling coil fed from the radio source and mounted in inductive relation with the loop antenna or with the 20-microhenry coil.

2. A calibrated attenuator of the resistance type terminating in a low impedance of known value (usually a resistance of about one ohm) which may be inserted in series with the artificial or loop antenna. This attenuator should be so constructed that all attenuation ratios are substantially independent of frequency within the broadcast band. It is preferably made variable in steps with additional provision for continuous variation between the steps. As an alternative to continuous variation with the attenuation network, provision may be made for continuously varying the measured current or voltage supplied from the source to the attenuator over a sufficient range to cover all values of receiver input voltage which lie between the steps of the attenuator. Design details of attenuators fulfilling these requirements are available in the literature. The combined range of ratios on the attenuator and variable currents from the source should be such as to allow a range of voltage across the terminal unit which feeds the receiving set of one microvolt to 200,000 microvolts.

(D) Output Measuring Circuit. The components of the output measuring circuit should be as follows:

1. A noninductive load resistor adjustable to any desired value between one and 20,000 ohms and capable of dissipating 10 watts at any setting.

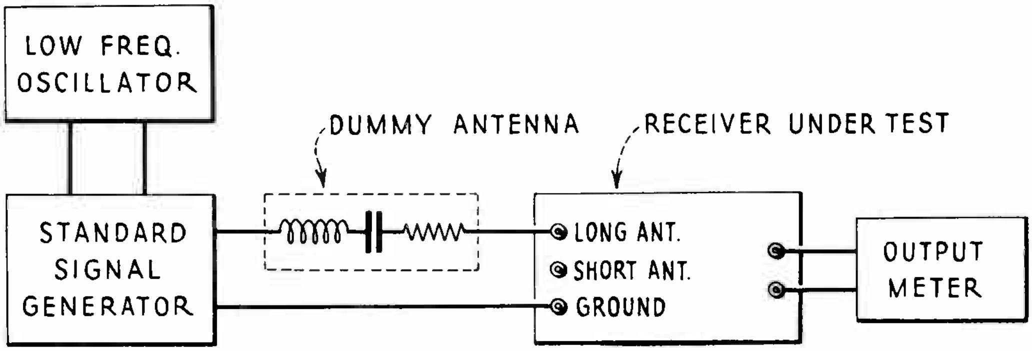

Figure 15

2. An output filter to be used with radio receivers normally having direct current in their outputs. This filter should fulfill the requirements given under definition D, section II, and a recommended form consists of an inductance of not less than 100 henries (with 50 milliamperes direct current in the winding) and a capacitance of not less than eight microfarads.

3. A vacuum tube voltmeter or an equivalent device which will accurately measure the root-mean-square values of output voltage. At normal test output the voltage is of the order from 10 to 20 volts for ordinary output vacuum tubes. For the sensitivity and selectivity tests the output meter need be calibrated only at these values. For the fidelity test continuous calibration is required, and for the overload level test calibration for much higher values is needed.

IV TEST PROCEDURES.

(F) Sensitivity and Tuning Range Tests.

1. The sensitivity test is as follows: The sensitivity is determined by impressing a radio-frequency voltage, with 400 cycles, 30 per cent modulation, in series with a standard antenna (definition G, Section II),

or by inducing a known radio-frequency voltage in the self-contained antenna, if the radio receiver is so provided, and adjusting the intensity of the input voltage until normal output is had under conditions stated in E and F, section II, for carrier frequencies between 550 and 1500 kilocycles per second. See Figure 15.

A graph is plotted with normal radio input voltage as ordinates and carrier frequency as abscissas. A uniform scale should be used for the abscissas and either a uniform or logarithmic scale may be used for ordinates.

2. The Tuning Range Test is as follows: In conjunction with the sensitivity test it is convenient to make a test of the tuning range of the radio receiver. Using the same test conditions as for the sensitivity test, the radio receiver tuning adjustment should be set for the lowest carrier frequency it is capable of receiving under normal operation. The radio-frequency oscillator is then adjusted in frequency until it is at that frequency which gives maximum output in the output meter. The output signal used should be approximately normal test output, to avoid inaccuracies due to overloading. The radio-frequency setting of the oscillator is then recorded as the lower frequency limit of the tuning range. If the radio-frequency oscillator is incapable of reaching the low-frequency limit of the receiver, the oscillator should be set at its minimum frequency and the receiver tuned to it. The dial scale reading of the radio receiver is then recorded for that frequency. The process is then repeated at the high-frequency limit of the range. The maximum and minimum frequency settings of the tuning control will generally correspond to the maximum and minimum dial scale markings. If they do not, the dial settings corresponding to the limit frequency settings should be recorded.

If a calibration of dial setting versus carrier frequency is desired, it can be obtained by adding to the limit values, a set of readings of the dial settings for each of the standard test frequencies used in the sensitivity test. The dial calibration is plotted in the form of a graph with carrier frequency as abscissas and dial setting as ordinates, both to a linear scale.

(G) Selectivity Test. The selectivity is determined by tuning the radio receiver to each standard test frequency (definition H, section II) in succession, with the receiver in the same condition as in the sensitivity test, and measuring the radio-frequency input voltage necessary to give normal test output at a series of carrier frequencies in steps not greater than 10 kilocycles per second at least up to 100 kilocycles per second on either side of resonance, or until the radio input voltage has increased to at least 1000 times its value at resonance (and preferably 10,000 times or more if the measuring equipment permits).

The conditions of modulation of the radio-frequency oscillator are to be the same as given under the definition for normal radio input voltage (definition F, section II). For each standard test frequency a graph is plotted with carrier frequency as abscissas and the ratio of input off resonance to the input at resonance, as ordinates. The scale of ordinates should be logarithmic and the most accurate representation is secured by plotting the graphs for selectivity with separate enlarged frequency scales, which should be uniform and alike.

On some receivers the volume control setting has an effect on the selectivity, and this fact should be considered when making this test.

(H) Fidelity Test. This is determined by tuning the radio receiver to each standard test frequency (definition H, section II) in succession, with the receiver in the same condition as in the sensitivity and selectivity tests, adjusting the impressed voltage to the normal radio input voltage, (definition F, section II) and then varying the modulation frequency from 40 to 10,000 cycles per second at 30 per cent modulation and constant radio-frequency input voltage throughout, taking readings of relative output voltage at convenient modulation frequencies. For each standard test frequency, a graph is plotted with modulation frequency as abscissa, and as ordinate, the ratio of the output voltage at the modulation frequency of measurement to the output voltage at the modulation frequency of 400 cycles per second. A logarithmic scale should be used for the abscissas and either a uniform or logarithmic scale for the ordinates.

It is often useful to make fidelity tests at output levels higher than normal test output. The output levels to be used are left to the discretion of the test engineer and should be stated in the results. Certain types of volume controls have an effect upon the fidelity of the receiver and this fact should be considered when making this test.

EXAMINATION QUESTIONS

1. Describe some of the characteristics of screen-grid receivers that differ from those employing other type tubes.

2. Why are there no neutralizing condensers or stabilizing devices required in screen-grid receivers?

3. How is the grid bias obtained for the 224 tubes in the receiver shown in Figure 1?

4. What is the result of impressing a signal voltage higher than the biasing voltage on a tube?

5. How may the signal voltage be reduced?

6. When is maximum power transferred from one circuit to another?

7. Upon what principle does a magnetic phonograph pick-up work?

8. (a) Define sensitivity, selectivity, and fidelity. (b) Why is each of these qualities important in a receiver?

9. (a) Give two advantages of the 247 tube over the 245 tube. (b) When is the 245 more desirable?

10. Why is shielding necessary in screen-grid receivers? What units must be shielded?

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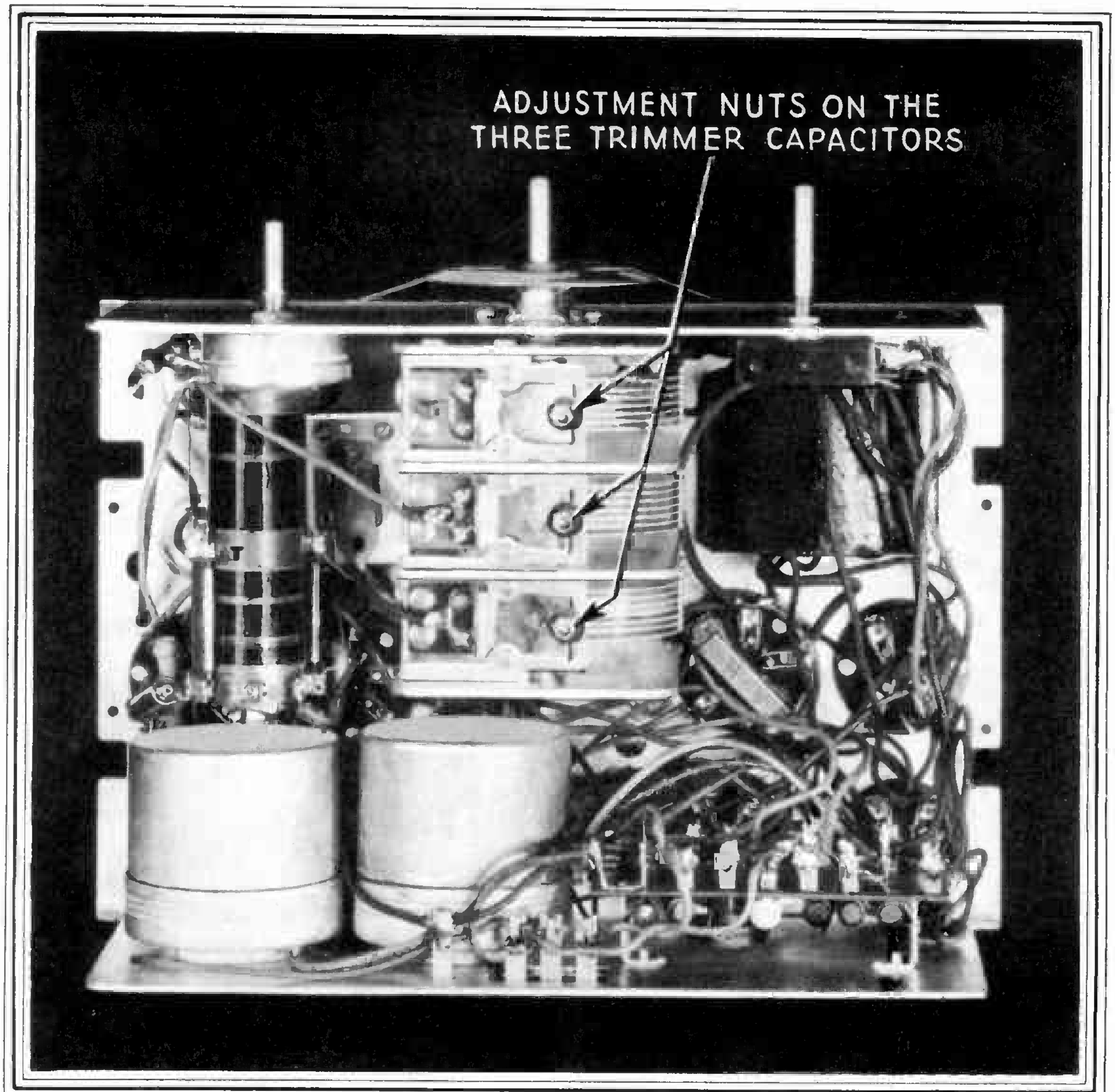

Bottom view of receiver chassis showing location of 3-gang tuning capacitors.

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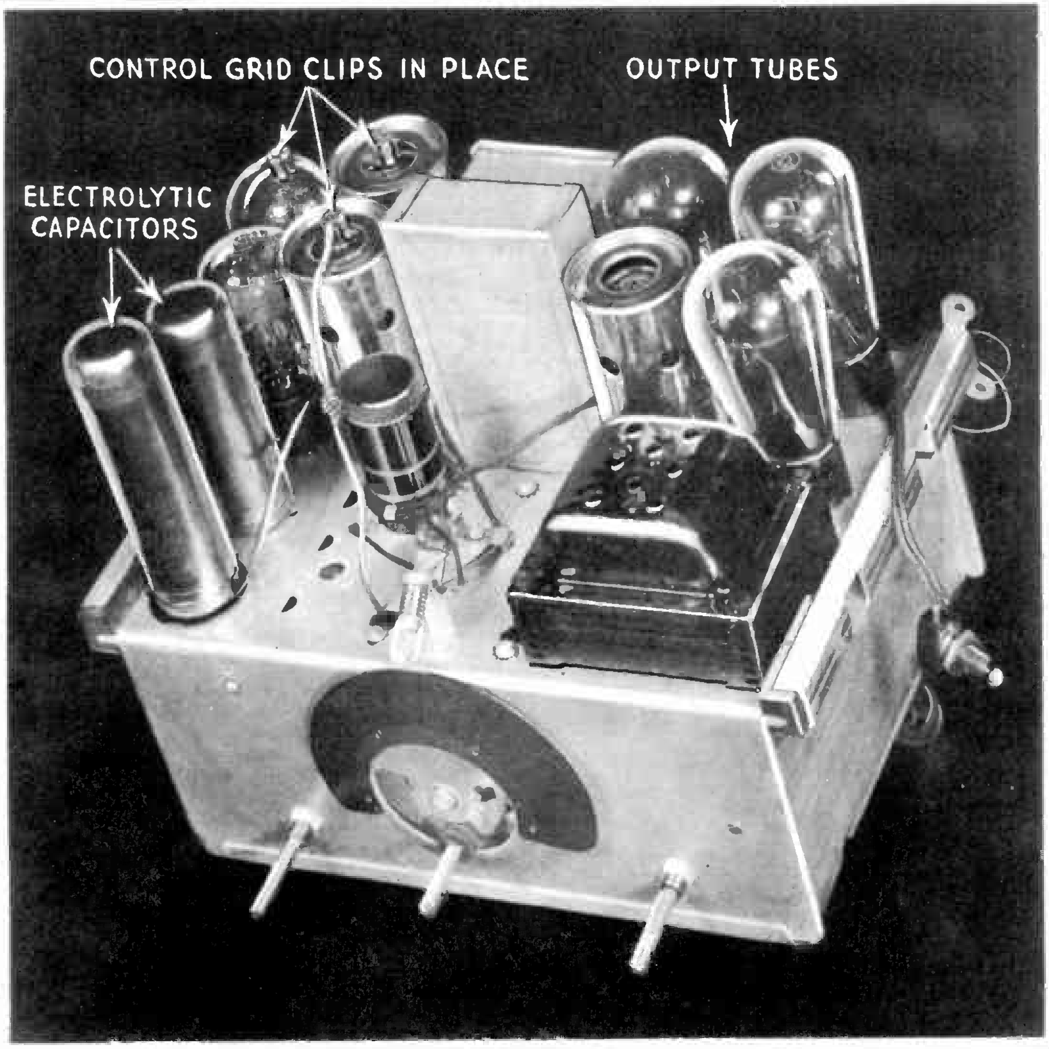

Broadcast receiver chassis using two electrolytic capacitors in filter system.

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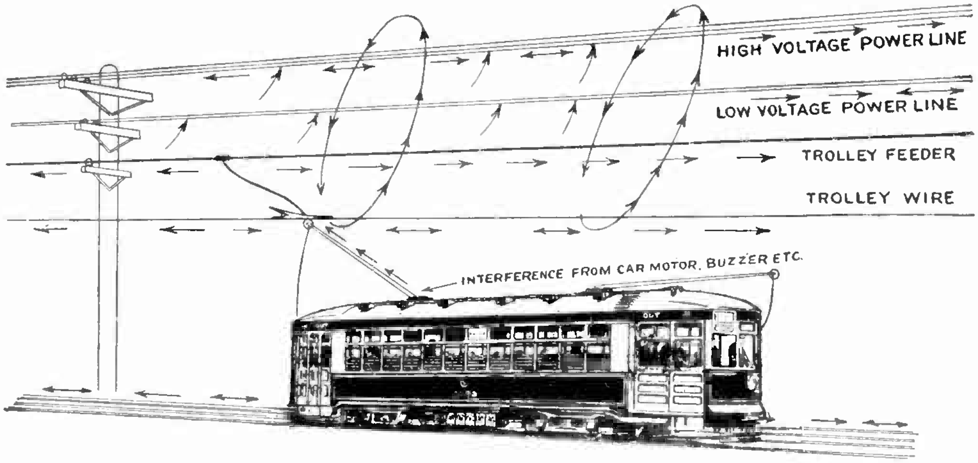


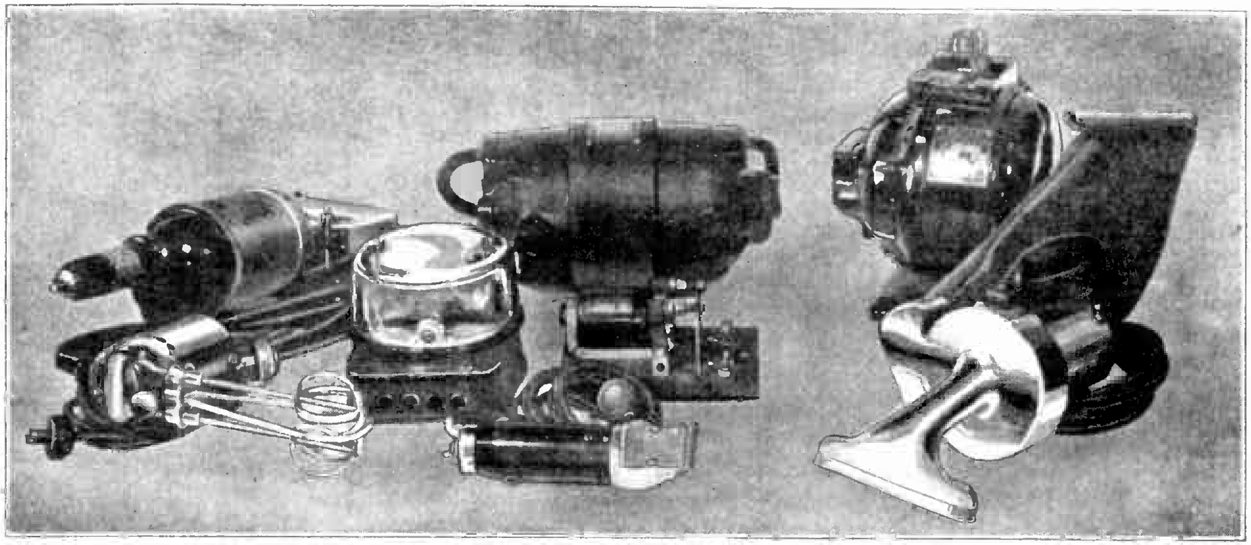
Diagram showing inductive transfer of interference from a street car to the feeder and primary and secondary distribution network.

INTERFERENCE ELIMINATION

Prepared jointly by the Tobe Deutschmann Corp., and the R.C.A. Institutes, Inc.

VOL.36, NO.5

Dewey Classification R360



Appliances of the type shown above are responsible for a large percentage of the radio interference in every city.

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INTERFERENCE ELIMINATION

The term "interference" in the broad sense of the word means that when listening to a broadcast program, sounds are heard from the loudspeaker which are not a part of the desired signal. These sounds form a disturbing background to an otherwise enjoyable program and they appear in different forms. They are usually unintelligible sounds which may be described as trifling, fluttering, squealing or queer blurring and buzzing noises. The cause of many of these disturbing sounds which detract from the radio program are readily understood while the cause of others is recognized usually only by the service man who has actually become experienced in this phase of the work.

Radio interference may be classified under six headings as follows:

1. Broadcast transmitters radiating energy on the same or nearly the same wavelength.
2. Nearby powerful broadcasting stations.
3. A neighboring receiver in an oscillating condition will act as a miniature transmitter.
4. Electrical atmospheric disturbances arising in space and commonly known as atmospheric or static cause interference.
5. Faulty parts of a receiver at times will give rise to disturbing noises.
6. Lastly, we have interference which originates from commercial electrical machines, power lines, trolley cars, elevator systems, subways, home electrical appliances and electrical apparatus used in the professional field, such as X-ray and violet ray equipment. This type of radio interference is more commonly referred to as man-made static.

Interference of the nature outlined under the first heading may be due to transmission problems or to lack of selectivity in the receiver. By transmission problems is meant the possible faults in the frequency control devices of the transmitting equipment or where two stations are operating on or about the same frequency at the same time or on frequencies not separated by at least 10 kilocycles.

A shrill whistle which forms a background to the program being received is sometimes caused by broadcasting stations transmitting on adjacent frequencies less than 10 kilocycles apart. When the proper separation of frequencies is not maintained and the receiver is tuned to either of the stations operating under such conditions two currents of different frequency pass simultaneously through the receiving circuit producing an entirely new frequency which is audible. The production of a third frequency or beat note when one frequency is superimposed upon another is called heterodyne. This phenomenon explains the meaning of the expression "the heterodyning of two stations". Such heterodyning not only will cause a shrill whistle, but on occasion when one of the transmitting stations carrier frequency is varying back and forth the resulting heterodyne beat note may be an audible note of varying frequency. Conditions of this kind, however, are rapidly disappearing due to the work of the Radio Commission assisted by the officials of broadcasting stations. Cooperation between officials of broadcasting stations and the Commission results in either a reallocation of wavelengths, a more active watch being maintained on the frequency control devices at the transmitters, or some equally satisfactory plan is put into practice whereby this familiar form of interference is eliminated.

From what has just been said you can readily realize that the serviceman cannot correct troubles of this nature. These difficulties must be removed by the engineers of the stations at fault.

The heterodyne signals resulting when the side band of two transmitters meet are reproduced with greater amplitude on the more modern receivers whose sensitivity is much greater than those of previous years manufacture. This is so because of the increased over-all amplification of the modern receiver as compared to the less modern receiver. Hence a receiver of this design in practically all cases will make an interfering signal audible under certain conditions, where a less sensitive receiver delivering less loudspeaker volume for a given signal on the antenna will not reproduce the interference. This means that the interfering signal may be present in the less sensitive receiver, but it is not amplified to the point of audibility.

The sensitivity of most of the modern receivers is governed by means of a volume control which functions independently of the selectivity control, therefore, the procedure to adopt when interference is experienced with an extremely sensitive receiver is to reduce the sensitivity of the receiver by the volume control. This condition is rapidly disappearing due to the new 50-cycle frequency control regulation of the Federal Radio Commission. Consequently, very little interference of this nature will be experienced in the future.

INTERFERENCE FROM POWERFUL NEARBY BROADCASTING STATIONS

This interference usually results from lack of selectivity of the receiver in question. That is, inability of a receiver to reject signals other than those of a frequency 5 kilocycles below or above that frequency to which the receiving circuits are tuned. Receivers now used for radio broadcast reception may be classified as follows:

1. Those which utilize one stage of tuned radio frequency and variable regeneration.
2. Those which utilize three stages of tuned radio frequency without the effective balancing or coupling between the radio frequency stages, each stage,

however, being heavily damped by what is termed the grid suppressor method which prevents oscillation between the RF circuits.

3. Those which utilize three radio frequency stages, with out the grid damping resistors, and employing more or less complete balancing of interstage coupling between the radio frequency stages; or else employing screen grid tubes as radio frequency amplifiers, with the consequent reducing in the tendency of feed-back, which causes oscillation to take place.
4. Receivers using three or more tuned or untuned radio frequency stages, which stages are preceded by a preselector or band-pass filter tuning circuit frequently called a link circuit.
5. Superheterodyne receivers in which both radio frequency and intermediate tuning stages are utilized.

Receivers under classification 1 are more selective than receivers consisting of a detector and an audio frequency amplifier only. Class 2 and 3 have a higher degree of selectivity than class 1 and greater selectivity may be obtained with classes 4 and 5 than either of the preceding types.

Individual receivers, however, may vary relative to the degree of selectivity they are supposed to possess regardless of their design, and especially when located in close proximity to a powerful broadcasting station. The types of receivers subject to interference because of their location to a nearby powerful broadcast transmitter are those mentioned under class 1 and others not classified, such as the single circuit type and some of the home constructed sets. The majority of receivers outlined under 3, 4 and 5 are usually factory products and little or no trouble will be experienced with them unless the gang condensers tuning their tuning circuits are not in proper alignment. This will require that the gang condensers be properly aligned in order that all tuning circuits be resonant to the same frequency at the same time. In the case of superheterodyne receivers this would require a complete realignment of the intermediate frequency, oscillator and radio frequency tuning condensers for maximum output at all points of the dial.

Occasionally, however, any receiver will vary as to its ability of selecting a particular frequency to the exclusion of others especially when located very close to a powerful transmitter, let us say, within a radius of 2 or 3 miles. When this is the case a device known as a wave trap may be employed to overcome the difficulty.

A wave trap is a device designed to reduce or eliminate radio interference when this interference is caused by stations other than the one desired. There are two principle wave traps one of which is known as the absorption and the other the rejector type.

A diagram of the absorption type wave trap appears in Figure 1. The two coils shown are wound on a 3 inch form. The small coil consists of from 5 to 8 turns of double cotton covered wire closely wound. This coil is connected directly in the antenna as shown in the figure.

The large coil is wound with 55 to 60 turns of #28 double cotton covered wire. A .0005 microfarad variable condenser is connected across this coil.

The degree of coupling between these windings offset both the elimination of the interfering signals and the position of the tuning controls of the receiver. To obtain close coupling, wind the coil 1 close to coil 2 thus decreasing the distance between them. This will materially aid in eliminating the interfering signal, but it has a greater effect upon the position of the tuning controls of the receiver.

To secure loose couplings wind coil 1 and coil 2 in such a manner that an open space separates the two windings. The results obtained will now be the reverse of those when close coupling was employed.

The correct spacing to allow between the two coils so that a satisfactory elimination of the interfering signal is secured and at the same time effecting the least change in the receiver controls from their normal tuning position is found by a little experimenting and when once found it can be made permanent.

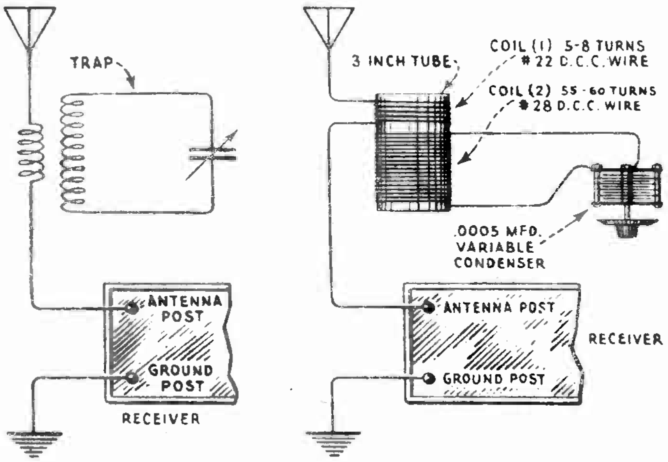


Fig. 1 - View and schematic of an absorption type wave trap.

To use the wave trap set the condenser to zero. Tune the receiver until the interfering signal is received with the maximum voltage. Then rotate the trap condenser until the undesired signal is reduced to minimum strength. Carefully readjust the receiver controls to the interfering signal a second time and readjust the trap condenser until the undesired signal entirely disappears or is reduced to minimum intensity. The wave trap control is now left in this position as long as this particular frequency is to be eliminated. The receiver is operated in the usual way to select the desired signal.

The wave trap functions as a resonant circuit in which alternating current is flowing. By varying the capacity of the variable condenser the capacitive reactance is made equal to the inductive reactance, thus cancelling out these two forms of opposition which oppose current flow at a particular frequency. The circuit is then reduced to one possessing only ohmic resistance and thereby allowing the maximum current to flow. The purpose of the wave trap in Figure 1, the absorption type, is to absorb energy at the particular frequency so that little or none of it will reach the receiver.

A view and schematic diagram of the rejector type wave trap is shown in Figure 2. It is composed of a three-inch tube on which is closely wound 50 to 55 turns of No. 22 double cotton covered wire and a .0005 microfarad variable condenser. The condenser is connected in parallel with the coil.

The operation of this wave trap is identical to the type just described and it has practically the same effect upon the tuning of the receiver as the former type.

The circuit consists of an inductance and capacity connected in parallel. This combination in turn is connected in series with the antenna. By means of the variable condenser it is possible to adjust the trap circuit to resonance with the frequency of the interfering signal. When this condition is obtained the trap circuit offers the least impedance to the interfering signal frequency and bypasses it from the main antenna circuit thereby allowing it to flow back and forth between the condenser and the coil. In this manner it prevents the undesirable frequency from reaching the receiving circuit. This arrangement is most successful when the

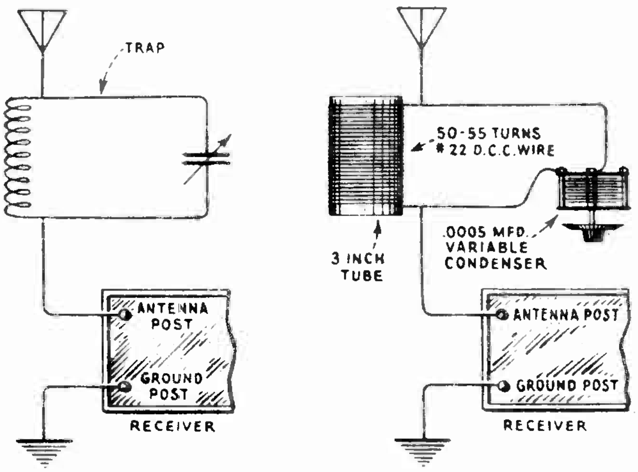


Fig. 2 - View and schematic of Rejector type of wave trap.

antenna is exceptionally long or where the receiver is connected to a poor ground; the wave trap, therefore, can be advantageously used in conjunction with the more or less non-selective types of receivers which are located near broadcasting stations. With the present day modern type of superheterodyne receivers whose degree of selectivity is positively of the order of 10 kilocycles even when very strong signals are present in the antenna system, it will hardly ever be found necessary to use wave traps on these receivers. When a problem of interference under this heading is found to prevail in this type of receiver, the remedy invariably will be to completely realign the receiver tuning circuit.

<u>OSCILLATING RECEIVERS</u>

Regeneration is the process of feeding back energy from the plate to the grid in a vacuum tube circuit. This is permissible, in fact, an asset to a receiver. When, however, carried beyond a certain point, regeneration in the proper sense of the word ceases and the receiving circuit becomes an oscillating circuit. As such it is a generator of high frequency oscillation and in this condition it is really a transmitter.

The power of the radiated energy from an oscillating receiver is weak compared to that of a broadcasting transmitter, yet it radiates sufficient energy to occasionally destroy a broadcast program being received by a neighboring set if the two sets are tuned to the same program. Manufacturers of modern receivers employing a regenerative detector always design the circuit so that oscillations of this nature are prevented from reaching the antenna, but some of the earlier types of receivers were not designed to take care of such a condition. Many of these older sets are still in use, and interference caused as a result of their improper operation should be recognized immediately by the serviceman. If a shrill whistle is heard at times breaking into the program with a violent jerk and at other times gradually rising and falling in pitch when the controls of the receiver are not being manipulated it is a fair indication that someone in the neighborhood is operating a receiver in an oscillating condition.

In the majority of cases the listener-in does not know when he is obtaining the best possible results with the particular receiver he is operating and in an endeavor to get maximum volume he forces the set beyond the best operating point, setting the circuit into oscillation. There is very little that one can do to eliminate this type of interference other than to locate the owner of the offending set and inform him that he is creating interference in his effort to obtain greater volume. Since, however, this type of receiving circuit is giving way to the more modern receiver this type of interference is very rarely met with these days.

ATMOSPHERIC INTERFERENCE

How often we have heard that word! Its tendency to interrupt and in many instances entirely ruin radio broadcast reception is not an uncommon occurrence. "Atmospherics" and "Strays" are synonymous expressions for static. All three of these words refer to the roaming electrical phenomena which are produced by nature. Static is a short way of saying static electricity, and because static electricity concerns us at this time we should know something more about it. The atmosphere of the earth is filled at all times with what is termed "charges of free electricity". This free electricity is static electricity. Where it comes from, no one definitely knows. Many opinions have been expressed in an attempt to arrive at a satisfactory explanation of its exact origin; it still remains, however, one of the secrets of nature.

A most vivid manifestation of the presence of static charges in the air is during thunder storms. The lightning seen at such times is the discharge between the clouds and earth (and between cloud and cloud) of great accumulations of static electricity. A discharge of this nature is immediately made known by a characteristic crashing noise being emitted from the loudspeaker. We say this noise is caused by static.

Fine weather may prevail at the location of the receiver, but the lightning discharges of a distant storm will still have its effect upon the receiver, even though it is thousands of miles away.

Why the receiver is affected by static is because of the discharge of static accumulations which set up an electromagnetic disturbance in the atmosphere. A thunder storm acts as the greatest producer of this form of electrical disturbance.

CARRIERS OF STATIC CHARGES

When listening-in to a program during a rain or snow storm it is not an uncommon occurrence to receive a slight hissing sound. The rain drops and snow flakes are carriers of minute static charges and, as they come in contact with the antenna wire, they impart this charge to the aerial system. Each of these charges set up a minute current which passes through the receiving circuit to earth, producing a slight oscillatory impulse in the tuned circuit which, in turn, is emitted from the speaker as a hiss.

In dry,hot weather the air is filled with small dust particles. These are also carriers of static charges which, on striking the antenna, give up an accumulated charge and produce interfering effects.

Other characteristic noises heard from the reproducing unit of a receiver, because of the effect of charged particles striking the antenna, are irregular "clicking" sounds or crashes resembling that which would be heard by throwing pebbles against a wall.

OTHER SOURCES OF ATMOSPHERIC DISTURBANCE

It is not uncommon, since radio broadcasting became popular, to read accounts of the "Northern Lights" (Aurora Borealis) and its effect upon radio broadcast reception. Why the Aurora Borealis should affect radio reception is not difficult to understand when we accept the scientific reasoning that is set forth as a possible explanation of the phenomenon.

Bodies in space are considered to be one of the sources of electrical phenomena affecting radio reception. This is especially true of the sun which may be thought of as an enormous generator, and which not only radiates heat and light waves, but electrical waves as well. The one particular form of electrical phenomenon in which we are interested, is one which is visible to us on earth; namely, the Northern Lights. Because of the tremendously high temperature of the sun, a continual forming, combining, and decomposing of its elements is in progress, and the atmosphere surrounding this body is considered to be of a gaseous nature. Heated gases originating within the body of the sun rise to great heights and in moving away they expand and cool. In cooling they naturally become heavier than the heated gases below them and they then have a tendency to fall back toward the surface of the sun. An opening may occur at a lower level in the sun's atmosphere, or perhaps at some spot on the surface of the sun into which these cooled gases sink. As they fall back they increase in velocity, rushing toward the openings at tremendous speeds until finally they become stupendous cyclonic storms embracing areas thousands of miles in diameter. This whirling body of gas rushing into the sun is considered to be charged with electricity and, in its downward motion, it sets up a magnetic disturbance of great proportions; so great, in fact, that they extend millions of miles into space. When a magnetic force of this nature emanates from the sun, and the earth is in a line with this force, it may make its presence known by the effect it produces, namely, the Aurora Borealis.

The lights of the Aurora Borealis are considered to be a condition of ionization of the gases in the earth's atmosphere. This does not take place on the surface of the earth, but at high altitudes called the "Auroral" region. This region is perhaps two or three hundred miles in height, at which point the gases of the earth's atmosphere are very low in pressure, i.e., rarefied.

The earth, in moving about its orbit at a speed of over 1,000 miles a minute, passes occasionally through one of these magnetic fields produced by disturbances on the sun. The rarefied gases of the auroral region then perform much like a closed conductor being forced through a magnetic field. An electromotive force is produced and current flows through the gas particles causing it to glow, resulting in a brilliant display of great ribbons of light across the heavens. This glow appears only at the heights in the atmosphere where the pressure is of the value that will cause ionization to take place.

The magnetic force, however, extends to the earth and, as the earth rushes through one of these magnetic storms, current is induced into all conducting mediums, such as antennae, telephone and telegraph lines, and so on. These in turn, produce the characteristic clicks called "Static". The effect of static due to the Northern Lights on telegraph and telephone transmission lines and on receiving antennae is peculiarly more noticeable and particularly annoying on transmission lines or antennae erected in an east to westerly direction. The effect on an individual antenna may not always be so pronounced, but in the case of telephone and telegraph lines, which extend for miles across the country, the induced voltage is often of sufficient magnitude to completely disrupt normal operation for several hours.

From the foregoing paragraphs it is understood that electrical disturbances which affect the reception of radio broadcast programs originate from different sources, and they create interference on all wavelengths.

A tuned radio circuit cannot entirely eliminate these disturbances, but it may greatly reduce them. If the interference is present on the same wavelength as the signal being received, there is no way to prevent it from passing through the circuit and causing audible response in the loudspeaker.

Many devices have been invented in an attempt to eliminate static. but so far the only practical method of reducing its effects is by employing loosely coupled circuits and short antennae. Static eliminators which have produced encouraging results are so elaborate as to prohibit their general use.

There are hundreds of devices on the market which promise to get rid of "Static", but stop and think; the biggest radio manufacturers in the world do not put these devices on their sets. Why? Because they know that they cannot be depended upon to work. The first thing anyone thinks of when he hears about static or interference for the first time is "something to go on the radio set". He doesn't know that the biggest companies in the world have been seeking for years to find such a device. When it is found, if it ever is found, the news will be on the front page of every newspaper in the country. Don't waste money trying "static" eliminators.

NOISE ORIGINATING IN THE RECEIVER

Noises which interfere with a broadcast program are often called static when in reality they originate in parts of the receiver. It is much better to classify this kind of interference as noise because static, strictly speaking, is the result of the antenna system absorbing electrical charges present in the atmosphere. Receiver noises are due to faulty units of the set, its accessories, poor design and careless construction work. It is well at this time to recall that such a thing as corrosion is ever present and frequently causes high resistance or intermittent contact at such points as vacuum tube socket contacts, switches, binding post terminals, sliding spring contactors and Hair Spring connectors to tuning condenser shafts, the junction of interstage shields, vacuum tubes base prongs, poorly soldered junctions and wire splices, etc.

If the on-and-off switch or change-over switch in a receiver becomes worn, the results will be a continual series of scratchy sounds. The worn contacts of the switch are subject to minor vibrations which may often cause circuits which the switch operates to be opened and closed, thereby interrupting current flow. A loss in sound intensity may also result due to poor or dirty contacts in switch parts causing the change of resistance in the circuit which the switch operates.

The rotor plates of variable condensers may become bent because of abuse, and when rotated they will short-circuit the condenser by making contact with the stator plate. When this occurs a click or rasping sound will be heard from the loudspeaker. Flexible leads connecting variable parts frequently become brittle and faulty and will produce crackling noises when the variable part is moved.

All binding post screws or terminal strips should be inspected and when found to be loose they should be tightened so that the wire end or the soldering lug on the cables connected to them will not shift position due to vibration.

Corroded soldered joints are the producers of much undesirable noise. This condition is quite prevalent in receivers several years old. When soldered joints are suspected of causing noise in a receiver, the best procedure is to resolder all of the soldered joints in the receiver by heating each joint allowing the old solder to flow off and replacing it with new solder. In this way an entire receiver can be resoldered in a few minutes and the result in operation of the receiver will more than repay for the time thus taken.

Excessive dirt or dust accumulations about open wiring between condenser plates and on the spring contacts of tube sockets will often be the source of crackling sounds. Such dust is very easily removed either with a strong hand bellows or with the blowing attachment on a modern vacuum cleaner. This will effectively blow off all dirt and eliminate the possibility of bending condenser plates when attempting to clean them by actually rubbing the dust off. The filaments of inferior tubes will often produce noise after they have been in operation for a long time.

A loose tube element shorting intermittently on other tube elements is frequently the cause of receiver noise; poorly designed and cheap grid leaks are very likely to give considerable trouble.

Tapping which occurs at more or less regular intervals may be due to a grid leak of wrong value. Try replacing it with various values until the tapping ceases. Loose control grid caps on screen grid tubes frequently will cause noise when the receiver is set into vibration. Also the control grid leads soldered to the control grid caps which fit on the screen grid tubes frequently are found to be open under the insulation of the wire. Such broken leads must be replaced. Defective resistors are the frequent cause of intermittent noises in a receiver. Such resistors usually open up at some point when they become warm after the receiver has been in operation for some time and since the open end of the wires do not move far enough apart, a continuous arc will take place across the open end. Such resistors must be replaced. Leaking filter condensers which have been in service for some time, particularly electrolytic condensers, tend to break down and the dielectric intermittently punctures.

This is a very common source of noise originating in receiver filter units and can be remedied only by replacing the filter condensers. Rectifier tubes with loose filaments frequently will cause such large variations with their current output as to make it impossible for the filter system to properly smooth out these large ripples. The only remedy in this case is to replace the rectifying tube with a new one. When audio transformer windings become open circuited, particularly secondary windings, they have been known to cause a continuous arc to take place across the open end. Small fixed condensers, used as by-pass and coupling condensers, will frequently function with very little leakage until a strong signal passes through the receiver. This usually results in higher voltages being impressed across these condensers and under this higher voltage they tend to puncture. Such condensers can only be located by unsoldering them from the circuit and applying a very high break-down voltage test to them. They must, of course, be replaced. On battery operated receivers the following conditions will also frequently cause circuit noises. Storage battery terminals often become corroded. The acid sulphate accumulating at these terminals is a source of trouble, sometimes completely preventing the flow of current. The increased resistance to the circuit caused by storage battery terminal corrosion will cause a faint high pitched whistle in some receivers. The remedy, of course, is to remove the corrosion and to treat the battery terminals and battery clips with a coating of grease or vaseline.

Broken plate supply leads in the receiver and in the receiver cables will produce loud clicking noises. Poor "B" battery connections will produce the same effect. When "B" and "C" batteries reach a discharge stage they are invariably noisy, that is, their internal resistance varies radically and this causes a varying current supply to the receiver. Frequently, even new "B" batteries or "C" batteries will be noisy due to poor or broken soldered connections between the primary cells of which they are composed. Corrosion of the wires on variable volume control resistors in any and all receivers result in poor and a high resistance contact between the sliding contactor and the wire. This constantly varying resistance of the circuit when the volume control is moved results in a scraping noise in the loudspeaker. It can be remedied by cleaning the wire at the point of contact and bending the contactor arm so that it makes better contact and coating the wire surface with vaseline to prevent further corrosion.

HOWLING

Howling may occur when the receiver cabinet or any of its controls are touched, or it may even occur when no one is near the receiver. This is caused usually by a microphonic tube. The howl caused by a microphonic tube is principally a problem of mechanical vibration. As you know, "sound" is the result of vibrating air particles and the vibrations of a loudspeaker set the air about the speaker into complex wave motions. If the loudspeaker is resting on a table, vibrations are imparted to the table top. The table top acts as a conductor for these vibrations and transmits them to other objects upon the surface of the table.

The vibrations from the loudspeaker may find their way to the tubes through the air, or by way of the table top. With the speaker isolated from the support holding the receiver, opening the lid of the cabinet will often result in this howl, which will cease when the lid is closed. It is clear in a case of this kind that the vibrations are reaching the microphonic tube by way of the air.

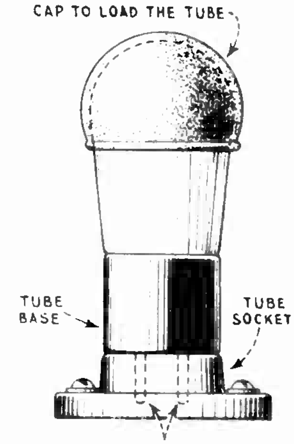


Fig. 3 - Tube loaded with rubber cap to prevent vibration.

Consider another case where the loudspeaker is resting upon the same table supporting the receiver. As soon as the set is placed in operation the howl starts; by removing the speaker from the table the howl ceases. This time it is evident that the vibrations were being transmitted from the loudspeaker directly to the tubes by way of the table top, cabinet, and the tube sockets. A remedy which is very often successful in preventing microphonic tube howl is to "load" the tube with a heavy cap. This cap is slipped over the top of the tube as shown in Figure 3. An arrangement of this kind prevents the tube from moving freely. It is still free to swing when vibrations strike it, but not to the same extent. Spring sockets also tend to absorb shocks and vibrations which would otherwise cause the tube elements to vibrate. The vibration period of the tube, when weighted down with a heavy cap, is perhaps only seven or eight times a second. A vibration pitch of this magnitude is far below the audibility range and will not be heard in the loudspeaker.

The new a-c. tubes rarely, if ever, show microphonic tendencies and very little trouble of this nature should be experienced in the new sets.

Vibration is indirectly the cause of this microphonic trouble, but not the actual cause, for why should it occur with one tube and not another? A microphonic tube is simply an ordinary tube in which one or more of the elements are loosely mounted when assembled. It is essential that all of the tube elements (grid, plate, and filament) be so mounted and supported that a rigid fixed position is maintained between them. If any of the elements move, the spacing between them is changed, and, as a result, the normal characteristics of the tube are changed.

For example, a tube designed to have a low voltage amplification factor is so constructed that the grid and plate elements are mounted close together, while in a tube designed to have a high voltage amplification the grid is placed close to the filament and some distance from the plate. If the sound vibrations cause the tube to move, the loose elements will move also. The distance between these elements consequently are changed and the plate current will follow these changes. The plate current changes are then magnified by the amplifying stages following the microphonic tube and reproduced in the loudspeaker as a swinging howl, varying in pitch as the vibration pitch of the tube changes. In some cases, interchanging the tubes in their sockets will eliminate this trouble. A tube having extreme microphonic tendencies should never be used.

MAN-MADE STATIC

If after making the tests described above for natural static, and for defective parts in the set, the same noises as before are heard, the chances are that man-made static is the cause of the trouble.

In the study of radio interference and its elimination, there are a few fundamental principles which must be clearly understood if you are to be successful in your treatment of interference problems. The first thing you need to know is, just what is interference.

Radio interference is an undesired radio signal of such intensity and frequency that it interferes with the reception of desired broadcast signals. This is the broad definition of interference. For the purpose of this course, a more specific definition will be considered.

Radio interference, man-made static,is generally understood to be an undesired radio signal resulting from an electrical disturbance on, or associated with, a wiring circuit. The disturbance may take any one of many forms and the interference may be distributed in many ways, all of which will be studied at the proper time.

Although broadcast listeners have difficulty in realizing that man-made static is not the fault of the receiver, and although there has seemed to be considerable mystery about radio interference, careful consideration of the definition of interference will indicate that the same principles which apply to the generation and transmission of broadcast signals apply to the generation and transmission of the undesired radio signals which are termed "Radio Interference".

It is therefore obvious that in the solution of any interference problem, it is necessary only to consider the interference source as a radio transmitter and to take the steps which are required to prevent the propagation of signals from this transmitter. Figure 4 shows the similarity of an electrical appliance to a fundamental spark transmitter circuit. Just as the transmitter consists of a spark gap coupled to a circuit containing suitable values of inductance, capacity and resistance, so an electrical appliance containing any type of circuit interrupter such as a commutator, thermostat, mercury switch, spark plug or relay, contains what is essentially a spark gap coupled to a circuit embodying inductance, capacity and resistance. As the electrical constants of the transmitter govern the frequency and intensity of the radiated signal, so the electrical constants of the appliance govern the type and intensity of the interference which is produced.

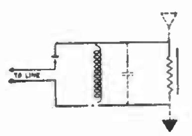


Fig. 4 - Diagram showing similarity of electric circuit to a spark transmitter.

Most types of radio interference have a characteristic sound. Listen carefully to the noise and see which of the following classes it comes under. Opposite each class of noise is a list of the kinds of electrical apparatus which are most likely to cause such a noise.

Whirring, Crackling, Buzzing, Humming, Droning, Whining

Sounds like these generally indicate radio interference which is being caused by an electric motor. Sometimes when the motor starts and stops, the sound will start low and rise in pitch until the motor reaches its full speed when the whine will remain at a certain steady pitch, usually rather high. This is especially true of commutator type motors. Repulsion-starting, induction-running motors may have a sputtering, whirring, crackling, buzzing or humming sound. When such sounds are heard hunt for one of the following:

- Adding Machines
- Automatic Towels
- Barbers' Clippers
- Beauty Parlor Devices
- Billing Machines
- Cash Registers
- Dental Engines
- Dishwashers
- Dough Mixers
- Drink Mixers
- Electric Addressing Machines
- Electric Computators
- Electric Elevators
- Electric Refrigerators
- Electric Vibrators
- Fans
- Farm Lighting Plants
- Floor Polishers
- Generators
- Hair Dryers
- Humidifiers
- Massage Machines
- Motor Brushes
- Motor Generator Sets
- Portable Electric Drills
- Printing Presses
- Sewing Machines
- Shoe Dryers
- Small Blowers
- Telephone Magnetos
- Toy Electric Trains
- Vacuum Cleaners
- Valve Grinders
- Washing Machines

Whistles and Squeals

Sounds of this sort generally indicate radio interference which is being caused by oscillation. Often the whistle or squeal starts high, dips to a low note and mounts again to a high-pitched squeal which may vanish entirely or remain at a steady, high-pitched whistle. Heterodyning broadcast stations have a sort of bubbling whistle, and can be recognized by the fact that they usually occur at the same spot on the dial. Old-fashioned radio sets which tune by the "squeal" of the wave, usually cause the squealing sound to be heard by all radio sets in the vicinity. The addition of a stage of non-oscillating radio frequency amplification will stop this. Whistling or squealing is usually caused by:

- Defective or incorrect value of filter condenser in super-heterodyne.
- Grid and plate leads so paralleled that there is an inductive pick-up between them.
- Grid-leak too high.
- Heterodyning broadcast stations - two stations of almost the same wave length operating at the same time so that the waves combine to form a "beat".
- Inductive pick-up of a loop.
- Intermediate stages of a superheterodyne in oscillation.
- Regenerative sets improperly tuned.
- Set picking up the squeal from a set in the neighborhood.
- Some R.F. stages not neutralized.
- Too much regeneration.

Rattles, Buzzes, Machine-Gun Fire

Sounds of this sort generally indicate radio interference which is being caused by telephone dialing, buzzers, or doorbells. It is not generally steady, but stops and starts. Short rattling sounds like machine-gun fire, varying slightly in length, indicate telephone dialing. Look for:

- Annunciators
- Automobile Ignition Systems
- Buzzers
- Dental Laboratory Motors
- Dial Telephones
- Doorbells
- Elevator Controls
- Sewing Machines
- Switchboards
- Vibrating Rectifiers

Violent, Heavy, Buzzing or Rushing Sound

Sounds of this sort generally indicate radio interference which is being caused by high-frequency apparatus. Such noises will usually be heard over a large area, a whole town, even, and often are so loud that they drown out the radio program completely. Look for:

- Air Purifiers
- Battery Chargers
- Diathermy Machines
- Doctors' Apparatus
- Dust Precipitators
- Flour Bleaching Machinery
- Violet Ray
- High Frequency Apparatus
- Insulation Testers in Cable Plants
- Ozone Devices
- Rotary Spark Gap of Transmitting Station
- Steady Oil-Burner Spark Ignition
- X-Ray

Crackling, Sputtering, Snapping, Short Buzzes or Scraping

Sounds of this sort generally indicate radio interference which is being caused by one or more loose connections. Sometimes the sounds are especially noticeable when the room is jarred or shaken by footsteps, street cars or traffic. Look for:

- Bad connections
- Burrs on plates of variable condensers
- Corroded or loose connections in radio sets
- Defective light-sockets
- Elevator control
- High tension lines
- Loose connections in floor lamps, appliance cords, broken heating elements, etc.
- Power lines grounded on branches of trees
- Street cars
- Trickle chargers

Clicking

Sounds of this sort generally indicate radio interference which is being caused by some sort of make-and-break connection, such as a thermostat, especially if it comes at fairly regular intervals. Look for:

- Defective Resistors in Eliminators
- Elevator Control
- Flashing Signs
- Heaters
- Heating Pads
- Incubators
- Irons
- Mercury Arc Rectifiers
- Ovens
- Percolators
- Shaving Mug Heaters
- Sign Flashers
- Soldering Irons
- Telegraph Relays
- Traffic Signals
- Typewriters

Heavy, Violent Buzzing, Usually Short

Sounds of this sort generally indicate radio interference which is being caused by arcing across a gap. This may occur as a short noise or a steady one. Look for:

- Arc Light
- Automobile Ignition
- Breaks in Third Rails
- Electric Car Switches
- Electric Cigar Lighters
- Electric Elevators
- Moving Picture Machines
- Pole Changers (Telephone Interrupter)
- Street Car Switches
- Street Lights
- Toy Electric Trains

Steady Humming

Sounds of this sort generally indicate radio interference which is being caused by improperly filtered alternating current. Such humming is often the fault of your set or eliminator. Look for:

- Dynamic speakers improperly filtered
- Faulty construction of set or eliminator
- Filter condenser blown or shorted
- Ground on set poor
- Improper wiring
- Poor tubes
- Wiring parallel with power lines

HOW IS MAN-MADE STATIC DISTRIBUTED?

In order to determine the best method of confining interference to its source it will be well to consider the ways in which man-made static and radio signals are transmitted.

The first and most generally understood method of radio signal transmission involves the radiation of energy from an antenna system and the transmission of this energy through the ether. Another method involves the use of wire channels on which the high frequency currents are impressed. This method of signal transmission is most widely used in what are termed "carrier telephony systems", whereby high voltage power transmission circuits serve as the wire channels for the distribution of high frequency currents.

In the distribution of radio interference, both methods of signal transmission are involved. By far the greater part of the interference is distributed by the carrier or "Wired Wireless" method. Further consideration of fundamental radio transmission principles will show why this is the case.

To obtain maximum radiation of energy, for transmission thru the ether, the antenna system provided must be correctly proportioned to be a part of the oscillatory circuit of the transmitter, at the desired frequency of transmission. Fortunately for radio listeners, the antennae (that is, the length of wiring connected to interference sources) associated with most sources of man-made static are not proportioned to provide maximum radiation of high frequency energy. Consequently, the direct radiation of interference is generally limited to a small area in the immediate vicinity of the interference source. Some energy, however, is radiated from all wiring circuits associated with any source of man-made static, and this possibility of interference radiation must be kept in mind whenever any apparatus is being filterized.

Except in extreme cases, interference radiated from an appliance seldom directly reaches the antenna of a radio receiver. This interference will, however, be transferred both inductively and capacitively to wiring circuits or to metallic objects and, once having been impressed on such circuits, may be distributed over a wide area.

In contrast to the transmission of radio-frequency energy through the ether is the transmission of such energy along wire channels. In order to transmit high frequency energy over a wiring circuit it is necessary only to couple the source of energy and the receiver to the wire line. In the case of a carrier telephone system, used in conjunction with a power transmission line, this coupling is provided by use of special coupling condensers as shown in Figure 5a or by use of a coupling antenna parallel to the power line, Figure 5b.

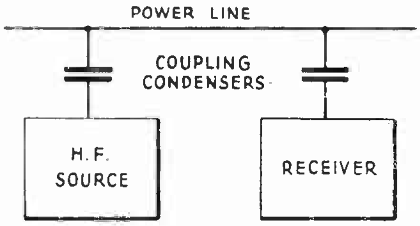


Fig. 5a - Showing method of coupling transmitter and receiver to power line in carrier telephone system.

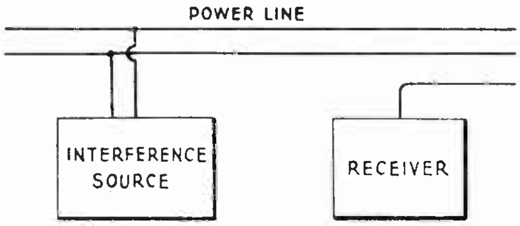


Fig. 5b - Showing capacitive coupling between broadcast receiver antenna and power line. Note similarity to Fig. 5a.

It is easy to see the similarity between interference distribution and carrier telephony. The source of high frequency energy is the making or breaking contact; the inductance and capacity which govern the signal frequency are contained in the windings of the apparatus; the distribution channel is the power supply line to the apparatus; and the coupling of signal source to distribution channel is provided both by direct connection of the interfering apparatus to the line and by inductive or capacitive coupling between the wiring of the apparatus and wiring circuits in the building.

Contrary to the accepted belief, the direct wire connection between the radio receiver and the power line seldom serves to introduce man-made static to the receiver. Tests will prove that, in practically every case, interference enters the receiver through its antenna and ground connection. This is due to the fact that there is bound to be considerable coupling between the antenna, the lead-in, the ground wire and all power wiring, telephone wiring, or other wiring circuits. Thus interference impressed on power or lighting circuits is transmitted to the receiver as indicated in Figure 6.

FUNDAMENTALS OF INTERFERENCE SUPPRESSION

It has been shown that the procedure to be followed in suppressing man-made static is the same as that required for suppressing the signals from a radio transmitter whose signals are undesirable. An outline of just what procedure is required should be helpful at this time.

First, take the case of two broadcast transmitters operating at the same frequency. An example of this condition may be found on the 1,230 K.C. channel on which WNAC in Boston, Massachusetts is operating. Listeners to this station experience an annoying interference from Station WFBM in Indianapolis, Indiana which operates on the same channel. Since both stations are operating at the same frequency, any receiver of sufficient sensitivity receives signals from both stations, and these signals are hopelessly intermingled in the loudspeaker.

Obviously, any wave-trap or other device applied to the receiver for the purpose of eliminating the signals from one of these stations would also eliminate the signals from the other. Consequently, the only relief to be obtained by listeners to one station is the suspension of operation of the other, its removal to a different frequency, or the application of equipment to keep its signals off the air.

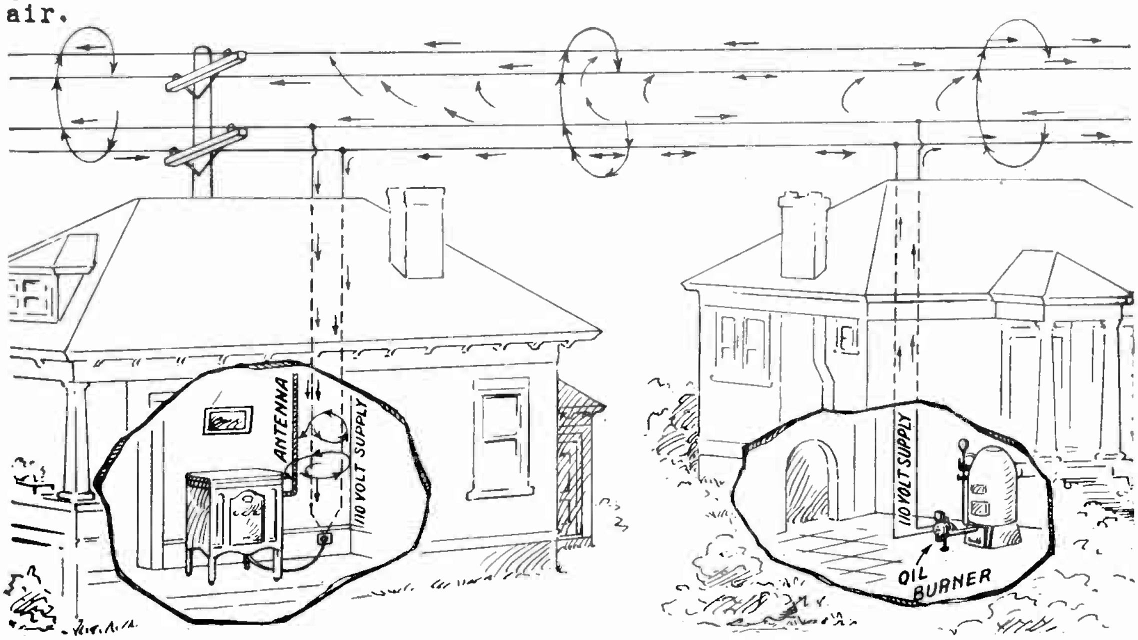


Fig. 6 - Diagram showing inductive transfer of interference from the input wiring of an oil burner to the antenna system of a receiver in a neighboring building.

With this example in mind it is easy to draw a parallel in the case of man-made static. The desired station may be any station, local or distant, operating at any frequency in the broadcast band. The undesired station may be any electrical apparatus, operation of which involves the making and breaking of an electrical circuit. The essential difference between the broadcast station and the interference source is that while the broadcast station has an established frequency, outside the limits of which it does not interfere with program reception, the electrical apparatus broadcasts a disturbance of indeterminate frequency, which mingles with signals from any broadcast transmitter and is inseparable from the desired signals.

It is, therefore, obvious that no device applied to the receiver will separate the broadcast signals from the man-made static. Any device which may appear to reduce interference, when applied to the receiver, will be found to accomplish this result only at the expense of receiver sensitivity and volume output of the receiver.

What, then can be done about interference which enters the receiver at the same frequency as the desired broadcast signal? Obviously it is no more possible to arrange for the suspension of operation of interfering electrical apparatus whenever a broadcast program is to be heard than it is to arrange for the shut down of an interfering broadcast station when this action might appear desirable. And since man-made static seldom has a definite frequency of transmission, but is intermingled with the signals of stations in almost every portion of the broadcast band, the removal of the undesired transmitter to a frequency outside the broadcast band presents a problem far different from that of changing the transmitting frequency of a radio station which interferes at one frequency in the broadcast band.

This brings us to the last mentioned and most generally satisfactory method of obtaining relief from interfering signals, namely, the application of suitable equipment, at the transmitter to keep the undesired signals off the air.

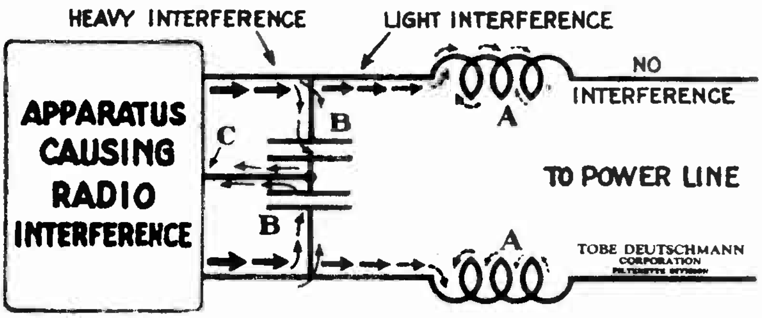


Fig. 7 - Showing how a filter connected between power line and interference creating device suppresses radiation of radio frequency energy.

FUNCTION OF FILTER COMPONENTS

Figures 7 and 8 show the operation of Filters applied to interference-creating electrical apparatus. As shown in these diagrams, the interference is impressed on the power supply line along which it may be carried for great distances and from which it may be radiated to reach the antenna of the receiver. As indicated in Figure 7 the interference, which has a high frequency, tends to flow through the condensers and back to the interference source. This is due to the fact that the impedance of the condensers, at high frequencies, is less than the impedance of the power line and as a result the relatively low interference voltage causes the interference current to flow through the condensers rather than along the power line. Thus a simple capacitive type Filter would be composed of two condensers "B-B" and a return connection "C".

It is important to note that the return connection "C" is not a ground connection. Figure 8 shows what would happen if this connection were grounded. The interference carried along the ground wire would be radiated from this wire to other wires or to the antenna of the receiver with the result that this supposed filter connection would cause an increase rather than a decrease in the interference. The same is true if the Filter is located too far from the apparatus which is causing the interference. Under these conditions a long return connection would be required and as a result interference would be radiated from this long lead as well as from the wiring between the Filter and the interference source.

To suppress this interference it is necessary to use an inductive-capacitive Filter as indicated in Figure 7. As shown in this diagram, the interference which over-rides the capacitive section of the Filter is dissipated in the inductive sections. Inductive-capacitive Filters may consist of sections A, B,B, and C or A,A,B,B, and C, the former combination being used when one side of the power line is well grounded and the latter when the service ground is more than 10 feet from the Filter.

IMPROPER WIRING CAUSES MUCH INTERFERENCE

The condition of wiring circuits in any building has considerable bearing on the results obtained from radio receiving equipment used in the building. Loose connections in wiring circuits, partial or intermittent grounds and high resistance, swinging short circuits may cause serious interference.

As has previously been explained, the voltage of the interference created by electrical apparatus is often so low that it will not

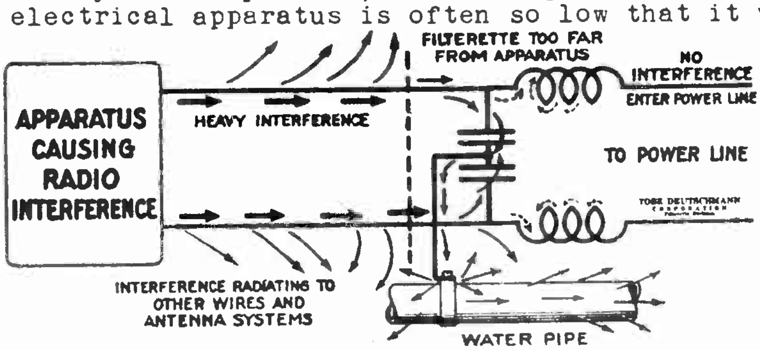


Fig. 8 - Showing the effect of connecting Filter a few feet away from the interference source.

overcome the normal R.F. impedance of the power line. In many cases however, the electrical apparatus may create radio interference at sufficient voltage to overcome the impedance of the power line. In such a case only a part of the interference will be bypassed by the condensers of a capacitive type Filter, and the remainder will be carried along the building wiring.

There are two possible ways to consider the effect of loose wiring connections. Considering the way antenna systems are commonly installed, it is obvious that building wiring is a part of the antenna system. When a short indoor antenna is used, the energy received by the receiver is the result not only of pick-up by the short antenna, but of pick-up by all of the building wiring and by every metallic object in the building. The energy thus collected may be transferred either inductively or capacitively to the short antenna actually connected to the receiver. Thus the effect of a much longer antenna is obtained.

If greater signal pickup were the only result of this coupling between the indoor antenna and the building wiring, there could be little said except in its favor. Unfortunately, the additional antenna system thus coupled to the receiver contains many potential loose connections conducive to noisy receiver operation. Every light switch, dial telephone, or home appliance containing a thermostat or commutator may cause a break in the antenna circuit. To appreciate the effect of such a break, it is necessary only to disconnect the antenna from the receiver and attach it intermittently to the antenna binding post. The resulting sound in the speaker shows very clearly the effect of loose connections in the antenna system. It is, therefore, evident when noisy reception is found and when the trouble cannot be traced to any defect in the receiver, that conditions within the building in which the receiver is operated may be responsible to a considerable extent for the noisy reception.

The first step to be taken in assuring clear reception is a careful inspection of all wiring and appliances in the building. This inspection should start at the power service entrance to the building.

The points to be covered at the service entrance are as follows:

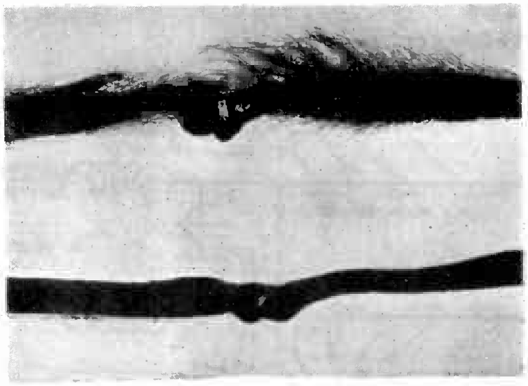


Fig. 9 - Badly worn lamp cords are fire hazards as well as sources of interference. Be sure lamps and appliances have approved cords.

1. Be sure that the service wires from the transformer to the building are not grounded to tree branches.
2. Be sure the service conduit is grounded.
3. Be sure the building wiring is grounded in accordance with the National Electric Code, and the regulations of the local power company.
4. Be sure the contacts of the service switch or switches are sufficiently firm to prevent arcing.
5. Be sure all fuses are firmly in place. This applies to branch circuits as well as mains.
6. Be sure the construction of the fuses is such that there is an uninterrupted flow of current through them. Some fuses have been found in which the connection between the link and the shell was not firm, with the result that arcing, causing radio interference, took place in the fuse.
7. Be sure that all wiring connections to branch cut-outs and mains are firmly made.
8. Be sure all lamps are screwed firmly into their sockets. Tap each lamp on the side to locate possible loose connections within the lamp. If such loose connections are found, the lamp should be discarded.
9. Examine all attachment plugs of floor or desk lamps and appliances, making sure that the prongs make firm contact with the receptacles, and that the terminal screws are holding the cord conductors firmly.
10. Examine all lamp and appliance cords, making sure that they are not worn excessively and that there are no

possible strands from one conductor making a high resistance contact with the opposite conductor.
NOTE: It is particularly important that lamp cords or other portable cords be maintained in the best possible electrical and mechanical condition as defects in such cords may create a serious fire hazard as well as considerable radio interference. Figure 9 shows a condition often found when unapproved lamp cords have been in use for long periods of time.

When all of the building wiring and home appliances have been inspected, and the necessary corrections made, a material decrease in noise level is likely to result, the reason being that many of the possible loose connections have been eliminated.

The second way of looking at this local interference problem is by consideration of the two fundamental sources of radio interference. In the final analysis, it may be shown that interference is the result of an interruption to the flow of current along a conductor, or to the discharge of potentials accumulated on a conductor. These phenomena may occur in the building in which the receiver is located and may thus be coincident with, and indistinguishable from the disturbance due to the loose antenna connections previously discussed.

In other cases, however, they will occur in neighboring buildings or at such distance from the receiver that they cannot be considered as loose antenna connections. Under these circumstances the way interference is distributed must be taken into consideration in deciding upon the best method of obtaining relief from this interference.

Interference due either to the making or breaking of an electrical circuit or to the discharge of a potential from one conductor to ground or to another conductor may be carried along any of the conductors in which the effect takes place and may be radiated from them. This radiated interference may be transferred either inductively or capacitively to other wiring circuits and the interference may thus be spread over a wide area. If any of the circuits on which this interference is traveling, enter a building in which a receiver having a short indoor antenna is located, it is then evident that the antenna system of the receiver in addition to accumulating broadcast energy, is carrying undesired electrical disturbances which are likely to interfere seriously with the reception of the desired signal.

When radiated interference is considered, the first thought is usually to provide shielding for the apparatus thus confining the radiated energy as closely as possible to its point of origin. While with some types of interference this shielding is not only theoretically advisable, but is a practical necessity, it is obviously impossible to shield all wiring on which interference may be carried. Under these circumstances, it appears to be necessary to locate the source of interference and there to take such steps as may be necessary to prevent the distribution of interference along wiring systems.

If the interference is due to the discharge of a potential from one conductor to ground or to another conductor, there are two possible methods of overcoming this interference, both of them involving the prevention of the discharge. The first is by providing suitable insulation between the two conductors and the second is by bonding them together. Two concrete examples of interference due to such a potential discharge as has just been described are as follows:

A broadcast listener found that whenever a certain hot water faucet was used radio reception was impossible. Examination disclosed the fact that a section of armored cable in the wall containing the hot water pipe feeding this faucet was not properly grounded. This cable was so located with relation to the hot water pipe that the slight vibration caused by the flow of water caused an intermittent contact between cable and pipe, allowing the discharge of a low potential from the armor of the cable to the water pipe. Grounding the cable sheath provided relief from the interference.

In another instance it was found that radio reception was out of the question when an electric refrigerator was being used. Examination of the refrigerator showed that the motor and thermostat were in

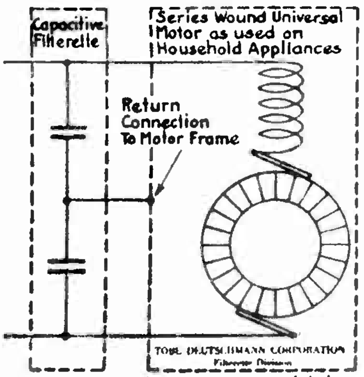


Fig.10 - Showing capacitive filter connected in motor power supply line.

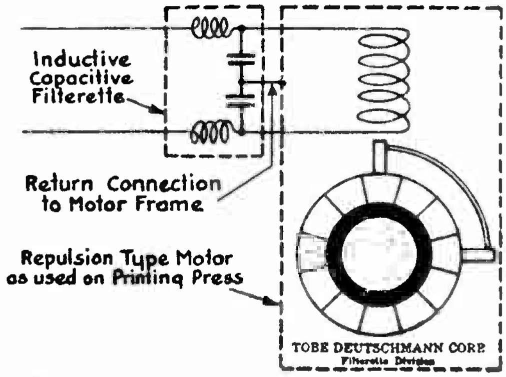


Fig.11 - Showing inductive capacitive filter connected to motor.

perfect condition, so that interference should not have been caused by this installation. In checking, it was found that the interference continued after the refrigerator had been entirely disconnected from the power line, and that this interference was noticeable as long as the compressor motor continued to rotate. Further examination of the refrigerator installation disclosed the fact that although the armored cable connected to the refrigerator was properly grounded, the refrigerator frame was not grounded. The result was that as long as the compressor motor rotated, the spring supports on which the compressor assembly was mounted allowed the mechanism to vibrate and make intermittent contact with the sheath of the armored cable. Bonding the cable to the compressor assembly removed all trace of interference.

It is, therefore, obvious that if freedom from interference is to be obtained, all metal objects likely to accumulate electrical charges should be grounded or should be so installed that there is no possibility of a potential discharge. Of the two methods, grounding is preferred. The broadcast listener or radio dealer may, by examination of the building in which the receiver is located, make sure that the potential discharges just described are not likely to occur.

There then remains the necessity for preventing the distribution of interference caused by interruptions to the flow of current along a conductor. This is accomplished by the application of suitable

Filters to the pieces of electrical apparatus in which these current interruptions occur. The application of a properly designed Filter will not only prevent the distribution of interference along the wiring to which the appliance is connected, but will also reduce, to a great extent, the loose antenna connection effect of the appliance operation.

With the exception of the electric refrigerator and the oil burner, a large majority of the household appliances in common use are operated by series wound or universal motors. Among the household appliances operated by this type of motor are the vacuum cleaner, electric egg beater, humidifier, drink mixer, and fruit juice extractor. By operating each of these appliances while the radio receiver is in use, the effect of the disturbance they create may be clearly observed. This disturbance is generally due to the two effects already described; the first that of a loose antenna connection, and the second the generating of a radio frequency impulse by the household appliance.

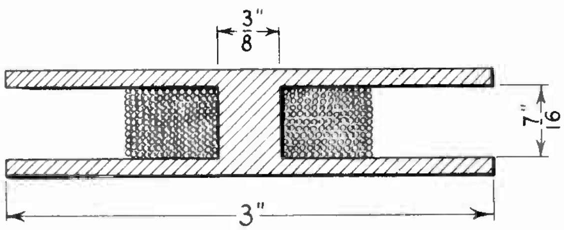


Fig. 12 - Showing details of filter inductor construction.

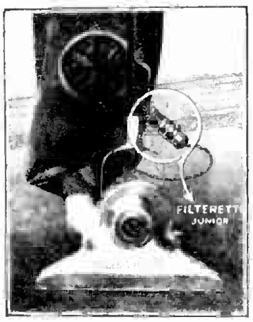


Figure 13

Fig. 13 - Application of Filterette Junior to a vacuum cleaner. Note the return wire from the Filterette binding post to the motor frame.

Figures 10 and 11 show the connection of a capacitive and an inductive capacitive filter to such commonly used sparking motor driven devices. The condenser sizes will range from .1 to 2 mfd. and the inductors will range in size from 150 to 300 turns of #18 D.C.C. (for load currents under 3 amperes) wire wound on a spool having the dimensions shown in Figure 12.

Since the radio frequency energy thus developed may be radiated from all wiring to which the appliance is connected, it is obvious that the Filter which is to prevent this disturbance from reaching the receiver must be installed as close as possible to the point at which the interference originates. In the case of a series motor, the interruptions to current flow occur at each brush. The Filter must, therefore, be connected as close as possible to the motor brushes. If the Filter is located at the end of a long attachment cord, it is evident that a considerable length of lead between interference sources and Filter may allow the radiation of much interference. This might be suppressed by shielding the attachment cord, but since this procedure would decrease the flexibility of the attachment cord as well as increasing its cost, it is not to be recommended. A more satisfactory result will be obtained if the Filter is connected in the attachment cord within a few inches of the point where this cord connects to the motor. Many appliances, particularly vacuum cleaners, are provided with a separable connector at the point where the attachment cord connects to the motor.

This renders the application of a **Filter** a simple matter. Figure 13 shows a simple capacitive Filter correctly installed at the motor of a vacuum cleaner. In order to prevent the interference from traveling beyond the Filter and being distributed along the building wiring, a return connection is provided to allow the return of the interference to the point at which it originates. In effect, the use of a Filter in connection with a household appliance provides a low impedance path for the return of the radio frequency current to the frame of the appliance, thus keeping the interference out of the building wiring. The loose antenna connection effect is largely overcome by the bypassing of high frequency currents by the Filter.

DIAGNOSING CAUSE AND APPLYING A REMEDY

We now have a definite idea of the possible sources of radio interference. The next logical step is to determine how the service man may logically determine which of the six different types of radio interference exists in a receiver and how in turn each of these may

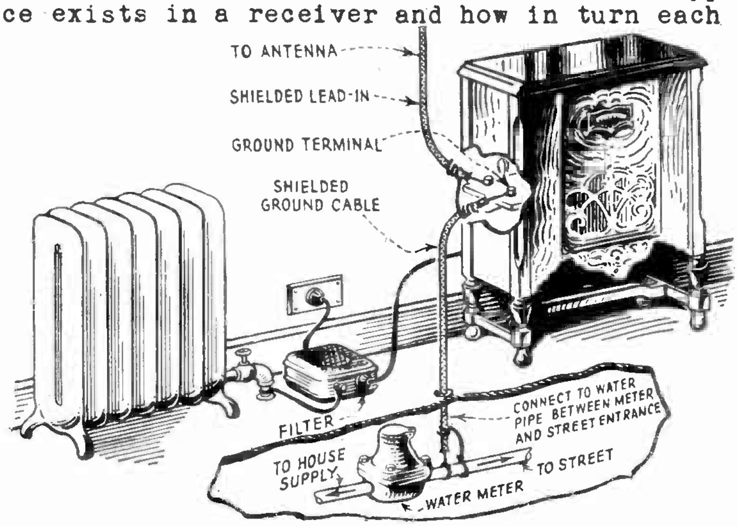
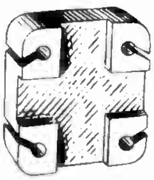


Fig.14 - Showing details of shielded antenna system installation at a receiver.

be remedied. The first two types which are really the reception of unwanted broadcast signals are usually due to lack of selectivity in the receiver. This in modern receivers can be overcome by proper alignment of the RF tuning stages and the elimination of an unwanted signal from a very nearby powerful broadcasting station can be accomplished by the use of either of the two wave trap circuits discussed in the early part of this lesson. Interference of the type listed under headings 3 and 4 cannot very well be controlled by the serviceman. However, interference originating within the receiver circuits themselves and that type originating in nearby electrical apparatus either entering the receiver via the power lines, the antenna system or the more sensitive unshielded portions of the receiver circuit can be controlled and eliminated by the serviceman who must, however, first determine in which of these three ways the interfering signal is entering the receiver. This is, however, not always so simple to accomplish. A successful method of properly diagnosing this condition is here outlined.

To determine whether the interference is entering the receiver through the antenna system remove the antenna and ground wire. Take a small piece of wire or a nail preferably and connect the antenna and ground posts with it. It is important that if wire is used that the wire be no longer than is necessary to make the connection between the antenna and ground posts. Turn the volume control "full on". The antenna system has now been removed and any noises you still hear are due either to radio interference coming in over the electric light line or second, to a defective part in the receiver circuit or third, the interfering voltage is being induced in some sensitive portion of the receiving circuit. This third condition means that there is a strong interfering field in the immediate vicinity of the receiver. Most modern receivers are sufficiently shielded to prevent interstage coupling. However many of the more modern very sensitive receivers are not so completely shielded as to prevent a strong interfering field in their immediate vicinity from inducing an interfering voltage in their circuits, the proof of this is the fact that many of them will pick up local signals without any connection to their antennae and ground binding posts. A method by which such local pickup may be stopped is to place the entire receiving circuit assembly in a completely enclosed shield with no other openings than those required for tuning controls, antenna and ground connections and power supply. Such a metal shield usually is quite costly to construct. Another quite inexpensive and very satisfactory method is to line the inside of the receiver cabinet with copper screening, insulating the entire receiving chassis from the screening. This includes the building of what is equivalent to a screen door for the back of the receiver cabinet which should be securely fastened to the back of the receiver cabinet in such a manner that the wire mesh on the door frame makes good contact (with no opening) to the wire mesh lining the inside of the cabinet. The only opening that should be left in this complete shield should be the opening required for the power supply cable and the antenna and ground wires, and the tuning controls.



Detail

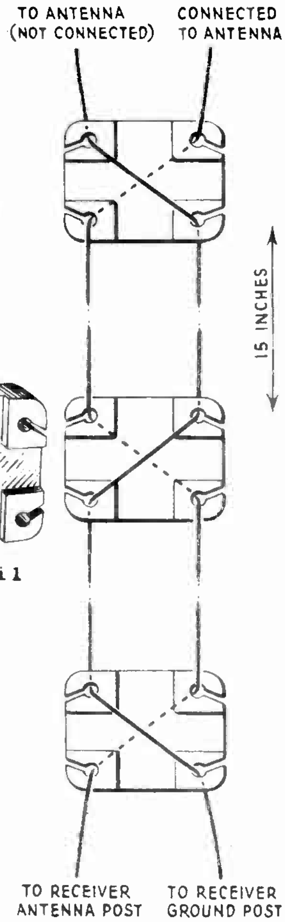


Fig. 15 - Transposed lead-in.

With the receiver thus shielded it is impossible for any local field about the receiver to induce interfering voltages in the vacuum tube circuits themselves. The shielding of the entire receiver as just described should only be attempted after the entire receiver circuit has been checked for possible sources of interference due to any of the conditions described under "Noise Originating in the Receiver", nor should the receiver be so shielded until a filter has been placed between the receiver power input and the power supply line. Thus, if the receiver has been checked for possible noises originating within its own circuit and the power line has been checked by the insertion of the proper filter for noises entering the receiver input, or tuned RF circuits, by means of induction from the field existing about the power line, and the noise or interference still persists, the complete shielding as outlined should be applied. All these tests should be made with the antenna and ground posts shorted.

Should the receiver be quiet when the antenna and ground posts are shorted this indicates that the interference is entering the receiver via the antenna and ground systems.

INSTALLATION OF NON-INTERFERENCE LEAD-IN AND GROUND

The next step in the reduction of the noise level is to decrease the coupling of the interfering field with the lead-in and ground system. Man-made static is generated close to the ground and remains close to the ground, except when it is carried, reflected, or reradiated by wiring, structures, etc., whereas the field of desirable broadcast signals is practically as strong or stronger at considerable distances above the ground. Numerous tests have shown that radio interfering fields seldom extend more than forty or fifty feet from

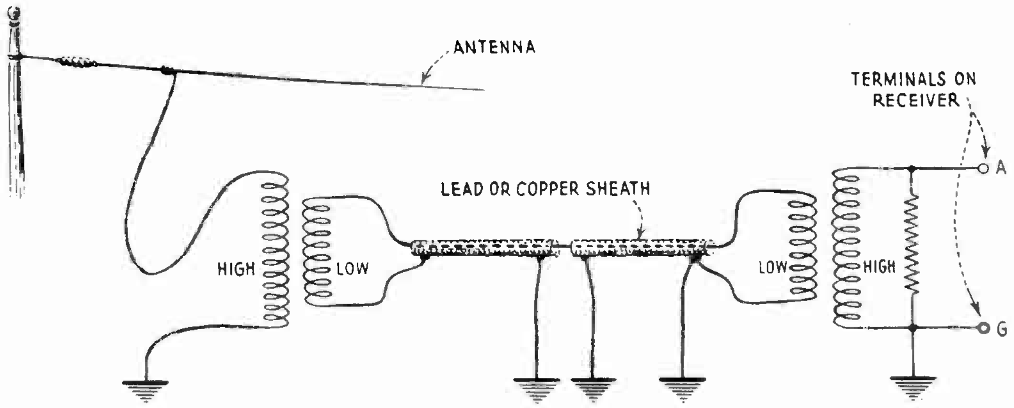


Fig. 16 - Schematic equivalent of the transmission line type of antenna system.

the conductor on which they may be carried. It may then be concluded that most of the man-made noise heard in a receiver are picked up by the aerial lead-in, or by those portions of the aerial ground system which are close to grounded objects, pipes, power supply and telephone lines, roofs, walls, etc., which conduct or reradiate undesirable high-frequency electrical or electrostatic noises.

The problem then resolves itself into one of:

1. Locating the horizontal pickup portion of the antennae out of the noise level.
2. Eliminating or greatly minimizing the pickup of the lead-in and ground conductor which must pass through the noise field to the radio receiver.

The location of a well constructed horizontal portion may be accomplished by following these rules:

1. Install as high as possible.
2. Install a horizontal portion of at least 100 feet to 150 feet long.
3. Install as nearly at right angles to other wires as practicable.
4. Install so that a clearance of at least 5 to 10 feet preferably 20 feet from all surrounding objects exists.

5. Use good strain insulators and allow a distance of at least 5 feet between point of support and the insulator.
6. Solder all joints with Resin-core solder only.

The construction of the antennae lead-in and the ground wire so as to decrease their interference pickup may be accomplished in one of three ways:

1. The installation of a shielded conductor for both lead-in and ground wires.
2. The installation of a transposed pair of conductors to serve as antennae and ground wires.
3. (a) The installation of a step-down transformer at the antennae end of the lead-in and (b) a step-up

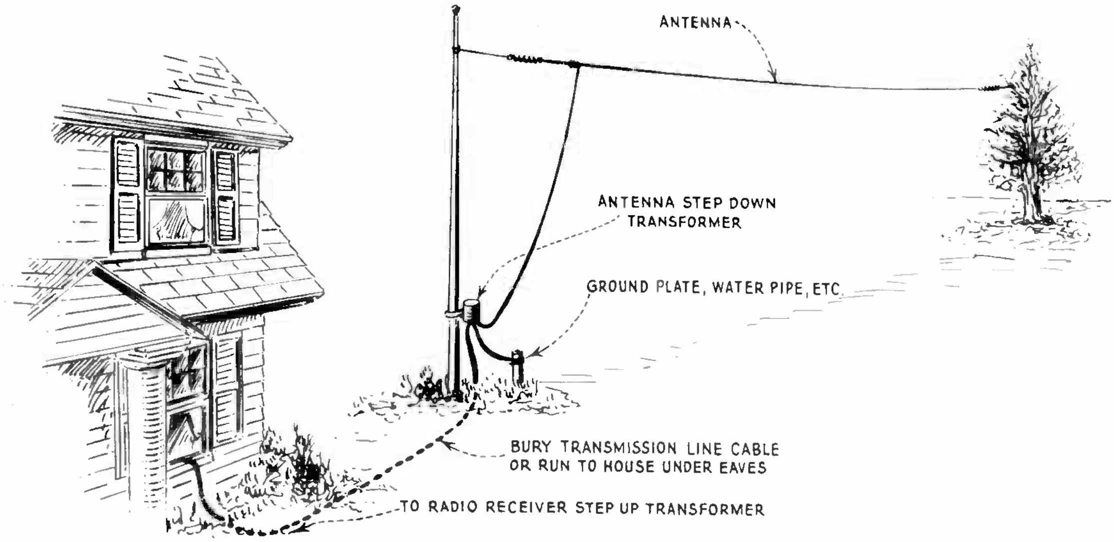


Fig. 17 - Showing the details of the construction of a transmission line antenna.

transformer (of the same turns ratio as the 1st) at the receiver end of the lead-in. The secondary of the first and the primary of the second R.F. transformer to be coupled by means of a pair of conductors either transposed or shielded (in lead or copper sheath). This is known as the R.F. transmission line method.

The details of the construction of these three types of noise reducing lead-in ground systems are shown in diagrams of Figures 14, 15, 16, 17, 18 and 20 respectively. It is important that no window lead-in strips be used with either of these three systems. Where shielded lead-in wire is used, the shielding should be unbroken from the horizontal antennae to receiver antennae post, and should also be unbroken from ground binding post to the ground connection. In shielded systems there is considerable loss of signal to ground between the shield and the wire inside of the shield. This can be remedied by using a shielded lead-in wire, in which the insulating material between wire and shield is very thick. The thicker this insulation or dielectric is, the smaller will be the capacity between shield and inside conductor.

Where a transposed or twisted pair is used the same condition holds true, but not to as great an extent due to the decreased capacity between the two conductors as compared to a single shielded conductor (Figure 19). Even the normal capacity between a pair of #14 twisted lighting conductors can be decreased by transposing them with the aid of separating insulators which are available on the market; thus twisting or transposing the wires, but keeping them separated by means of the special transposing insulators as shown in Figure 15.

STOPPING INTERFERENCE AT ITS SOURCE

In our consideration of the interference problem thus far, we have considered the causes and possible sources of radio interference.

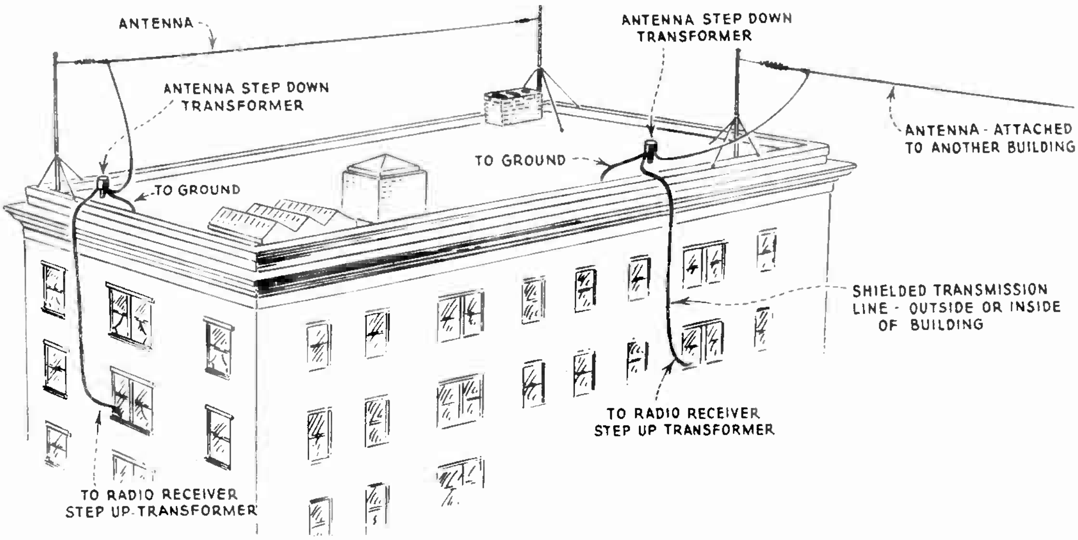


Fig. 18 - Showing the details of construction of a transmission line antenna system for apartment houses.

We have also studied in detail just how the interference enters the receiver and the methods that may be used to keep the interfering field from inducing voltages in its more sensitive circuits.

These methods are the ones which will produce the quickest remedy at the lowest possible cost to the receiver owner. There is however another method in which the problem may be solved and that is by suppressing the interference at its source. This method requires that suitable filters be placed in the power line supplying the interfering device. This will require one of the various types of filters previously described.

These filters should be installed as close to the apparatus generating the interfering signal as possible, and should preferably be mounted directly on it. The coils should be so constructed so that there is no possibility of a breakdown in their insulation to ground at normal operating voltages. Any condensers used should have an operating voltage rating at least twice that of the line voltage on which used.

Fuses should be connected in series with the line and the filter. This is necessary in order to avoid possible overloading of the line should the condenser connected across it break down. See F1 Figure 21.

An additional precaution that is frequently advised is that fuses not larger than 5 amperes be connected in series with the condensers connected across the line. These are indicated as F_2 in Figure 21.

The coils should be wound of wire sufficiently large in order that the I^2R loss in them be low enough to prevent any appreciable rise in their temperature when in continuous use.

The entire filter assembly should be mounted in a metal box with suitable provision made for the connection between power line wiring and the device to be filtered. Filters designed for use on apparatus normally connected to the power line by means of a cord and plug should have a plug receptacle on the output side and a cord and standard plug on the input side. Those designed for use on apparatus having connections to the power line in conduit (piping) or flexible metal sheathed cable should have punched holes in the sides of the box in which the filters are mounted, in order that the cable or conduit may be fastened to the box by standard connectors. Standard knock-out boxes, such as are used in electrical lighting and power wiring systems are suitable for this use. In general filters should be so constructed that they will meet the requirements of the National Board of Fire Underwriters Laboratories and those of the Local Electrical Ordinances.

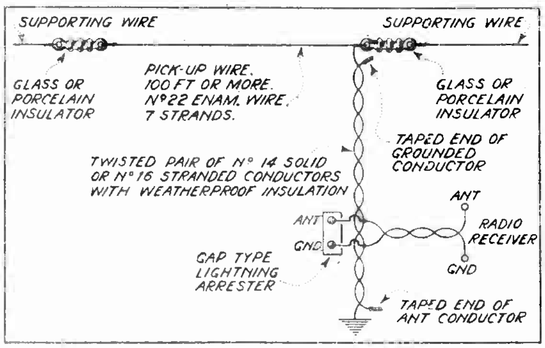


Fig. 19 - Details of the Transposition Aerial installation.

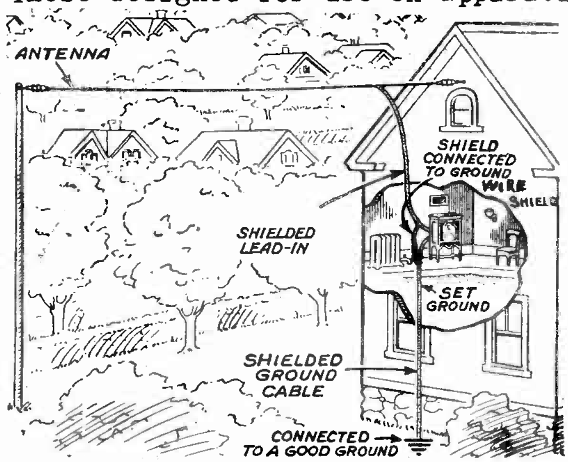


Fig. 20 - Typical antenna installation with shielded lead-in and ground cable.

DETERMINING THE TYPE OF FILTER REQUIRED

Since the intensity and frequency of the interfering signal at its source varies between very wide limits, it is a hopeless task to attempt to design one filter suitable for all purposes. Interference engineers have long realized this as one of their major problems, and in order to simplify the selection of a suitable filter the Tobe-Deutschmann Co. of Canton, Mass., (the largest manufacturer of interference eliminating apparatus and to whom we are indebted for much of the material in this lesson) have designed a Filter Analyzer the operation and application of which is described in the text that follows.

Statistics indicate that more than half of all interference arises in the home. It therefore, behooves every broadcast listener to clear interference from his own home in order that appeals to others in behalf of improved radio reception may be given the attention they deserve. To determine the correct Filterette for application to every household appliance the Filterette Analyzer should be used.

HOW TO USE THE FILTERETTE ANALYZER

The Filterette Analyzer is an electrical instrument designed for use by Authorized Filterette Service Stations. Its purpose is to enable the interference engineer to analyze the interference being created by any electrical appliance connected to the power supply lines by means of an attachment cord and plug. By using the Filterette Analyzer you can determine which of the three plug-in type Filterettes will be required for application to the interfering appliance. The use of the Filterette Analyzer enables you to prescribe the correct Filterette without following the cut and try method of applying Filterettes of various types until the desired interference reduction is obtained.

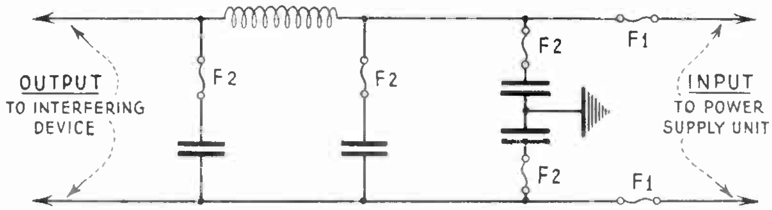


Fig.21 - Showing location of fuses in filter as safety precaution.

Fig.22 -Filterette Jr.

In order to understand the operation of the Filterette Analyzer it is necessary that you be familiar with the three most commonly used Filterettes: The Filterette Junior, Filterette Senior and Filterette No. 110-PO. These three Filterettes have been named in the order of their effectiveness. Filterette Junior, shown in Figure 22 is the simplest type of Filterette, consisting of a single capacitive Filterette section contained in a bakelite housing and provided with attachment prongs and a receptacle to facilitate connection of the Filterette to the interfering appliance. The Filterette is provided with a binding post from which a short wire must be connected to the metal frame of the interfering appliance to complete the Filterette installation. The Filterette Junior is suitable for application to most vacuum cleaners, drink mixers, barbers' clippers and other electrical appliances driven by small universal motors.

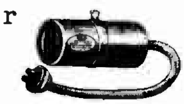


Fig.23 -Filterette Sr.

For application to appliances which create a more intense interference than may be suppressed by use of the Filterette Junior, Filterette Senior is required. This Filterette, shown in Figure 23 consists of the capacitive section used in Filterette Junior plus one inductive section connected in series with one side of the line. Filterette Senior is contained in a cylindrical metal housing and is provided with a receptacle and a short attachment cord and plug to facilitate the connection of the Filterette to the interfering appliance. This Filterette also is provided with a binding post from which a short return connection must be made to the frame of the interfering appliance. This Filterette is designed primarily for application to electrical appliances supplied from a wiring system having one side grounded in accordance with modern wiring practice.

It is usually most effective when the inductive section is in the "hot" side of the line

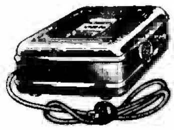


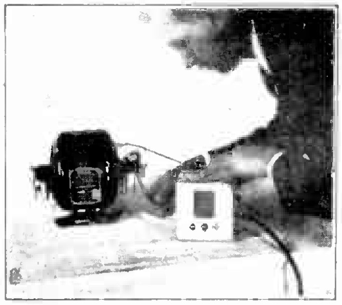
Fig. 24 - Filterette 110-PO.

Filterette No. 110-PO, shown in Figure 24 is designed for applications similar to those requiring the Filterette Senior, when the apparatus creating the interference is supplied from an ungrounded line or is located so far from the point at which the wiring circuit is grounded that the ground is not effective as far as interference is concerned. Filterette No. 110-PO contains a somewhat larger capacitive section than is contained in the Filterette Junior and also has an inductive section in each side of the line. See Figure 11. This Filterette also is provided with an attachment cord and plug and a binding post for connection of the return wire.

It is not always possible to tell simply by looking at the appliance, or by hearing the interference which it creates, just which type of Filterette will be required to provide maximum reduction of interference. Consequently, the Filterette Analyzer must be used. This instrument shown in Figure 25, consists of groupings of the fundamental Filterette circuits contained in the three Filterettes which have just been described. By manipulation the effectiveness of each type of Filterette may quickly be determined, and the correct Filterette may be applied to the interfering apparatus.

Fig. 25 - Tobe Filterette Analyzer. Switch setting shown indicates Filterette Junior.

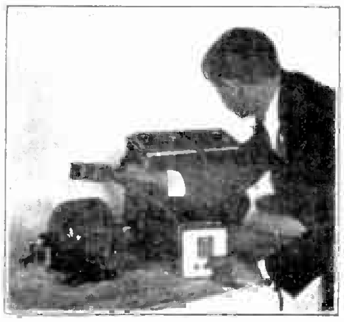
The use of the Filterette Analyzer is indicated in Figure 26 and as will be seen from these photographs, the attachment plug of the interfering appliance is inserted in the receptacle of the Analyzer. When making the test, the attachment cord of the appliance must be coiled into the smallest possible space in order that there may be no radiation of interference from the attachment cord. A short wire, preferably not more than 6" long is then connected from the binding post on the side of the Analyzer to a clean part of the metal frame of the interfering appliance. This connection should preferably be made



Method of Connecting a Dental Laboratory Motor for Filterette Analysis. Note Return Wire to Motor Frame

Figure 26.

A Tobe Interference Locator gives an Accurate Comparison of the Effectiveness of Various Types of Filterettes



to the frame of the motor which is used for operating the appliance. The attachment plug of the Filterette Analyzer is now inserted in the power receptacle to which the appliance was originally connected.

You are now ready to analyze the interference, and to determine the Filterette required for suppressing it. The positions of the three analyzer switches for obtaining standard Filterette combinations are indicated on the name plate of the Analyzer. In using this instrument it is advisable to start with the simplest type of Filterette and gradually to progress to the more effective types. For this reason it is recommended that, before the Analyzer is connected to the power supply line, the switches be set in the Junior position ↑ ↑ ↓. The appliance may then be set in operation and the amount of interference present may be determined.

If, with the Analyzer switches in the Junior position, the appliance may be operated without objectionable interference, it is not necessary to proceed further with the analysis. A Filterette Junior may be applied to the apparatus at once. If, with the Analyzer switches in the Junior position, some interference remains, the switches may then be set in the Senior position, and the result noted.

In analyzing interference to determine whether the Filterette Senior may be used, there are two possible settings for the instrument. The first setting is as indicated on the name plate of the instrument ↓ ↑ ↓ The second position, which is not shown on the name plate, is simply a reversal of the two left-hand switches ↑ ↓ ↓. Reversing these switches transfers the inductance of the Filterette Senior from one side of the line to the other side, thus accomplishing the same thing as would be accomplished if the attachment plug of the Analyzer were reversed in the power receptacle. It is always advisable to try both possible Senior settings because in a great many cases the Filterette Senior will be highly effective when its attachment plug is inserted in the power receptacle in one position, and it may be relatively ineffective when the attachment plug is reversed in the power receptacle. If either Senior setting of the Analyzer provides satisfactory interference reduction, a Filterette Senior may be applied to the interfering apparatus. In applying the Senior it may be necessary to reverse its attachment plug in order that the inductance may be located in the correct side of the line to be most effective.

If neither of the Senior settings of the Analyzer provides the desired reduction of interference. The Analyzer switches should then be set in the No. 110-PO position ↓ ↓ ↑ and the effect noted. In practically all cases, this setting of the Analyzer will provide satisfactory reduction of the interference. If it fails to do so, the indication is that interference is being radiated from wiring of the appliance or from the attachment cord. In order to overcome this interference it is necessary to shorten the attachment cord so that there will be no effective length remaining for interference radiation. When this is done, satisfactory results should be obtained.

The Filterette Analyzer is designed for test purposes only and must not be placed on continuous duty.

EXAMINATION QUESTIONS

1. What is meant by the term "man-made static"?

2. Under what condition would you use a wave trap on a receiver?

3. Name some of the causes of static interference.

4. Why are some receiving circuits more selective than others?

5. How is the interfering signal from radio interfering electrical devices transmitted?

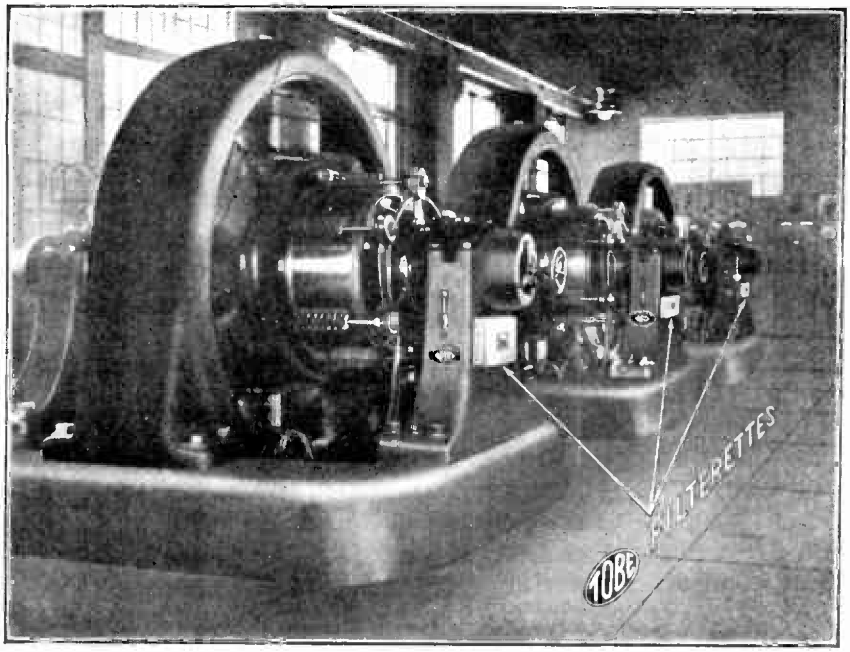
6. How does man-made static enter the receiving circuits?

7. How would you determine whether noise in the receiver originated in the receiver's own circuits, or entered the receiver via the antenna system, or via induction in the sensitive unshielded circuits of the receiver?

8. How would you install a receiver in a location in which man-made static made reception noisy?

9. How would you install an antenna in order to avoid interference signal pickup in the lead-in and horizontal portion?

10. How would you prevent interference created by an electrically operated device from being radiated or transmitted? That is, how would you confine it to the device itself?



Street railway converters filterized by application of Filterette No. 60. The converters shown are 500 K.W. machines.

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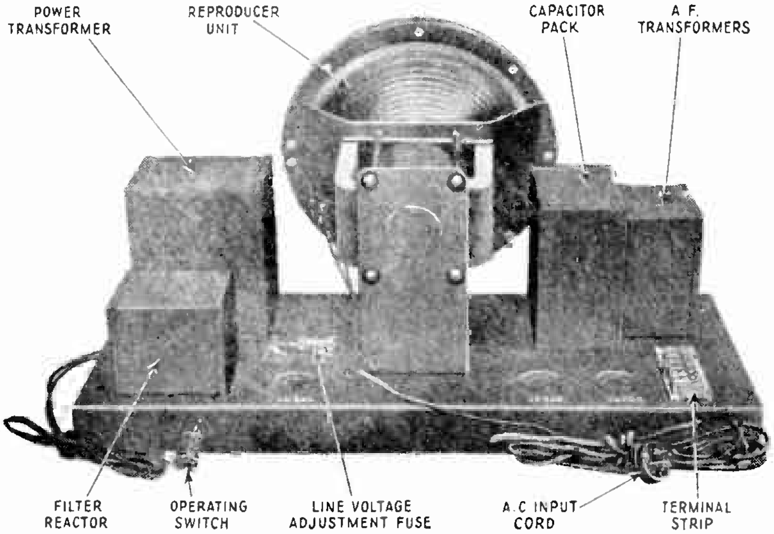
Low and High Voltage Rectifiers and Power Supply Units

VOL. 36, NO. 6

Dewey Classification R360



Rectifier, power-amplifier and speaker assembly of a modern super-heterodyne receiver, showing main units of rectifier and filter system.

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RCA INSTITUTES INC.

LOW AND HIGH VOLTAGE RECTIFIERS AND POWER SUPPLY UNITS

Circuits in which vacuum tubes are used as R.F. or A.F. amplifiers, oscillators, or detectors require a very constant D.C. voltage supply to maintain the grids and plates positive or negative with respect to the Electron Emitting Element, and to supply power to these elements when required. Such a source of supply can only be obtained directly from batteries of primary or secondary cells, whereas commercially, alternating current is almost universally in use and much more economical than the use of cells.

Alternating current, as you know, derives its name from the fact that its polarity reverses a definite number of times each second.

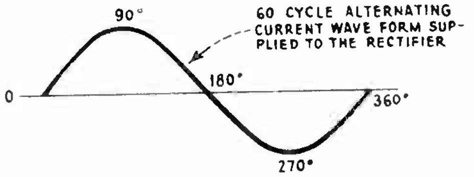


Figure 1.

These reversals are called alternations and two such alternations as referred to are one cycle. Whenever you hear the expression "110 volts 60-cycle system" you will know it means that the power in the electrical system has an electrical pressure, i.e., potential of 110 volts, and it alternately becomes positive and negative 60 times in each second, which means that the current reverses its direction 120 times per second.

Power of this type could not be directly applied to vacuum tube circuits designed for D.C. operation because of a steady 60-cycle hum which would be heard in the audible output, caused by the constantly changing value of current as shown in Figure 1, and because the available voltage might not be that required for proper operation of the circuits.

For this reason special power supply units are required which are usually composed of the following parts:

1. A device for transforming the A.C. supply into alternating currents at different voltages is required. This device is the transformer and is composed of two or more windings on a laminated steel core. It has no moving parts, and operates at a relatively high efficiency.

2. A rectifying device is incorporated in the power unit, the function of which is to change the form of the current in such a way that it does not reverse its direction each 1/120th of a second, but leaves the rectifier in the form of a uni-directional pulsating current as shown in Figure 2.

There are several types of rectifiers available such as the (1) Hot Cathode Vacuum Tube, (2) Gaseous Conductor Tube, (3) Hot Cathode Gaseous Tube, (4) Hot Cathode Mercury Vapor Tube, (5) Dry Metallic Disc Rectifiers, (6) Vibrating Mechanical Type, the operation of each of which will be covered in this lesson.

The current in the form indicated in Figure 2 is still unfitted for use because of the rapid changes in each pulse of current. It is, therefore, necessary to use:

3. A filter which is a device for smoothing out the pulsating D.C. into a steady or continuous direct current as shown in Figure 3. This almost invariably consists of combinations of inductors (choke coils) and condensers.

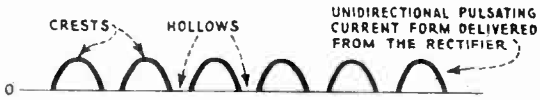


Figure 2.

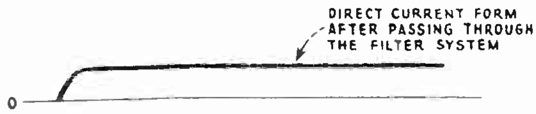


Figure 3.

4. Finally, a means for obtaining the various D.C. voltages required for the operation of the vacuum tube circuits is necessary. This is usually a resistor which is tapped at various points, and this functions as a multiple potentiometer to furnish the various D.C. voltages required by the various tubes and tube elements which the unit is to energize. This unit is called a voltage dividing system.

A power unit as described, if properly designed, will furnish a steady unfluctuating current without any objectionable hum.

To be able to thoroughly understand the operation of a power unit of this kind it is best to divide the entire unit into the four main parts just outlined, and study each part separately by following the schematic diagrams of Figures 4 and 5.

THE TRANSFORMER

The first part of every alternating current operated rectifying power unit is the power transformer. The secondary winding of the transformers have the proper number of turns to supply to the rectifying device the proper voltages required for its operation, and are wound of sufficiently large wire to be able to supply the maximum power to the rectifier that may be demanded by the circuits which the power unit is to operate (with a minimum of voltage drop and heating in the secondary windings) under load. These transformers are almost invariably of the shell core type. The primary and secondary windings are wound one over the other on the center leg of the laminated steel core with suitable insulation between windings and core, and between one winding and another.

RECTIFIER TUBES

As previously stated, there are four general types of rectifying tubes.

1. One employing filament in a vacuum, often called the Hot Cathode vaccum type.

2. One employing no filament which is known as the gaseous conductor type.

3. The third employing a filament sealed in mercury vapor, known as Hot Cathode Mercury Vapor type.

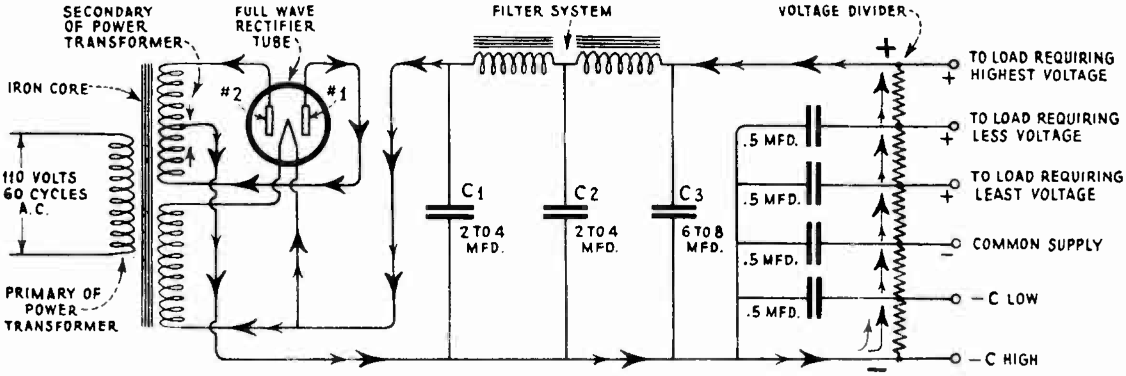


Figure 4.

4. The fourth employing a filament sealed in a gas instead of a vacuum as in the first type and known as the hot cathode gaseous type.

Before going further, we should understand the meaning of the words cathode and anode. Cathode means negative electrode; anode a posi-

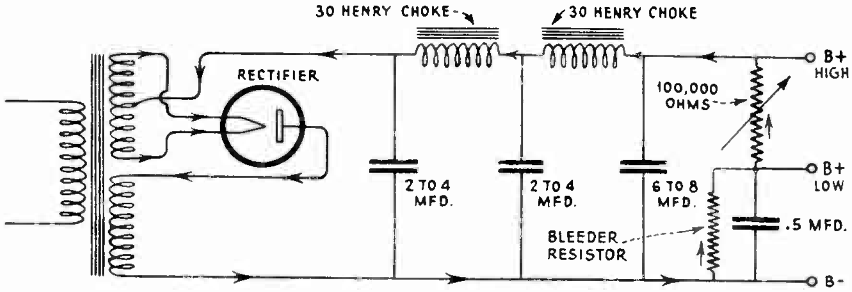


Figure 5.

tive electrode. Both of these words are frequently used in radio literature when referring to positive and negatively charged bodies; for example, cathode refers to the filament of a vacuum tube to distinguish it from the plate or anode. When discussing the gaseous conductor rectifier, Anode is the name given to the two small electrodes, while cathode applies to the single large electrode. Let us now study how each of these tubes act in operation and how they accomplish the process of rectification.

Hot Cathode Vacuum Type Rectifier tube functions as a rectifier due to the property of the heated filament to emit; that is, throw off electrons which move in one general direction, toward the plate and are attracted by the plate when the plate is charged positively, but when the plate is negatively charged it prevents the electrons emitted by the filament (cathode) from reaching it by repelling them. The two plates in the full wave rectifier tube, Figure 4, are connected to opposite ends of the secondary winding of the power transformer and have alternately impressed on them a positive and negative charge by the alternating voltage cycle; that is, during the time that one of the plates is charged positively by the voltage across the transformer secondary terminals (during one half of the A.C. cycle), the other plate will be charged negatively.

A reversal of this action takes place on the next half cycle. The arrows in the Figure 4 indicate the current flow through the rectifier during one complete cycle. The heavy arrows indicating the current flow through the rectifier and its associated apparatus when plate 1 is charged positive and the light arrows indicating the current flow when plate 2 is charged positive.

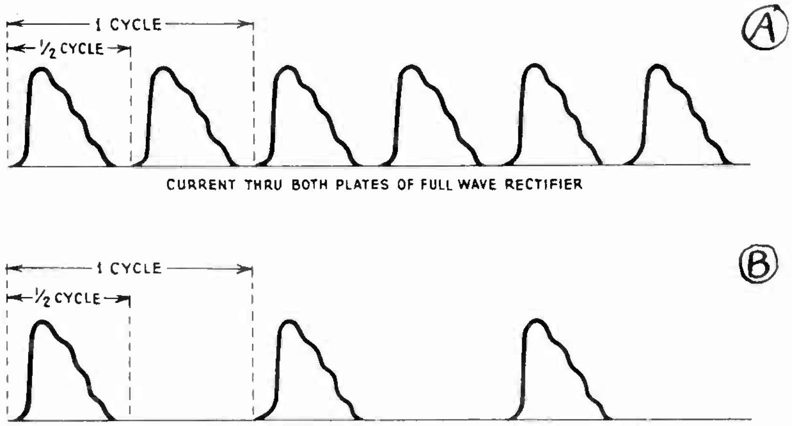


Figure 6-A-B

During each cycle one of the plates is positive for one alternation and this same plate becomes negative the next alternation; this action reverses each alternation and the plate which was positive during the first alternation now becomes negative and the previously negative plate becomes positive. The electrons emitted from the filament (cathode) pass to the positively charged plate (anode) and are repelled by the negatively charged plate. In this way both halves of the cycle of alternating current are utilized to produce a uni-directional current in the output circuit of the rectifier.

This pulsating current is shown in graph form in Figure 6a. Such a pulsating current is said to be a pulsating current resulting from full wave rectification. Each succeeding pulsation representing the current through plate 1 and plate 2 alternately.

A half wave rectifier operates upon the same principle as described for full wave rectification with the exception that only ½ of the cycle is utilized. Figure 5 shows the connection for this type of filament emitting - Hot cathode vacuum tube; the arrows indicate the direction of the current flow through the transformer, rectifier, filter and voltage divider during that half of each A.C. cycle when the plate is charged positively. During the other half of each cycle the plate is charged negatively and consequently no current flows.

Thus only one half of each A.C. cycle is utilized. The output current of a half wave rectifier to the filter is shown in Figure 6b, and you will note that current only flows during that time representing the ½ cycle when the plate was charged positively.

The commercial form of full wave rectifier just described is the UX280 type tube. This tube is rated as follows:

Filament voltage	5 volts
Filament current	2 amperes
Max. A.C. Volts per plate	400 volts R.M.S.
Max. D.C. output current	110 ma.
Max. A.C. peak inverse Voltage Plate to Plate	1550 volts (approx.)
Max. D.C. peak inverse Voltage Plate to Fil.	770 volts

The commercial form of half wave rectifier is the UX281 type tube. This tube is rated as follows:

Filament voltage	7.5 volts
Filament current	1.25 amperes
Max. D.C. output current	85 ma.
Max. A.C. Volts per plate	700 volts R.M.S.
Max. D.C. peak inverse Voltage - Plate to Fil.	1000 volts

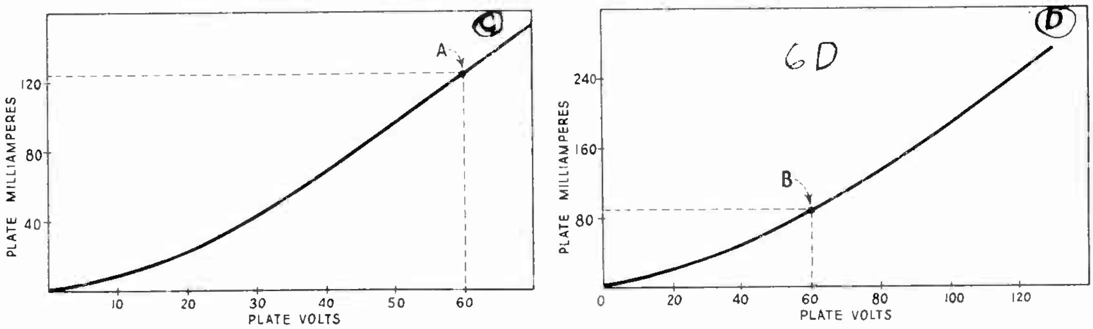
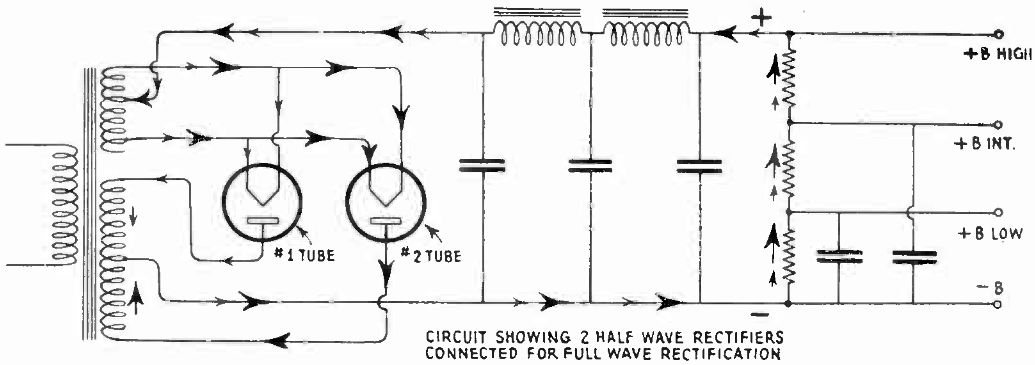


Figure 6-C-D

With the maximum rated load currents shown above, both the half and full-wave tubes have a drop in voltage within the tube from Plate to filament of 60 volts. This rises rapidly as the load current is increased and drops as the load current is decreased as shown in Figures 6c and d respectively, at points A and B.

For output voltages greater than 300 volts and where the load current does not exceed 85 ma., the half-wave rectifier as shown in Figure 5 is used instead of the UX280. However, when more than 85 ma. output current is required at voltages above 300 volts - two such UX281 tubes are used as a full wave rectifier as shown in Figure 7, and when so operated a total of 170 ma. can be obtained at the maximum output voltage with no more than 60 volts drop in the rectifier tube. The arrows in Figure 7 show the direction of the current flow through the two tubes during the alternate half cycles. Since the plates of tube #1 and 2 are connected to opposite ends of the power transformer, the plate of tube #1 will be charged positively, and the plate of tube #2 charged negatively during one half cycle and during the next half cycle the charge on the plates of the tubes will be reversed. The light arrows show the current flow through tube #1 and the associated circuits during one-half cycle when its plate is positive. The heavy arrows show the current flow through tube #2 during the alternate half cycle when its plate is positive.

Maximum Peak Inverse Voltage is a term which should be thoroughly understood. Maximum peak inverse voltage is the highest peak voltage that a rectifier tube can safely stand in the direction opposite to that in which it is designed to pass current. It is a measure of the insulation or voltage break down of the tube when the plate is negative. In other words, it is that voltage which if exceeded would cause a break down of the insulating properties of the vacuous space between plate and filament when the plate is negative which would result in a reverse current flow through the tube destroying its properties as a rectifier. Assuming a sine wave shape, the peak inverse voltage on the given tube is approximately 1.4 times the R.M.S. voltage applied to the tube.



CIRCUIT SHOWING 2 HALF WAVE RECTIFIERS CONNECTED FOR FULL WAVE RECTIFICATION

Figure 7.

Filter System: Having a rectified current now to deal with, but pulsating in form, refer to Figure 2. We will direct our attention to the third part of the power supply unit whose function is to take the "humps" out of the pulsating uni-directional current and change it to a smooth direct current. The third part of the Rectifying Power Unit shown in Figures 4 and 5 is seen to consist of choke coils and condensers.

The filter system, as shown is practically universal in use and is known as the "brute force filter". Figure 8 shows one adaption of this filter, known as the single filter, while Figure 9A illustrates the double type which is simply two choke coils in series, and an additional condenser.

Practically all filter systems are built up according to the latter classification. The value of the choke coil is in practically all cases 15 to 30 henrys while the values of the condensers may vary depending upon the type of Power Unit used. C1 can be any value from 2 to 4 mfd. capacity; C2 the same as C1, and C3 from 6 to 8 mfd. capacity.

Let us study the function of the filter system to learn the purpose of each part. It has been previously stated that the rectifying device changes the alternating current to a uni-directional pulsating current which is still in such form that it cannot be applied directly to the tube elements to be operated. If we refer to Figure 6a we find that this pulsating current consists of a number of pulses of current rising from zero value to a maximum strength and then falling again to zero, then a short interval of time elapses before the next pulse of current comes along. These pulses of current, as they come from the rectifier tube, are as varied in magnitude as the varying magnitude of the A.C. producing them. It, therefore, can be realized that a current having such variable characteristics cannot be directly applied to the plates of vacuum tubes without producing an effect which is called "ripple" or "hum".

We know that the plate of the vacuum tube must have a source of constant potential applied to it, such as would be obtained from a battery. The entire filter system, then, is designed to give us a source of potential just as closely paralleling that which would be obtained from a battery as can be had, and in order to have that form of energy from a widely varying pulsating current our filter system must perform certain functions.

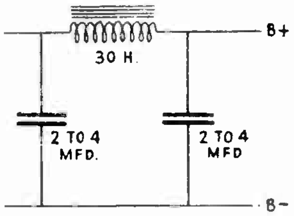


Figure 8.

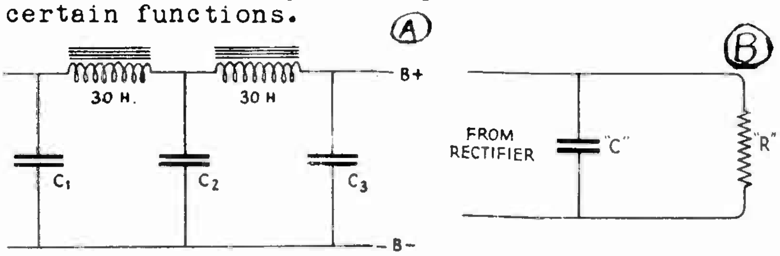


Figure 9A-B

Let us now insert between the voltage divider and tube output of Figures 4 and 5, a single condenser and see how it would function. This is shown in Figure 9b where for the sake of brevity the transformer and tube have been omitted. The voltage across the resistor "R" as we know depends upon the current flow through it. If the current through the resistor were constant the voltage across the resistor would be of constant amplitude. However, the current through "R" pulsates as shown in Figures 6a and 6b, and, therefore, the voltage across "R" will pulsate. If we now connect the condenser "C" across "R" as shown, every time the current tends to increase through "R" and the voltage drop across it increases, some of the current will flow into the condenser instead of through "R" and this prevents the voltage from rising to as high a value across "R".

This diversion of some of the peak current into the condenser "C" tends to keep the voltage across "R" and the current through "R" from rising. When the current decreases through "R" the voltage across "R" decreases too, and becomes lower than the potential across "C" whereupon the condenser discharges through "R", thus raising the voltage across it by increasing the current through it. The variations in voltage across "R" and the current through it, can, therefore, be maintained more nearly constant. The larger the capacity of "C", the steadier will be the voltage across, and current through "R". However, in practice, "C" would have to be extremely large to reduce the variation or ripple to the degree which would make the voltage across "R" as constant as battery voltage, or even suitable for use on vacuum tube plates or grids. Hence, another device known as a choke coil, retard coil, or inductor is incorporated in the filter unit.

The choke coil is placed in series with the load as shown in Figure 8 and finally a condenser is placed across the load after the choke coil.

The manner in which the choke coil smooths out the pulsations is as follows: The choke coil is a coil of wire, in this case wound upon an iron core. The iron increases the amount of magnetic flux set up in the core by a current flowing through the coil over that which an air or other non-magnetic core would. As long as the current flows at a steady rate through the coil, the magnetic flux set up in the case is steady also. As long as the flux is steady, no voltage is set up in the coil of wire except the normal IR drop due to the ohmic resistance of the wire.

Let's suppose now that the current tends to decrease. The flux would tend to decrease, too, since it is directly proportional to the current. When, however, the flux changes (decreases) a voltage is induced in the coil by the collapsing flux. This voltage is in the same direction as the current flow and, therefore, tends to maintain the current at its original value. Now if the current tends to increase, the flux tends to increase too and by thus changing, induces a voltage in the coil in a direction opposite to the current flow, and thus tends to prevent the current from increasing.

Thus the current sets up, through the agency of its magnetic flux a voltage opposing any change in the magnitude of the current.

The student may at this point ask how, for instance, a current can be maintained by the choke coil at practically its initial value when the impressed voltage, which is causing it to flow, decreases. In other words, from where does the energy come? The answer is, that energy has been stored in the choke coil in the form of a magnetic field. This energy originally came from the electrical source when it originally built up the current to its present value. If the potential of the source is lowered, energy is immediately extracted from the magnetic field in order to maintain the present magnitude of current. If the potential of the source increases and thus tends to make the current increase, more energy is stored in the magnetic field in the form of an increasing flux, and thus prevents the current from immediately rising to its final higher value until this energy has been completely stored.

The student has no doubt also noted how this action is exactly the same as that producing a counter voltage in the primary of a transformer. In fact, when the secondary, or secondaries, of a transformer are left open-circuited, it becomes nothing more than a choke coil.

We have seen how the choke coil helps to prevent the current from pulsating through itself and hence through the load, and thus also maintain the voltage across the load constant. The current will pulsate to a slight degree through the inductance. These small pulsations are prevented in a large measure from passing through the load by the second condenser, "C2" (Figure 9A).

If the filtering action of this first section is not sufficient a second filter may be used, as shown in Figure 9. This two-section filter is usually sufficient and is the type most commonly used, although for extremely smooth current flow a three-section filter is sometimes employed. Thus, by the use of choke coils and condensers, a steady direct current is obtained at the desired high voltage from the alternating current source.

Condenser "3" in Figure 9A, which is the last condenser at the output of the filter system in addition to serving as a reservoir to eliminate any hum voltage that may still remain after the current has passed through the second choke coil, also fills another very important function.

When a voltage at the frequency which produces the bass notes of the lower audible register or a voltage of a large magnitude is impressed upon vacuum tube grids, more plate current is necessary to faithfully reproduce such notes. This large increase in load current would cause a momentary increase in the IR drop across the filter choke coils and rectifier tube or tubes, thus causing the voltage across the rectifier output terminals to drop. When this drop in output voltage of the rectifier occurs condenser C3 functions, discharging into the line, and supplies the required energy. In order that C3 may be able to supply sufficient power to the circuit, on sudden load current increases, a large condenser is usually used as the output condenser, usually ranging in value from 4 to 8 mfd. We have then in the filter system a device which changes the widely fluctuating uni-directional pulses into smooth direct current and also stores up energy to be released into the circuit as required.

When the conventional two-section filter shown in Figure 9A is used in conjunction with a full-wave rectifier tube as in Figure 4, the rectifier tube peak plate current is considerably higher than the load current. The highest peak current that a rectifier tube of the hot cathode vacuum type can safely stand in the direction in which it is designed to pass current, is limited by the ability of the filament or cathode to emit electrons. If we attempt to cause a higher peak plate current to flow, than the filament will emit, the life of the tube is considerably shortened. In Figure 10 is shown the instantaneous value of current in a 280 type rectifier when the load current at the output of the rectifier is 125 milliamperes.

Referring to Figure 10b, you will note that current flows through the tube only after the plate voltage has attained considerable amplitude. The reason for this is that, on the previous half cycle, the input condenser "C1", Figure 4, was charged (as previously described) and is now discharging due to the lower voltage. It has not, however, discharged completely and this voltage across the condenser represents a positive charge on the filament of the rectifier tube. Since the filament has a positive charge on it, current will not flow from filament to plate, until the plate becomes more positive than the filament, or in other words, until the transformer voltage exceeds the first filter condenser voltage, as shown at point A in Figure 10a and b. Now, when current does flow through the tube not only does the 125 m.a. load current flow, but also the current required to charge the filter condenser. Thus the peak current through the tube is the sum of the load and condenser charging currents. This is shown at point B in Figure 10b. The charging of the first condenser in the filter, therefore, causes a very large current to flow through the tube for a short time, reaching a peak value of 300 milliamperes approximately. Since the average load current is only 125 milliamperes the peak current through the tube reaches a value of two and one half times the average load current. Thus the filament must be heavier and longer than would be the case if the rectified current could flow for a longer period so that the high peak could be avoided.

When the first filter condenser is omitted and the tube output feeds directly into the choke coil, a reduction in the value of the peak current is obtained. This is shown in Figure 11, which shows the instantaneous value of current through the tube as compared to transformer voltage and load current when a choke coil input type of filter is used. It will be noted that the peak current is only 140 milliamperes, or one and one-tenth times the load current. This lowering of the peak tube current is so because the tube no longer

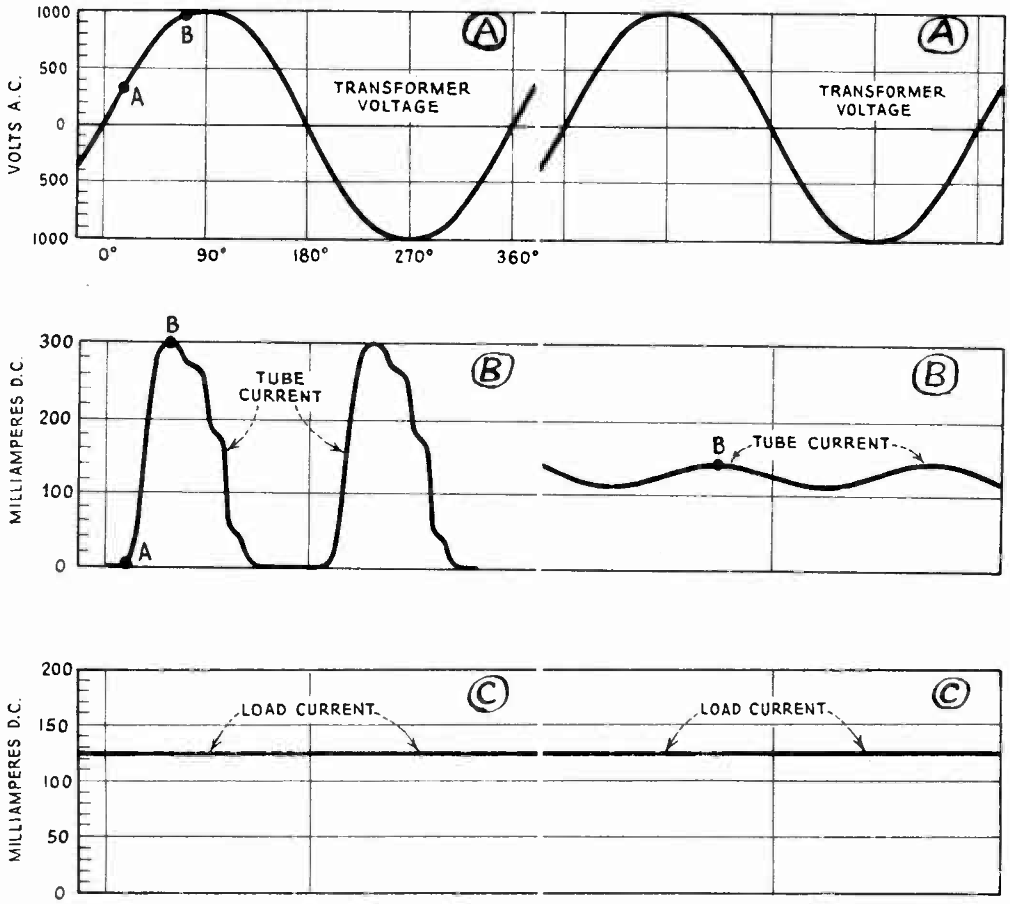


Figure 10. Figure 11.

feeds directly into a condenser, and the choke coil keeps the current flowing through one plate or the other during the entire cycle. Some voltage, however, is lost due to the opposing action of the choke coil and this lowers the tube output voltage to the filter system, as compared to the output voltage obtained when a condenser input filter system is used. Since, however, the choke coil is a reactance load, there is no loss in power. The efficiency of the two systems is the same. However, the advantage of the choke coil input lies in the fact that operating at a reduced peak current extends the life of the tube filament, and allows a lower value of emission as the tube ages, before it must be discarded. For instance, a tube having a maximum of 200 milliamperes filament emission could be used satisfactorily in the circuit represented by

Figure 11, but not in that of Figure 10. The disadvantage of the choke input system lies in the fact that the ripple voltage will be higher than with a condenser input. Hence, the condenser normally used across the input circuit should be added across the output circuit; that is, parallel to "C3" in Figure 4. Another

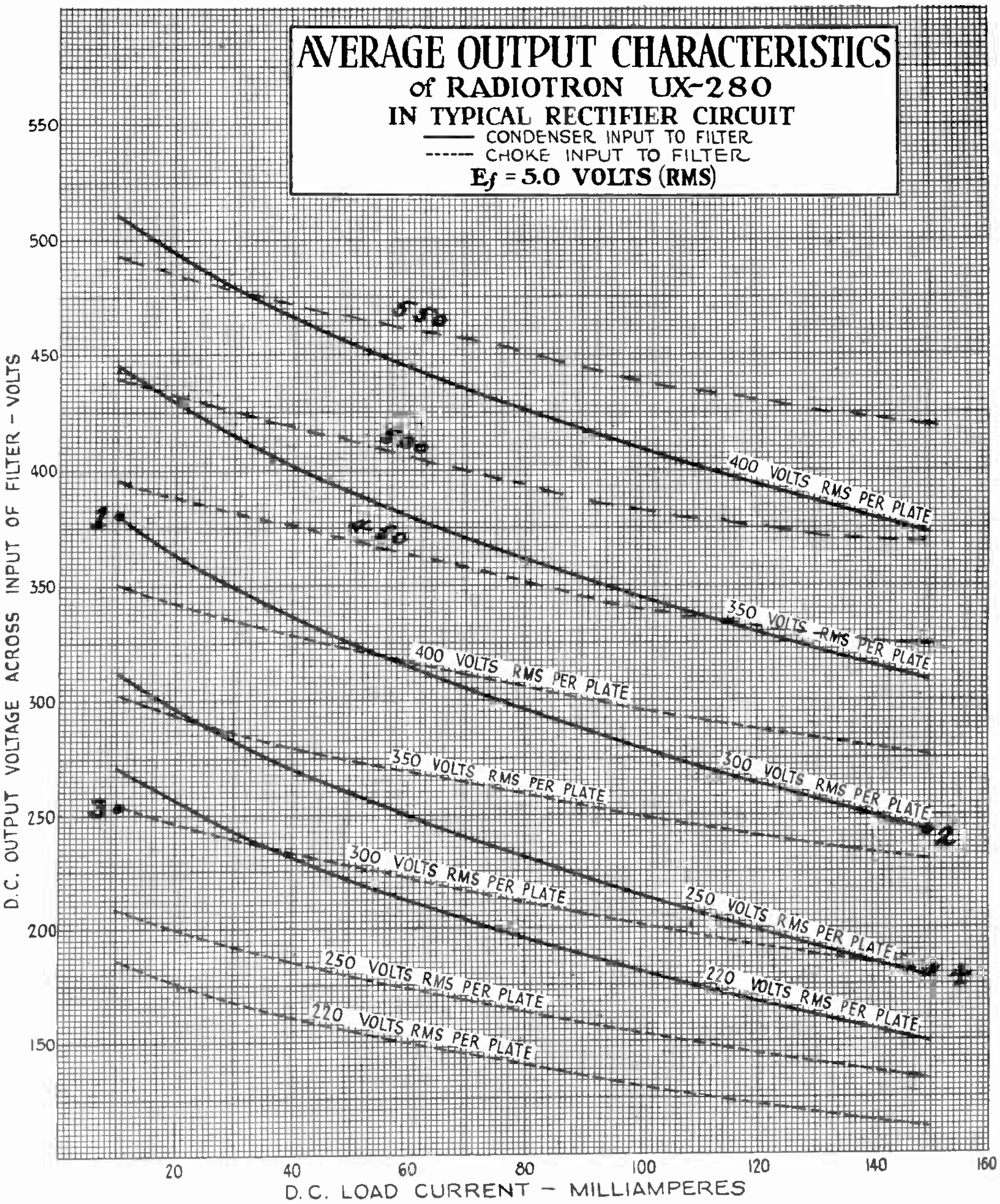


Figure 12.

disadvantage of the choke input is the fact that the rectifier output voltage is lower. However, this is overshadowed by the fact that since the peak current is much lower the voltage regulation is more constant with a varying load when using the choke input than when using a condenser input type filter.

In Figures 12 and 13 are shown the rectifier tube output voltage variations to the filter input for the UX-280 and 281 tubes respectively, at different transformer voltages, and for various load currents at the filter output.

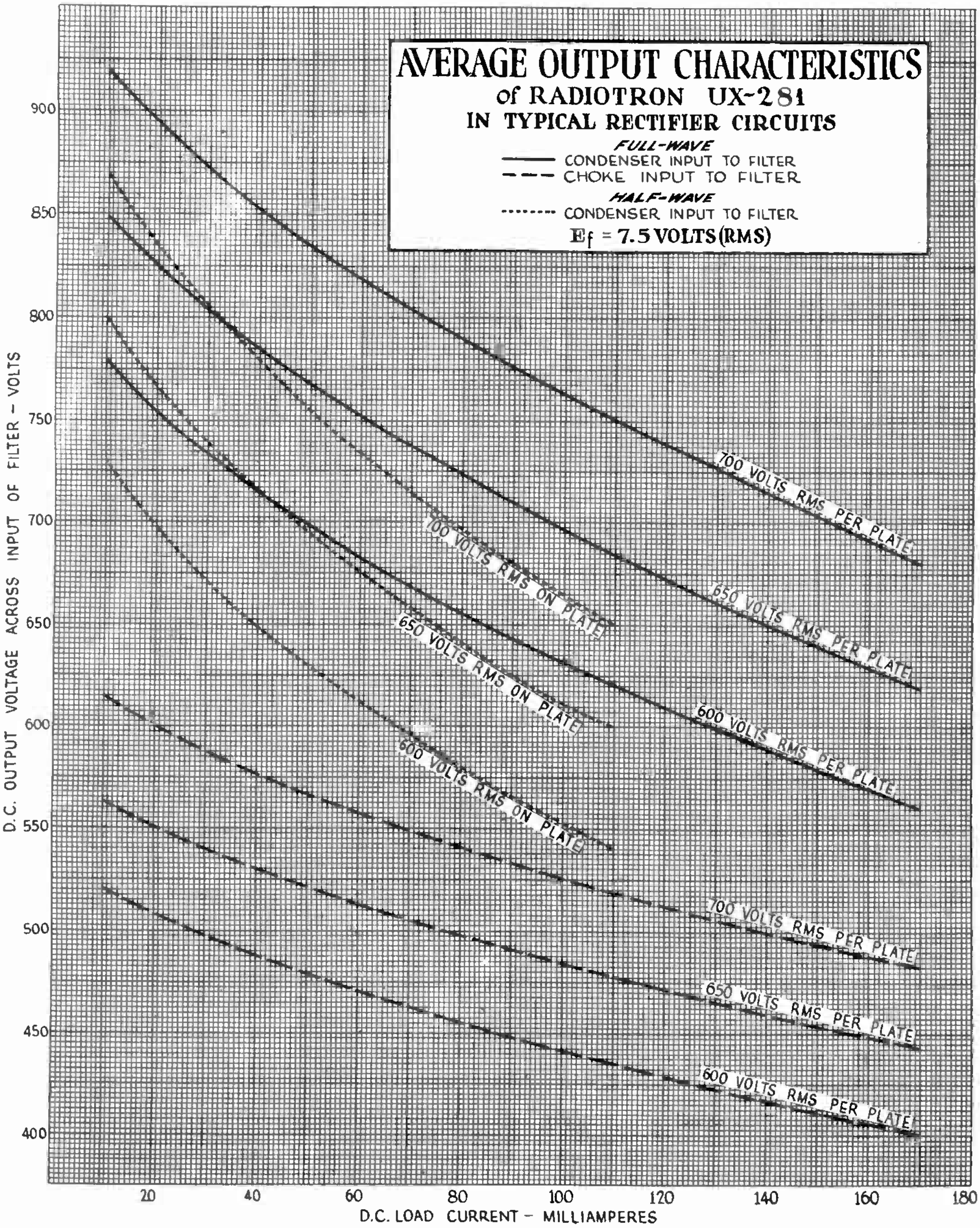


Figure 13.

Referring to Figure 12 it will be noted that with 300 volts A.C. per plate with a condenser input type filter the D.C. voltage at the input to the filter varies from 380 volts with a load current of 10 milliamperes to 240 volts at a load current of 150 m.a. a change of 140 volts as shown at points 1 and 2 respectively. When, however, a choke coil input type of filter is used the rectifier output voltage at a 10 m.a. load is 255 volts as shown at point 3, and at a 150 m.a. load it drops to 180 volts at point 4, or a voltage variation of 75 volts for a 140 m.a. load variation as compared to a voltage variation of 140 volts when a condenser input type of filter is connected to the rectifier output.

In all of the circuits considered so far in this lesson the choke coils have been shown connected in the positive side of the rectifier output. However, sometimes the chokes are placed in the negative side of the filter unit. This has the advantage, that, the difference in potential between the windings and the core is very low since the negative side of the filter system output is usually grounded as are also the choke coil cores. This lower potential difference between windings and core decreases the possibility of a break down in the insulation between windings and core and enables lower break down insulation with the attendant lower cost to be used in the construction of the choke coils.

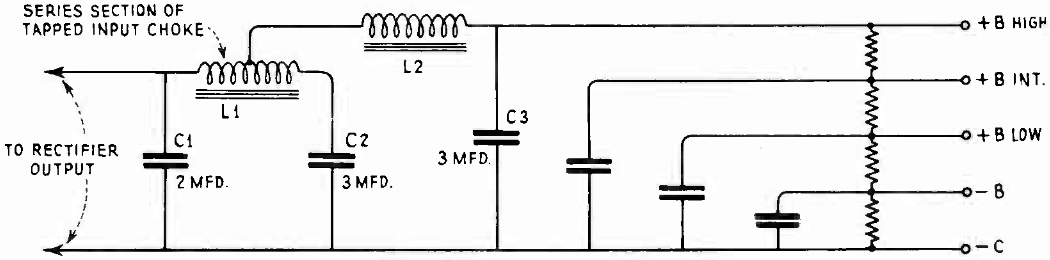


Figure 13a.

TAPPED INPUT CHOKE FILTER SYSTEMS

In some rectifiers a filter system which varies slightly from the two-section "brute force" filters just described is used. Since it is somewhat different from the usual arrangement, a study of its operation will enable us to more easily understand its action. A diagram of this system is shown in Figure 13a. The condensers function in the usual manner, acting as reservoirs to hold the current from one impulse to the next. It will be noted that the first or input choke coil is tapped. The one section of it is connected in series with the load and second choke coil. Therefore, the D.C. load current flows through it. The second section of this tapped choke is connected in series with condenser "C2". There is an A.C. voltage across this second section due to transformer action, similar to an Auto-transformer.

Since the voltage in the secondary of a transformer is 180 degrees out of phase with the primary voltage, the voltage in this second section of the choke coil is 180 degrees out of phase with the ripple voltage across the second condenser C_2 and, therefore, to a large extent cancels out the ripple in the current which would flow through the succeeding circuits. This results in the output of this section of the filter being substantially free from ripple. The second filter section choke is connected in series with this output and removes any slight ripple which may remain. The condenser values shown in Figure 13a are those used in a commercial application of this circuit. However, the value of "C_2" is critical and will vary with the value of the tapped choke coil used and the number of turns in that tapped section as compared to the total turns in the tapped coil. This condenser value may readily be determined by experiment by substituting condenser values until the ripple or hum voltage output of the entire filter system is at a minimum. The advantage of this type of filter system is, that lower values of inductance and capacitance may be used for a given output ripple voltage, as compared to the ordinary filter. Or in other words, with the same values of L and C as ordinarily used in a 2-section "brute force" filter, the hum output will be of the order of .002 per cent or less.

The field coil winding of the dynamic speaker in most modern receivers is used as the second choke coil in the filter system. In this manner the field winding is made to serve two purposes, first, that of a choke coil in the filter system, and second, to supply a strong constant magnetic field in which the voice coil is to work. The D.C. resistance of these field coil windings is usually of the order of 750 to 1500 ohms.

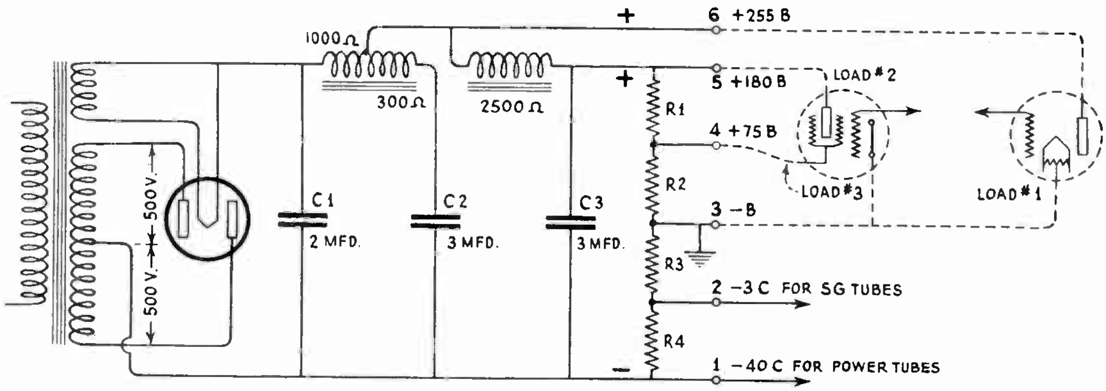


Figure 14.

VOLTAGE DIVIDER SYSTEMS

We now come to Part 4 of our original rectifier. This is known as the voltage dividing systems. The one shown in Figures 4 and 5 will be considered first. This type is known as a parallel voltage dividing system because the voltage dividing resistor bank, as shown in Figure 14, is connected across the rectifier output parallel to the load devices, for which, the direct current output of the power unit is to serve as plate, and grid voltage, in the place of battery supply. This resistor bank is really nothing more than a multiple potentiometer with fixed taps. The current flow through the various sections of the resistor is not the same, because some current is diverted from each terminal to the load connected to that terminal. Due to this fact it is not so simple a matter to calculate the value of the various sections of the resistors between the taps. An example of the calculation will, therefore, be made here to show how this is done. Let the various voltages and current desired (for the tube circuits, which the rectifier is to supply) be as follows:

	Plate Volts +	Plate Current	Grid Volts −	Screen Volts +	Screen Current	Connected Across Taps
Load 1	255+	60 ma.	40 −			3 + 6
Load 2	180+	18 ma.	3 −			3 + 5
Load 3				75	2 ma.	3 + 4

In Figure 14 the loads, that is the amplifier tubes, are shown connected in phantom and are represented by the dotted lines. Load number 1 is shown connected across terminals #6 and #3. The difference in potential required for the plate supply on this load is 255 volts + and in addition a Grid Voltage, 40 volts negative to −B is required. This is to be obtained between terminals #3 and #1. The total voltage drop across R3 and R4 must, therefore, be 40 volts. The total voltage drops across R1, R2, and the filter output choke coil must be 255 volts. An explanation of the connection of terminal 6 to the junction of the first and second choke coils will enable the student to understand why such an output connection is permissible. The output stages of an amplifier in many cases are push pull connected. When tubes are so operated they do not require current as completely filtered as do the previous stages. Therefore, it is not necessary to draw current for the push pull stage through both filter chokes, but only through the first, as shown. The advantage is, that the second choke can thus be made of smaller wire as it does not have to carry the large direct current drawn by the power tubes. The other tubes require more perfectly filtered current, hence they draw this current through both choke coils out of tap #5.

Load number 2, which is the plate current required for several screen grid tubes, let us say, is shown connected across terminals #5 and #3. The difference in potential required for the plate supply of these tubes is to be 180 volts. This voltage will, therefore, be the total voltage drop required across R1 and R2. The voltage (i.e. IR drop) across the second filter choke will, therefore, be the difference between 255 and 180 volts or 75 volts.

Load #3, which is the screen grid current required for the tubes, whose plate supply is obtained between terminals 5 and 3, is shown connected to terminals 4 and 3. The voltage required for the screen grids is 75 volts, therefore, the voltage, i.e. IR drop, across resistor R2 must be 75 volts. If the voltage across R2 is 75 volts, and the total voltage across R1 and R2 is 180 volts, the voltage across R1 must be the difference between 180 and 75 volts or 105 volts. We also require a potential of 3 volts negative to −B for grid voltage on the screen grid tubes; this is to be obtained by the IR drop across R3 which must, therefore, be 3 volts. If, therefore, the voltage drop across R3 is to be three volts and the total voltage across R3 and R4 combined is to be 40 volts as we previously decided, then the voltage drop required across R4 must be the difference between 40 volts (the voltage across both resistors) and 3 volts (the voltage across R3) or 37 volts.

We now know exactly what voltage drop we require across each section of the voltage dividing resistance and across the last filter choke coil in order to have available for the vacuum tubes, the voltages which we require. Let us now determine exactly how much current will flow through each resistor and choke coil in order to determine what value of resistor will be required in each section of our bank of voltage dividing resistors.

The voltage divider of Figure 14 is reproduced in Figure 15 with milliammeters inserted in various parts of the circuit. The current flow through each of these milliammeters and consequently through the various parts of the circuit is indicated.

Let us now trace the path through which the three load currents must flow. This will enable us to determine what the total current through each of the four sections of the voltage divider will be. When we then know exactly how much current will flow through these resistors, since we already know what the desired voltage drop across them must be, we can determine by Ohm's Law, what the values of the resistor sections should be to produce the proper voltage between the various voltage divider terminals.

As we trace the path of the three load currents indicated by the arrows through the various milliammeters the student should tabulate on the chart of Figure 16 each individual load current in milliamperes as has been done for load #1.

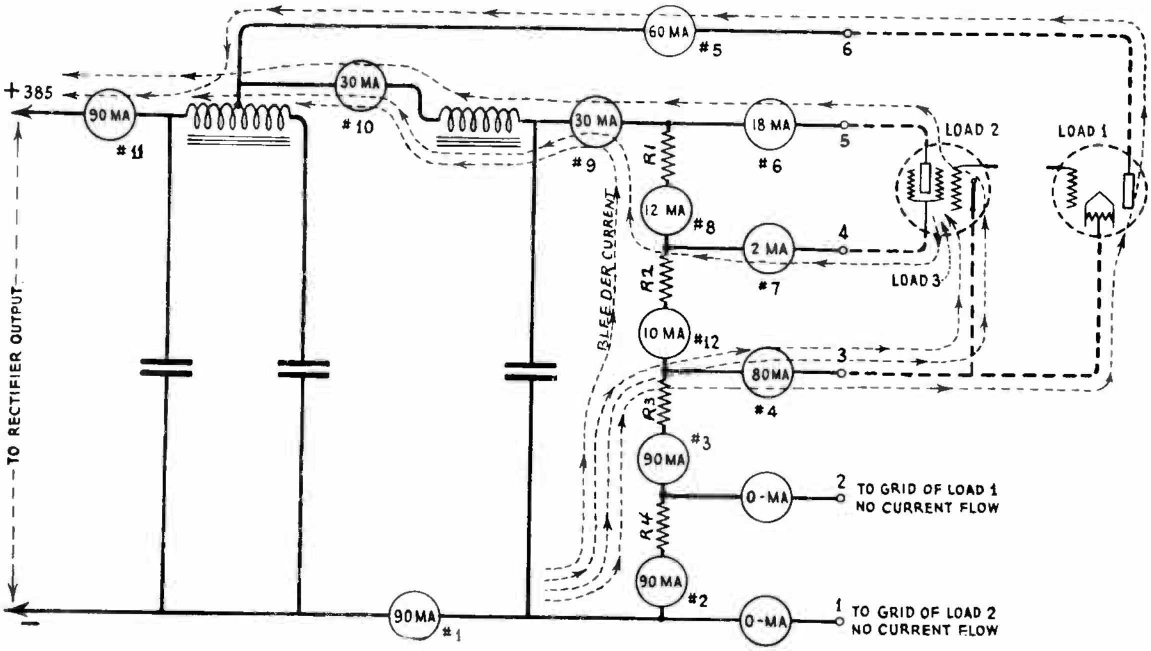


Figure 15.

Tracing the path of the current through load #1 from negative rectifier output through the voltage divider and the load, we find that it takes the following path as indicated by the arrows. From negative rectifier, through ma. #1, then through ma. #2 and R4, through ma. #3 and R3. The current then flows through ma. #4 to the filament of load #1. From filament to plate, returning to terminal #6 and through ma. #5 to the tap on the tapped choke coil, through the choke coil and ma. #11 and thus to positive rectifier output. This load as we originally stated, is a 60 ma. load at 255 volts. Therefore, we have listed in Figure 16, 60 ma. for Load #1 under each of the milliammeters through which we have just found it to be flowing. Let us now trace Load #2.

This is the plate current load of the screen grid tubes (shown in Figure 15 as a single tube for the sake of simplicity) Load #2 is an 18 ma. load at 180 volts. Tracing the path of the current flow from negative rectifier we find that this 18 ma. of current must flow through the following milliammeters and parts. From negative rectifier through ma. # 1, through ma. #2 and R4, through ma. #3 and R3, then through ma. #4 to the cathode of the screen grid tube.

Thence from cathode to the plates of the tubes, from the plates to terminal #5 through ma. #6, through ma. #9 through the second choke in the filter system and ma. #10, and returning to positive rectifier through the first choke in the filter system and ma. #11. The student should now list in Figure 16, 18 ma. for load #2 under each of the milliammeter numbers corresponding to the numbers of the milliammeters in Figure 15 through which we have just traced the current flowing through load #2.

The path of the 2 ma. current of load Number 3 is traced next. This 2 ma. is the screen grid current which flows from cathode to screen grid in the same screen grid tubes. Starting again at negative rectifier and tracing the path which the current must take, we find that this 2 ma. of current flows through the following parts in consecutive order. Through ma. #1, ma. #2, and R4, through ma. #3 and R3, through ma. #4 to the cathode of the screen grid tubes, from cathode to the screen grid element, from screen grid element to terminal #4 then through ma. #7 through ma. #8 and R1, and from R1 back to + rectifier output through ma. #9, second filter choke, ma. #10, first filter choke, and ma. #11.

M.A. No.	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12
Load 1	60	60	60	60	60	0	0	0	0	0	60	0
Load 2												
Load 3												
Bleeder												
Total												

Figure 16.

This 2 milliamperes should now be listed in Figure 16 for load #3, under each of the ma. numbers corresponding to the numbers of the milliammeters in Figure 15 through which we have traced the current of load #3.

BLEEDER CURRENT

We have now traced the path of all the currents which the tube loads will draw from the terminals of the voltage divider of our power unit. In addition to the loads drawn by the tubes, there will, however, be another load on the rectifier at all times, whether the tube circuits are connected to the power unit or not. This additional load is the current that will flow through resistors R1, R2, R3, and R4, from the negative to positive side of the filter system output. Referring to Figure 16 you will notice that none of the tube load currents flow through ma. #12 or through R2; therefore, the only factor, excepting the resistance of R2, determining the voltage drop across R2 will be that current flowing directly through all of the resistors from negative to positive output terminals of the power unit. It is this current (which is drawn from the rectifier irrespective of whether or not a vacuum tube load is connected to the power unit) which is called the "Bleeder Current". The Bleeder Current serves two useful purposes. The ordinary rectifier tubes have a rather high internal plate to filament resistance across which there is an appreciable IR drop, (60 volts at normal load) and in addition there is an IR drop in the filter chokes. The IR drop in both the tube and choke coils must be subtracted from the original A.C. voltage to determine the voltage across terminals 1 and 5. If no current were drawn the voltage across terminals 1 and 5 would be that rectified by the tube, and this is considerably higher than the normal voltage. This would stress the filter condenser dielectrics unduly, and also that of any by-pass condensers which might be connected across the various taps of the voltage divider. By drawing a constant "bleeder current" the voltage is kept down to a safe value even if the amplifier tubes were not connected to the power unit terminals.

The second purpose is to maintain the voltage between the various taps fairly constant and independent of the variations in the current drawn by the various tubes of an amplifier connected to the power unit. For instance, the current flow at terminal #2 and through R1 was found to be 2 ma., and the voltage drop across R1 is to be 105 volts. If, however, the current through load #3 were to change to 1.5 ma. the change in the voltage drop across R1 would be proportional to the change in the current flow through it or a change of 25%. If, however, we assume a 10 ma. bleeder current to be flowing steadily through R1 in addition to the 2 ma. load current, a total of 12 ma., then a change in load current of ½ ma. would represent a change in current flow through R1 of 1/24, approximately a 4.2% change in voltage drop as compared to a change of 25% with no bleeder current flowing through R1. This clearly illustrates how bleeder current helps to stabilize the voltage between the output terminals of the power unit.

Some value of bleeder current must be assumed for any voltage divider and we will assume a value of 10 ma. for this problem. The value of bleeder current which, in practice, has been found to be the lowest value which will effectively stabilize the output voltages of a voltage divider is a bleeder current of 10% of the total load on the rectifier. Thus for a 100 ma. total tube load the minimum value of bleeder current usually chosen would be 10 ma.

The student should, therefore, list a 10 ma. bleeder current in Figure 16 under the following ma. numbers, through which milliammeters the bleeder current would flow in its path from negative to positive rectifier output in Figure 15; namely Milliammeters #1, 2, 3, 12, 8, 9, 10 and 11.

The student should now add up (and list the sum obtained in the total column) the currents found to be flowing through each of the milliammeters. The total for each milliammeter should correspond to the current flow values listed in Figure 15.

Knowing the current flow as just determined, and the voltage drop required in each portion of our voltage dividing system, we can now determine what value of resistance is required in each case to produce the desired voltage difference between the various output terminals of our power unit. The value of R in each case being according to Ohm's Law voltage drop desired.

Part #	Current in Amps.	Voltage Drop Desired	Resistance in Ohms
R1	.012	105	8750
R2	.010	75	7500
R3	.090	3	33.3
R4	.090	37	411
2nd Choke	.030	75	2500

Assuming that the series section of the tapped filter coil had a D.C. resistance of 1000 ohms, there would be a difference in potential across it of 90 volts.

BY-PASS CONDENSERS

The vacuum tubes in amplifiers, whether A.F. or R.F., draw a variable or pulsating current from the power unit due to the varying signal voltage applied to their grids. This pulsating current would have to flow through the sections of the voltage dividing resistor bank and set up a pulsating voltage in it. This pulsating voltage caused by one of the tubes would be applied to the plate or grid of a preceding tube and thus be fed back through the tube coupling circuit to the grid of the same tube originally producing the pulsations. We would thus have a kind of feed-back or regenera-

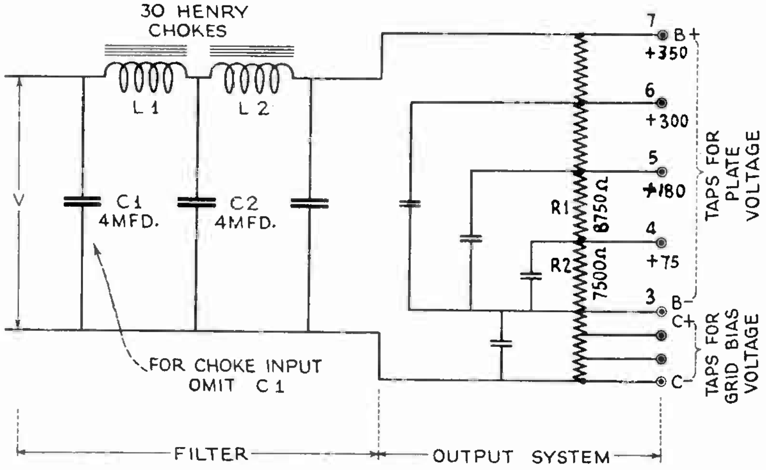


Figure 17.

tive action, and the amplifier would oscillate and either distort the incoming signal, produce hum, or both. To prevent this, a condenser of the proper value is connected between each tap of the voltage dividing resistor and ground or -B the common return as shown in Figure 17. The proper location for these condensers is not at the voltage dividing resistor, but at the plate circuits of the amplifier. This does away with the pulsations being forced to flow through the leads connecting the amplifier and power unit, which would cause coupling between stages in the plate voltage supply leads themselves. The value of a by-pass condenser required across a point of difference in potential in a voltage divider in order to effectively maintain a fairly constant potential even though the load current were varying, is under ordinary conditions and in practice, that size by-pass condenser whose capacitive reactance in ohms at the lowest frequency at which current is expected to flow in the various loads is 1-10 of the resistance in ohms of the voltage divider across which it is to be connected. As an example, let us again return to Figure 14.

If we wished to determine the value of a by-pass condenser required between terminal 5 (+ 180V), and terminal 3 (-b), of the power unit, we first determine the value of the voltage divider resistances R1 and R2. We find this to be 16,250 ohms, since R1 has a resistance of 8750 and R2, 7500 ohms. Let us assume that the lowest frequency signal we expect to be impressed upon our amplifier tube grids is 50 cycles. By calculation at random of the reactance of several condenser sizes, we will find that the reactance in ohms of the following sizes of condensers at 50 cycles is:

.1 mfd.	31,847 ohms
.25 mfd.	12,739 ohms
.5 mfd.	6,369 ohms
1.0 mfd.	3,184 ohms
2.0 mfd.	1,592 ohms

Since the resistance of R1 and R2 combined is 16,250, we find on inspection that the reactance of a 2 mfd. condenser at 50 cycles is slightly less than 1/10 the resistance of R1 and R2 and if we wanted effective by-passing with no feed back or regeneration, a 2 mfd. condenser would be used.

SERIES VOLTAGE DIVIDING SYSTEM

Another method of obtaining the different voltages required for the various tube circuits which might be connected across the output of a power unit is to feed them direct from the high voltage output tap of our power unit instead of from the lower voltage taps of a parallel voltage divider. This method is shown in Fig.27, page 33.

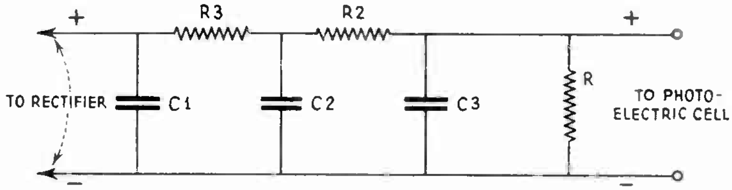


Figure 18.

Here the plate voltages of tubes 1 and 2 are fed through resistors R1 and R2 respectively. These resistors reduce the high voltage from terminal 5 of Figures 14 or 15 to the rated value required by the tubes.

The pulsations in tubes 1 and 2 are led directly back to their respective cathodes by condensers C1 and C2 respectively and do not have to flow through resistors R1 and R2 to any appreciable extent. In this way the A.C. component of the plate current (current pulsations) of either Tube does not affect the plate voltage of the other tubes, and thus regeneration is avoided. This method can be varied in several ways, and is very effective for this purpose. It has an additional advantage which must not be overlooked. That is, since the amount of current flow through the individual resistors is only the current flow through the tube in series with whose plate they are connected, the wattage dissipation (that is, I^2R loss) in each resistor is lower, consequently, resistors of lower wattage rating with the resultant decreased cost may be used for the series dividing system with every bit as effective voltage dividing action.

RESISTANCE CAPACITY FILTERS

The above resistors also act as filter units for the rectified plate supply. Thus any ripples in the current coming from the power unit have difficulty in flowing through R1 and R2, and the small amount that still remains is by-passed effectively by C1 and C2 so that very little is applied to the plate of either tube.

Such resistance capacity filters are sometimes used in circuits where very little current is required, as for photo-electric cells, where the current is of the order of microamperes. Often in sound motion picture work and in home talkie projectors, the high voltage plate supply has to be reduced to a much lower value, say 90 volts, for the photo-electric cells, by the use of resistors, so that the latter are frequently used for filter purposes as well. A filter

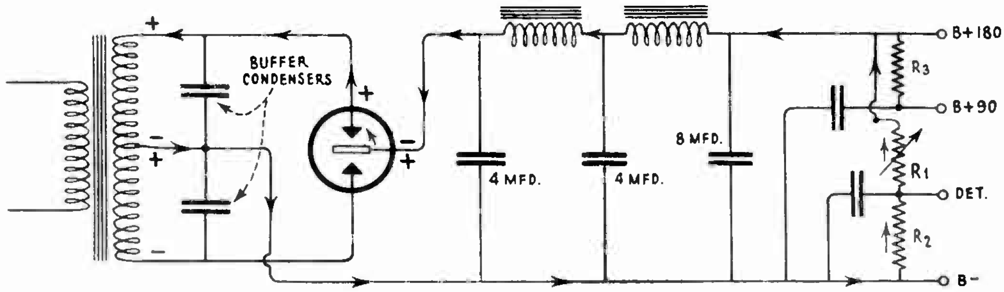


Figure 19.

of this type is shown in Figure 18 and consists of 2 sections. R is the bleeder resistor and R2 and R3 are the filter as well as voltage reducing resistors. C1, C2 and C3 are the filter condensers, C3 also serves to by-pass the A.C. component (current pulsation) from the photo-electric cell. The advantage of a resistor over a choke coil is that the choke coil has a very low permeability to magnetic flux for such extremely low current (microamperes) through its winding, so that its inductance is very low, and a choke coil of very many turns would be required in order to effectively serve as a filter. Resistors are, therefore, not only lower in cost, but quite effective for small currents.

THE GASEOUS CONDUCTOR RECTIFIER

This gaseous rectifier tube has no filament. Its action depends upon a gas content in the tube which, upon being ionized, permits a current to flow through the gas (makes the gas conductive). A rectifier circuit using this tube is shown in Figure 19. The tube has two small electrodes, about the size of a number 14 or 16 wire and about ¼" long, and one electrode in the form of a metal plate which completely surrounds these, the two small electrodes. A sketch of a cross sectioned tube of this type is shown in Figure 20. The small electrodes are connected to the opposite ends of the power transformer secondary terminals and are the anodes while the large electrode is connected to the external load circuit and serves as the cathode. The space between the electrodes is filled with helium (an inert gas) at low pressure.

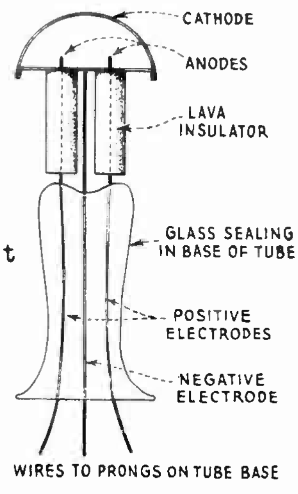


Figure 20.

THE ACTION OF THE GASEOUS TUBE

Perhaps you have seen an Xray machine in operation. You observed the soft purple glow emitted by the tube. This subdued light was caused by what is known as IONIZATION. Ionization is the splitting up or separating of electrons from an atom and may apply either to a gas, chemical solution, or chemical compound.

All atoms, when in a normal stage, manifest no unusual electrical characteristics, but if by some means an electron is taken away from or added to a normal atom then electrical properties of the atom so changed are exhibited by attractive and repulsive effects. The atom is then said to be ionized.

Therefore, when a normal atom for any reason takes on an additional electron or an electron is caused to leave a normal atom, the particle thus formed by the first condition is called a "negative ion" and by the second condition a "positive ion". This process as a whole is termed "ionization".

The small gas content in a rectifier tube represents billions and billions of atoms. They are continually on the move; their movement is similar to so many rubber balls dumped into a confined space all taking haphazard paths in their line of flight, but, of course, the atoms move at tremendously high speeds.

For many years it was known that gas, under certain treatment, possessed the property of being an insulator and that, under other conditions, it would become a perfect conductor. This phenomenon was for many years a mystery. The constant research work by the physicist to learn more about matter has, however, disclosed many wonderful things and the study of ions, electrons, and atoms, which constitute matter, is a very important one.

In connection with the gaseous rectifier it was found that when a high potential exists between either of the small electrodes and the large electrode of the gaseous tube it would cause the gas atoms to be set into violent agitation sending them in every conceivable direction and at terrific speeds, bumping into each other with such force that each time a collision between the atoms occurred an electron would be knocked free, and thus ionization of the gas was accomplished. The gas atom on losing an electron becomes positively charged and is often termed a <u>POSITIVE ION</u>.

Since the two small electrodes are connected to opposite ends of the transformer one will be charged positively and the other negatively, the charge on them being reversed every half cycle while the large electrode being connected to the center tap of the power transformer secondary through the load circuit will be negative with respect to the small electrode which is positively charged and positive with respect to the other small electrode.

Since Helium gas atoms are in the space between the Plate (cathode) and Pin Electrodes (anodes), when the potential difference between them becomes great enough (as the voltage during one half A.C. cycle increases) the gas atoms will become ionized. As a result of ionization, the previously normal gas atoms will show electrical characteristics and since they are minus their regular complement of electrons, will at once seek the cathode element (the plate) where they take on an electron thus completing their balance, only, however, to be crashed into again by some neighboring atom and reionized, upon which they again return to the cathode to acquire another electron. This action takes place over and over again.

The electrons released by the collisions at once seek a positively charged electrode and travel to the small pin electrode which is at that moment positively charged and are attracted by it. It is these electrons which are released from the gas atoms as a result of ionization which constitute the current flow from cathode (the plate) to the anode (the positively charged pin) and thence through the external circuit. During this period just described the second anode is charged negative in fact even more negative than the plate (cathode) since its surface (the negative anode) is but a small fraction of one per cent of the surface of the large plate, the intensity of the negative field about it and consequently its ability to attract the heavy gas ions is proportional to the surface of the charged area as compared to that of the cathode (plate). Thus the ability of the positive gas ions to strike the small electrode is greatly diminished and in their attempt to make contact with this small electrode, since their mass or size is quite great as compared to an electron, they pile up a positive space charge about the small electrode which tends to repel any further positive ions attempting to reach this electrode. A few ions, because of their greater speed, manage to force their way to the negatively charged pin and detach an electron from it causing a small back current to be set up. For all practical purposes, however, this is so minute that it may be considered as negligible. During the opposite half cycle the same conditions take place excepting that the pin electrode to which the electrons freed by ionization are attracted will be the one which during the previous half cycle was charged negatively.

It should be noticed in Figure 19 that a two-section condenser input type filter is used with this type of rectifier, and is the type recommended for use with it. Also notice that two 0.1 mfd. condensers (usually built together in a common case) are connected across both halves of the power transformer secondary. These prevent surges in the current which might cause a change in the character of the current through the tube or damage to the transformer and tube. They are not necessary when using any rectifier using a filament as electron emitter.

Any of the described voltage dividing systems may be used with this type of rectifier.

These tubes are known commercially as Raytheon rectifiers and are available in the following ratings:

Type	B H	B A
Maximum A.C. Volts per anode (RMS	350	350
Maximum D.C. output current	125 ma.	350 ma.
Maximum D.C. output voltage	300	300

The most commonly used type is the B.H. which because of its extremely long life is used in most separate B supply units where it is desired to eliminate B batteries on a receiver or amplifier designed for battery operation. It is estimated that more than 1 million such B eliminators are still in use in the United States. Hence, it is important that the student be familiar with their operation and construction.

HOT CATHODE MERCURY VAPOR TYPE RECTIFIER

This type of rectifier tube consists of an oxide coated filament which, when heated to the proper temperature, serves as the cathode or electron emitter and has either one or two plates (i.e. either half or full wave rectifier). It will be noted from the description that the tube is similar in the construction of its elements to the 81 and 80 type tubes previously discussed. However, it differs from the ordinary hot cathode vaccum type rectifier, in that, when in the process of construction all the gases have been evacuated from the glass envelope containing the elements and from the surface of the elements themselves, just before the envelope is sealed a small quantity of pure mercury is introduced into the glass envelope. Then the tube is sealed.

When the filament of this type of tube is heated it also heats to some extent, the glass envelope and the space surrounding it, thus causing the mercury to vaporize. The vapor given off by this mercury plays an important part in the operation of this tube. The quantity of liquid mercury in the tube is such that at normal operating temperatures within the tube and with provision made outside the tube for natural air circulation, there will always be some liquid mercury in the tube which has not been vaporized.

The rectifying action of the full and half-wave rectifiers of this type of tube is identical with that of the 81 and 80 type tubes considered earlier in this lesson in all respects but one; that is, that the electrons emitted by the filament (cathode) and traveling toward the plate do not traverse a vacuous space, but instead, must pass through the large number of atoms of mercury vapor which fill all the space within the envelope not occupied by the elements, and on colliding with the mercury atoms cause them to become ionized (i.e. lose electrons).

The events which occur when these emitted electrons attempt to move to the plate are the factors which cause the mercury vapor rectifier to exhibit such desirable advantages over the hot cathode vacuum tube as, 1, almost 80% less voltage drop within the rectifier at normal load, 2, constant voltage drop at all loads that do not exceed the electron emitting ability of the filament; and 3, higher output wattage with lower filament wattage dissipation, all three factors resulting in the following comparative statement: The hot cathode mercury vapor rectifier has a higher efficiency than the hot cathode vacuum type rectifier.

The above advantages are the result of the following conditions taking place during operation between the filament and plates of the tube.

1. Lowered plate to filament resistance within the tube, caused by the positive mercury ions (being attracted to the negative filament) neutralizing the negative electron space charge which normally exists about the electron emitters of all vacuum tubes, as discussed in the elementary lesson on vacuum tubes.

2. Constant plate to filament voltage drop at all loads so long as the load does not exceed the ability of the filament to emit electrons. This is caused by the fact that the plate to filament resistance actually decreases as the load is increased due to the fact that as more electrons pass from filament to plate, this larger quantity of electrons bombard and ionize (knock electrons off of) more and more mercury atoms. These positive ions travel toward the filament in order to obtain theelectron or electrons necessary to restore them to a neutral or uncharged state. This increased number of ions crowding around the filament (when the load

is increased) reduce the negative space charge around the filament as the current flow increases and since as we learned in an earlier lesson the plate to filament resistance of an electron-emitting type of tube increases and decreases as the negative space charge about the filament increases and decreases, it is apparent that if as the current through the tube (I) increases; the resistance (R) decreases that the product of I x R which is the voltage drop will remain constant irrespective of the load within safe limits.

If, however, current in excess of the total effective emission of the filaments is drawn, the tube voltage drop will increase rapidly with the current increase. Many more mercury ions will be produced, in fact, many more than the filament can supply the necessary electrons for. These positive ions, for which the filament cannot supply electrons, will crash into the negatively charged filament with such impact as to knock the oxide coating off of the filament and thus permanently destroy its emitting property, and if allowed to continue even for a short time, will actually tear down the filament wire structure causing it to break.

The effect of the mercury vapor in these tubes, therefore, is to neutralize the space charge voltage drop so that it amounts to only about 15 volts at normal operating temperatures and loads. It is apparent, therefore, that this tube under operating conditions has a very low internal resistance, and that the current it delivers will depend upon the resistance of the plate supply transformer secondary windings, the choke coils in the filter system and the load resistance. Therefore, sufficient protective resistance or reactance must always be used with this tube to limit its current to the recommended maximum value. As an added precaution a fuse having a rating approximately no more than 50% above normal load requirements should be inserted in the primary of the power transformer. This fuse is necessary to prevent damage to the power transformer or tube in case of excessive current which may flow under abnormal conditions, such as, if a filter condenser should fail or the rectifier output be accidentally short circuited.

It is characteristic of mercury vapor rectifiers that no appreciable plate current will flow until the plate voltage reaches a certain critical value in its rise during each half a.c. cycle. This is so because the mercury vapor atoms are very heavy and electrons must attain considerable speed under the influence of the attraction of the positively charged plate before they can bombard the atoms with sufficient force to ionize them, thus liberating large quantities of electrons which are immediately drawn toward the plate. When the plate voltage reaches this critical value, the plate current rises rapidly to a high value in a small fraction of that half cycle. This surge of current, recurring each time the plate becomes positive, may excite (by induction) circuits in the vicinity of the tube to damped oscillations and result in noisy receiver or amplifier operation. In circuits of low sensitivity this noise may not be apparent, but in sensitive circuits with sufficient gain it may be necessary to enclose completely the mercury vapor rectifier tube with perforated metal or wire mesh shielding to eliminate objectionable noise. The shielding must be designed to provide sufficient ventilation to prevent overheating of the tube.

Ventilation is a very important consideration since, if the temperature of the bulb rises much above 120 degrees Fahrenheit, the mercury vapor atoms between the plate and filament will ionize more readily because more mercury will be vaporized, due to the higher temperature within the bulb. The vapor atoms will be packed more densely and the gas will tend to become conductive more readily, under the voltage stress between filament and plate (when the plate is negative during the reverse half cycle). This condition usually results in an arc back, or reverse current flow, and destroys the rectifying action of the tube.

In high power rectifiers of this type such as are used for transmitting purposes, the bulb must be maintained at even lower temperatures to prevent arc back. High power rectifiers of this type will be considered in a later lesson devoted entirely to this subject.

The shielding of the mercury vapor tubes is, however, not essential if the tube is located at the most remote point in the assembly of the rectifier and the circuits it is to supply with plate power; that is, provided, that the usual precautions have been taken in the shielding of the sensitive tube circuits which is always necessary to prevent local (stray field) inductive pickup in all sensitive amplifying circuits whether R.F. or A.F.

In order to take full advantage of the regulation capabilities of this mercury vapor rectifier, the resistance of the transformer windings and the filter choke windings should be as low as practicable. Since the drop through the tube is practically constant, any reduction in rectifier voltage when the load is increased, is due to the drop in the transformer and/or the filter windings.

If it is impracticable to use a transformer with sufficiently low resistance to give the desired regulation, improved regulation of the output voltage may be obtained by employing a bleeder across the filter circuit.

Filter circuits of the condenser input or the choke input type may be employed provided that the maximum voltages and currents tabulated under RATING AND CHARACTERISTICS are not exceeded.

If the condenser input type of filter is used, consideration must be given to the instantaneous peak value of the a-c input voltage which is about 1.4 times the RMS value measured from plate to filament with an a-c voltmeter. It is important, therefore, that the filter condensers (especially the input one) have a sufficiently high break-down rating to withstand this instantaneous peak value. It should be noted that with condenser input to the filter, the peak plate current of the tube is considerably higher than the load current. With a large condenser in the filter circuit next to the rectifier tube, the peak current is often as much as four times the load current.

When, however, choke input to the filter is used, the peak plate current is considerably reduced. This type of circuit, therefore, is to be preferred from the standpoint of obtaining the maximum continuous d-c output current from the mercury vapor tube under the most favorable conditions.

DIRECT CURRENT POWER UNITS

Where direct current is available as a source of power, the power supply problem is greatly simplified as there is no power transformer involved in the circuit and the eliminator comprises simply a filter circuit, the function of which is to eliminate the commutator ripple of the direct current generator supplying the line from which the power unit is taken. The voltage divider operates on the same principle as in any type of power unit.

An eliminator circuit for supplying plate potential only is shown in Figure 21; approximately 90 volts is the maximum voltage obtainable due to the losses in the filter circuit, the greatest loss of voltage occurring in the choke coil. If more than 90 volts is re-

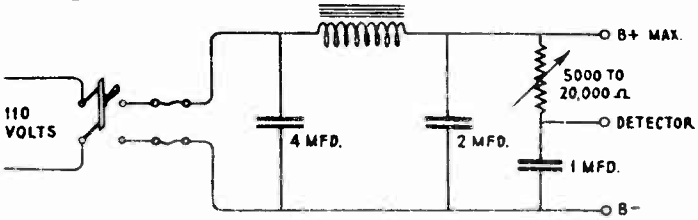


Figure 21.

quired, 45 volt "B" battery blocks may be connected in the positive leg of the circuit as shown in Figure 22.

Figure 22 shows a direct current power unit designed for "A" and "B" power. Since the device is operating from a direct current line of 110 volts the losses of the system will reduce the available voltage at point B+ to approximately 90 or 100 volts; therefore, if more voltage is required it is a simple matter to connect 45-volt heavy duty "B" battery block units in the positive side of the output until the value required to operate the tube used in the power stage is reached.

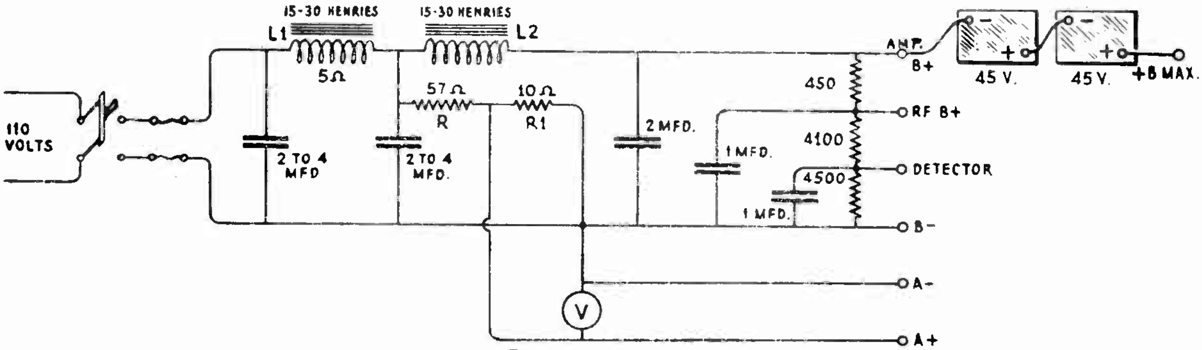


Figure 22.

The values of the resistances R and R1 will depend upon the total amount of current in amperes that the tube filaments of the set draw, and then use the proper resistance in ohms. For five UX-201A type tubes the values given are correct, provided the resistance in ohms of L1 has a value which does not exceed 5 ohms. Under circuit conditions existing in Figure 22, the voltage drop across L1 due to "B" current would be negligible, but the 1.25 amp current flow from A- to A+ and the .5 ampere current flow through R1 making a total of 1.75 amperes would flow through R and L1 thus the voltage drop across L1 would be approximately 5 volts and that across R approximately 100 volts, leaving 5 volts drop between A- and A+, if the line voltage is 110 volts. It is very important that the resistance of L1 be as low as possible, never in excess of 5 to 6 ohms, otherwise there would be appreciable voltage drop across it, consequently lowering the voltage available for "B" supply. Also the wattage dissipation in L1 would become excessive and it would overheat. In calculating the resistance of R, the following factors must be considered: The voltage and current desired at terminals A- and A+, and the DC resistance of L1.

The resistance of L2 and the voltage drop across it will, of course, determine the voltage available across the extreme voltage divider terminals. With ordinary loads, not in excess of 100 milliamperes, the resistance of L2 should be between 100 and 200 ohms. If a choke coil of higher resistance than this is used the voltage at the "B" filter output will be less than 90 volts. The value of the voltage dividing resistors will, of course, have to be calculated as described previously in this lesson. The sections shown have been calculated to give the following voltages at the specified load current between the taps:

B- to detector	45 volts at 1 milliampere
B- to RFB+	90 volts at 12 milliamperes
Bleeder current assumed - 10 milliamperes	
B- to Amp.B+	100 volts

The precautions when using this type of power unit are: (1) always connect a fixed condenser having a capacity value of at least 0.5 mfd. in series with the ground lead of the receiver. (2) Make sure the antenna is free from any possibility of grounding. (3) See that all the tubes are properly seated in the sockets. (4) Do not remove a tube from its socket until after the filament switch of the set has been opened.

CHEMICAL RECTIFIER

The chemical, or electrolytic rectifier, is one that employs a chemical solution in which two dissimilar metals are immersed. One of these metals acts as a conductor to bring the current in contact with the chemical solution (electrolyte); the other metal is called the "valve metal" because it allows current to pass in one direction only. There are a number of metals suitable as a valve electrode, a few of which are aluminum, tungsten, magnesium and bismuth. The other electrode may be any inert metal which is not subject to attack by the electrolyte; for example, lead or iron. The lead electrode has no part in the rectification action other than offering a means to lead the current into the electrolyte.

The electrode acting as the "valve electrode" is always connected to the positive side of the filter system when the rectifier is used for vacuum tube plate excitation. Where this type of rectifier is employed as a trickle charger the valve electrode is always connected to the positive terminal of the battery to be charged. The two metals most commonly employed are aluminum, which is the valve metal and lead as the electrode to lead the current into the electrolyte. When aluminum and lead are used as the electrodes the electrolyte is made by dissolving ammonium phosphate, or common Borax, in distilled water, combining the crystals with the distilled water until the saturation point has been reached; the point of saturation is reached when the crystals will no longer dissolve and combine with the water. The solution should be mixed in an earthenware container and, when thoroughly mixed, the clear liquid poured into the containers used as rectifier jars or cells.

It is very important that the water and the chemical used be pure; i.e. free from foreign substances. Impurities such as chlorine will, if combined with the water used in the electrolyte, retard the rectifying action and may stop it entirely. Since city water is in many instances treated with chlorine it should never be used. Distilled or filter rain water only is the best to use in the electrolytic rectifier. The aluminum electrode should be pure aluminum. The commercial grade may prove satisfactory, but in many instances it will not because of traces of copper which it may contain and which will cause the electrode to overheat. The jars should never be entirely enclosed; a free circulation of air around each jar is necessary to prevent the unit as a whole from overheating.

The principal upon which the electrolytic rectifier operates is by virtue of a film of bubbles which forms on the aluminum electrode (the valve metal in this instance). This film is an insulator and forms a dielectric between the aluminum plate and the electrolyte.

Since the aluminum and the electrolyte are both conductors a condenser effect is formed by the film, the insulating property of which is dependent upon the amount of gas covering the aluminum electrode. This film acting as the dielectric about the aluminum electrode prevents current from flowing through the device when the aluminum electrode is made positive by one half cycle of the alternating current. When the lead electrode is made positive by the next alternation the film does not form at either electrode thus allowing a free path for the current to flow.

The advantage of the electrolytic rectifier lies in the fact that the voltage drop with an increase in load is less than other types of rectifiers due to the low internal resistance of the cells. It is objectionable, however, from the standpoint of its size and the care necessary for its upkeep.

METALLIC RECTIFIERS

The metallic contact rectifiers are different from all other types. They consist of a number of prepared plates of a special copper alloy which are pressed together hydraulically and then bolted to insure as near as possible a perfect close contact between the different plates. The theory of operation regarding this type of rectifier is based on certain phases of the electron theory.

In any body of metal there are a few electrons which are free to shift about, the number able to change in position depending upon the metal. These free electrons move in an electronic field and may travel only a short distance from the surface of the metal and are then drawn back.

The theory of one way conductivity is based upon this electronic field produced by the different alloys used to make up the plate of the rectifier. If the electronic field of one is more dense than the other, electrons will pass with comparative ease toward the metal having the more dense or stronger field, while they will be prevented from reaching the plate having the less dense or weaker electronic field.

The actual passage of the electrons take place only at the junction point where the two electronic fields meet and, as the electron can move only an extremely short distance from the surface of the metal, perhaps less than a half millionth part of an inch, a perfect metallic contact must be maintained between the alloy plates.

THE VIBRATING RECTIFIER

The vibrating rectifier is a mechanical device for changing alternating current to a uni-directional current for battery charging purposes. This type of charger is used principally for charging 6 and 12-volt storage "A" batteries.

A step down transformer, shown in Figure 23, is incorporated in the device for reducing the voltage of the house lighting system to a proper value. The transformer not only steps down the voltage but, by means of a center tap taken off the secondary winding, it provides a return for the rectifier D.C. current.

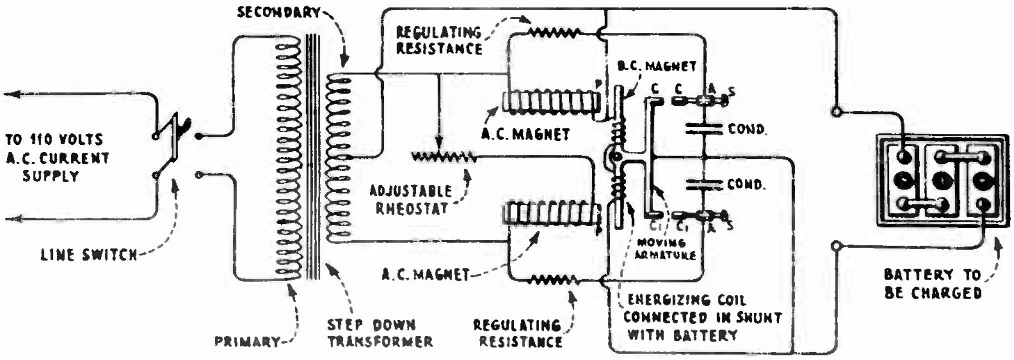


Figure 23.

When connected to the battery and with the line switch closed, the current flows from one end of the secondary winding of the transformer through the regulating resistance, through one set of contacts CC which close at the correct instant, thence to the center point of the moving armature from which it passes to the positive terminal of the battery under charge. This completes one alternation. During the next alternation of the cycle the voltage of the secondary winding is reversed; this time current flows from the other half of the secondary winding through the regulation resistance to the other set of contacts C1 C1 to the center of the moving armature, and then to the positive terminal of the battery.

The efficient operation of this device is dependent upon a vibrating mechanism which opens and closes contacts CC and C1 C1 exactly in synchronism with the voltage reversals so that the current carrying circuit to the battery is opened at the time the current flow is zero.

The vibrating part of the system consists of a polarized relay which is caused to function by two alternating current magnets in such a manner that it moves backward and forward in step with the alternations of the current. The bar marked D.C. magnet is energized by a coil which is connected in shunt to the battery so that its polarity never changes. The two permanent electro-magnets shown as A.C. magnets are wound in such a way that the ends PP are of the same polarity at the same time. On one alternation, the current flows through the A.C. magnet windings in one direction and, we will say, causes the ends PP to become of north polarity. With this condition existing the south end of the D.C. magnet will be attracted to the A.C. magnets of north polarity and since the arm marked "moving armature" is rigidly secured at the center point at the D.C. magnet (one end of which has now been attracted toward the A.C. electromagnets) one set of contacts will close.

When the A.C. current reverses on the succeeding alternation both the A.C. electromagnet ends PP will become of south polarity and then the north end of the D.C. magnet will be attracted toward the permanent A.C. magnets, thus closing the other set of contacts secured to the moving armature. This will reverse the connection of the alternating current circuit to the direct current circuit, but the direction of current has also reversed, therefore, the current flows into the circuit supplying the battery as it did on the first alternation.

The contacts CC and C1 C1 are thus opened and closed each time the

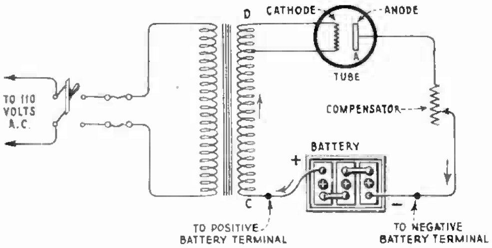


Figure 24.

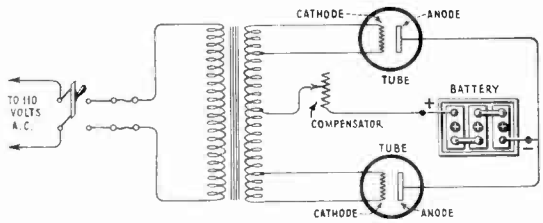


Figure 25.

current reverses in direction and, because of this, a uni-directional pulsating current is continually fed into the battery in the proper direction. An adjustable resistance is provided and connected in series with the alternating current magnets so that exact timing for the opening of the direct current carrying circuit is secured at the instant when the battery and transformer voltages are opposite and equal and no current flowing. This tends to insure a minimum amount of sparking at the contact points.

The condensers are connected across the contacts to further assist in reducing the sparking at the contact surfaces due to a variation in the line voltage.

THE HOT CATHODE GAS FILLED RECTIFIER

Figure 24 shows the connections of a half wave rectifier in which is employed the "hot cathode type rectifier". It consists of the tube with cathode and anode. The cathode consists of a filament of small tungsten wire coiled into a closely wound spiral, while the anode is a plate made of graphite which is secured to a rod by means of a screw thread.

A transformer and a compensator, with which is combined the filament transformer and reactance, is also a part of this rectifier unit. The compensator is illustrated in the drawing as an adjustable resistance. This resistance is not actually used in practice, but we have shown it in place of the compensator for the purpose of simplifying the drawing. An illustration of the rectifying tube is shown on back cover. When full wave rectification is desired the circuit shown in Figure 25, which is in simple form, is employed.

For a number of years scientists have known that a vacuum tube containing a hot and a cold electrode functions as a rectifier and it was from these principles that the Tungar Hot Cathode gas filled rectifier was developed.

A vacuum is created in the glass envelope containing the Cathode and Anode and then a small quantity of inert gas (Argon), at low pressure, is introduced. The name "Argon" comes from the Greek, meaning lazy or inactive, because it combines with no other element.

Electrons are emitted from the cathode when it is heated to incandescence, ionizing the argon gas particles which in this state acts as the principal current carrier. Rectification takes place because, on the half cycle, when the graphite anode is positive the electrons emitted from the incandescent cathode are being drawn toward the Anode due to the voltage impressed across the anode and cathode by the secondary of the transformer. The electrons collide with the gas molecules and ionize them; that is, make them conductive in the direction of cathode to anode.

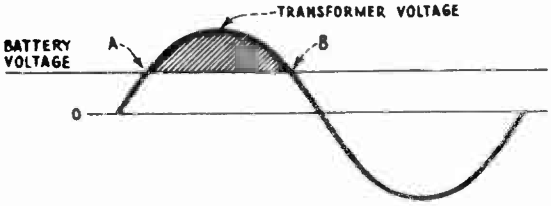


Figure 26.

During the other half cycle when the Anode is negative, electrons that are emitted are forced back to the filament, due to the negative space charge about the filament becoming dense so that the gas does not form a conducting path during that half cycle.

Assume, for example, that side D, Figure 24, of the alternating current supply is negative, the current then follows the direction of the arrows across the gas filled space between cathode and anode, through the compensator and thence through the battery being charged, returning to the opposite side "C" of the transformer secondary.

Now the alternating current supply reverses and the side "C" becomes negative; the current will be prevented from flowing because any electrons emitted are repelled back to the cathode by the negative space charge which immediately builds up around it, so that the gas in the tube is nonconductive during this interval.

From the foregoing we see that the current is allowed to pass from the cathode to the anode during one alternation of each cycle and thence to the external circuit.

The principle on which the storage battery is charged from this type of rectifier is graphically shown in Figure 26. The illustration shows one cycle of half wave rectification.

During the upper half of the cycle, when the transformer voltage exceeds the battery voltage, point A, the Anode of the tube becomes positive making the tube conductive and the charging current flows through the battery. When the transformer voltage drops below the battery voltage, point B, the tube is no longer conductive and the charging current ceases on the lower half of the alternation. The transformer voltage adds to the battery voltage and since the Anode does not become positive, the tube cannot conduct current.

A rectifier, then, is a device for converting alternating current to uni-directional current.

The full wave rectifier utilizes both alternations of the alternating current cycle. Both the positive and negative impulse of the cycle pass through the rectifier.

The half wave rectifier rectifies only one of the alternations, therefore, only one impulse of current passes through it for each full cycle of alternating current. The other alternation is not lost, but simply prevented from passing through the rectifier to the output circuit.

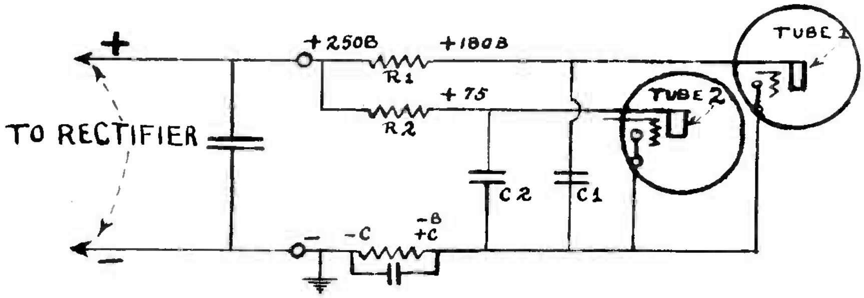
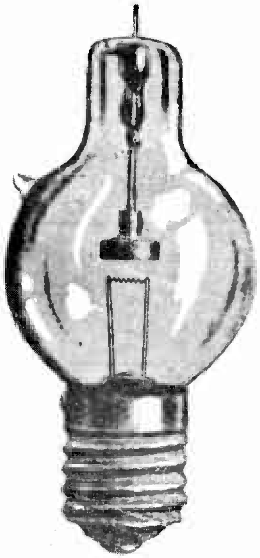


Figure 27.

EXAMINATION QUESTIONS

1. What is the function of the transformer used in A.C. operated power supply units?
2. Name three different types of rectifying tubes.
3. What would be the difference in the output voltage of a power unit using a 280 type rectifier if the first condenser at the input side of the filter condenser were omitted?
4. State in your own words the action taking place in a full wave hot cathode mercury vapor rectifying tube during one cycle.
5. What precautions must be taken in the operation of a hot cathode mercury vapor type tube.
6. What is meant by inverse peak voltage rating of (a) a full wave rectifier, (b) half-wave rectifier of the hot cathode vacuum type tube?
7. Explain the function of the parts in a two section brute force type filter system.
8. What is meant by bleeder current? Of what advantage is it?
9. Show the calculations necessary to determine the value of the resistor sections in the voltage divider of Figure 22.
10. What are by-pass condensers, why are they used and what determines their size?



Hot Cathode Gas Filled
Rectifier.

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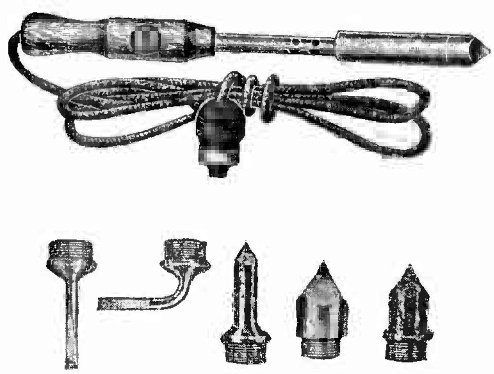


Electric Soldering Iron
With Changeable Tips

SOLDERING

ITS IMPORTANCE IN CIRCUIT WIRING

Vol.36#12

Dewey Classification R360

Some Standard Soldering Products
in Common Use

SOLDERING

Its Importance in Circuit Wiring

The present day receiver is a highly developed, quality instrument in performance. However it is natural that some of its parts should fail to function under abnormal load conditions or abuse. The service technicians job is to locate these defective parts by test. The next step is to disconnect that part from the circuit and replace it with a new one. In many instances it is even necessary to disconnect some parts such as condensers and R.F. or audio transformers from the circuit in order to be able to subject them to a test individually. The parts of modern radio apparatus are in almost all cases connected together by means of wires which are soldered to the terminals of the respective parts. Hence every time we wish to remove some piece of apparatus from a radio receiver's circuits it is necessary that the wires connecting it to the other circuit parts be unsoldered.

Purpose of Using Solder. The repair of any radio receiver usually entails the making of a number of soldered connections, and it is essential that the radio service man should know how to solder the connections correctly, because the many connections in the wiring of a radio receiver must be so treated in order to eliminate losses arising from high-resistance joints. It is recommended that, after carefully studying this subject, you put into practice the instructions contained herein. An hour or so spent with a simple soldering kit and a few scraps of copper wire should enable you to acquire the knack of making a neat, well-soldered joint. Any joint in the wiring of a receiver, in order to be good, must possess low electrical resistance and high mechanical strength.

If the surfaces of two copper wires are scraped until clean and bright and then firmly twisted together, the joint thus formed will possess good mechanical strength and low electrical resistance when first made. But with the lapse of time, inevitable vibration of the wires will tend to loosen the joint and this undesirable loosening will be further aggravated by expansion and contraction of the metal with temperature changes. Furthermore, due to the action which the oxygen in the atmosphere has upon the metal, oxidization of the surface of the metal will take place and eventually this oxidation will penetrate to every crack and cranny of the joint. As the oxides thus formed are very poor conductors of electricity, it can be readily appreciated that the result will be troublesome. This oxidization of the metal takes place slowly, but as this action progresses, inevitably the resistance of the joint becomes higher and higher until its resistance in extreme cases may become of such a value as to be nearly non-conductive.

Noisy and fluctuating reception volume is often due to poor joints. The amount of energy received by the antenna in the first place is very small and must be conserved to the greatest extent possible. There should be no waste of an appreciable amount of this energy which would be the result if it traversed high-resistance joints.

Solder, therefore, is applied to each and every joint in the wiring of a receiver for the purpose of enhancing the mechanical strength of the joints and to preserve their initial low resistance.

Although solder (an alloy of tin and lead) has greater resistance than copper, it is possible in the practical application to so form the joints that they will possess very low resistance. To accomplish this it is necessary to make joints, splices, and connections so that they will be mechanically secure and electrically conductive without the use of solder. Solder is then applied to preserve the stability of such joints both mechanically and electrically.

Action of Heat Applied to a Joint to be Soldered and Use of Soldering Flux. When soldering a connection it is necessary to heat the joint to a temperature at which the solder will melt and flow freely, and for this purpose the soldering iron is used. However, heated metal oxidizes rapidly and to prevent such oxidization, and to dissolve such oxides when they do form, a fluxing agent is applied to the joint to be soldered.

There are a number of fluxes available and the choice of the proper flux is of prime importance. The flux to be used in radio receivers, or in any delicate electrical work, must be both non-corrosive and non-conductive. Should corrosive flux be used, joints made by its use will eventually possess high-resistance due to such corrosion. Therefore, never use an acid flux.

Of all the fluxes available rosin flux and "Nokorode", or equivalent, are the best for radio use. Each has its advantages and disadvantages, as set forth below, and as the methods of application differ slightly the use of each will be taken up separately.

Nokorode is the easier of the two to handle and its use enables one to easily and quickly make well-soldered connections. However, although it is non-corrosive, Nokorode, or equivalent, possesses the disadvantage of being partially conductive and this point should be borne in mind when using it about a radio receiver. Moreover, it creeps rapidly when melted by the heat of the soldering iron, and should it run between two or more terminals in the receiver it would create a leakage path between such terminals. Even a very thin film of this flux, so slight as to be scarcely noticeable, permits the possibility of current leakage with consequent detrimental effects upon the efficiency of the receiver. Also, as this flux is made in the form of a grease-like paste, it readily collects dust, which, when occurring between two terminals, does not add to the efficiency of the receiver. It is permissible to use Nokorode, or equivalent, on joints where there is no possibility of its creeping and forming a more or less high resistance leak between different portions of the circuit. If it should creep between terminals or conductors placed in close proximity to one another, it must be wiped off carefully with a clean cloth, preferably a cloth dipped in alcohol.

Rosin Flux and so-called "Rosin Joint". Rosin flux, although it is more difficult to handle than Nokorode, or equivalent, is the best flux for all soldering operations about a radio receiver. It is both non-corrosive and non-conductive; as a matter of fact, the insulating qualities of rosin are excellent. Hence, if residual rosin is allowed to remain between two or more terminals or conductors, no harm is done and when it hardens it presents a smooth, glazed surface which does not readily collect dust.

Because of the fact that rosin will not introduce leakage between circuits, as the case with paste flux, it is used almost exclusively today in the manufacture of radio receivers.

On the other hand, rosin flux improperly used is quite apt to result in what is termed a "rosin joint". The creation of a rosin joint is to be avoided, for the resistance of such a joint may be easily so high as to constitute an open circuit. However, by exercising reasonable care in applying the rosin flux, such joints will not occur.

The Soldering Iron is made with a Copper Tip and Should not be Allowed to Overheat. The soldering iron consists of an insulated handle, an enclosed heater resistance unit and a copper tip. There are many electric irons on the market at very low prices, but the purchase of such irons is not recommended. These cheap irons invariably are poorly made, with the result that they either draw an excessive amount of current, furnish an insufficient amount of heat, or fail to stand up under continued usage; i.e., the heating unit burns out, thus rendering the iron useless. It is economical to pay more in the first place for a well made iron. Such irons are not expensive.

The proper degree of heat of an electric soldering iron is predetermined by the design of its enclosed heating unit and will always be right when used on an electric lighting circuit of correct voltage. Thus, the user is saved the inconvenience of having to heat the iron repeatedly, as is the case when electricity is not available and a plain iron must be used. Plain irons, although they cost less than the electric variety, must be heated with a blow-torch or in a gas flame. If the iron is heated in a gas flame, care must be exercised to keep it cleaned of the soot that will be deposited upon it. The proper degree of heat of any soldering iron is that at which it will melt the solder as soon as it is applied. In an electric iron the correct soldering temperature is automatically provided for by the design of the heating element. Electric soldering irons are made in various sizes, and are rated according to their electrical power consumption. Standard sizes range from those consuming as little as 15 watts to those consuming 300 to 400 watts.

The choice of a soldering iron for radio receiver work, since there are so many sizes to choose from, should be determined by the following considerations:

The iron should be efficient in design, that is: For the electrical power consumed a large percentage of the heat developed in the heating unit should be conducted directly to the tip, and should not be radiated by the heating unit to where it does no useful work.

The iron should not be too hot. Irons with a high power consumption are usually large, having very large tips (sometimes as much as several inches in diameter). These are designed for heating and soldering very large pieces of metal. In radio receiver and amplifier tube circuits it is only necessary that an iron be able to heat joints between wires very seldom larger than #14 in size. If an iron of very high wattage rating is used for such small work its tip will become excessively hot and as a result will become badly oxidized. This oxide acts as a heat insulator preventing the conduction of heat from the tip of the iron to the metals to be soldered and to the solder. Such an iron would have to have its tip continually scraped free from oxide in order to be able to use it.

When heating a soldering iron with a blow-torch or gas flame, be careful not to overheat the iron, and under no circumstances allow it to become red hot. The proper degree of heat is indicated by the appearance of a green flame about the iron.

The iron should be no larger than is necessary and should be of a size with a tip surface large enough and a heating element large enough to maintain the tip at a temperature slightly above that at which it will melt solder under continuous use.

The iron should be small in diameter, not more than ¾". This includes heating element as well as tip and should preferably be smaller in order that it be possible to get the iron into remote places where there is very little clearance between wiring and parts.

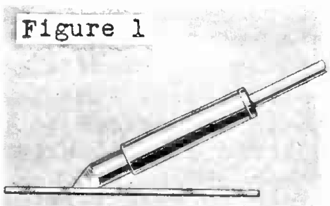
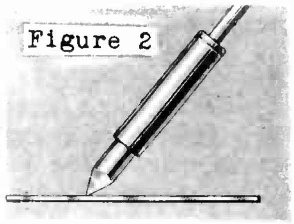


Figure 1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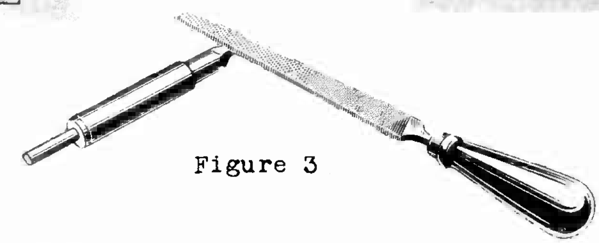
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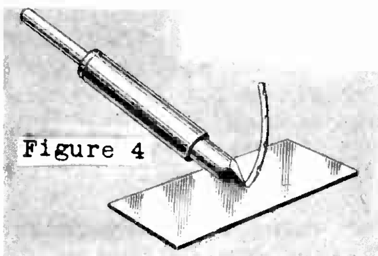


Figure 4

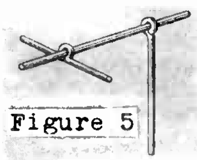


Figure 5

The iron if it has the above qualities will heat quickly and cool quickly (within 2 to 4 minutes). If the iron is of efficient design an iron of about 40 watts and not more than 60 watts rating, is sufficiently large enough for receiver circuit work. Inefficiently designed irons in order to meet the above requirements have a rating of from 75 to 100 watts.

When soldering wires larger than #14 and thin sheet metal and for heavier work irons having a rating of from 75 to 150 watts should be used because the smaller size irons would quickly cool to a temperature below that at which solder melts.

The point of the soldering iron should be properly shaped. Figure 1 illustrates a well shaped point. By the use of such a point, with its working surface held parallel to the work as shown, heat conduction from iron to joint is expedited, resulting in quick and efficient heating of the joint to proper temperature.

Figure 2 shows a poorly shaped point. To hold the working surface of such a point parallel to the work will often necessitate an awkward positioning of the iron. Where the nature of the layout of the receiver will not permit of a correct positioning, only a limited part of the iron's working surface can be brought into contact with the work. Result: Slow and limited heating of the joint and consequent possibility of producing a poorly soldered connection.

How to tin the Soldering Iron and Preparation of Joint for Soldering. Before soldering can be accomplished properly the iron must be "tinned". To tin the iron it is first heated and the working surfaces filed until the copper shows clean and bright, Figure 3. Do not bear down heavily upon the file for it is only necessary to remove such dirt and oxide as may have collected upon the surface of the copper. A daub of flux is now placed upon the surface of a piece of clean, bright tin, the heated iron is applied thereto

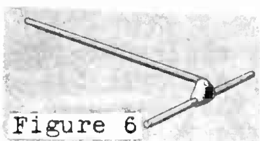


Figure 6

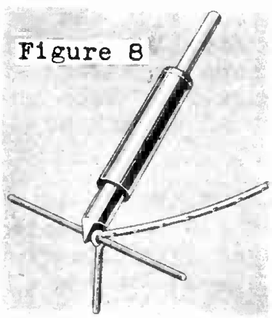


Figure 8

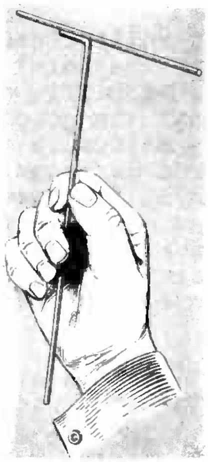


Figure 7

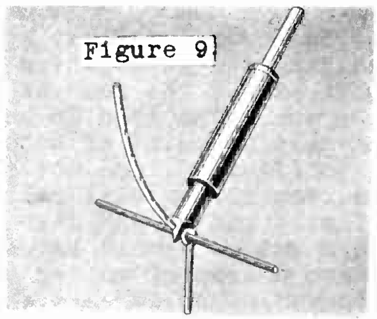


Figure 9

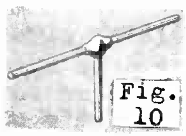


Fig. 10

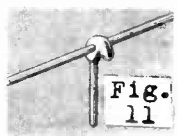


Fig. 11

and at the same time solder is melted by contact with the iron, Figure 4. The iron is now worked back and forth in this molten solder until its working surfaces are uniformly coated. The iron is now tinned and ready for use.

Soldering the Joint. Before a properly soldered connection can be made the surface of the wires must be scraped or sandpapered until clean and bright--THIS IS IMPORTANT. The joint is then made mechanically secure as shown in Figure 5. A loop is formed in the wire by means of a pair of long-nosed pliers. This loop is then slipped over the wire to which connection is to be made and pinched into place, resulting in a secure, self-supporting joint.

Compare the connections in Figure 5 with Figures 6 and 7 wherein are shown what are known as "abutted joints". The making of such joints should be avoided as they are insecure and very apt to possess poor electrical conductivity. To attempt to hold the wire of an abutted joint in position while soldering is certain to result in an unsatisfactory joint, for it is a physical impossibility to hold the wire absolutely steady for the length of time necessary for the solder to solidify. The slightest tremor of the hand at this critical stage will result in a fracture of the solder and, although this fracture may be so slight as to be quite unnoticeable, it nevertheless detracts from the strength and conductivity of the joint. Another objection to the making of abutted joints arises from the necessity, often encountered, of making two or more connections close to one another. While soldering one connection the heat will be conducted by the metal to the other connection and should this other connection be an abutted one, it will promptly fall apart. Having made the joint mechanically secure, the next step is the application of the flux. Of the two fluxing agents already mentioned as being suitable for radio and other delicate electrical work, namely Nokorode, or equivalent, and rosin, we will consider the use of Nokorode first.

Nokorode, or equivalent, can be applied to the joint either before or after it has been heated, but to apply to the joint before it has been heated is perhaps preferable. Assuming that the service man is soldering a joint as shown in figure 5, Nokorode flux is first applied to the joint. This paste should be used very sparingly, only enough to cover the joint with a thin film. If an excess of this flux is used it will creep rapidly as it melts, and this is highly undesirable for reasons already stated.

The soldering iron, properly heated and well-tinned, is now applied to the joint, melting the paste which runs into the joint where it accomplishes its purpose; i.e., the removal of any slight film of oxide that may have formed thereon. The iron is held against the joint until the joint is heated to the melting point of solder. The solder is then applied to the joint, as shown in Figure 8, and not to the iron as shown in Figure 9. When properly done, the solder will melt as soon as it comes in contact with the joint and will run in and over the joint making a neat, workmanlike job. Only enough solder should be used to cover the joint, as shown in Figure 10; do not leave a lump of solder on the joint as shown in Figure 11. Such unsightly "gobs" of solder are wholly unnecessary and present an unworkmanlike appearance.

If any of the flux remains on the joint or adjacent insulation, which it usually does, it should be carefully wiped off with a clean cloth. Special care should be exercised in this respect in case the residual flux has crept between two or more wires or terminals. In any case, it is best to use a clean cloth that has been dipped in alcohol. The alcohol materially aids the thorough cleansing of the joint and adjacent insulation by dissolving the left-over flux.

Incidentally, the handiest and most practical forms of solder for radio use are ribbon and wire solder. Wire solder is made with a core of rosin flux, a very convenient arrangement, for by its use flux and solder are applied to the joint in one operation.

When using rosin-core solder a somewhat different procedure is in order insofar as the flux is applied to the joint after it has been heated. First, apply the iron to the joint until the joint is well heated; then apply the rosin-core solder. Be careful to apply the solder to the joint, as shown in Figure 8. The rosin flux in the core of the solder will at once melt and run upon the joint, fluxing it. The solder will also melt rapidly and follow the flux to the joint, resulting in a neat, well soldered connection.

Even as the use of Nokorode, or equivalent, has one pronounced disadvantage; namely, the likelihood of current leakage due to the presence of residual flux; so has rosin flux one pronounced disadvantage, and that is the possibility of producing a "rosin joint". A rosin joint is the result of burned rosin collecting on the joint and is due to the improper manipulation of the soldering iron and solder. The solder will often flow over such a joint giving the appearance of a well soldered connection, when, in reality, the burned rosin in the joint results in a high-resistance connection and in severe cases even an open circuit. To avoid the making of rosin joints the rosin-core solder must be applied to the heated joint, not to the iron. If the rosin-core solder is applied to the iron, as shown in Figure 9, a rosin joint will very likely be made for the following reason. The melted rosin flowing upon the iron will result in the active ingredients of the rosin flux literally "going up in smoke," while the useless burned residue will flow down onto the joint. As that active ingredient in the flux which accomplishes the proper fluxing of the joint has been evaporated by the heat of the iron, the burned rosin remaining is of no use as a fluxing agent and only serves to obstruct the soldering operation. Therefore, care should always be exercised in the use of rosin-core solder. When handled correctly, however, rosin-core solder is really excellent for radio use. If an iron is used which is of a temperature just slightly higher than that at which solder will melt, it will not burn the rosin and as a result the forming of rosin joints is avoided. You can therefore readily see that the selection of a soldering iron of the proper type and rating is important in order that high resistance joints be avoided and much waste time and money saved.

It is often necessary in the wiring of a radio receiver to carry the solder to the joint on the soldering iron. This is greatly facilitated by notching the iron with a file, as shown in Figure 12; this notch serves to hold a bubble of molten solder while the iron is brought to the joint. When a bubble of solder is brought into contact with the joint it will heat the joint very quickly and, provided the joint has been properly fluxed, the solder will flow readily to it.

Practical Application of Solder to Metal Units or Parts of Receiver, Wiring, Terminals, Lugs, etc. It is impossible to solder to nickel plated surfaces when using these fluxes permissible in radio work. Therefore, when solder-to an instrument or terminal which is nickel plated, it is necessary first to scrape the plating from that part of the instrument or terminal which is to be soldered until the base metal, usually brass, is exposed. Soldering is then accomplished in the usual manner.

It is always best to solder connections, but when soldering wires to certain apparatus it is sometimes necessary to modify this rule. When it is inadvisable to solder a connection directly to the binding post terminal of an instrument, the wire should be soldered to a connecting lug and this lug should be then clamped tightly beneath the nut of the binding post. Bear in mind, however, that such a connection does not constitute a soldered joint. The actual connection between lug and binding post terminal of the instrument is a mechanical one and every care should be exercised that it be not only good but permanent; i.e., the contact surfaces of lug and terminal should be scraped, or sandpapered, until clean and bright, and the lug then clamped tightly beneath the nut of the binding post.

Figure 13 illustrates a commonly used type of connecting lug. These lugs are usually made with a small hole in the shank and through this hole the wire is slipped and pinched securely into place by means of pliers. Solder is then applied to this joint to insure the preservation of its mechanical strength and electrical conductivity. If the lug has a small trough, as in B, Figure 13, the wire is clamped into place in this trough and solder then run into it.

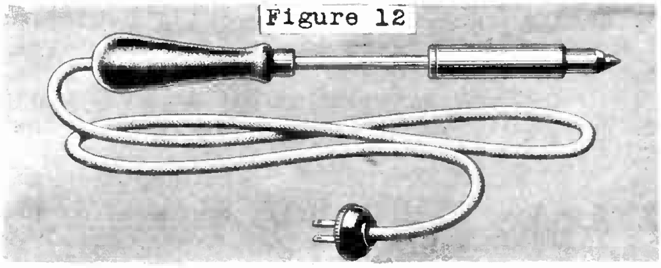
Instruments to which it may be inadvisable to solder directly are a. f. transformers, small fixed condensers, grid leaks, and fixed and variable high resistance units.

Many makes of audio-frequency transformers are equipped with binding post terminals, and it is not good policy to solder directly to these. Solder the wire to a lug and clamp the lug tightly beneath the binding post nut. The wires leading from the windings of the transformer are usually soldered to the shanks of the binding posts inside the casing.

An attempt to solder directly to such terminals will possibly cause the connections with the case to become unsoldered, resulting in an open-circuited transformer. However, many of the later types of audio-frequency transformers are provided with lug terminals. It is quite safe to solder to these as the manufacturer has anticipated, and provided against, the loosening of the interior connections during the soldering operation.

Some types of small fixed condensers are made with plates of flimsy tinfoil. Do not solder connections directly to such condensers, as the heat of the iron is likely to damage the plates. Connection should be made by slipping a small (8/32) brass machine screw through the hole usually provided for such a purpose and clamping a lug, to which the connecting wire has been soldered, beneath the nut of the machine screw. However, connections may be soldered,

Figure 12



without fear of damage to those types of condensers having plates of sturdy copper foil, or thin strip brass, and solidly moulded in a protective casing of bakelite.

Grid leaks and other tubular high resistance units are almost invariably mounted by slipping them between two metal clips which serve to hold them firmly in place and make contact with their terminals. As a rule, the amount of heat necessary to solder connections to grid leaks and tubular high resistance units will damage the resistance thereof or will loosen, or entirely detach, the small metal end-caps which serve as the terminal of such devices.

When the grid leak or high resistance unit is a solid rod or such material as carborundum or graphite, or if it is a resistance unit of wire, it is not safe to make soldered connections to such devices unless the manufacturer specifically states that soldering will not damage his product. Instead, make a firm, secure, mechanical connection by means of the terminal provided for this purpose.

A method of splicing comparatively coarse wires, such as are used for the antenna, lead-in and ground wires, is shown in Figure 14. The wires are twisted once, as shown at point A, then bound tightly one about the other, as shown at points B and C. A slight space is left between these adjacent turns of the wire to allow the flux and solder to penetrate to the innermost crevices of the joint.

The foregoing instruction upon soldering may be summarized in a few simple rules, as follows:

1. The joint to be soldered must be clean, mechanically secure and electrically conductive.
2. The soldering iron must be clean, well tinned and heated to the proper temperature. (Use an electric iron, it is by far the best.)
3. Never use an acid flux.
4. Use the right flux, such as Nokorode, or equivalent, or rosin, and use it sparingly, keeping in mind the limitations of each.
5. Flow just enough solder on the joint to cover it.
6. If a paste flux such as Nokorode, or equivalent, is used, wipe away the residual flux with a clean cloth, preferably a cloth dipped in alcohol. Preferably use rosin core solder.

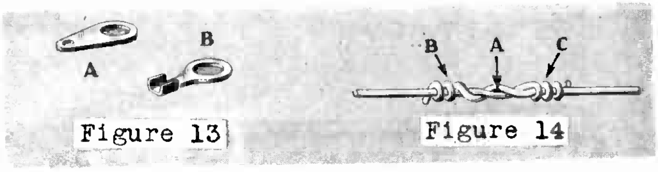
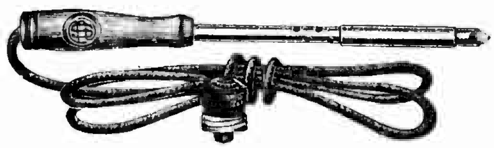


Figure 13 Figure 14

EXAMINATION QUESTIONS

1. What are the primary requirements of a good joint?
2. What is meant by "tinning" the iron?
3. State briefly the advantages and disadvantages of:-
   (a) paste fluxes.
   (b) rosin fluxes.
4. Why is solder used in making joints?
5. What precautions should be observed when using paste flux?
6. What is an abutted joint? Is the making of abutted joints considered good practice?
7. How much solder is necessary to make a good joint?
8. What precautions should be observed when using rosin flux?
9. What happens when a joint is left unsoldered?
10. Is the use of acid flux permissible in radio work? State why.



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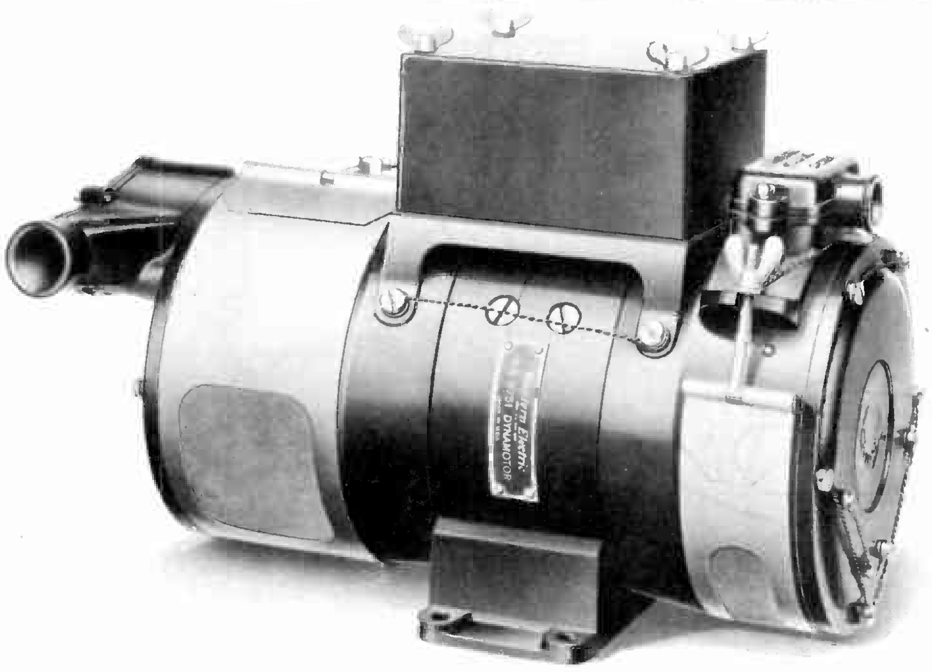


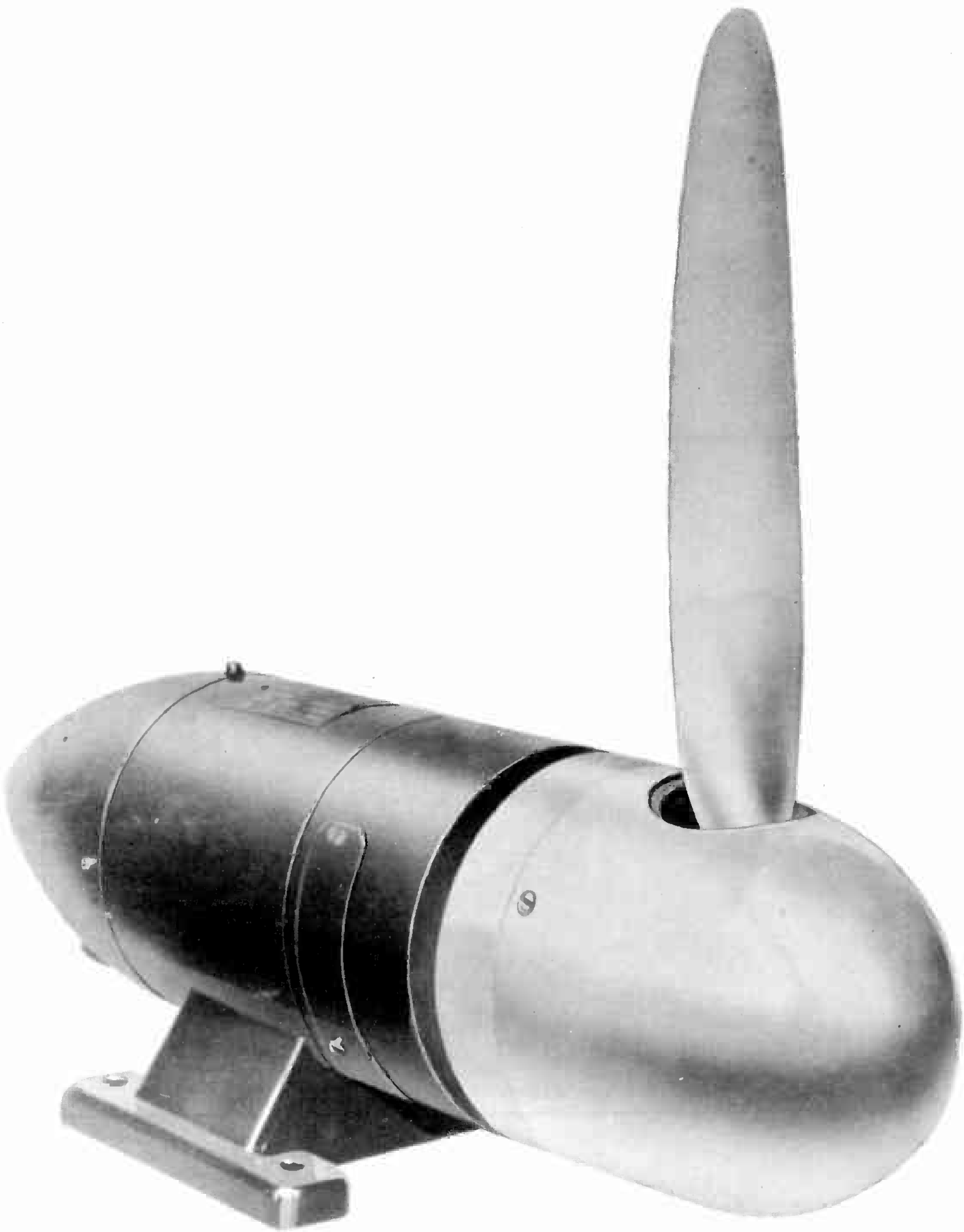
Courtesy Bell Telephone Laboratories

One part of an Aircraft Radio Power System.

Aviation Radio Power Equipment

Vol. 52, No. 5

Dewey Classification R 520



Courtesy Bell Telephone Laboratories

One type of Deslauriers wind driven generator.

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AVIATION RADIO POWER EQUIPMENT

Power supplies used in aviation in conjunction with radio sets can be classified in many ways. The broadest classification is probably best indicated by considering the sources of power available at ground stations and the apparatus used to secure power for the radio sets on planes. Remember that the word, "aviation" applies to all of the activities associated with the flying of heavier-than-aircraft, whereas the word "aircraft" means, so far as we are concerned, the transport and private plane. The transport plane carries a transmitter and a receiver; the single pilot mail plane a receiver.

POWER SUPPLIES AT GROUND STATIONS. The choice of apparatus to be used to supply power at aviation radio stations depends upon whether or not there is a commercial source of electricity available. Most civic airports and many of the airways stations are situated close enough to some city or some power line to purchase electrical power. Some intermediate landing fields and airways beacon stations are so isolated that they must generate their own power. Gas engines are usually used at such station. In fact, all government airways stations have a gas engine-driven generator unit as an auxiliary source of power. Practically all ground stations also have a bank of storage batteries which can be used in an emergency. The problem of planning out a suitable power installation at a ground station becomes comparatively simple when it is known what that station is to be used for. This is true because every radio transmitter and receiver requires certain voltages, whether AC or DC. Therefore, when commercial power is available, the dynamotor or motor generator, and battery become a part of the general equipment. The dynamotor selected is one that will run when supplied from the current commercially available. The generator end of this dynamotor will deliver a suitable voltage for charging the storage battery used as an auxiliary source. This battery can usually be made to drive the motor end of another motor generator set or dynamotor.

Typical power installations as found at numerous airways stations will be described later on. In the meantime, remember that they consist of a primary source such as a generator, either owned by some power company or installed at the airways station, some kind of rotary converter device for creating the kind of electricity needed at the station, and storage batteries which are kept fully charged, as reserve power. (Figure 1 shows one type of motor generator set now in use at certain radiobeacon stations.)

AIRCRAFT RADIO POWER SYSTEMS. This term should not be confused with plane power systems, even though some part of the plane power supplies may be used as a part of the radio power supply system. (As in the case where the plane's storage battery or its charging generator, is also used in connection with the radio installation.) The various pieces of apparatus which go to make up the power supply unit for an airplane radio installation is commonly referred to as a "power unit" or "power pack". These radio power supply systems are usually made up of some combination of the following units: (1) Batteries, dry and storage; (2) Generators, wind-driven and engine-driven; (3) Dynamotors. There is another power system coming into use which utilizes rectifiers, but the three units just listed above are the three which we must consider most important.

It will be well for you to note at this time that there are certain very desirable qualities which all power packs should possess. The most important of these is reliability. Planes will actually be ordered to stop flying if their source of radio power fails. It is also essential that the power supply remain adequate; that proper voltage and amperage be deliverable at all times. A power pack should be designed to stand a certain overload, although the operator should not overload his set. A third quality desired is that any DC voltage delivered be without ripple and that any AC voltage delivered be of constant frequency. An important requirement from the commercial point of view is that power equipment not be too expensive, either as to original cost or upkeep. It should be rugged, well shielded and not too heavy.

Storage batteries are much favored in aviation as an A(filament)-voltage supply for aircraft receivers, although planes desiring lighter radio equipment sometimes use dry batteries. The voltage desired does not usually exceed 10.5. As you know, the plate circuit of a receiver requires a much higher voltage than the filament. For this reason, special dry batteries delivering up to 235 volts are available. When a higher voltage than this is desired aboard an airplane, a dynamotor is usually employed. These dynamotors usually supply any specified voltage, 1050 being the highest voltage now employed. Generators, either wind or engine-driven are available which will supply both a low and a high voltage in the one machine. These will be described in detail in this lesson.

BATTERIES.

The student has already learned a great deal about batteries as primary and storage batteries were both fully discussed in previous lessons. As batteries are an extremely important part of the power equipment of radio equipped planes and at airways radio stations, they will be again discussed at this time.

DRY BATTERIES. Dry batteries are often used as B batteries in connection with aircraft radio receivers. When first installed, they are tested for voltage three ways: open circuit, with the normal load imposed by the receiver; and (momentarily) under a dead short condition. A "log" or record is kept of the total ampere-hours furnished by each B battery installed and this record, combined with the periodic voltage-reading tests, as mentioned, will furnish the operator and radio maintenance crew with accurate information as to the condition of the B batteries. Briefly, the condition of the battery is the most important thing for a radio operator to know about the B battery.

B batteries should be replaced at once in the event that they fail to maintain voltage under the operating conditions imposed upon them. This statement holds true whether the batteries are old or new, and whether or not they have delivered their total rated ampere-hours.

CONNECTING DRY CELLS. The e.m.f. of a dry cell in good condition is about 1.5 volts on open circuit. Due to its internal resistance, the terminal voltage drops a little when the cell starts to deliver current.

A test of a cell with a voltmeter is of no value when the cell is not delivering current, for even a cell that is almost entirely discharged will test close to 1.5 volts on open circuit. When delivering maximum current the voltage of a new cell should remain as high as one volt.

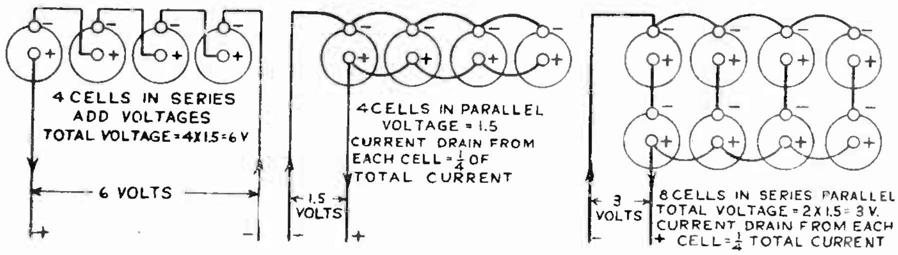


Fig. 1 - Showing different methods of connecting dry cells.

The method of testing dry cells in practice is to connect an ammeter of low resistance (less than .01 ohm) directly across the terminals of the cell. On this short circuit (through the low resistance of the ammeter having a scale reading up to about 50 amperes) a 6-inch dry cell will generally deliver a current of from 25 to 30 amperes. The ammeter should be left across the terminals only long enough to take the reading. As a dry cell becomes old, its internal resistance increases so that the amount of current flowing during the short circuit test through the ammeter decreases. A 6-inch cell should not be used with aircraft radio sets if it reads less than 5 amperes on this so-called ammeter test.

In all radio diagrams a single cell is represented by a pair of parallel lines, one long and thin representing the positive terminal and the other short and thick representing the negative terminal. Figure 1 shows the various methods of connecting dry cells.

AIR-CELL BATTERIES. A new form of primary batteries has recently been developed which is an especially good type for supplying constant voltage to the filament of the two-volt tubes often employed in battery operated receivers. This new form is known as the air-cell battery. In this type the oxygen used as a depolarizer is absorbed directly from the surrounding atmosphere instead of being supplied in the cell in the form of manganese-dioxide as is the case with the ordinary dry cell. The electrodes are made of zinc and carbon. Whereas the ordinary dry cell uses a depolarizer in the form of a paste to prevent the hydrogen (an insulator) from forming on the carbon electrodes, the air-cell uses an electrolyte solution in conjunction with a plate which is formed of a recently invented carbon of special grade. This carbon is highly porous to oxygen and has the peculiar property of extracting oxygen from the supply existing in the surrounding air. This oxygen combined with the hydrogen on the zinc electrodes causes water to form within the cells. The electrolyte used is a solution of sodium hydroxide (caustic soda), and the active ingredient is zinc. As the zinc dissolves in the electrolyte, a chemical reaction takes place which produces as a waste product, sodium zincate. In addition to these elementary materials, the battery also contains a certain amount of calcium hydroxide. The purpose of the calcium hydroxide is to rejuvenate the spent electrolyte. The sodium zincate, which results when the zinc goes into solution reacts on the calcium hydroxide with the result that calcium zincate is produced, plus sodium hydroxide. Inasmuch as sodium hydroxide is the required electrolyte, this material evolved from the above reaction is available for further dissolution of zinc.

To place the battery in service, all that is needed to be done is to remove the covers from the electrodes so that they can "breathe" oxygen, punch out the membranes in the bottom of the filter holes, and fill the two compartments with cold drinking water. A total of about six quarts of water is required. This battery has a very definite overload point which should not be exceeded. The overload point is determined by the maximum rate at which the carbon electrode can extract oxygen from the surrounding air and amounts to approximately .75 amperes. At current drains below this figure, the porous carbon is able to replenish the oxygen as rapidly as it is consumed within the battery, and as long as the carbon contains oxygen, it repels water and remains dry. This type battery has a current capacity rating of 600 ampere-hours. Remember that it is a primary battery, and therefore <u>cannot be recharged</u>. When <u>completely discharged</u> it is worthless and must be discarded.

STORAGE BATTERIES. Aircraft radio storage batteries are not essentially different from ordinary radio batteries, except that they are equipped with non-spillable vent plugs and are usually placed in an additional container, which is often clamped shut.

It is desirable that the aviation radio operator have a good general knowledge of the construction and theory of storage batteries so that he may properly inspect, repair and service them. The most important work in servicing batteries, of course, is the charging and discharging. The charging of batteries is usually done by some radioman in the ground crew whereas the discharging is under cognizance of the operator who uses the battery after it is installed on the plane. Many companies require that the radio operator assigned to a plane test and maintain fully charged two or more batteries assigned to his plane, two or more being signed for by him in order that he may have available, by proper management, one fully charged battery at the beginning of each scheduled flight. In this case the operator keeps a complete record of all service rendered by the battery in ampere hours and all service rendered to the battery in the way of charging, testing, etc.

A storage battery is defined as a connected group of two or more electro-chemical cells for the generation of electrical energy in which the cells after being discharged may be restored to a charged condition by connecting current to flow in a direction opposite to the flow of current when the battery discharges. Common usage permits this designation to be applied to a single cell used independently.

A storage cell is defined as the unit of the battery, consisting of positive and negative plates, separators, electrolyte and container, for the generation of electrical energy and capable of being recharged by an electric current.

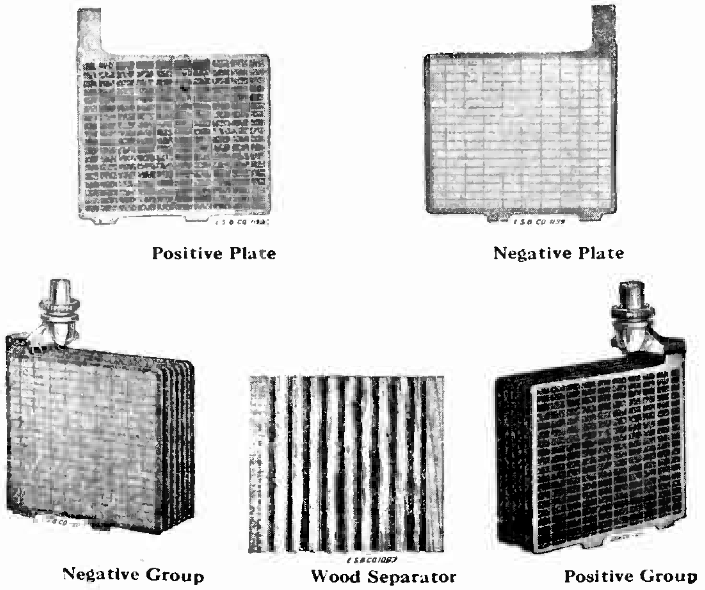


Fig. 2A - The different parts of a lead storage battery.

Active materials are the materials on plates which react chemically to produce electrical energy during the discharge. The active materials of storage cells are restored to their original composition in the charged condition, by oxidation or reduction processes produced by the charging current. In the charged condition the active materials are as follows:

Plate	Lead-acid cells	Nickel-iron alkaline cells(Edison)
Positive	Lead peroxide	Oxides of nickel
Negative	Sponge lead	Iron

The grid is a metallic framework for conducting the electric current and supporting the active material. The positive plate is the grid and active material from which the current flows to the external circuit when the battery is discharging. The negative plate is the grid and active material to which the current flows from the external circuit when the battery is discharging.

Electrolyte is an aqueous solution of sulphuric acid used in lead cells and of certain hydroxides used in nickel-iron alkaline cells. The concentration of the solutions varies somewhat with the type of cell, its use and condition. The electrolyte of charged cells at 70° Fahrenheit (21° cent.) will ordinarily fall within certain limits of specific gravity.

The number of ampere-hours which can be delivered by a cell or battery under specified conditions as to temperature, rate of discharge and final voltage is the capacity of the cell or battery.

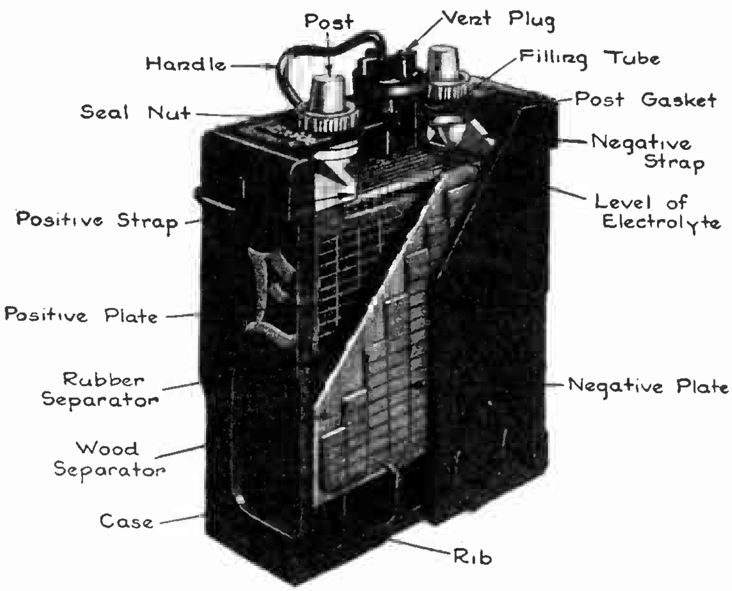


Fig. 2B - A cut-away view of lead storage cell.

Watt-hour capacity is the number of watt-hours which can be delivered by a cell or battery under specified conditions as to temperature, rate of discharge and final voltage.

The time-rate is the rate in amperes at which a battery will be fully discharged in a specified time, under specified conditions of temperature and final voltage. Example, the eight-hour rate or the twenty-minute rate.

Charge is the conversion of electrical energy into chemical energy within the cell of battery. This consists of the restoration of the active materials by passing a uni-directional current through the cell or battery. A battery or cell which is said to be "charged" is understood to be fully charged.

Discharge is the conversion of the chemical energy of the battery into electrical energy.

The charging rate is the current expressed in amperes at which a battery is charged. The finishing rate is the rate of charge expressed in amperes which the charging current for some types of lead batteries is reduced near the end of charge to prevent excessive gassing and temperature rise.

A charge in which the current is maintained at constant value is called a constant-current charge. For some types of lead batteries this may involve two rates, called the starting, and the finishing, rates.

A constant voltage charge is a charge in which the voltage at the terminals of the battery is held at a constant value. A modified constant is usually one in which the voltage of the charging circuit is held substantially constant, but a fixed resistance is inserted in the battery circuit producing a rising voltage characteristic at the battery terminals as the charge progresses. This term is also applied to other methods of producing automatically a similar characteristic.

A boost charge is a partial charge, usually at a high rate for a short period.

An equalizing charge is an extended charge given to a battery to insure the complete restoration of the active materials in all the plates of all the cells.

A trickle charge is a continuous charge at a low rate approximately equal to the internal losses and suitable to maintain the battery in a fully charged condition. This term is also applied to very low rates of charge suitable not only for compensating for internal losses, but to restore intermittent discharges of small amount delivered from time to time to the load circuit.

"Floating" is a method of operation in which a constant voltage is applied to the battery terminals sufficient to maintain an approximately constant state of charge.

The electrolyte of lead-acid batteries increases in concentration to a fixed maximum value during charge and decreases during discharge. The concentration is usually expressed as the specific gravity of the solution. The variation of specific gravity of the solution affords an approximate indication of the state of charge.

The specific gravity of the electrolyte in nickel-iron alkaline (Edison) batteries does not change appreciably during charge or discharge and therefore does not indicate the state of charge. The specific gravities, however, are indication of the electrochemical usefulness of the electrolyte.

Gassing is the evolution of oxygen or hydrogen, or both. Batteries are usually rated in terms of the number of ampere-hours which they are capable of delivering when fully charged and under specified conditions as to temperature, rate of discharge and final voltage. For different classes of service, different time-rates are frequently used.

LEAD STORAGE BATTERY. Lead storage batteries used in aircraft radio work areclassified as portable type batteries. The 6-cell or 12-volt type is more often used than the 6-volt type, especially when a dynamotor is used. The monobloc rubber or composition case is now in almost universal use in most portable batteries. This case is made of hard rubber or composition, formed under pressure, the cell partitions being in one piece with the walls and bottom. This eliminates the use of separate rubber jars for each cell and makes a case which is not affected by acid, dirt, water or oil. While installing, removing, or inspecting batteries, the radioman should carefully note any cracks, dents or abrasions that may develop into a leak.

The cells are arranged in the case in such a manner that the positive terminal of one cell is adjacent to the negative terminal of the next cell. A short, heavy bar of lead called a top connector is used to connect the cells of the battery in series. After all the top connectorsare in place there will be a positive post of one cell and a negative post of another cell available as battery terminals. Terminal connectors are placed on the terminal posts to connect the battery to the electric circuit of the radio set.

The cell or battery unit contains five fundamental battery parts: the positive plates, the negative plates, the insulation between the plates, the electrolyte or battery solution and a hard rubber jar. The cover is also of hard rubber and is sealed into the jar with a plastic sealing compound. The cover is fitted around the posts of the element to prevent any leakage of the battery solution at this place.

Ribs or plate rests are placed in the bottom of the jar. These ribs, besides supporting the plates in place, provide a space of collecting the material that has been worn from the plates during service. In the cover of each cell is an opening into which is secured a vent plug. This opening provides a place for the regular testing of the solution and replenishing with distilled water which is necessary. The hard rubber vent plug should always be fastened in place when the battery is in service as it prevents a spilling of the solution and provides a means of escape for the gas which forms within the cell. <u>Non-spillable plugs are fitted in all aircraft batteries</u>.

A battery <u>element</u> consists of a group of positive plates and a group of negative plates assembled together with the necessary insulation between them. For special purposes the plates are limited to a certain size and the common method of building up the elements is to increase the number of plates, to increase capacity.

In the construction of <u>groups</u>, a number of plates of one kind are welded to a connecting strap by the process known as lead burning. The number (and size) of plates so used determines the capacity. It will always be found that there is one more negative plate in each element than there are positive plates in order to permit the uniform working of all the positive plates in the group. The radio and lighting battery generally contains from three to eight positive plates and four to nine negative plates in the respective groups.

The positive and negative plates are made up of a frame work or grid, the openings of which are filled with a paste of lead oxides. These oxides become the active material of the finished plate. One form of grid is cast from an alloy which consists principally of lead to give the proper mechanical strength.

After the plates are pasted, they are dried and formed, that is, the lead oxides are changed into the active material by placing them in tanks of weak acid solution and charging them at a low rate. When completely formed, the paste in the positive plate has become peroxide of lead and the paste in the negative plate has become sponge lead. The finished positive plate can be determined by its color which is chocolate brown while the finished negative plate is a dull slate gray.

A battery element is defined as a group of positive and a group of negative plates assembled together with the necessary insulation between the plates. The insulation is placed between the plates so that there can be no contact between any of the positive and negative plates within the cell. If, at any time, a connection occurs between the two groups, causing a short circuit, the battery becomes inoperative. Proper insulation between the plates, therefore, is of vital importance.

The materials used between the plates of various aircraft radio and lighting batteries may be grouped as follows:

1. A wood sheet or separator.
2. The combination of a perforated hard rubber sheet and a wood sheet.
3. Threaded rubber insulation.

Thin pieces of porous wood are used in the manufacture of wood separators. These pieces of wood are grooved vertically and are then treated. This treatment removes the principal injurious substances the wood may contain which would be detrimental to the operation of the battery. The separators are then washed in water and usually kept in a moist condition until they are used between the battery plates.

Wood separators are cut from selected Port Orford Cedar and treated by the most improved processes, making them as near perfect as wood insulators can be. The treatment they receive removes all substances that would be detrimental to the battery. At the same time it assures separators of uniform porosity without reducing the natural strength of the wood. (Remember this when replacing, during overhaul.)

To assist in conserving the life of wood, thin perforated hard rubber sheets are sometimes used in connection with the wood separators. These thin rubber sheets are perforated to permit circulation of the battery solution. The addition of this sheet (and also the increase in space between the plates due to this additional sheet) reduces the battery's capacity at high rates and also its voltage on discharge. This is especially noticeable when the battery is at a low temperature and when it is discharged at a high rate. The student is advised to inspect a torn down lead battery at his first opportunity.

Four of the five fundamental parts that are essential to a storage battery have been discussed. We now come to the battery solution which is termed electrolyte. The electrolyte is a mixture of chemically pure sulphuric acid and pure water.

Specific gravity is defined as a comparison of the weight of acid with the weight of an equal volume of water at the same temperature. For practical purposes, instead of weighing a sample of electrolyte to obtain the specific gravity, a much simpler method has been devised. The specific gravity is obtained by means of a syringe hydrometer. (Examine one, if you are not familiar with their construction.)

In a fully charged aircraft radio battery, the specific gravity of the electrolyte should be between 1.275 and 1.295 (31.0° to 33.5° Baume). A gravity reading of 1.220 (26.5° Baume) indicates that the cell containing the electrolyte with this density is half charged. Gravity readings of 1.150 (19.5° Baume) or lower indicate that the cell is completely discharged and should be placed on charge as soon as possible. See Figure 3.

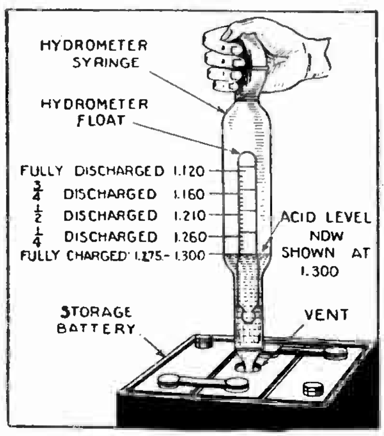


Fig. 3 – Testing with hydrometer.

Batteries in tropical countries use a lower maximum specific gravity electrolyte. When fully charged their specific gravity should be between 1.200 and 1.225. When partly charged their specific gravity is of course comparatively lower. To read the specific gravity of the electrolyte in the battery it is only necessary to:

1. Remove vent plugs from cells.
2. Compress bulb of syringe hydrometer.
3. Insert rubber tube through vent hole into electrolyte.
4. Release bulb until sufficient solution is drawn into the tube to cause the hydrometer float to rise and float freely.
5. With the syringe in vertical position so that float does not touch sides of tube, but is suspended freely in the acid, and

with the rubber bulb fully expanded, the specific gravity reading is taken on the graduated scale at the surface level of the solution.

6. Compress bulb and return electrolyte to the same cell from which it was taken.

7. Replace vent plugs.

A test made immediately after water has been added will not register correctly, since the solution must be given time to thoroughly mix. The test should be made before water is added or after the battery has been on charge or in use for a few hours.

Do not expect accurate readings from small inexpensive or inaccurate hydrometers. To get the best results use large shop type hydrometers, - and keep both float and barrel clean.

To determine the actual or true specific gravity of the electrolyte, it is necessary to check the temperature of the solution with a thermometer. If the temperature is normal (80° F.) the reading will be correct. However, if the temperature is above or below this figure, it will be necessary to make an allowance to determine the actual specific gravity. This is due to the fact that the liquid expands when warm and the same volume weighs less than when it is at normal temperature. The reverse is also true and when the temperature is below normal or 80° F. the liquid has contracted and the same volume weighs more than it does when normal.

There is a Correction Chart furnished aircraft radiomen which shows the figures to be used to make these corrections. For example, when the specific gravity, as shown by the hydrometer reading is 1.290 and the temperature of the electrolyte is 60°, it will be necessary to subtract eight points of .008 from 1.290 which gives 1.282 as the true specific gravity.

If the hydrometer reading shows 1.270, at a temperature of 110° F., it will be necessary to add twelve points or .012 to the reading which gives 1.282 as the true specific gravity.

It is never necessary to add acid to the cells of a battery unless some of the solution has spilled or leaked out. The use of an accurate voltmeter and the taking of cell voltage readings is of added help in determining the state of charge. The voltmeter is a valuable auxiliary to the hydrometer, but to use it correctly requires a more detailed knowledge of the electrical characteristics of cells on charge, effect of temperature, etc.

If both specific gravity and voltage of all cells reach the expected maximum and show no rise over a period of several hours of continuous charging, the radioman can be doubly sure all cells are charged. All voltage readings must be taken with current at the finish rate passing through the cells. If the current varies from this rate, the readings will be misleading. Open circuit readings are valueless.

All batteries have the terminals plainly marked. Positive is marked "POS" or "P" or "+"; the negative is marked "NEG" or "N" or "-". To put a battery on charge always connect the positive terminal of the battery to the positive charging wire and the negative terminal of the battery to the negative charging wire.

If battery is not connected to the charging wires correctly the current will pass through it in the opposite direction to that necessary to charge it. The plates will change their polarity, making positive plates out of the negative and negatives out of the positive. The reversal of plates usually ruins them.

The best way to determine the polarity of a direct current line is to use a high resistance, direct current voltmeter of sufficient range to measure its voltage.

In summer weather and in tropical climates it may be difficult to keep the temperatures of aircraft batteries on charge under 110° F. (43° C.) A safe rule to follow is to take the battery off charge and allow it to cool as soon as the temperature exceeds 110° F. is only a few degrees below the critical temperature (between 120° F. and 130° F.) at which plates and separators are seriously damaged.

Regular and systematic checking of the cell temperatures is recommended particularly when the plane habitually flies to high altitudes as the change in temperature is bound to hurt the battery. These "cold" batteries should receive a warming up charge, before the regular charging rate is applied.

There is only one practical rule for all charging: - Charge until all cells gas freely and the specific gravity of all cells stops rising over a period of several hours continued charging.

Hydrometer tests should be made every few hours during charge. If at any time the specific gravity exceeds the desired maximum, 1.295 (33° Baume), remove some electrolyte, add water and continue to mix thoroughly - then test again, repeating adjustment if necessary.

When the cells are fully charged the specific gravity should be fairly uniform (within .010 points) in all cells. The actual specific gravity of the cells should be between 1.270 and 1.295 at 80° F. (31° - 33° Baume at 25° C.) Old batteries, those which have lost some material through shedding, will have a somewhat lower maximum specific gravity when fully charged than new batteries will have.

It is seldom necessary to increase the specific gravity of the solution by the addition of acid. There is sufficient acid in the solution when the battery is built to last out its life, for none is lost in the gassing action or in use. This original amount of acid is in exact proportion to the amount of active material in the plates, and to increase it will damage if not ruin, both plates, and separators, shortening the life of the battery. However, when electrolyte has leaked or spilled out of the cell, adjustment of the electrolyte should be made. Bring all cells to a fully charged state, then adjust by removing some solution and adding acid (not over 1.400) then charge and test again; or else dump out all acid and replace with new at proper specific gravity.

EDISON STORAGE BATTERY. The Edison storage battery is made up with the following units: the plates are made of compounds of nickel and iron packed into reinforced perforated steel pockets. The tubes and pockets are mounted on steel grids placed in an alkaline solution and contained in a welded nickel-steel container held in hardwood trays. Figure 4 shows the interior of an Edison cell.

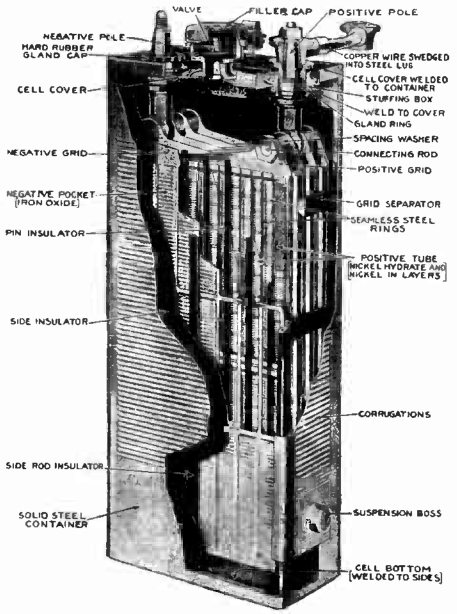


Fig. 4 - Sectional view of Edison cell.

The positive grid is made of a thin nickel-plated steel plate. This plate holds a number of tubes containing the active material, which is nickel oxide with layers of pure nickel in the form of flakes. The tubes are made of thin sheet steel and are perforated and nickel plated.

The negative plate is made of a number of rectangular pockets supported on nickel-plated steel grids. These pockets are made of finely perforated steel and are filled with the active material, which is iron oxide. These pockets, filled with the active material, are placed in the grids and put under great pressure, which forces them into perfect contact with the grid as one solid mass. After the plates are connected into one unit, special insulating strips of hard rubber are placed between them to separate and insulate them from each other. The positive pole is designated by a hard, red-rubber bushing around the positive pole together with a plus mark stamped on the cell cover near this positive pole. The negative pole is designated by a black bushing around it and has no marking on cell cover.

Cell-to-cell connections are made of nickel-plated copper soldered into lugs of nickel-plated steel. The lugs fit snugly over the tapered portions of the cell poles.

The electrolyte consists of a 21 percent solution of potash in water with a small percent of lithia. The density of the solution is 1.210, becoming slightly less as the battery ages.

The first or initial charge reduces the iron oxide to a metallic iron, while converting the nickel hydrate to a very high oxide, black in color.

On discharge the metallic iron goes back to iron oxide, and the high nickel oxide goes to a lower oxide, but not back to its original form of nickel hydrate. On every cycle thereafter the negative charges to metallic iron and discharges to iron oxide, while the positive plate charges to a high nickel oxide and discharges to a lower oxide. Current passing in the direction of charge or discharge decomposes the potassium hydrate of the electrolyte and brings about the oxidation and reduction of the active material. An amount of potassium hydrate equal to that decomposed is always formed at one of the electrodes by a secondary chemical reaction. In consequence, none of the potassium hydrate is lost, and the specific gravity of the electrolyte remains constant. As the specific gravity remains constant, hydrometer readings are worthless, and in order to ascertain the state of charge or discharge it is necessary to read the cell voltage while the battery is on charge or discharge.

Under proper treatment Edison cells will improve with use. A new cell will continue to increase in capacity for a period of at lease 30 cycles of charge and discharge. If a new battery or one which has been standing idle for a long time operates somewhat sluggishly, use it as much as possible, giving it occasional complete discharges, and it will soon pick up to normal capacity. If the capacity of the battery falls off, it is usually an indication that the electrolyte needs to be changed. Empty old electrolyte and refill with new solution, taking care to use a black iron funnel and earthenware pitcher. Never use tin or enamel funnel. Keep the salt deposits that collect on tops of cells cleaned off at all times, and keep cell tops and containers coated with vaseline compound. (Never put acid in an Edison battery.) An Edison cell can remain idle for long periods without charging and not sustain serious damage. Always keep in a dry place. Never bring a naked flame near any battery that is being charged, as hydrogen and oxygen gasses are given off and will ignite very readily. Edison batteries will freeze in temperatures of 25° F. below zero. If possible, an even temperature, not too warm, should be maintained.

GENERATORS.

The generation of electricity has been discussed in previous lesson texts. Remember that to generate electricity there must be relative motion between conductors and a magnetic field. The application of the principles involved in the generation of electricity by means of the generators used in aircraft radio installations becomes the subject of special interest in this part of the course. The d.c. generator, used in aircraft, consists of a rotating armature between one or more pairs of magnetic poles. It should be borne in mind that a.c. is induced in this armature and that a commutator is mounted on the rotating shaft which carries the armature for the purpose of leading this a.c. out of the armature in one direction only. It is most important that this commutation be as perfect as possible and that all voltage ripple due to commutation be filtered out of the radio circuit.

You have already learned that there are two conditions that must be met in order that electricity may be produced from a generator of the d.c. revolving armature type being discussed - the field coils must be excited and the armature must be revolved. Electricity is required for the excitation process and mechanical energy is required to rotate the armature. The more current fed into the field coils, the greater will be the field strength and, (when the armature is being driven at a constant speed) the greater the field strength, the greater the voltage generated in the armature. Every effort is made in aviation radio work to maintain the revolutions per minute (r.p.m.) at a predetermined fixed value, consequently the varying of the field strength by controlling the field current becomes the means by which the voltage of the generator is controlled.

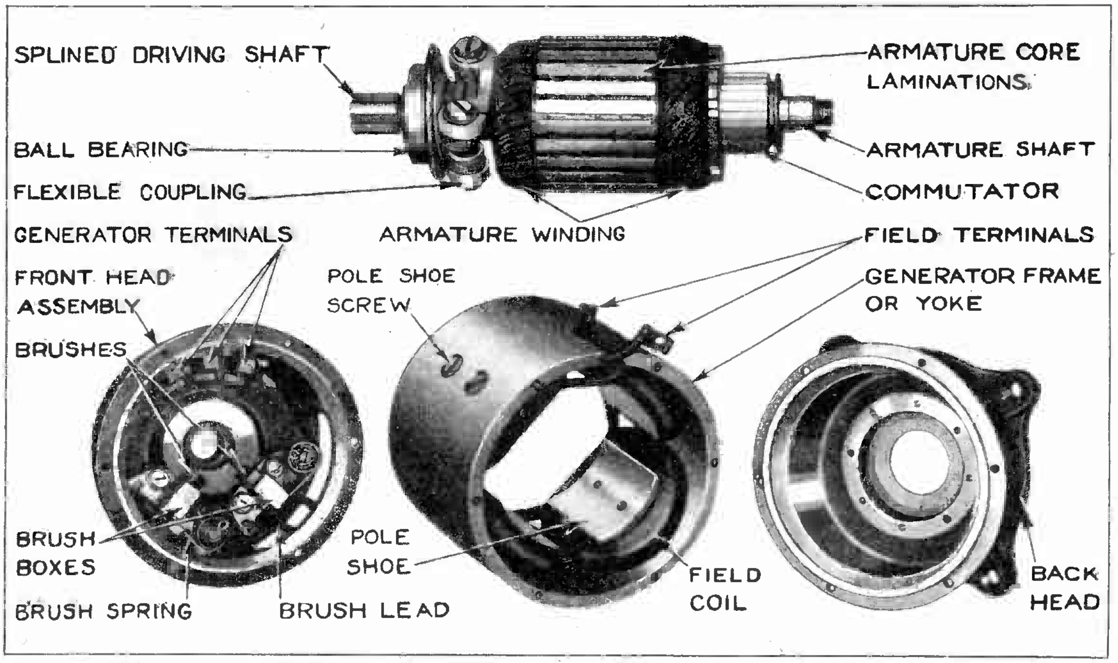
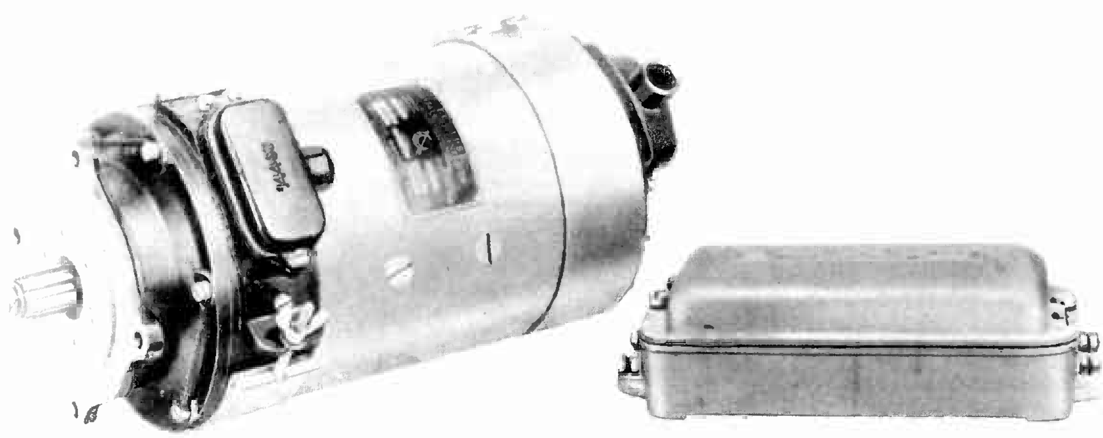


Fig. 5A - Disassembled view - Eclipse engine-driven generator.

ECLIPSE DIRECT AIRCRAFT ENGINE-DRIVEN GENERATOR.

Figure 5A shows the parts of an Eclipse constant voltage type generator manufactured by the Eclipse Aviation Corporation. It is marketed by several distributors of aircraft radio sets, particularly Western Electric Company in conjunction with their aircraft radio sets. This is a D.C. shunt wound self excited type, having 4 poles. It is bolted to the engine and is driven by the airplane engine through a splined driving shaft. A flexible spring coupling is usually connected between a driving shaft and the armature to absorb the vibratory torque from the engine crank shaft. This generator develops one voltage only, - 14.5 volts. (Other "double voltage" Eclipse generators deliver 1050 volts and 12 volts, or almost any two voltages as required by the radio set with which they are used.) Figure 5B shows the Eclipse generator and control box.



Courtesy Bell Telephone Laboratories

Fig. 5B - Eclipse constant voltage engine-driven generator and control box.

THE CONTROL BOX.

The voltage regulating unit is shown on the left hand side Fig. 7 showing the control box board assembly, and consists mainly of a frame on which is mounted a core having a shunt winding connected across the generator terminals. A fixed contact is mounted on the frame and a movable contact fastened to an armature and held closed against the fixed contact by an adjustable retracting spring which at the same time holds the armature away from the core. A resistance unit is connected across the contacts. The position of the fixed contact can be adjusted by means of the screw, on which it is mounted.

The operation of the unit is as follows. The current in this winding and resultant magnetic pull on the armature is dependent upon the voltage developed by the generator. With increasing generator speed the voltage increases until it reaches the normal value for which the regulator is adjusted. With a further increase in generator speed, the voltage will tend to rise above the normal value. When, however, this value is exceeded by a very small amount, the increased pull exerted on the armature carrying the moving contact overcomes the pull of the spring and the armature will be drawn towards the core, thus opening the contacts and inserting the resistance in the generator's field circuit.

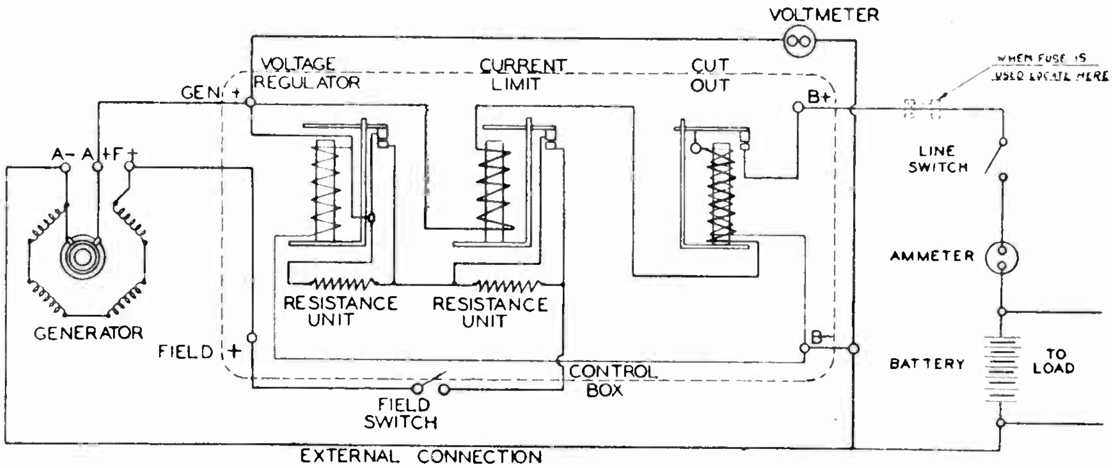


Fig. 6 - Schematic wiring diagram of Eclipse generator and control box CB-2.

The added resistance in the field circuit decreases the exciting current in the field winding and the voltage developed tends to drop below the normal value.

A control box, as shown in Figures 6 and 7, is supplied with each Eclipse generator. There are three distinct elements within the control box, namely; the reverse current cutout, load limit controller and voltage regulator element. The function of the first two named is to automatically open and close at the proper time, the electrical connection between the generator and storage battery. A device of this kind is necessary to prevent the battery from discharging back into the generator when the generator is idle or operating at a low speed.

The "cut out", shown on right hand side of Figure 7, consists of a magnet core having two windings on it, a stationary contact, and a moving armature with contact. One of the windings is a shunt coil of many turns of fine wire and is connected across the generator terminals. The other winding consists of a few turns and is connected in series with the generator battery circuit when the contacts are closed. When the generator is not running, the contacts are held apart by the spring which is fastened to one end of the cut out armature. When the generator is run and has developed sufficient speed, the shunt winding is sufficiently energized to attract the armature carrying the movable contact, thereby closing the circuit between the generator and battery. With this circuit closed, a small current flows through the series winding and energizes it. The pull exerted by this winding reinforces the pull of the shunt winding and holds the armature of the cutout in its closed position. When the generator is "dead" or the voltage falls below that of the battery, a discharge of the battery through the series winding takes place and demagnetizes the coil, thus allowing the spring to break the contact.

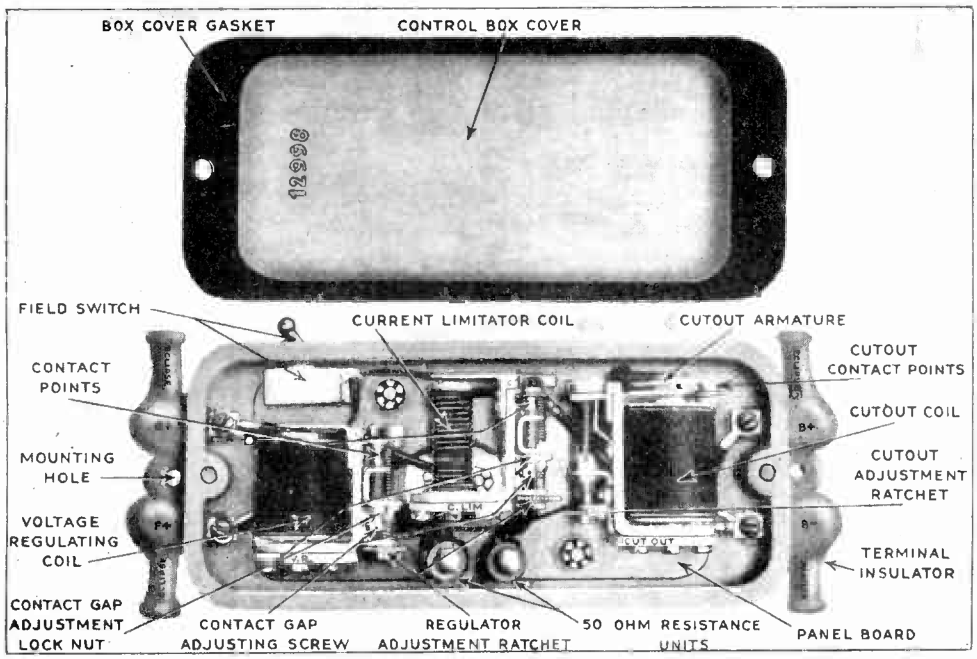


Fig. 7 – Interior view – Type CB-2 Control Box for Eclipse generator.

SERVICING THE GENERATOR.

Removal of the generator from the engine for periodic inspection is advisable. The most convenient time to do this is when the engine is taken down for overhauling. If in disassembly of this generator, it becomes necessary to dismantle the flexible coupling, before doing so, the exact position of the spring holders should be noted. Upon re-assembly, if the holders are set up to their original position, the correct spring tension in the coupling will be maintained. After the assembly the holders should be re-wired with brass tie wire to prevent disturbance.

All parts should be thoroughly cleaned and bearings properly packed with a good grade of neutral grease of high melting point. New oil sealing washers should be installed at this time and the generator given a run at about 400 r.p.m. or more over a period of one hour on a test bench, before re-installation on the engine.

Figures 8 and 9 show the current limitator and cutout, respectively.

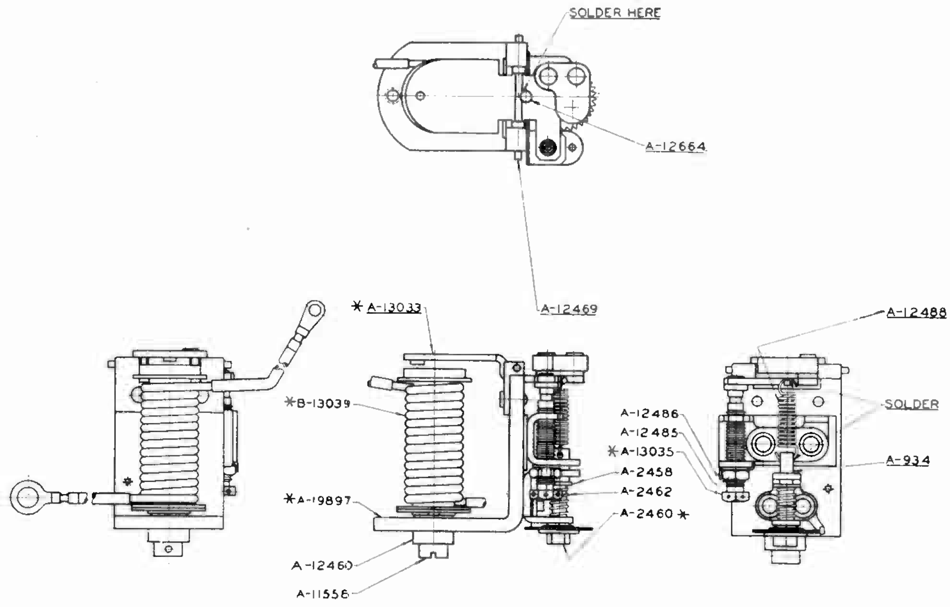


Fig. 8 - Current limitator, detailed assembly.

Grease and oil should not be permitted to collect on the commutators. If dirt, oil, or grease is present, it should be removed and the commutators cleaned with a clean cloth. DO NOT SANDPAPER the commutators unless absolutely necessary to remove roughness. In time the commutators SHOULD be covered with a dark, semi-transparent film which should be preserved thereon.

The natural wear of the brushes causes carbon dust to collect on the interior of the generator; and this accumulation mixed with oil vapor will form a gummy paste, which readily adheres to the brushes, causing the latter to stick. The brushes should be kept free in their respective boxes and when necessary may be washed in gasoline and thoroughly dried before reassembling.

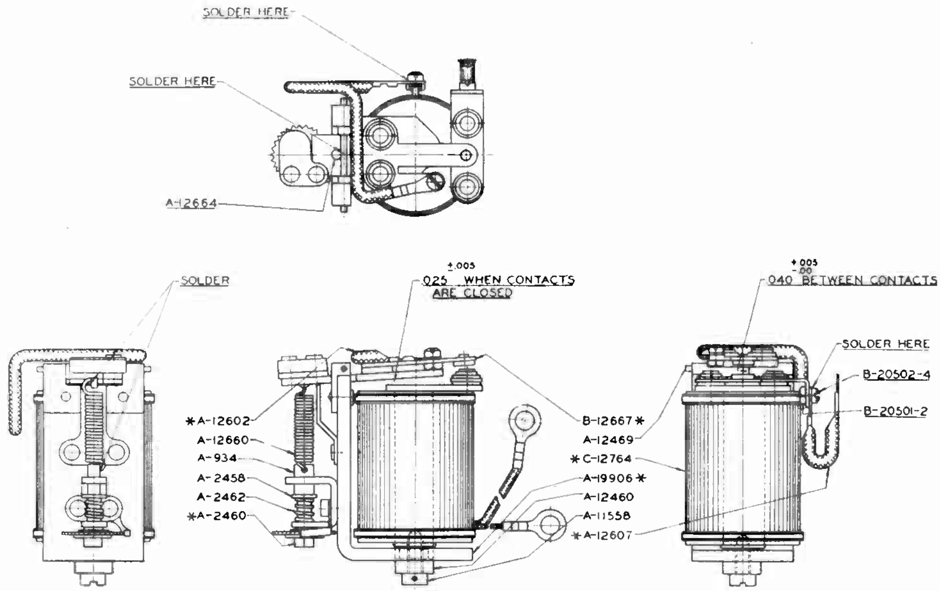


Fig. 9 - Cutout - detailed assembly.

It is of extreme importance that the generator brushes make full contact with the commutator surface. Reseating of the brushes may be quickly accomplished if necessary, by inserting a strip of No. 00 sandpaper (sanded side against brush) between the brushes and commutator, then withdrawing sandpaper against the rotation of the armature. Sand particles should be blown out of the generator after this operation. This should be carefully and thoroughly done.

Before reassembling the generator, the oil seal washers should be examined and if found to be damaged or worn, they should be replaced at once. No difficulty with engine oil seepage should be experienced if oil seals are properly assembled.

The following points should be carefully noted:

1. Bearings should be properly lubricated.
2. Window cover straps should be kept tight.
3. Brushes and brush boards should be kept clean.
4. Commutators must be smooth and free from dirt and grease.
5. Brushes must make full contact with commutator surfaces.

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6. Brushes must move freely in their respective holders.

7. Brush spring pressure on low voltage brushes should not exceed 24 ounces. The high voltage springs should have 12 ounces of pressure.

Figure 10 gives you the wiring diagram for the Eclipse generator.

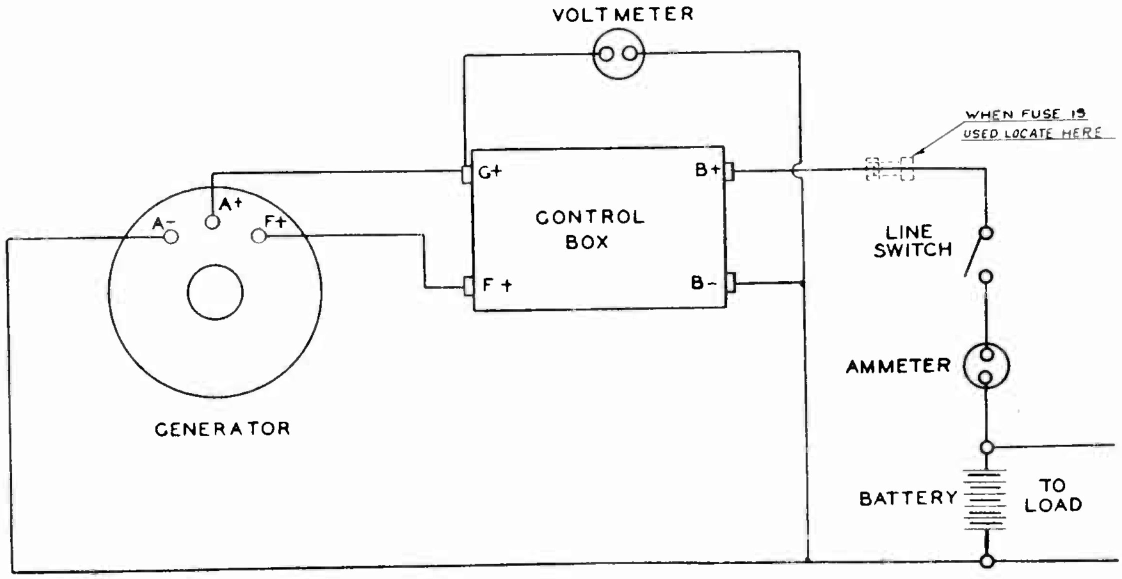

Fig. 10 - External wiring diagram of generator and control box.

It is extremely important that the interior of the control box be kept thoroughly clean in order to avoid the entrance of dirt particles between the contact points of the regulating and cutout devices. Dirt causes the burning and oxidization of the contacts, which in turn causes the relay units to become erratic and finally inoperative.

These contact points should be restored to their proper condition by smoothing with a small strip of Crocus Cloth every 50 hours of operation. Meter readings are the only accurate method of ascertaining the proper functioning of the apparatus.

Should any of the units require adjustment, turning the ratchet wheel in a clockwise direction raises and turning in a counter-clockwise direction reduces the voltage or overload settings. The cutout is properly set at the factory and no attention need be given to it except for occasional inspection of the contact points.

The contact gaps on either the voltage regulators or the current limitator should not be changed and under no circumstances should the regulator spring tensions be changed in an endeavor to increase the charging rate or the "cut-in" speed of the generator.

CONSTANT SPEED AIRPLANE ENGINE DRIVEN GENERATORS.

The aviation industry is coming to regard the airplane engine-driven generator as one of the most desirable types of aircraft radio power equipment. Entirely satisfactory performance, however, has not been obtained with this type of generator in the past. The difficulties encountered with engine-driven generators have been due, principally, to the necessity of providing constant voltage at the variable engine speed, necessary in flight maneuvers. Attempts have been made to use many kinds of electrical regulators, but only one type of regulator has proved at all practical. This is the vibrating contact regulator already described. It is difficult to keep this type of regulator in correct adjustment because of the continual burning of the contacts. Operators state that they are fairly satisfactory for battery charging if they are "kicked" occasionally when the contacts stick. For <u>double</u>-<u>voltage</u> radio generators they are of doubtful value. Not only does the rate of contact burning increase with the increased size of the generator, but also the value of the voltage obtained is very irregular.

As generator voltage is dependent on generator speed, the electrical regulator could be dispensed with altogether if a speed regulating mechanism could be developed which would hold the generator speed within close limits in spite of variations in engine speed.

Such a speed regulating mechanism has now been developed by Westinghouse Electric and Manufacturing Company. The generator is designed so that it will be revolving at the required speed when the airplane engine is turned over at slightly below the cruising speed of the airplane. The generator itself is driven through a friction mechanism which is centrifugally controlled. Therefore, if the generator reaches a speed higher than its rated speed, there will no longer be any driving friction. The generator operates at a speed where the driving torque balances the required torque. If you increase the load on the generator, you increase the torque. In this case, the generator will decrease the r.p.m. just enough to develop the additional torque required. As the regulating mechanism is developed, a small change in speed is equivalent to a large change in torque. In short, the generator speed is independent of the driving speed. The slipping mechanism has this advantage; it protects the generator from the vibratory torque on the direct driven type of generator. This coupling usually contains rubber blocks and springs and is not entirely satisfactory. The constant speed generator has this advantage: no such coupling is necessary.

The friction elements in the Westinghouse speed regulating mechanism will last from 600 to 1,500 hours, according to the service to which the generator is subjected.

It has not been considered desirable by Westinghouse to develop a double voltage direct current generator using this mechanism. The alternating current machine is much more compact, is considered much more reliable and efficient and is much lighter in weight than the direct current machine.

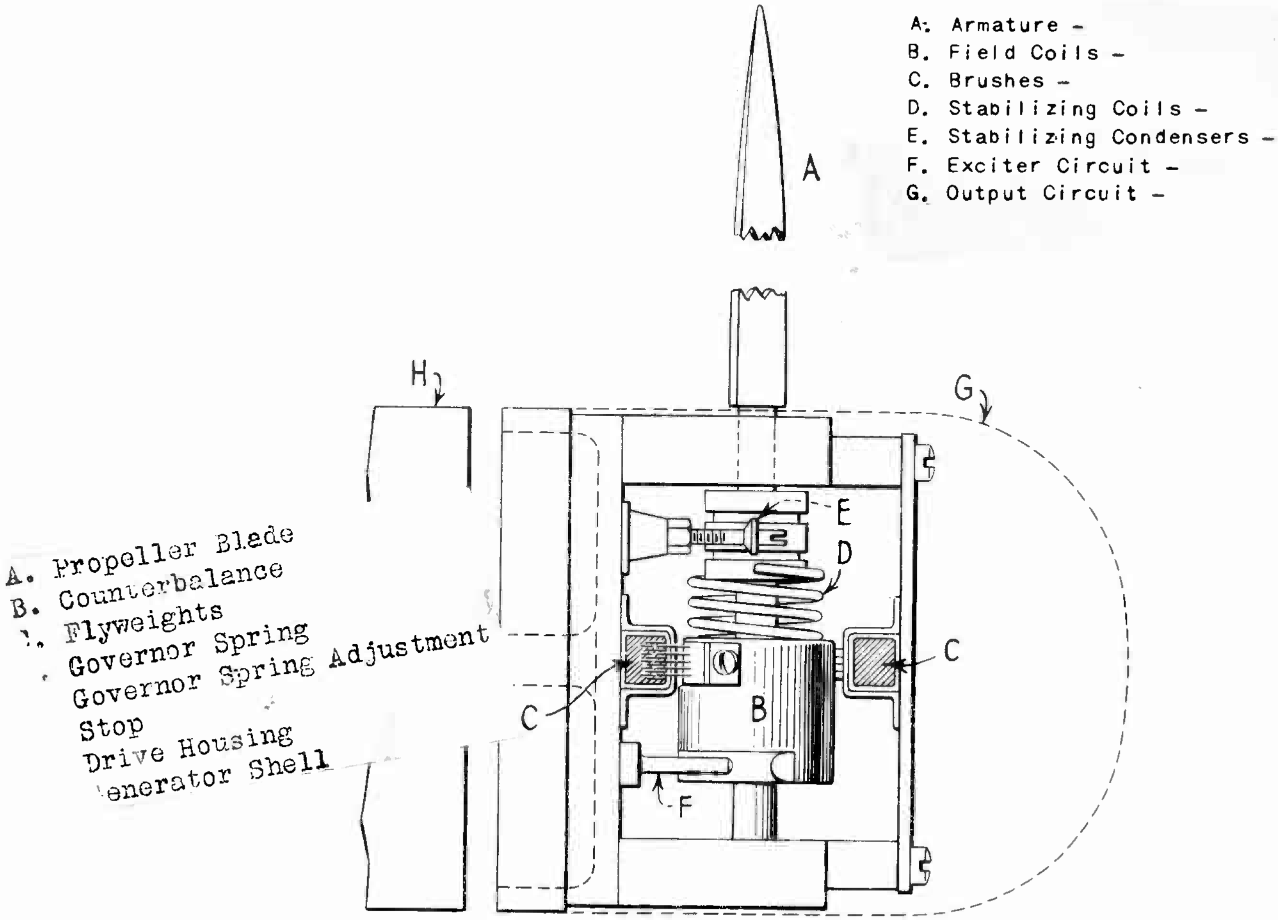

Fig. 11 - Diagrammatic sketch, Deslauriers propeller head mechanism.

Mathematically, the efficiency of a mechanism of this type, which delivers the same torque that is applied at less than the applied speed, can be expressed by the following simple formula where N is the generator speed and Nd is the driving speed:

$$\text{Efficiency} = \frac{N}{Nd}$$

From this it will be seen that the efficiency is a direct ratio between the generator speed and the driving speed.

Where emergency power is required, that is, for battery and dynamotor systems, the constant speed, 15 volt generator is an ideal machine for keeping the battery charged. For control it requires only an ammeter to indicate the charging rate at the desired value and a reverse current relay. It should outlast the engine with no attention other than routine lubrication and cleansing.

When one set of friction elements has been worn out a new set can be installed without difficulty.

Operating tests have been made by Westinghouse Electric and Manufacturing Company on constant speed generators for nearly a year now and this type of generator has been found to be satisfactory beyond all expectations. The a.c. machines were originally received with considerable skepticism, but all who have operated them have given favorable reports on their performance.

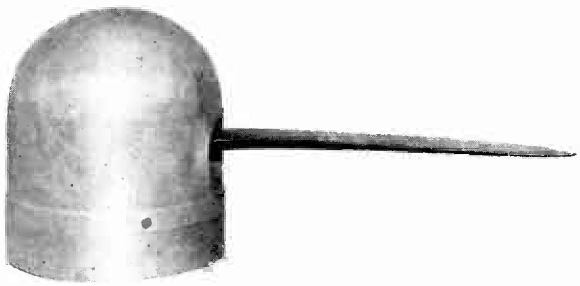

Fig. 12A - Deslauriers propeller and head.

WIND-DRIVEN GENERATORS. The electrical characteristics of wind-driven generators are precisely the same as engine-driven generators. The control of speed, which directly influences the voltage generated, however, becomes an important item. The propeller most used in this country is the Deslauriers propeller. Practically all wind-driven generators, no matter by whom manufactured, are known as Deslauriers generators because they are invariably equipped with the

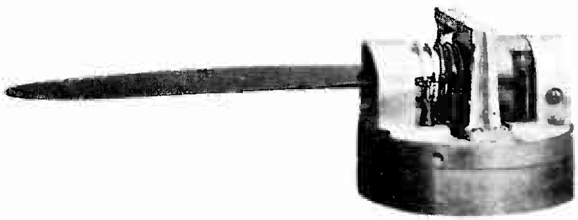

Fig. 12B - Deslauriers propeller showing head mechanism.

Deslauriers propeller. This propeller is a single bladed type with a slight double camber. Figure 11 shows the general scheme of this propeller with its governing mechanism in the head of the generator. The overall case, which is stream lined, is shown in Figure 12A, the interior mechanism in Figure 12B. Figure 13 shows the circuit of one type of Deslauriers generator, designed to be separately excited from an outside source of from 10 to 14 volts. Practically all Deslauriers generators have shunt or compound wound field coils; most of them have the shunt field separately excited.

The method of regulating the speed is most interesting and important. The propeller is turned over by the impact of air due to the plane being in flight. It can also be made to revolve by mounting the generator in the "slip stream" of the airplane engine propeller, in which case power can be secured from this type generator whenever the airplane engine is running, even if the plane is not flying. It is desirable, however, for the aircraft radio generator to run at a constant speed, irrespective of the air speed of the plane which varies over a wide range, minimum speed being attained at the maximum climbing angle of the plane, and maximum air speed being attained in a full dive position. There are also short intervals during some flights when the plane is "slipping" down sideways, or "skidding" up sideways, during which time a plane actually does

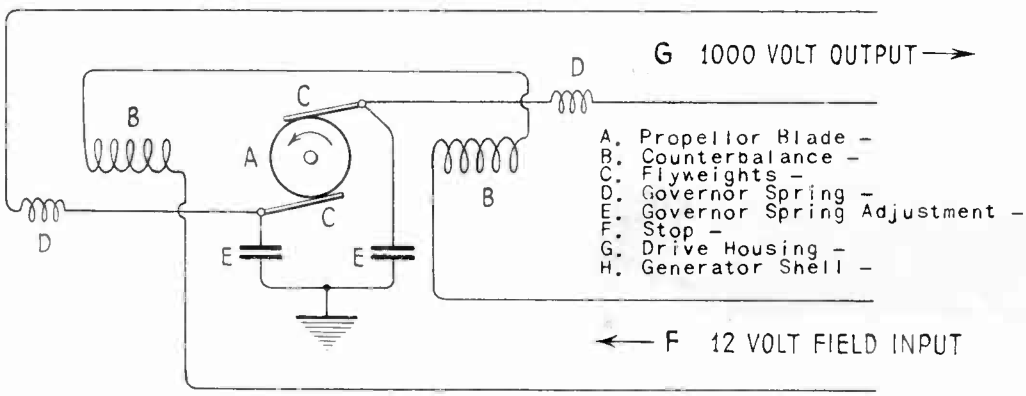

Fig. 13 - Wiring diagram of separately excited Deslauriers generator.

not have flying speed. At such times there is no relative movement (no air speed) between the plane, as to forward motion, and the atmosphere. Because of these varied conditions of flight, ranging from 100% less than normal air speed (the stalling position of the plane) to about 60% more than normal flying speed (force of gravity being in full play), the governing of the speed of a wind-driven generator is absolutely essential. This is true for two reasons in particular. One is that electricity is desired from the generator at all times and the other is that if the r.p.m. is decreased, the voltage will decrease, while if r.p.m. is increased the voltage will increase up to the point where considerable damage will be done by the excess voltage generated.

The theory of the Deslauriers propeller is very simple. All propellers act as screws. It is easy to understand that in the case of a fine screw thread - a large number of threads to the inch - less energy is required to turn it than if the thread is coarse. In the first case, we say that the bite of the screw (or the pitch of the propeller), is less than in the second case. Power for driving the Deslauriers propeller is received from the blast of air. This propeller pivots at its base so that the pitch decreases with an increase of air pressure - in other words the blade flattens out as the airplane increases speed. Look at Figure 11 again. Observe that the propeller is held in position by the spring D. The centrifugal force due to the propeller revolving, carries the flyweights C out from the center, until they act as a governor. The governor spring adjustment is provided to increase the tension of the governor spring for each desired r.p.m. Propellers as installed on aircraft

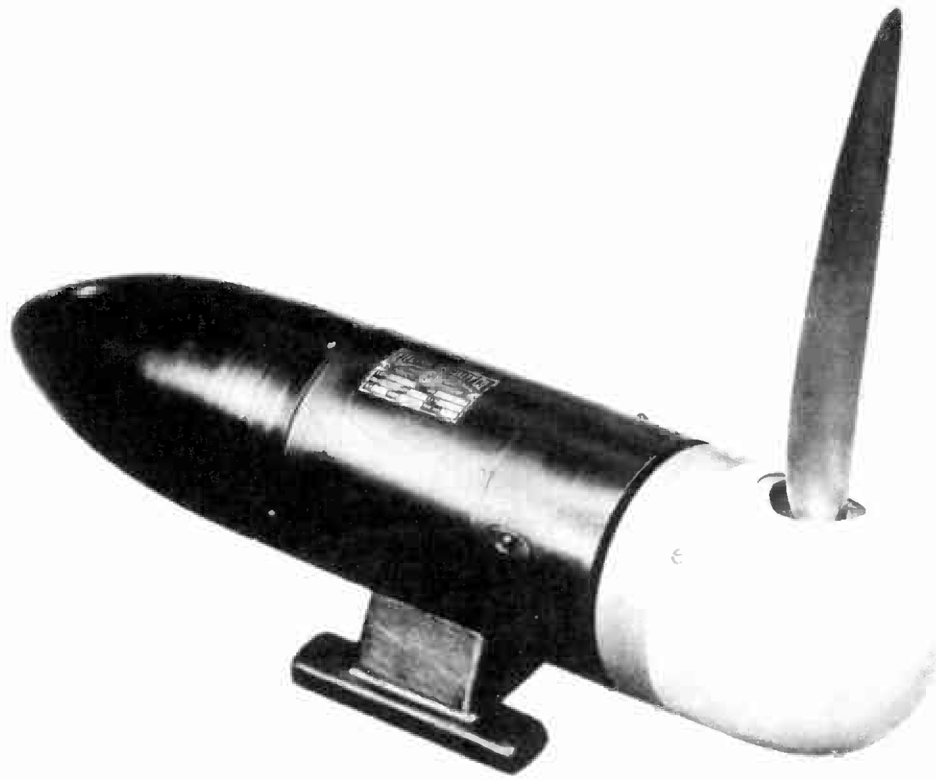

Fig. 14 – Double voltage generator with constant speed Deslauriers propeller.

radio generators are adjusted for the specified r.p.m. desired as the normal air speed of the plane on which the generator is to be installed is known beforehand. The mechanism just described will then operate to maintain the r.p.m. throughout the most extreme fluctuations in air speed attained by the plane in flight. For this reason it is not necessary to have a voltage regulator device such as has been explained for use with the engine-driven generator. Deslauriers propeller-driven generators can be used to supply power to receivers and to transmitters. They are often wound with two armature windings in order to provide two sources of e.m.f. of different value. (Such as shown in Figure 14.) There is also a Deslauriers wind-driven generator supplying both high and low voltage, which in case of a forced landing can be operated as a dynamotor from a storage battery, giving full emergency communication. The propeller for this generator is equipped with a ratchet device eliminating even the necessity of removing same when operated as a dynamotor. The battery which "floats" across the low tension side of generator is fully charged at all times and ready for dynamotor or emergency operation by simply throwing a switch. Another advantage of this ratchet device is that if the plane is flying below the speed at which the propeller will develop its full load, the switch can be thrown while in flight, and full communication maintained. This is exceedingly important in case of a forced landing, because on the glide to such a landing, the switch can be thrown if the speed falls too low, and communication maintained continuously.

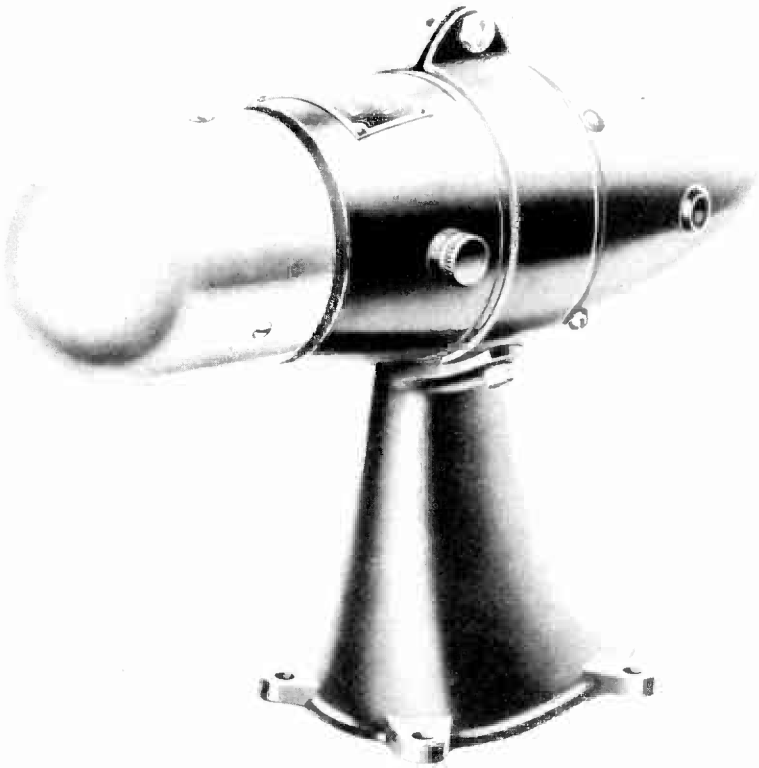

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Fig. 15 - Wind-driven generator mounted in bracket.

Figure 15 shows a wind-driven generator fastened in a mounting bracket manufactured by the Electrical Specialty Company for the Western Electric Company. This machine is a double-voltage generator which may be used as a source of power supply for Western Electric aircraft radio receivers. The low voltage winding will supply either 1.6 or 3.2 amperes at 13 volts and the high voltage winding will supply either 25 or 50 milliamperes at 220 volts when the machine is operated at its rated speed of 6,500 r.p.m. In order to prevent any frequency noise produced at the brushes of the generator from affecting the receiver a radio frequency filter is placed in the plus 13 volt lead. This filter consists of a retardation coil and a condenser. As this generator is only to be used with radio receivers having equipotential cathode tubes, it is not necessary to have an audio frequency filter in the low voltage supply.

The generator should be mounted on some convenient part of the plane using a mounting bracket as shown in Figure 15. As the power of the propeller is sufficiently great to insure that the generator comes up to operating speed for all air speeds greater than 70 miles per hour, it is not necessary that the generator be mounted in the slip stream of the airplane propeller.

The power cable from the generator to the other apparatus should be run in the body of the plane. A hole is provided near the upper part of the mounting bracket in order that the cable may be run inside the bracket and thus have only the short length from this hole to the cable opening in the generator tailpiece exposed. In all cases the cable should be fastened to the leading edge of the strut (at intervals not exceeding 8 inches) as this has the least detrimental effect on the stream lining. Any desired method of fastening which is sufficiently solid may be used.

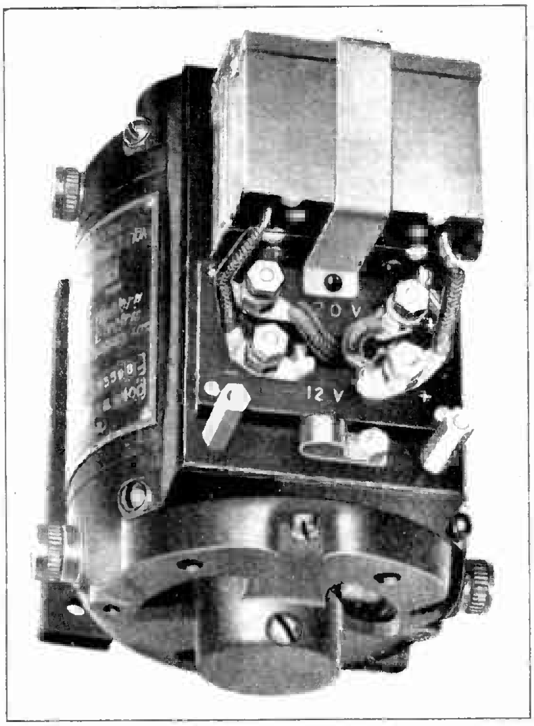

Fig. 16 - Dynamotor showing filter.

When installed in an all-metal plane the cable should be bonded to the metallic surface at frequent intervals. When installed in a plane which is not of all-metal construction, the cable should be bonded to any metallic surface with which it comes in contact. This bonding should be done with a considerable degree of care, as poor joints which make intermittent contact will introduce a great deal of noise due to the varying resistance of the ground return path.

DYNAMOTORS.

Generators and motors are both dynamo-electric machines. A generator is a dynamo-electric machine whereby mechanical energy is converted into electrical energy, whereas a motor is a dynamo-electric machine whereby electric energy is converted into mechanical energy. You realize that any d.c. generator can be used as a motor and vice versa.

The need for a motor in connection with aircraft radio sets lies in the fact that it is considered very desirable to be able to generate a suitable source of d.c. without having any power available due to the movement of the plane in flight, or any due to the running of the airplane engine either. For this reason, dynamotors are used. A dynamotor consists essentially of a rotating armature having double windings and double field pole windings. These armature coils are wound in the same manner as in the case of a double voltage generator. There are two commutators on the shaft, one at each end of the armature. One commutator is connected to what is called the motor armature coils, or the primary end, and the other commutator is connected to the generator coils or the secondary end. Such a dynamotor is shown in Figure 16. This dynamotor (No. KS-6589) is made by the Electric Specialty Company for the Western Electric Company. A dynamotor like this is practically required when a receiver is used which requires a fairly high voltage for the plate circuit.

When the 12-volt starting and lighting battery of the plane is utilized for operating the radio receiver, the No. KS-6589 dynamotor is used to supply the necessary high voltage for the plate circuit. This dynamotor takes approximately 3.5 amperes at 12 volts and delivers 0.050 ampere at 220 volts.

As mentioned before, any type of rotating electrical machinery using brushes produces radio frequency noise when operating because of sparking between the brushes and the commutator. In order to suppress this interference at the source this dynamotor is equipped with a filter which consists of two 1-microfarad condensers, one of which is connected across each set of brushes. This filter will eliminate any radio frequency interference due to sparking at the brushes.

Dynamotors may be installed at any convenient part of the airplane, the only requirement being that the axis of the armature is horizontal under normal operating conditions. It is desirable to mount the machine in such a position that the total length of lead carrying a comparatively heavy current from the storage battery to dynamotor be as short as possible. As the control switch for starting and stopping the dynamotor is located in one of the other control units, the total length of battery cable consists of the length from the storage battery to the control unit plus that from the control unit to the dynamotor.

The dynamotor is not completely shielded, so in order to prevent direct pickup of radio frequency disturbance the machine should be located as far as possible from the radio receiver and antenna, within the limits imposed by the requirement that the battery supply lead be as short as possible.

While it is unnecessary to provide for thorough ventilation, the machine should not be placed in a small closed compartment where there is no circulation or air.

ECLIPSE AVIATION DYNAMOTOR - TYPE A. The Eclipse Type A dynamotor has been designed by the manufacturer to operate from the standard airplane battery delivering from 12 to 15 volts. The capacity of the airplane battery should be 65-ampere hours or more, although a smaller battery may be used if absolutely necessary. A pilot's switch and a magnetic relay switch is furnished with this dynamotor in order that the dynamotor itself may be mounted very close to the storage battery. This arrangement makes it possible to use heavy wire to connect the storage battery with the dynamotor, and a smaller, lighter wire for the pilot's switch, which may be placed anywhere on the plane that is most convenient. The relay is so designed and connected that the field of the dynamotor itself is energized before the armature terminals are connected to the power supply line, an arrangement which presents a large initial inrush of current at the instant of starting. This dynamotor is a four-pole machine delivering ten hundred and fifty volts at .4 amperes with an input of 11.5 volts and 65 amperes. Both the high and low voltage windings are mounted in the same armature slot and are so insulated that the armature may readily meet the standard installation breakdown test prescribed by the American Institute of Electrical Engineers. The connectors from the high and low voltage winding are brought out to commutators at opposite ends of the armature shaft.

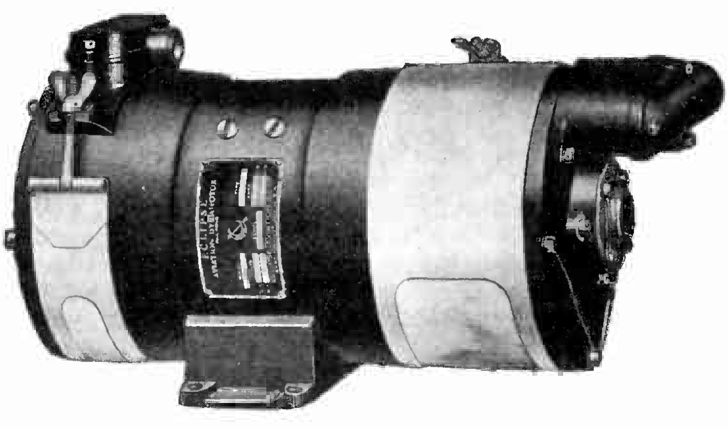

Fig. 17 - Eclipse Type "A" Dynamotor.

The fields are properly excited when the low voltage power supply, from the airplane storage battery, is so connected that the rotation of the armature when viewed from the low voltage commutator end of the shaft is clock-wise. To reduce electrical interference from the occasional sparking of the brushes and to aid in shielding, the low voltage negative terminal of the machine is grounded to the generator frame. When low voltage current is applied to the low voltage armature winding, the armature is caused to revolve as a motor. Care should be taken in the hookup of this machine because if the high voltage side was connected to the plane battery the winding would not stand the overload.

The Eclipse Type A generator is shown in Figure 17. Mounted on top of the dynamotor and connected internally to the proper terminals is the filter unit. The purpose of this filter unit is to minimize the effects of slot, pole and commutator ripple, as well as to by-pass any radio frequency current set up by occasional sparking at the brushes. The manufacturers of this machine have

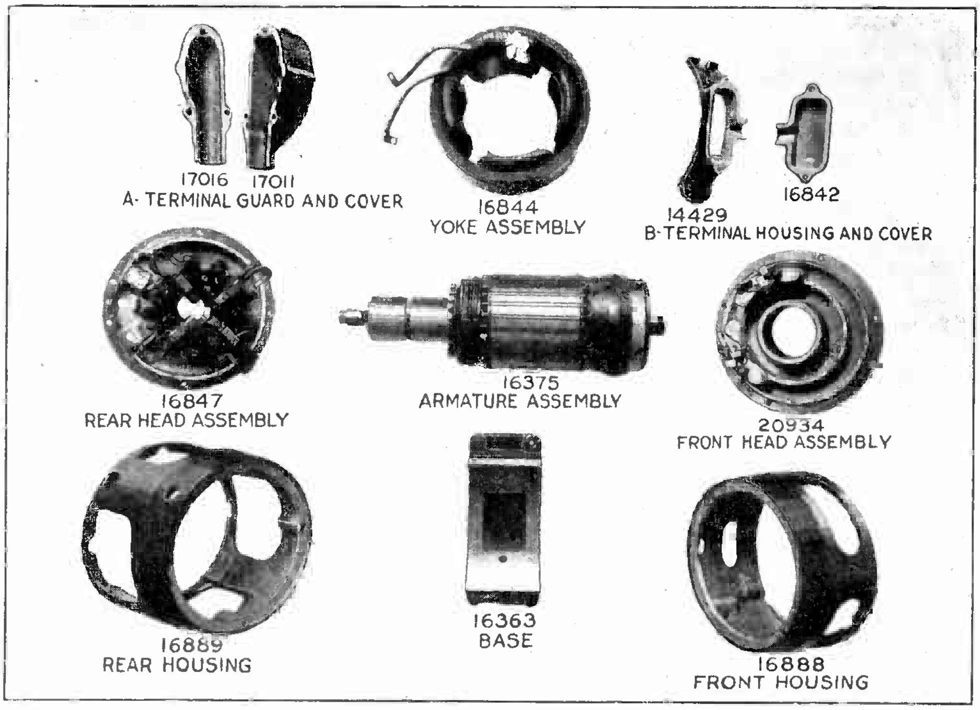

Fig. 18 – The parts of an Eclipse Dynamotor.

issued very complete instructions as to the maintenance of the dynamotor. The following points should be carefully noted:

1. High voltage brushes must be examined for wear every hundred hours of operation and low voltage brushes every two hundred hours.
2. Bearings should be properly lubricated with an approved grease of right consistency. We recommend the use of Bosch U. S. No. 501 Special High Temperature Grease distributed by the United American Bosch Corporation, Springfield, Mass. and its distributors.
3. Window cover straps must be kept tight.
4. Brushes and brush boards must be kept clean.
5. Commutators must be smooth and free from dirt or grease.
6. Brushes must make as near FULL CONTACT as possible with commutator surface.
7. Brushes must move freely in their respective holders.
8. Brush spring pressure on low voltage brushes should be 16-18 ounces. The high voltage springs require not less than 2 or more than 3 ounces to just lift the brush follower from the top of the brush box. This is done with the brush removed.

9. Neither high voltage nor low voltage commutator mica should be undercut.

If dirt, grease or oil collects on the commutator it should be removed and the commutators cleaned with a clean cloth. DO NOT SANDPAPER the commutators unless absolutely necessary to remove roughness. In time the commutators should become covered with a dark semi-transparent film which should be preserved thereon.

The natural wear of the brushes causes carbon dust to collect on the interior of the generator and this accumulation mixed with oil vapor, will form a gummy paste, which may adhere to the brushes, causing them to stick. The brushes should be kept free in their respective boxes and when necessary may be washed in gasoline and THOROUGHLY DRIED before reassembling. New brushes may be quickly seated by inserting a strip of No. 00 sandpaper (sanding side against brush) between the brushes and commutator, then withdrawing sandpaper with the rotation of the armature. Sand particles should be blown out of the dynamotor after this operation. The brushes should be given a final finish with No. 0000 sandpaper. This should be carefully and thoroughly done by personnel with experience in the process of sanding brushes.

Figure 18 shows the Eclipse generator disassembled, with all parts named.

EXAMINATION QUESTIONS.

1 - What is meant by aircraft radio power supplies systems?

2 - How are B batteries in aviation tested?

3 - Show by sketching a diagram how you would connect four dry cells to deliver six volts.

4 - What is the difference between air cell and the old form of dry cell?

5 - Define storage battery, electrolyte, grid, boost charge, trickle charge, floating.

6 - Briefly describe the Edison storage battery.

7 - Discuss the Eclipse engine-driven generator and control elements.

8 - Describe the Deslauriers wind-driven generator.

9 - Describe an aviation dynamotor.

10 - Describe a typical power supply system on a transport plane, naming all of the power units that make up the system.

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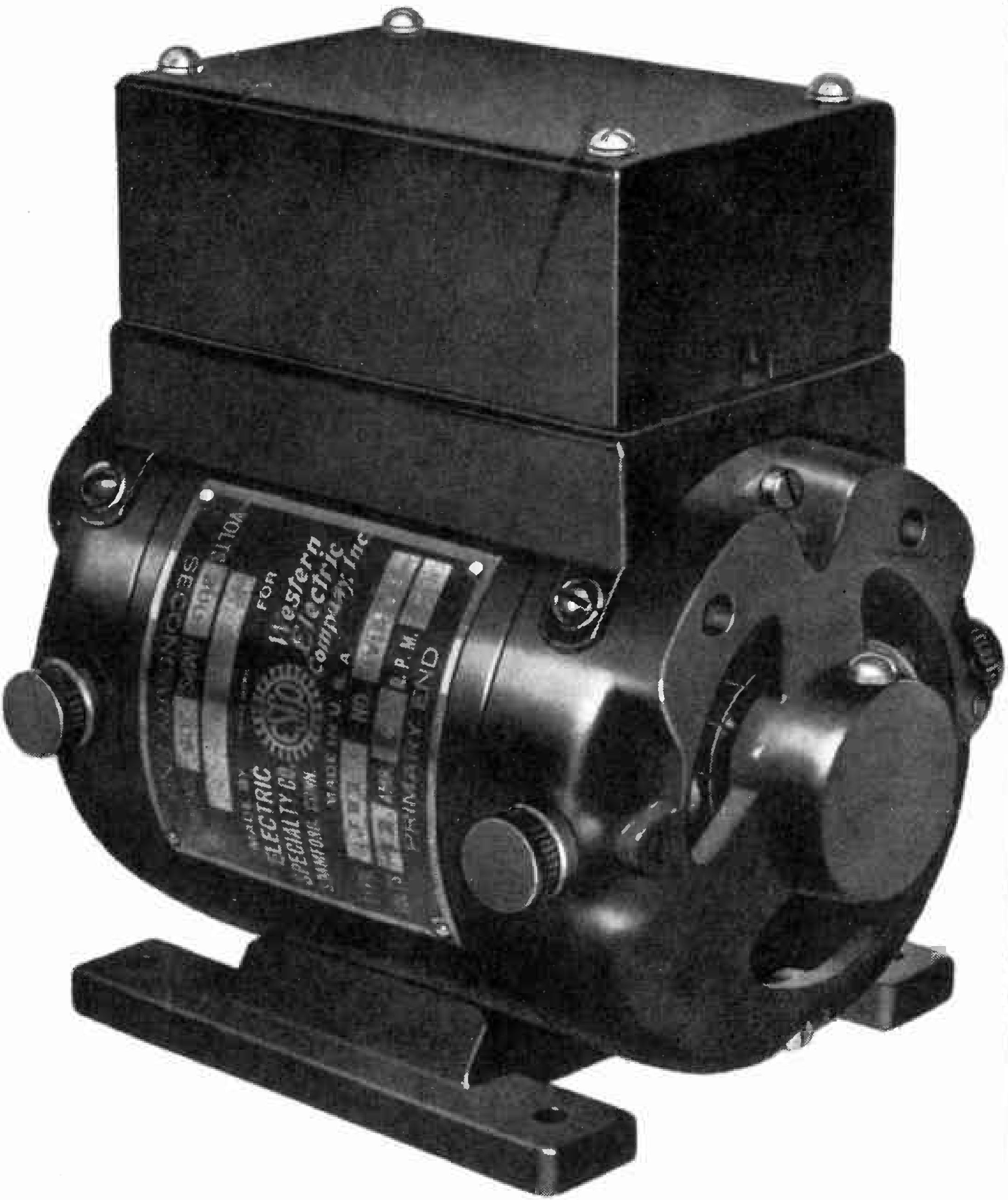
Courtesy Deslauriers Column Mould Co., N.Y.

Deslauriers Gear Reduction Unit with Deslauriers Constant Speed Propeller.

PRINTED IN U.S.A.



Aircraft Radio Dynamotor.

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A SIX INCH CARBON RECORDER WITH ITS RECORDING AMPLIFIER AND SYNCHRONOUS DRIVE MOTOR

Facsimile and Picture Transmission and Reception

VOL. 58, No. 1

DR. ALEXANDERSON AND CHARLES J. YOUNG STANDING BEFORE THE FACSIMILE MACHINE WHICH RECEIVED THE ELECTRICAL IMPULSES AND PRINTED THE NEWSPAPER PAGE SHOWN BELOW

WEATHER

LATEST

Link Banks in $118,000,000 Julian Plo

WIFE KIDNAPED, BEATEN BY 6 MASKED MEN

4 Trapped on Rock Wait Tide

COMEBACK PLANS TOLD BY DEMPSEY

THIS FRONT PAGE OF A SAN FRANCISCO NEWSPAPER WAS REPRODUCED IN SCHENECTADY ONLY THREE HOURS AFTER IT WAS PRINTED ON THE PACIFIC COAST — SOME 2500 MILES DISTANT

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FACSIMILE AND PICTURE TRANSMISSION AND RECEPTION

The beginning of facsimile transmission is marking a new era in radio. It means the sending of intelligence in a form which the eye can use instead of the ear — a picture instead of a story, a printing machine instead of a loudspeaker.

For, after all, if you want to impart an idea to someone else speech is a rather limited method. You can only talk so fast and you can only tell one story at a time. Or, if you are distributing news to many people it is like asking them to read their newspaper through a hole which covers only one sentence at a time. That is not the way one reads his paper. He scans the entire sheet, notes the headlines of many stories and their relative importance, and then reads those of interest to him. From looking at a simple picture, he becomes instantly acquainted with a situation which it would take many minutes to portray in words.

It is because one of the objects of radio is to transmit facts and ideas clearly that facsimile will be of great importance. The threshold has already been crossed. Pictures have been sent from point to point both in this country and abroad. Recently, the front page of a San Francisco newspaper was reproduced in Schenectady only three hours after it was printed on the Pacific Coast — some 2500 miles distant. This feat has been made possible as a result of a long series of developments in the radio laboratories of the General Electric Company under the direction of Dr. E. F. W. Alexanderson.

Facsimile transmission, picture transmission, and television have many things in common. Light, lenses, photoelectric cells, amplifiers and radio signals all play important parts in these systems.

A SYSTEM USING PHOTOGRAPHY IN ITS PROCESS

In the first part of this lesson we take up the principles of the photoradiogram system. Photography has its use in photoradiogram work. Only that part sufficient to give us an idea of the meaning of "positive" and "negative," as applied to films and prints, will be taken up. The taking and finishing of a photograph requires five operations; namely, the preparation of the plate, exposure of the plate to light rays, developing of the plate, the fixing of the plate and, finally, the printing of the picture.

In the preparation of a photographic plate a solution of silver bromide is precipitated, that is, caused to separate and then held in a watery suspension of gelatine. The gelatine mixture is maintained at a warm temperature and allowed to age, thus rendering it more sensitive to light rays. This mixture, better called emulsion, is then applied to glass plates or is spread over strips of transparent celluloid. If we speak of photographic plates we refer to the glass plate, if a film is mentioned we refer to the emulsion covered celluloid strip. Plates are not usually employed by the amateur photographer; either film pack or film rolls are used.

When this prepared film is exposed to light by the opening of a shutter allowing light to enter the camera through a lens, the rays of light fall upon the prepared gelatine surface and a chemical change takes place, which to the eye produces no visible effect. But the silver bromide under proper treatment can now be more easily reduced to metallic silver and this reduction will be in proportion to the intensity of the light that falls upon the surface containing the silver bromide. To bring this reduction about a reducing agent, which is an alkaline solution of pyrogallic acid or hydro-quinone, is applied and possesses such slight activity that its effect on portions of the bromide film not exposed to illumination is practically zero. This reduction works very rapidly and deposits more metallic silver where the illumination is of the greatest intensity.

This explains why the film becomes more opaque where the object being photographed is brightest and more transparent where the object is the darkest. Because of this reversal the name "negative" is given the developed plate or film. Since white light rays are the ones to most affect the bromide during the exposure the developing is carried out under a red light which has practically no action on the silver bromide. If nothing further were done with the developed film, daylight would in time gradually reduce the remaining unchanged bromide to silver, therefore, the developed film is placed in a "fixing" bath or hypo, where the bromide is dissolved out. The negative is now placed in a quantity of clean pure water and washed to remove all the chemicals except the gelatine and silver image. This is the finished negative that is used in photoradiogram transmission.

A "positive" print or film may be obtained from any negative film by allowing a sensitized photographic paper or unexposed film to be illuminated through the negative. The denser portions, that is, more opaque portions protect the light sensitive paper or film from being acted upon by the light, while the light readily passes through the transparent parts of the negative, bringing about a chemical action in the light sensitive paper, or film. This is developed and the result is a "positive", or image just the reverse of the "negative" in light and shade.

Before discussing regular photoradiogram equipment a simple set-up will be explained in order to fix the principle in mind. Figure 1 shows a source of light, lens and photoelectric cell with associated circuit and indicating device. When light enters the cell the meter will be deflected showing that current passes through the circuit.

If an opaque substance is placed between the light and photocell, the meter will return to zero showing that no current will flow when the light is prevented from reaching the light sensitive element of the cell. Suppose in place of the solid opaque screen we perforate a number of openings in the screen; for example, like that shown in Figure 2 and then pass this between the light source and the photocell. As light passes through the openings of group #1, a slight flicker of the meter needle will take place, then a longer sustained deflection.

Passing through group #2, a sustained deflection will first result followed by three short deflections. If an extremely sensitive buzzer were connected in the circuit instead of the meter you could read the signal "A B" in code (by sound) as these openings passed between the light and the photoelectric cell.

Suppose we prepare another screen as in Figure 3; a strip of material is placed in the opening which, beginning at A, is transparent but so

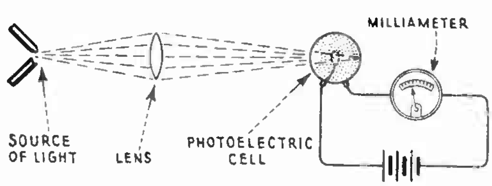


Fig.1 - A DEFLECTION IS SEEN ON THE MILLIAMMETER WHEN LIGHT RAYS STRIKE THE PHOTOCELL.

made that as it approaches point B it gradually passes less and less light until at B it is opaque allowing no light to pass. Assume from B to C just the reverse is true. When this screen is passed between the light and the photocell the needle will show a maximum deflection as point A passes, then as the strip moves across the light beam toward B the needle will show a decreasing deflection, until at point B it will drop to zero. As the strip is moved on, the milliammeter needle will indicate an increasing current strength and when C is reached maximum deflection will again be noted.

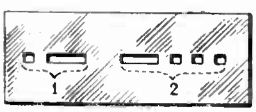


Fig.2 - OPAQUE SUBSTANCE STAMPED TO RECORD CODE LETTERS "A" AND "B."

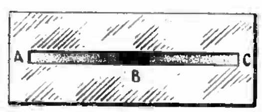


Fig.3 - MORE OR LESS LIGHT REACHES THE PHOTOCELL DEPENDING UPON THE OPTICAL DENSITY OF STRIP ABC.

Now if you will examine a negative of a snapshot by holding it between your eyes and the light you will see that it consists of transparent, translucent and opaque areas. If such a screen is placed between the photoelectric cell and a source of light the milliammeter needle will show deflections of various magnitudes depending upon the amount of light that the film allows to pass and strike the light sensitive element of the cell.

WORKING PRINCIPLE OF A PHOTORADIOGRAM TRANSMITTER.

Figure 4 takes us a step further and gives us an insight into the working principle of a photoradiogram transmitter. This sketch is only for the purpose of explaining the principle of operations. Consider the housing H which incloses the photoelectric cell P E and lenses L3 and L4 all mounted upon a carriage which travels laterally side to side. Attached to the same movable carriage is the rigid arm A-A supporting the arm C-B, which passes through the center of the glass cylinder and supports lenses L1, L2 and prism P.

Now, starting the electric motor utilized to drive the carriage upon which the housing H is mounted, the entire movable system, comprising H with its lenses L3, L4 and photoelectric cell P E, together with arm C B supporting the lenses L1, L2 and prism P, will travel to the left and right as one unit. When the lamp L in the reflector R is lighted, L1 will collect the rays and direct them to L2 where they converge to a small point and pass into the prism P which now reflects the small pencil of light at right angles directing it into the lenses L3 and L4 and finally into the photoelectric cell PE.

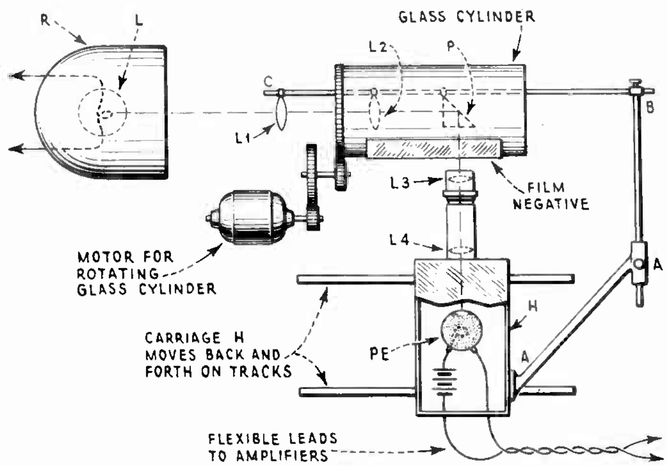


Fig.4 - ILLUSTRATING WORKING PRINCIPLE OF A PHOTORADIOGRAM TRANSMITTER.

Let us place a negative on the glass cylinder and clamp it in such a way that it conforms with the curvature of the cylinder. As soon as this is done the pencil of light, upon leaving the prism, will no longer have a direct unobstructed path in which to reach L3, L4 and the photoelectric cell, but must first penetrate the negative. It follows then that the amount of light reaching the photoelectric cell will depend upon the transparency of the negative, and the output of the photoelectric cell will be directly proportional to the light reaching it through the clear elementary areas of the negative.

With the negative in place and the electric motor started, the small intense point of light will move back and forth across the inside of the cylinder and for each single crossing of the prism the light will

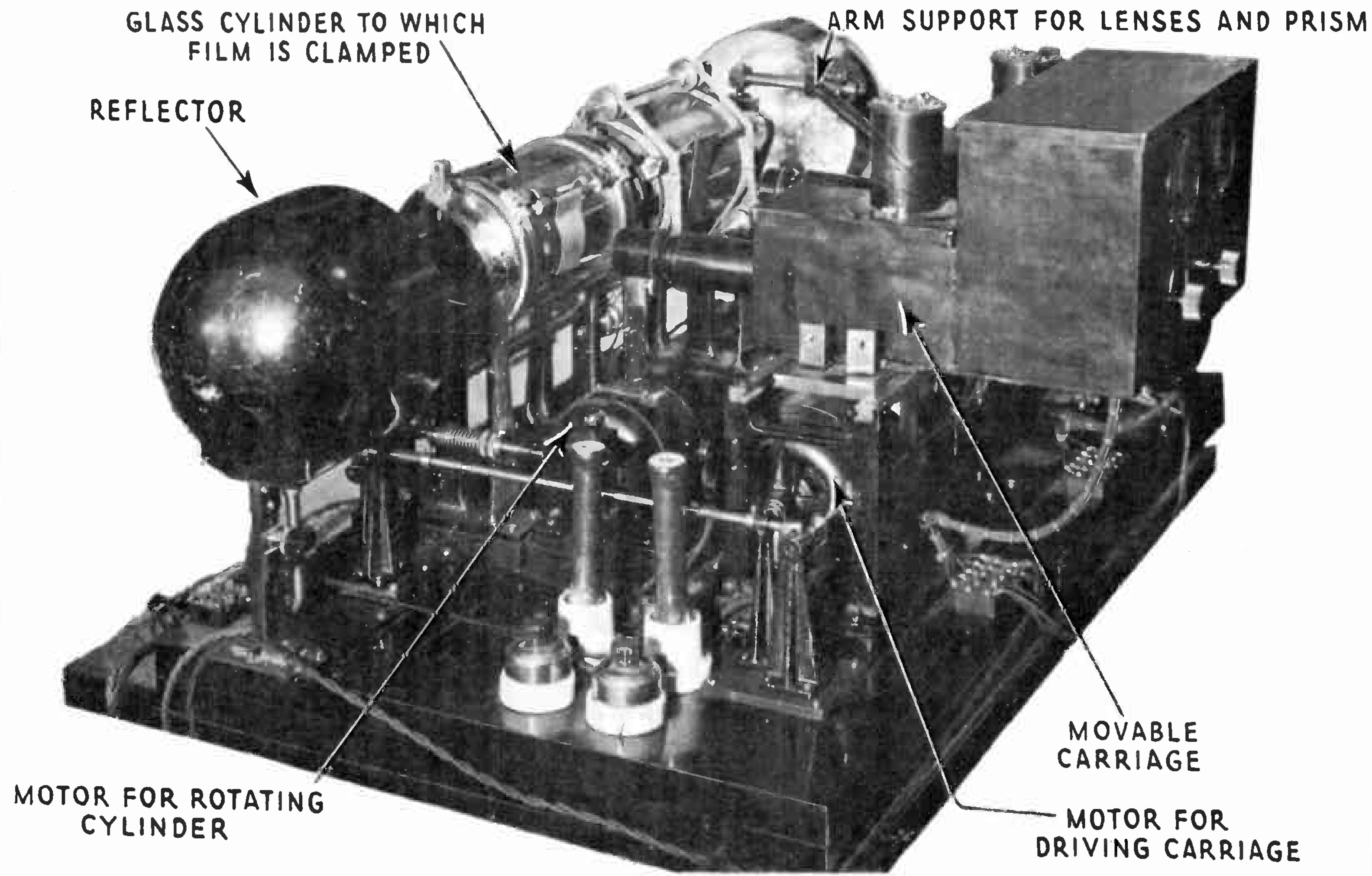


Fig. 5 - AN ASSEMBLED VIEW OF A COMMERCIAL TYPE PHOTORADIOGRAM TRANSMITTER.

have covered a very narrow line width of the negative. At the end of each stroke the glass cylinder is rotated very slightly by means of a motor geared to the end of the cylinder to present a new line width of the negative to the small spot of light as a return stroke of the system takes place. If the spot of light traverses a transparent, i.e., light portion of the negative, it has no difficulty in passing through to the photoelectric cell. On the other hand, if a dark width of the negative is in the path of the light little or no light will penetrate the negative, and correspondingly little or no current will be passed by the cell.

Since the photoelectric cell functions practically instantaneously, that is, without time lag, the moment the slightest change in the amount of light reaches the cell there will be a corresponding change in the output current of the cell. Because of this the photocell, figuratively speaking, sees the most minute variations of shading and records electrically thousands upon thousands of different current impulses as the searching spot of light sweeps back and forth across the negative, each current impulse corresponding with the light and dark elementary areas of the negative.

The currents thus produced are extremely minute in magnitude, in fact, too weak to be of any practical value in themselves. Therefore, they are fed into vacuum tube amplifiers and made many times stronger in the same way that a radio signal is increased in strength by the amplifier in any receiver.

The amplified current impulses are then ready to control a large radio transmitter through a series of relays in such a manner that the transmitted signals convey impulses of radio-frequency energy which in a way resembles the dots and dashes of code but actually they correspond to light values of the negative. These impulses are, of course, unintelligible so far as deciphering them is concerned and they cannot be read as you would read the alphabet of continental code.

CONTROL OF THE SIGNAL.

The actual control of these signals is accomplished as follows: When the spot of light is passing over a light part of the film very little current, if any, is radiated; this corresponds to a few dots or none at all. Then, as the light beam sweeps across a shaded strip of the negative a great many small impulses are released from the antenna which corresponds to a great many short dots. As the sweeping spot of light passes over a dark section of the negative, long and continuous heavy impulses are radiated which correspond to long heavy dashes.

A fully assembled view of the commercial type photoradiogram transmitter just described is shown in Fig. 5. When the undecipherable code impulses are released, it is necessary to operate some sort of apparatus that will translate them into light and shade—each electrical impulse in the form of a dot or dash performing a certain task in such a way that a picture is built up as each impulse is received.

The signals picked up by the antenna at the receiving station are weak impulses, exactly as are those received from a broadcasting station, and they must be detected and amplified in precisely the same manner. Before we put this signal to work we must pause for a moment

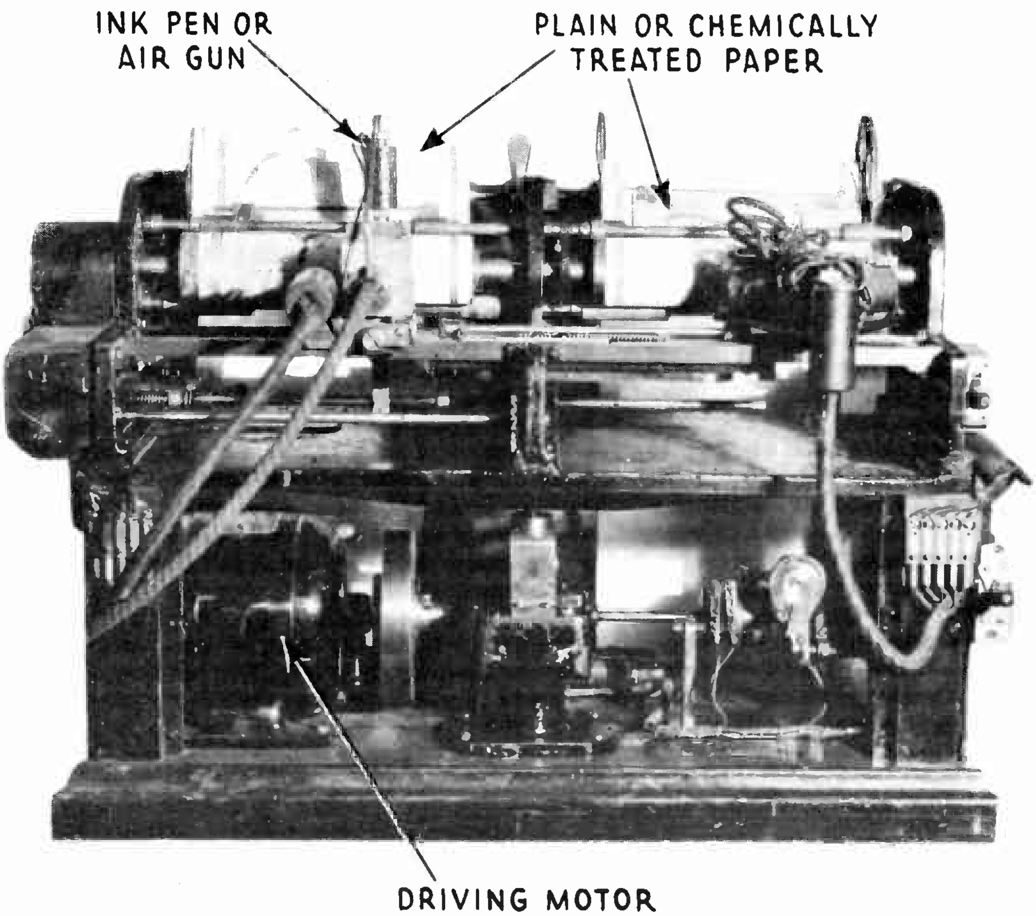


Fig.6 - THROUGH A SET OF GEARS THE MOTOR IN THIS FACSIMILE RECEIVER DRIVES A PEN CARRIAGE BACKWARD AND FORWARD IN FRONT OF A ROLL OF PAPER.

and study the mechanical and electrical features of the receiver shown in the photograph of Fig. 6.

An electrical driving motor is installed in the base of the receiver. Through a set of gears this motor drives a pen carriage backward and forward in front of a roll of paper. A most important function of this carriage is that it moves through each stroke in absolute synchronism with the carriage of the transmitter; this is a rigid requirement because, should the receiver lag the slightest amount behind the transmitter, a blurred and unrecognizable reproduction would result, therefore, exact synchronism must be maintained by the use of special driving motors. Once the transmitter and receiver are synchronized the receiver is ready to build up the picture. The pen carriage supports a small pen controlled by a tiny electrical relay in such a way that as each signal impulse passes through the electromagnets of the relay the pen is moved to the surface of the paper and leaves a fine ink mark as long as it is in contact. If the signal impulse is steady a straight ink line will result, but if the current passing through the relay magnets is varying in strength then the pen will wabble in step with the varying current impulses resulting in a wavy ink record. Back and forth across the paper, line by line, a picture is finally reproduced.

A picture of ex-president Coolidge which was transmitted by the photoradiogram system over a distance of 3000 miles and one of Bobby Jones transmitted from London to New York are shown on the back cover page.

INK PEN AND HOT AIR SYSTEMS.

In a later development the ink pen was replaced by a hot air method of reproduction. Instead of the ink pen a small air gun is mounted on the carriage which projects a fine column of air (which has been previously heated) toward a roll of chemically treated paper. The hot air acts as thousands of minute burning bullets which, upon striking the paper, instantly produce a sepia mark. (Sepia is a shade of brown.) Since the hot air is projected continuously toward the paper some means must be utilized to prevent it from striking the paper at times when no impression is desired. To accomplish this a stream of cold air from a second gun is arranged to blow aside the hot air at the proper interval. A small electrically controlled valve actuated by the incoming signal controls this cold air blast as follows: When a signal is coming in on the receiver, small electromagnets actuate a tiny valve which shuts off the supply of cold air; the hot air stream then, having no interference, strikes and burns the paper leaving the small brown impression.

Every time a ray of light from the transmitter finds its way through a clear space of the negative, and into the photocell, an impulse is transmitted in proportion to the intensity of the ray and this impulse, when intercepted by the receiving antenna, actuates the small electromagnets in the receiver thus controlling the duration of the cold air stream.

Thus in this system for every clear space in the negative traversed by the spot of light at the transmitter end a corresponding brown mark is made on the paper at the receiving end, and as the spot of light explores the negative line by line a positive print is built up by various shades of brown.

FACSIMILE TRANSMISSION

Facsimile means to make an exact copy of the original and differs somewhat from photoradiograms in that the original does not require a special preparation before transmission as does the negative in photoradiogram work. We can divide the methods of picture transmission into two classes; first, the photoradiogram, which requires a special preparation before transmission, and second, the facsimile, which can be transmitted directly from the original without special preparation. The methods requiring the preparation of a transparent master, either in positive or negative form, are still in use, and in such transmission which has been explained the transparent original is explored by a sharply defined pencil of light which pierces each elementary area as it passes across the original, one line at a time, activating a light sensitive cell on the opposite side. The amount of light reaching the photocell depends upon the variation in optical density of the original, and consequently controls the electric current delivered by the cell.

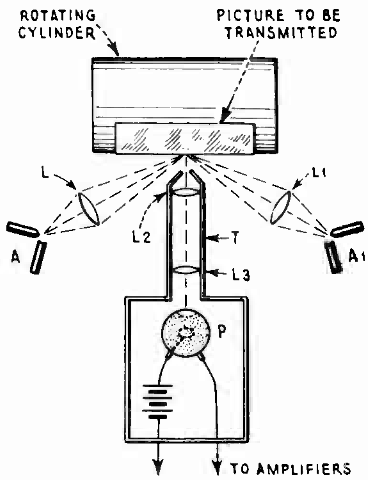


Fig. 7 - A REFLECTED SPOT OF LIGHT FROM THE PICTURE IS DIRECTED ONTO A PHOTOCELL THROUGH A LENS SYSTEM.

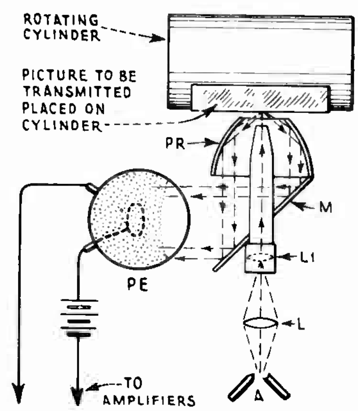


Fig. 8 - IN THIS SYSTEM THE EXPLORING PENCIL OF LIGHT IS REDUCED TO THE REQUIRED DIMENSIONS BY THE LENSES.

The trend, however, is toward greater speed in the transmission of pictures, therefore, engineers had to devise other methods to meet this demand and "facsimile" was the result. This makes possible more rapid work; a typewritten letter, checks, newspaper clippings, pictures from magazines, postcards or photographs, and so on, may be clamped to a glass cylinder, and instead of a spot of light passing through the original it is shot directly at it and the reflected light utilized to actuate a photocell.

1ST METHOD.

One of these methods is to illuminate the original by a strong diffused or concentrated light and then isolate or cut off a small spot of the light flooded area; the reflected light from this spot is then directed into a photocell. Figure 7 indicates how this may be accomplished. A source of light A, A1, is collected by lenses L and L1 and projected to a small area on the picture to be transmitted. Close to this illuminated area is placed a hollow tube T, which cuts off a small spot of reflected light from the brightened area which passes into the tube; this is collected by a system of lenses L2 and L3 inside the tube and directed into the photoelectric cell P. It is known that a light area will reflect considerable light while a dark surface reflects only a small amount of the light directed against it. Therefore, if a spot of light sweeps across a surface of light and shade more light will be reflected from the light area than from a dark space. The photocell, of course, is affected according to the amount of light reaching it. The cylinder moves forward a small line width at the end of each stroke of the sweeping light spot, and in this respect there is very little mechanical change in design from the photoradiogram equipment.

2ND METHOD.

Another system that will provide a facsimile is to first reduce the exploring pencil of light to the required dimension by a special system of lenses and then use all the light reflected instead of capturing or cutting off a small section of the total illuminated area. Figure 8 fundamentally illustrates this system. The light from A is collected by the lens L which focuses it upon the optical system in L1 in order that the size of the spot will be independent of the size of its source and strikes the surface of the picture in an extremely small but intense spot of light.

The reflected light from the picture is then picked up by the parabolic mirror P R and reflected to a plain mirror M which in turn reflects the light into the photocell P E. The current from the photocell is amplified and actuates the receiver. Any standard short-wave receiver may be used for the reception of picture signals. Mechanically, the receiver is identical with the transmitter. A standard bromide photographic paper is used on the receiving cylinder and the recording is accomplished by means of a small helium glow discharge tube. A special mask restricts the glow to the required size. The varying intensities of glow from this tube is dependent upon the light picked up by the transmitter photocell and blackens the sensitized photographic paper accordingly. The receiver employed with the system mentioned in connection with Figure 7 may also be an electrically controlled ink pencil or a hot air gun as described under "Photoradiograms".

FACSIMILE RECEPTION

CARBON RECORDER. The carbon recorder for facsimile reception prints directly on a continuous strip of paper and has an advantage over earlier facsimile machines where photographic developing of the image was required before it could be read. A photograph of a six inch carbon recorder with its recording amplifier and synchronous drive motor, as developed by the General Electric Company and the RCA-Victor Company, is shown on the front cover page of this lesson. This machine provides a very practical method of securing instantaneous prints. It has abolished all photographic processing at the receiver, as just mentioned. Its use is limited to subjects having extreme contrast, such as printed or typed matter, maps, and line drawings.

The printing mechanism consists of two strips for causing pressure of carbon paper against white paper. These may conveniently be in the form of two rolls which unwind simultaneously. One pressure strip is a straight narrow-edged bar which is pressed forward a fraction of an inch by the signal coming to an electromagnetic mechanism. This bar would naturally make its mark as a long black line across the paper but for the second pressure strip which is behind the white paper. The latter metal strip is set into a spiral groove around a metal cylinder and sticks up above the cylinder a short distance. The two strips therefore cross each other at some one point along the horizontal line which is determined by the position of the cylinder. This rotates in synchronism with some rotary part of the transmitting scanner so that, whenever the straight bar is pressed, the one point of pressure against the cylinder strip will be placed in the record of this receiving equipment at a spot identical with the spot of the original then being scanned. Of course this requires a uniform unrolling of the white paper to make each picture line fall in the proper succession on the record.

By this system a whole front page of a newspaper has been transmitted by radio across the continent and received at Schenectady.

NEWSPAPER BY RADIO — CALIFORNIA TO NEW YORK

In making this transmission the front page of the newspaper was cut in three strips and each strip fed in succession through the scanning machine in the transmitting station at Oakland, California. As a result radio signals were sent out on 17 meters wavelength which were interrupted in accordance with the light and shade on the picture. These were picked up at the Sacandaga receiving station near Schenectady and sent in to the laboratory over a telephone line. There they were properly amplified and used to operate the recording or printing machine.

This recording machine prints by a carbon method directly on a continuous strip of paper, and the copy feeds steadily out as fast as the original goes through the scanning machine. It has an advantage over earlier facsimile machines where photographic developing of the image was required before it could be read.

At the present time the printing paper used is 8-1/2 inches wide, but for special services a wider machine could be developed. The signals for facsimile are not necessarily sent out on short waves, as any good radio circuit will do.

The utilization of the facsimile invention will, of course, lead to many new types of service. There will be transmission of written messages, charts and photographs.

MODULATION PROBLEMS

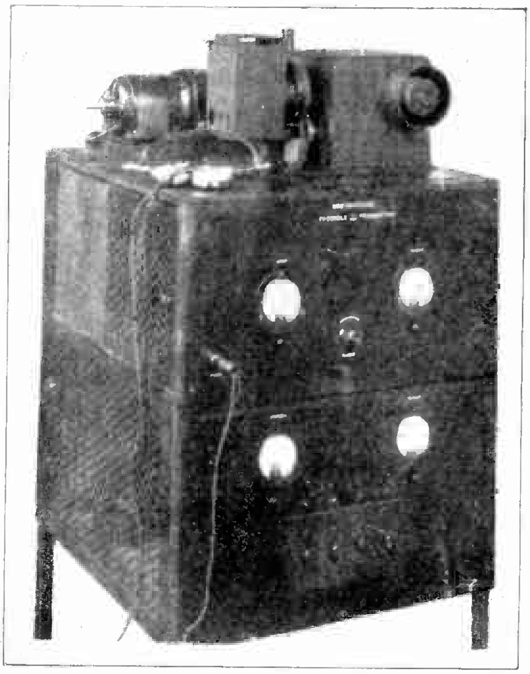
It has been stated that the picture signal modulates the radio-frequency power of the transmitter. This is the early way; improved results have been secured with a system requiring the intermediate use of an audio signal of constant frequency and amplitude, locally generated by an alternator or oscillator. Very gradual changes in intensity of a picture negative are the equivalent of a very low frequency signal which is difficult to amplify at high power. But it is possible, at low power, to impress this picture signal on the steady audio tone referred to, which becomes modulated by the picture signal. An additional vacuum tube performs this pre-modulation function. The radio power of the transmitter is then modulated by the picture-modulated tone signal. At the receiver the radio detector output provides the audio-frequency tone whose amplitude is modulated by the picture-signal. An audio amplifier, selective to the frequency of the constant tone plus its picture side bands, may be used to secure a good level of signal and selectivity against static and other interferences. The modulated tone signal is fed into another detector which makes available the picture modulation signal which is the counterpart of the photoelectric cell current at the transmitter. It is seen that such a use of a signal tone requires two steps of modulation at the transmitter and therefore two steps of demodulation or detection at the receiver.

The work of pre-modulation is sometimes done without the use of the extra vacuum tube in the transmitter. The method is simple, and merely requires the use of a "chopper" in the beam of light which is used for scanning. The chopper may have several forms; probably the simplest to understand is an opaque disc which has holes punched in it at regular distances along a circle. As this disc rotates at constant speed, the chopper disc alternately passes and stops the light directed into the cell, producing therein an audio-frequency current variation of constant frequency which depends on the number of holes in the chopper disc and its revolutions per second. The amplitude of successive current waves depends as before on the efficiency with which the scanning light is transmitted through the picture negative, or reflected from the positive print, as the case may be.

Another thing to remember is that the transmitting and receiving systems must be co-ordinated so that white becomes white, and black becomes black, in the transfer from point to point. At the transmitter it is perfectly arbitrary with the designing engineers as to whether an increase in whiteness of an original causes an increase in radio power transmitted or the opposite, where a decrease in whiteness (darkening) may cause an increase in power. Usually the choice is dictated by the effects of static and other interfering electrical disturbances on the received picture. Here the print is usually made on white paper, or on paper which will turn out as white if no recording is made on it. If the white areas of the original picture cause an increase in radio power transmitted, then any static added to the signal received at a distant point will only cause increased whiteness in the corresponding areas of the record. If static occurs when a dark portion is being recorded the visible effect of the static is stray dots and lines of white, which are not very objectionable as there is always in a received picture a certain percentage of space (white) in between adjacent dark markings.

On the other hand, if an increase in darkness along a scanned line of the original causes an increase in power transmitted, the addition of static to the received signal causes dark spots in the entirely white areas. The contrast is less desirable than under the previous method.

Frequently a receiver is equipped to receive on either method, as transmitting stations may differ on this point. Even when a receiver is used only for a fixed service where the modulation method of the transmitter is known, it is desirable to be able to change the recording equipment to make either positive or negative prints. This can be done by a switch which changes the tone demodulator tube from grid-leak to grid-biased detector operation, or by reversing one winding of a transformer between that demodulator and the output stage used for recording purposes. By this means an increase in whiteness on a scanning line at the transmitter may be made to record either as an increase or decrease in whiteness in the received record. This provides either a positive or a negative at will.



A COMMERCIAL FORM OF FACSIMILE SCANNER WHICH HAS THE OPTICAL ARRANGEMENT OF FIGURE 8. (COURTESY OF WESTINGHOUSE E. AND M. CO.)

EXAMINATION QUESTIONS

1. What is a negative?

2. How does light affect a photographic film?

3. What does a negative look like when closely examined?

4. How is the hot air in a photoradiogram receiver controlled?

5. What is the difference between photoradiograms and facsimile?

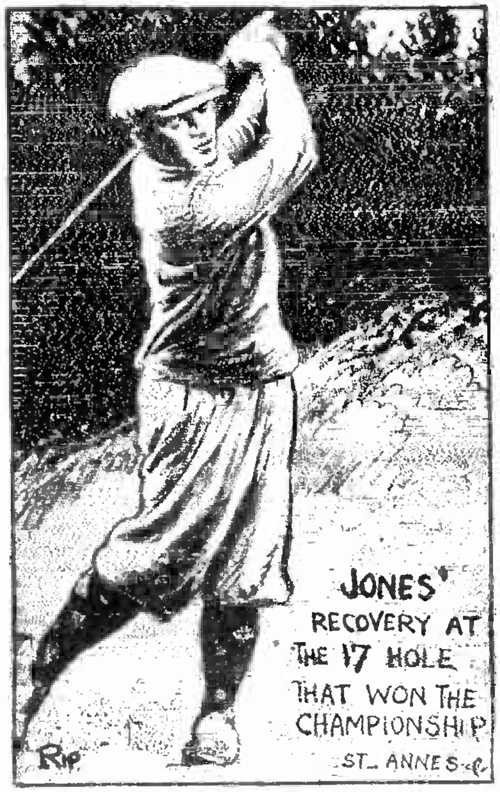
6. Why is a photoelectric cell used in picture transmission?

7. What two motions are necessary in a recorder?

8. Describe briefly the fundamental difference between two optical systems used for facsimile scanning.

9. Why must the light path of a scanning system be shielded from outside lamps or other light sources?

10. How may a recording system be changed from positive to negative recording?



THE REPRODUCTION OF A
DRAWING TRANSMITTED
BY RADIO FROM LONDON
TO NEW YORK

A PICTURE OF EX-PRESIDENT
COOLIDGE WHICH WAS
TRANSMITTED BY THE
PHOTORADIOGRAM SYSTEM
OVER A DISTANCE OF
3000 MILES

RCA INSTITUTES INC.
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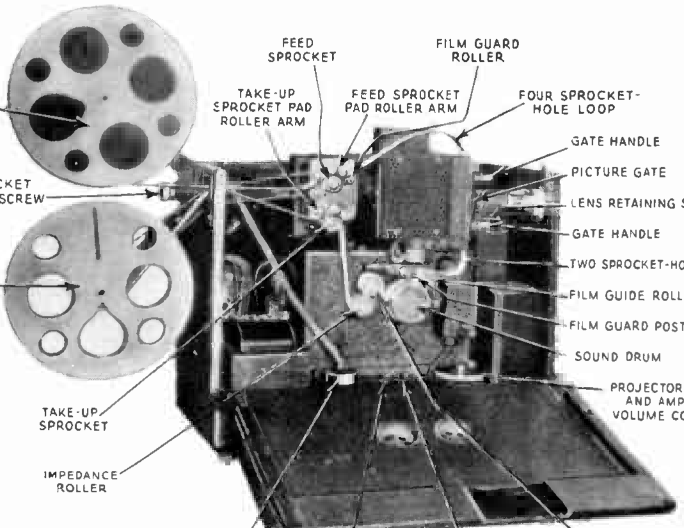
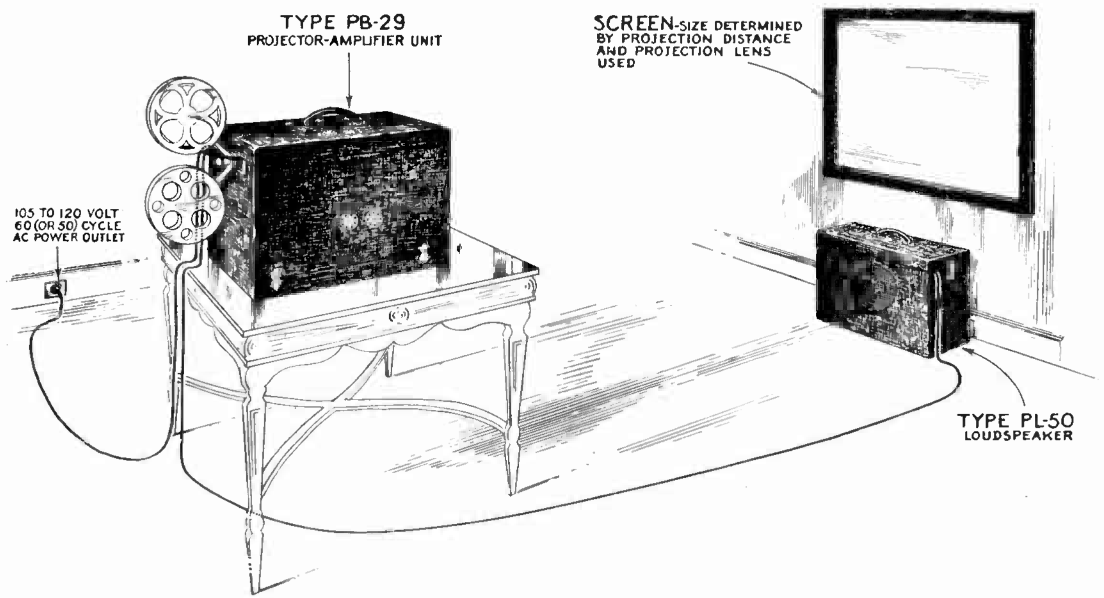


16 MM. SOUND-ON-FILM PHOTOPHONE JUNIOR PORTABLE WITH CASE OPENED AND EQUIPMENT THREADED FOR OPERATION.

"Home Talkies" Sound-On-Film Equipment

V-58 #2



THE 16 MM. SOUND-ON-FILM PORTABLE EQUIPMENT
SET UP FOR OPERATION.

V-58 #2

PRINTED IN U.S.A.

America's Oldest Radio School

RCA INSTITUTES INC.

A Radio Corporation of America Subsidiary

HOME OFFICE
75 Varick Street, New York

PORTABLE 16 MM. SOUND-ON-FILM EQUIPMENT FOR HOME AND EDUCATIONAL USE

At the present time there are two types of sound equipment for 16 millimeter film, namely, sound-on-disc and sound-on-film. In this lesson we shall study the latter type of equipment developed especially for use in homes, small size halls, church and club rooms, in schools or other places where a compact portable machine is desired to provide silent or sound pictures. This equipment is known as a Junior portable projector and will provide a 52" x 39" picture size giving good illumination at a projection distance of 23 feet.

Before going into details regarding this portable type sound-on-film 16 mm. projector, let us examine some of the fundamental problems that had to be solved before this type of equipment was ready for practical use.

In the first place, a film 16 mm. wide is used in this machine whereas, the width of standard film is 35 mm., as you already know. Hence, the picture size of a 16 mm. film is but 0.36" wide by 0.30" high. It was not considered advisable to cut down the width of the picture to make room for the sound track, because the track would have to be very nearly as wide as for standard sound film and this would mean a complete change in the ratio of the picture dimensions.

One reason why the sound track must be as wide or nearly as wide as in standard film is because the same kind of pickup device is employed for both sizes of film. The pickup we refer to is the photoelectric cell. It is to be understood that the sensitivity of a photocell itself cannot be increased and therefore, the present day commercial type of photocell would not compensate for a sound track if it were reduced in width.

This fact has an important bearing upon the operation of the equipment since the loudness of the sound reproduced depends upon the amount of the light fluctuations impinging upon the photocell, and in turn the amount of fluctuation of light depends upon the amplitude of the photographed sound wave on the film. If the width of the sound track were cut down it would also cut down the amplitude of the photographed wave and consequently more stages of amplification would be required to compensate for this difference.

However, there is one disadvantage which presents itself in this connection, for if we increase the stages of amplification, we also increase the amount of hum voltage in the output to the loudspeaker.

Furthermore, tube noises would increase correspondingly which would require more filtering of the "B" supply for the amplifier required, providing a-c supply is used as would be necessary for operating this type of equipment. Also, expensive and cumbersome shielding, interstage isolation, and other items would be required that would raise the cost and size of the equipment to a point entirely beyond practical limits for home use.

Another important reason for retaining the sound track at nearly its present width is technical in nature. It is well known that the range in sound intensity is at least one million to one, at least for orchestral music. The ordinary 70 mil standard sound track cannot accommodate so great a range, however, since the maximum amplitude for variable area recording, for instance is one-half or 35 mils, the minimum intensity would be represented by an amplitude so small as to be comparable to the grain size of the photographic emulsion. These low intensity sounds would therefore be "drowned out" in the surface noise coming from the grain of the film and other noises present in the system.

Now, if we decrease the width of the sound track, we shall decrease still further the limited volume range of the recording to a point where unsatisfactory results will be obtained. Another point to mention is that most 16 mm. films are reductions of standard 35 mm. theatre film and hence, some automatic means would be necessary in the re-recording to prevent the normal volume range of the standard sound track from over-loading the narrower 16 mm. sound track.

The problem therefore, was how to accommodate a normal or nearly normal width of sound track on a 16 mm. film. One solution would be to increase the width of the film, but this would make the entire equipment non-standard, and incapable of projecting 16 mm. silent film as well.

As an alternative, it was decided to omit the sprocket holes on one side of the film, and place the sound track on that side. The film was therefore pulled through the projector by means of sprocket wheels and an intermittent claw which had teeth only on one side. To compensate for the increased pull on this side, the claw was constructed to engage two sprocket teeth at a time, and the film also engaged more sprocket teeth on the sprocket wheels than on the usual 16 mm. projectors.

The next problem that arose was that of reduced film speed — 36 feet per minute instead of 90 feet per minute. This means that the recording must be compressed in order that the same number of photographic peaks and valleys pass the light slit in a second, and thus give rise to sounds of the same pitch. For a tone of the same pitch, the peaks and valleys (in variable area recording, or the alternate opaque and transparent bands, in Movietone recording) must be reduced in height from the 35 mm. to the 16 mm. film in the proportions of 90 to 36, respectively.

This means that for the same size optical slit image of one mil, let us say, the cut-off frequency is 7200 cycles instead of 18000 cycles, and marked attenuation occurs at frequencies as low as 4000 cycles per second. Furthermore, these frequencies become comparable to the photographic grain, and other difficulties attendant upon commercial developing of sound recording, such as fogging around the outline of the peaks, come into effect and result in excessive surface noise and wave shape distortion. For all these reasons it was not deemed advisable to attempt to record or reproduce frequencies above about 4000 cycles per second. This allows as great a frequency range as the ordinary phonograph records, and gives satisfactory reproduction of speech and music.

We are now ready to proceed with the study of the 16 mm. sound-on-film machine. The RCA Victor Photophone Equipment Type PG-38 consists of a 16 mm. projector combined with an amplifier and a dynamic type loudspeaker. Both of these units are built into cases resembling small suitcases and the entire equipment is designed primarily for home or educational use. The only additional equipment necessary for operation is a suitable screen or wall surface and the necessary film.

ELECTRICAL SPECIFICATIONS

Voltage Rating	105–120 Volts
Frequency Rating	50 and 60 cycles
Power Consumption	200 Watts
Number and types of Radiotrons	3 UX-245, 1 UX-280, 1 UY-224-A, 1 UY-227, 1 RCA-868, Total 7
Type of Exciter Lamp	Mazda 4 volt, 0.75 ampere, S-8 bulb, Single contact bayonet base
Type of Projection Lamps	Mazda 110 Volt, 100 watt, T-8 bulb, Single contact bayonet base
Type of Projection Motor	Capacitor type operating at a speed of 1725 R.P.M.
Type of Loudspeaker	Electro-dynamic with directional or flat baffle
Wattage dissipation in L. S. Field	10 Watts
Undistorted Output	3.0 Watts

PHYSICAL SPECIFICATIONS

Projector Unit

Height	13⅞ inches
Width	14½ inches
Depth	8¼ inches
Weight Alone	46 lbs.
Weight Packed for Shipment	67 lbs.

Loudspeaker Unit

	4PL59A1	4PL50A1
Height	17½ inches	16¼ inches
Width	14½ inches	19 inches
Depth	16 inches	9½ inches
Weight Alone	65 lbs.	23 lbs.
Weight Packed for Shipment	71½ lbs.	32 lbs.

Fig. 1 - ELECTRICAL AND PHYSICAL SPECIFICATIONS FOR THE 16 MM. PG-38 EQUIPMENT.

A concrete idea of the size, weight, and electrical output of this device can be obtained by examination of the electrical and physical specifications given in the chart in Figure 1.

The student should note the following features incorporated in this model.

1. Universal use. The type PG-38 equipment may be used for both silent and sound pictures. Silent pictures with either single or double row sprocket holes or sound pictures with single sprocket holes may be used with this equipment. The student should note, however, that Photophone 16 mm. sound film adapted for use in this projector is not adapted for use in the ordinary silent 16 mm. projector requiring sprocket hole perforations on both sides of the film.

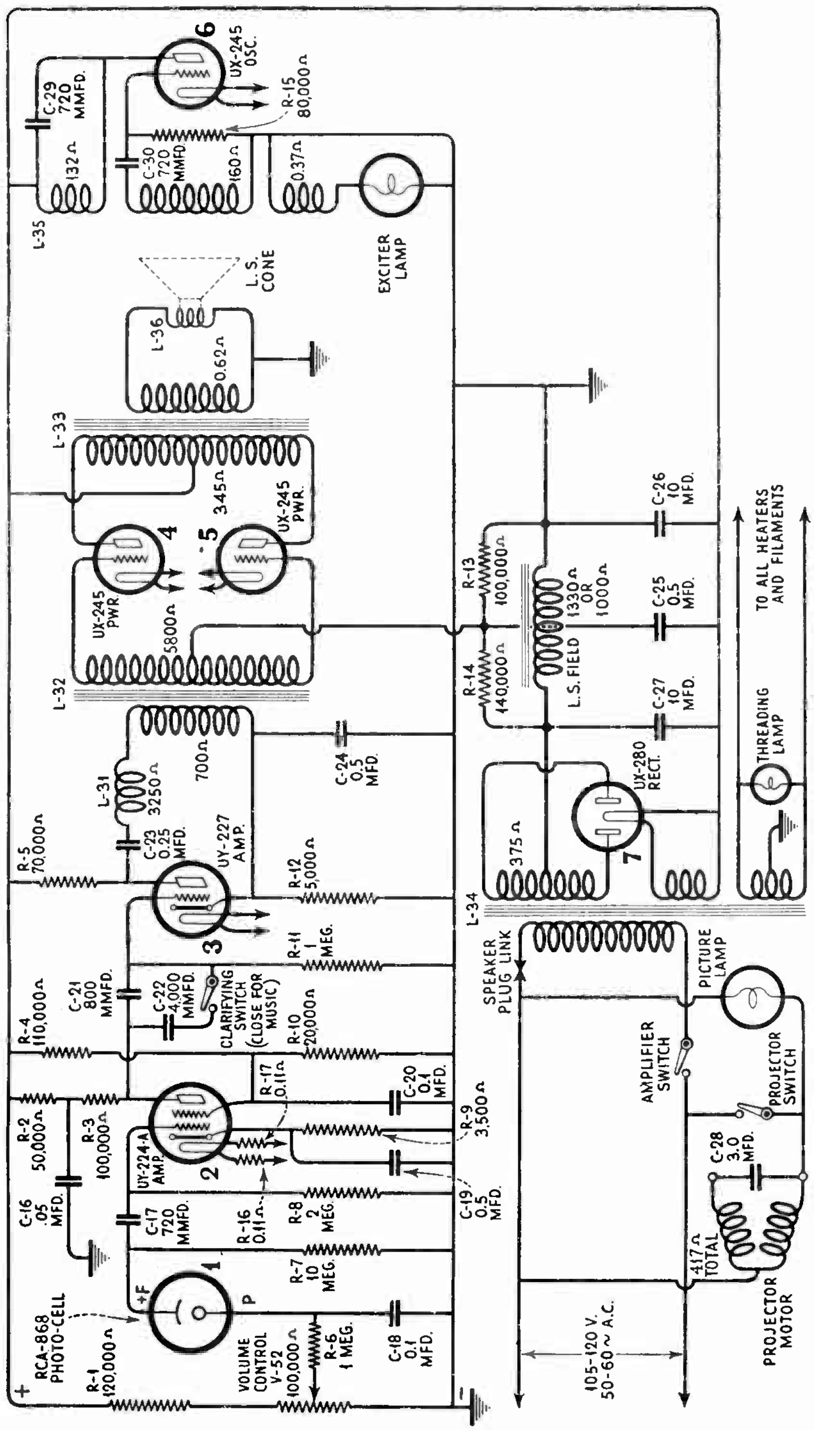


Fig. 2 - SCHEMATIC CIRCUIT DIAGRAM OF THE PG-38, 16 MM. EQUIPMENT.

2. Compact construction. The amplifier and projector are built into one compact unit that weighs but 46 lbs. The PL-50 loudspeaker with flat baffle unit weighs 23 lbs. and has ample room for the carrying of 8 reels of film. The PL-59 loudspeaker with directional baffle weighs 65 lbs. and has room for carrying 4 reels of film.

3. High quality sound reproduction. Due to a properly designed sound system and an efficient loudspeaker, the quality of sound output is comparable to the best reproducing systems. The power output is sufficient to fill small size halls or any size home.

4. Adaptable to sound films using records. Projector-Amplifier Models 4PB29D1 and 4PB29D2 are provided with an extension shaft so that a single synchronous turntable may be used. This makes the instrument available for use with films, the sound for which is recorded on records instead of films. On such models two pin jacks are provided for connecting the magnetic pickup to the amplifier. The pickup is connected from the control grid of the UY-224-A to ground and requires its own volume control, but no input transformer. When returning to operation of sound-on-film the pickup leads must be removed.

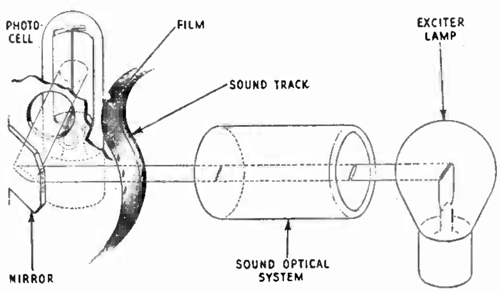


Fig. 3 - GENERAL VIEW OF SOUND SYSTEM.

Let us now proceed to a study of the electrical circuit used.

ELECTRICAL DESCRIPTION OF CIRCUIT. The circuit of the PG-38 being somewhat different from that of the conventional amplifier, a description of it will be found useful as a help in the proper understanding of the functioning of the various parts. Refer to Figure 2.

The projection lamp is operated direct from the 110 volt a-c line with a power consumption of 100 watts. It should be noted that its maximum voltage rating is 120 volts. This must not be exceeded, and for higher line voltages some line voltage reducing device is required, as the projection lamp life will be extremely short at greater operating voltages.

The exciter lamp is operated from radio-frequency current supplied by the UX-245 oscillator. The oscillator is tuned to 15 kc. so that the r-f voltage variations are beyond the audible range, and will not be amplified or reproduced by the loudspeaker. Even if they were, they could not be heard by the human ear, so that such high frequency exciter lamp supply is equivalent to a direct current as far as results are concerned. This system thus avoids the necessity of rectifiers and batteries and is very stable in operation.

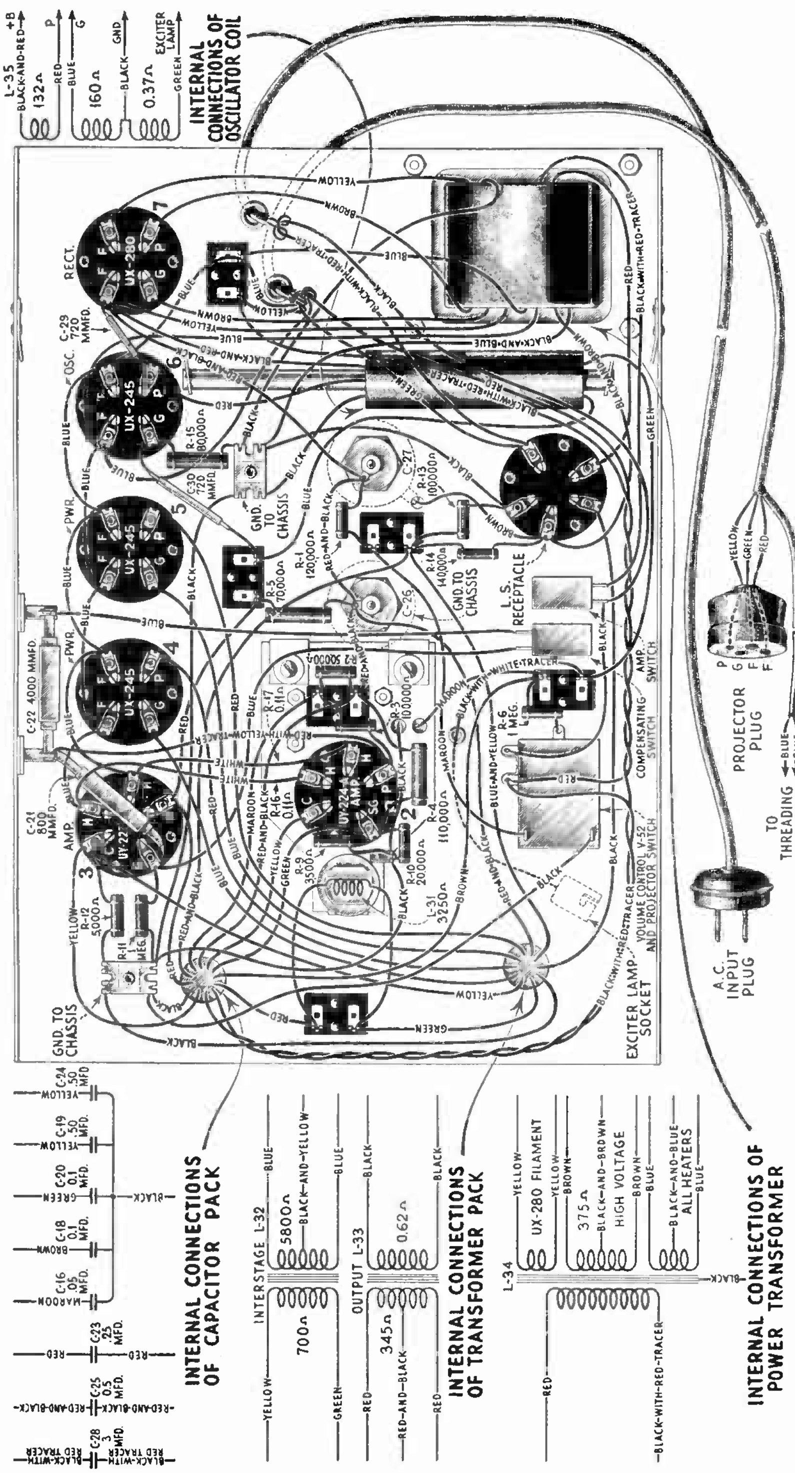


Fig. 4 - WIRING DIAGRAM OF THE AMPLIFIER.

The light from the exciter lamp, after traversing the sound track (see Figure 3) of the film acts upon the photocell and thereby sets up audio voltage variations across the resistor in its plate circuit. An adjustable resistor — the volume control — is provided in its anode circuit for controlling the anode voltage and thereby the volume output of the unit. The cathode of the photocell is coupled to the control grid circuit of the UY-224-A voltage amplifier by means of resistance coupling.

The output of the UY-224-A is also coupled by means of resistance coupling to the grid of the UY-227. This tube is then coupled by means of transformer coupling to the UX-245 push-pull power amplifier which in turn is transformer coupled to the moving coil of the dynamic type loudspeaker.

It should be noted that the coupling capacitor between the UY-224-A and UY-227 is adjustable by means of a switch. This provides for increased low-frequency output when reproducing music. The overall characteristics of this amplifier are very good, its undistorted output being approximately 3 watts, which is more than ample for the average home or small hall.

You may have occasion to service this equipment some time, and with this in view we have included the following valuable service data and charts for facilitating such work. In Part I you are given data concerning the electrical part of this equipment, and in Part II data about the optical and mechanical adjustments. In addition to the foregoing instructions are included regarding general troubles. It is recommended that you study this information very closely so that you will become thoroughly acquainted with the details of the operation of the unit and learn the important points regarding possible improper functioning of its components.

PART I — ELECTRICAL DATA

(1) AMPLIFIER

Service work in conjunction with the amplifier is essentially the same as that of other Photophone amplifiers or radio receiver units. Such work generally consists of the location and replacement of a defective part. Figure 2 shows the schematic wiring diagram, Figure 4 the amplifier wiring and Figure 5 the assembly wiring. It is recommended that the fault be located by a systematic process of elimination. This is the procedure followed by an experienced service man because he knows that if he were to jump from one part to another it would be very easy to miss a simple defect which might be the cause of all the trouble.

(2) TESTING CAPACITORS

The internal connections of the by-pass capacitors are shown in Figure 4.

They can best be tested by freeing their connections and charging them with approximately 200 volts d.c. and then noting their ability to hold the charge. After charging, short-circuiting the capacitor terminals with a screw driver should produce a flash, the size of which depends on the size of the capacitor and the voltage used in charging. A capacitor that will not hold its charge is defective and requires replacement of the entire unit.

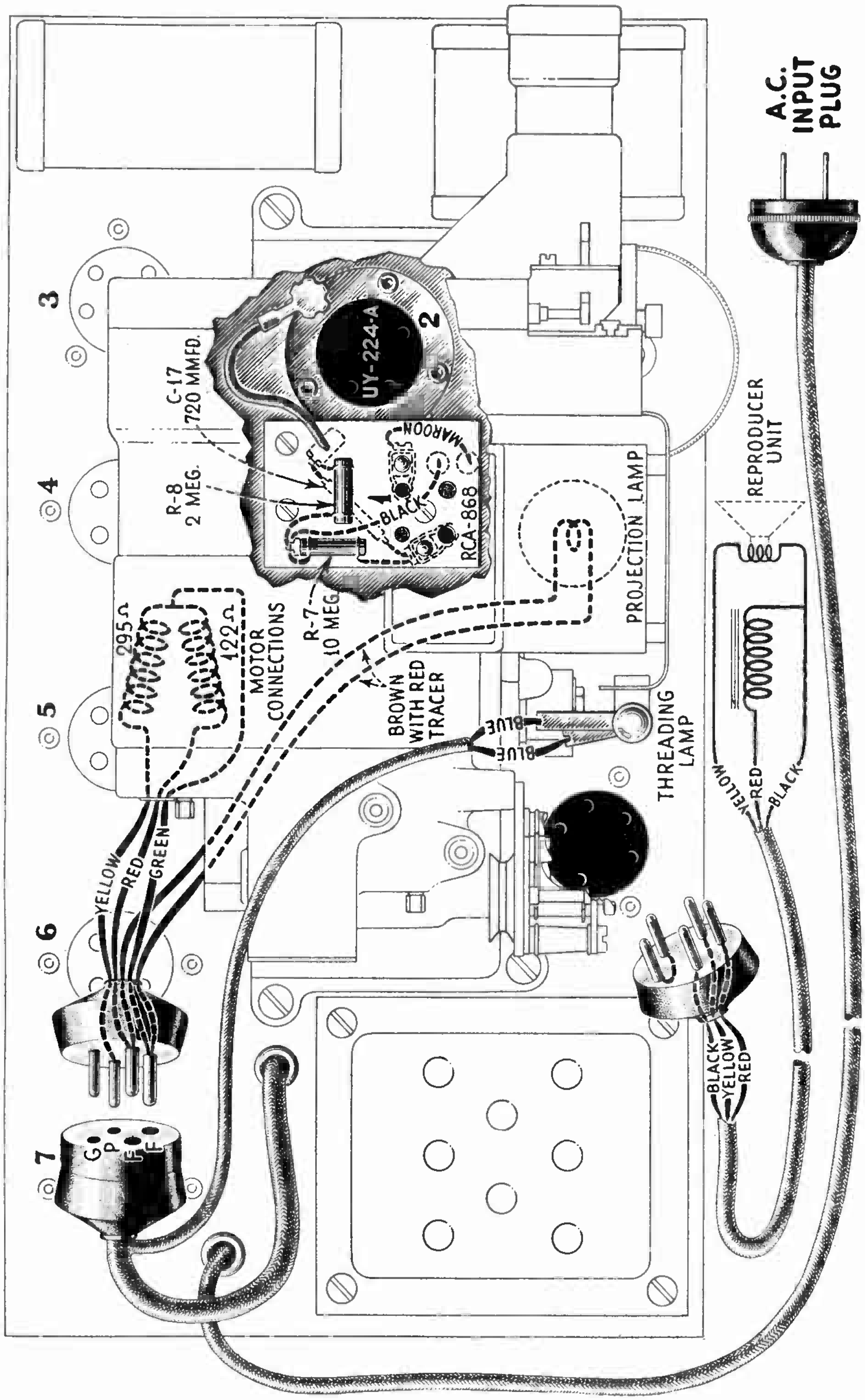


Fig. 5 - ASSEMBLY WIRING DIAGRAM.

The electrolytic capacitors can best be tested by measuring their leakage current. This should not exceed 2.4 m.a. for either 10 mfd. capacitor when measured at 400 volts d.c. The center contact is the positive terminal of the capacitors, and care should be exercised not to reverse the polarity during the testing operation, as a very large current, which will ruin the condenser, will flow if this is done.

(3) LOW OR NO SOUND OUTPUT

Low volume or no sound output may be caused by any of the following:

(a) Defective photocell. A defective photocell RCA-868 may be the cause of low or no volume.
(b) Defective tubes in other sockets. These can be checked against the values given in the table in Figure 6.
(c) Poor contacts in shielding. The cover over the UY-224-A and photocell RCA-868 should be snug and made a good fit. Also the contact between the projector and amplifier base should be tight.
(d) Photocell not properly seated in its socket. The RCA-868 base must rest squarely against the socket so that the light is projected into the proper area from the reflecting mirror.
(e) Improperly adjusted sound optical system. The sound optical system must be accurately adjusted as described in Part II Section 2.
(f) Improperly adjusted exciter lamp socket. Adjust the exciter lamp socket as described in Part II Section 2.
(g) Dirty optical system. Clean any oil, dust or dirt from the optical system lenses. Also make sure the hole in the casting is clean.
(h) Defective exciter lamp. An intermittently open filament in the exciter lamp will not be noticeable to the eye, but will cause hum, distortion or no sound.

(4) SOCKET VOLTAGES OF THE TUBES

The voltages (see Fig.6) taken at each tube socket with the amplifier in operating condition should prove of value when checking with a standard test set. The plate currents shown are not necessarily accurate for each tube, as the cable in the test set will cause some circuits to oscillate, due to its added capacity. Small variations

Volume Control at Minimum

115 Volt Line

Radiotron No.	Control Grid to Cathode or Filament Volts	Screen Grid to Cathode or Filament Volts	Plate to Cathode or Filament Volts	Plate Current M. A.	Filament or Heater Volts
2–UY-224-A	0.1	28	150	0.5	2.3
3–UY-227	1.5	—	110	2.0	2.5
4–UX-245	35	—	240	30	2.5
5–UX-245	35	—	240	30	2.5
6–UX-245 Osc.	75	—	240	25	2.5

Fig. 6 - VOLTAGE AND CURRENT VALUES FOR THE PG-38.

of voltages will be caused by different tubes and line voltages. Therefore, the following values must be taken as approximately those that will be found under varying conditions. The numbers in column 1 indicate the tube socket numbers shown in Figure 5.

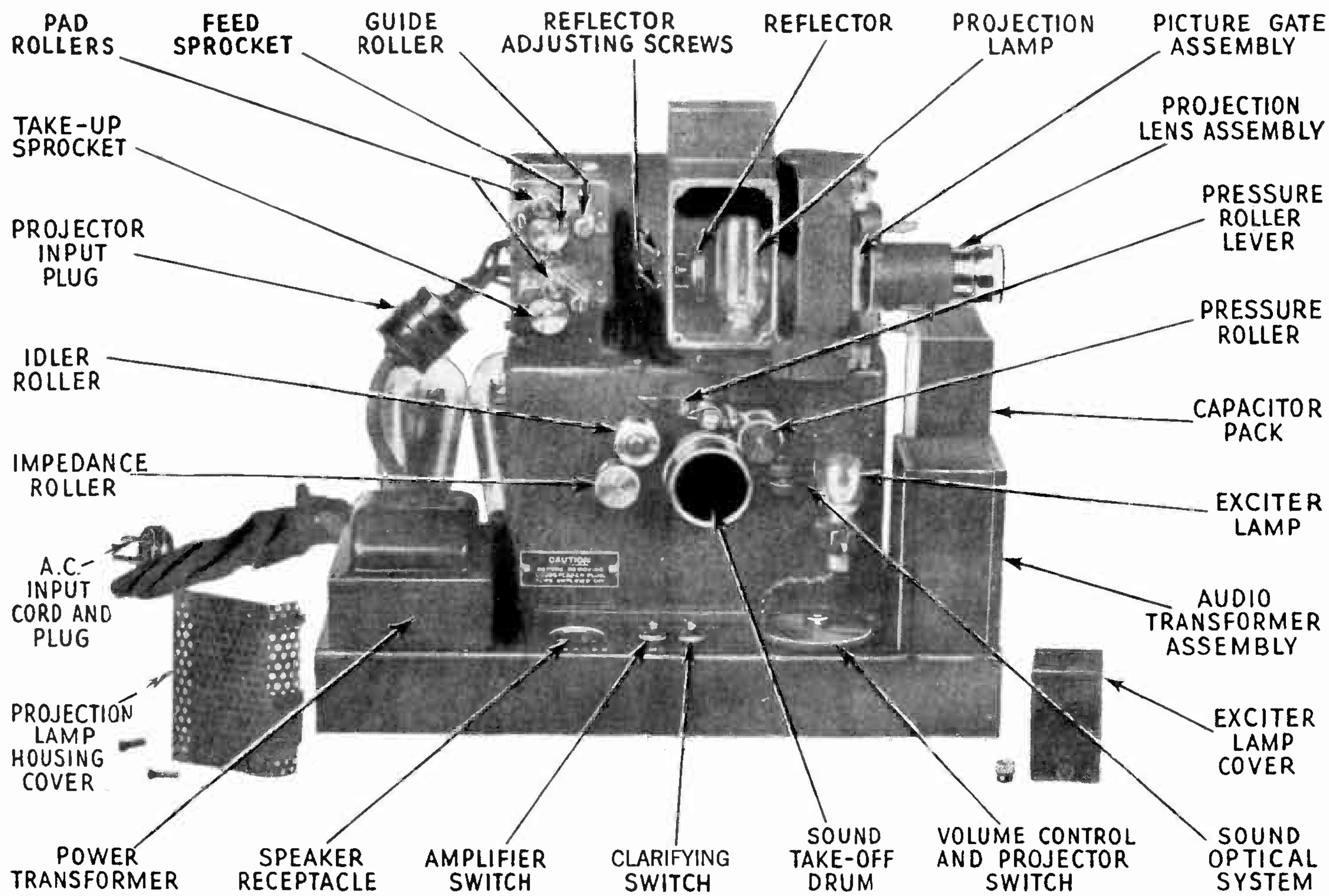


Fig. 7 – GENERAL VIEW OF THE PROJECTOR-AMPLIFIER UNIT.

PART II—OPTICAL DATA

In the PG-38 equipment there are several adjustments on both the picture and sound optical system that may become necessary due to the replacement of parts or ordinary wear and tear on the equipment. The following descriptions of the correct manner in making these adjustments should be carefully read and applied when adjustments are to be made.

(1) ALIGNMENT AND FOCUS OF PICTURE OPTICAL SYSTEM

Reflector. Several adjusting screws are attached to the reflector so that an adjustment can be easily made. Refer to Figure 7. Proceed as follows:

(a) Turn "on" the power to the projection lamp.
(b) Remove the projection lens by unscrewing from the holder.

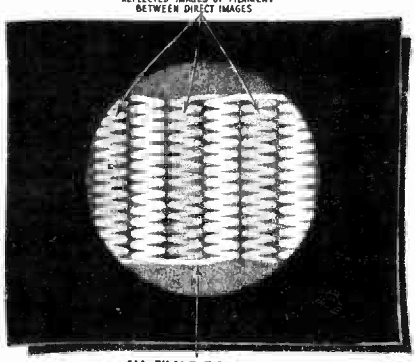


Fig. 8 - CORRECT PROJECTOR LAMP FILAMENT IMAGES.

(c) Place a small card directly in front of the lens so that an image of the filaments of the projection lamp is projected on the card.
(d) The filament image should be such that the reflected image of the filaments is between the actual filament images. See Figure 8. Also the light should be evenly distributed throughout the entire opening. If these conditions do not exist, then adjustment of the several reflector adjustment screws or projection lamp socket should be made until the desired effect is obtained.

Picture Jump and Correct Framing. The picture jump of the PG-38 should not exceed $\frac{1}{2}$ of 1% of the vertical or horizontal picture size in their respective direction. This may be checked by raising or lowering the film gate as described in Part II Section 5 so that a frame line of the picture is visible and may be used as an index. Excessive picture jump is an indication of excessive wear of the claw and intermittent assembly or a general wear on all parts in the picture head.

(2) ALIGNMENT AND FOCUS OF SOUND OPTICAL SYSTEM

In order to properly focus the sound optical system it will be necessary to have several pieces of equipment. These are as follows:

Output Meter. An output meter must be either connected across or substituted for the cone coil of the loudspeaker. This may be a low reading a-c voltmeter, a thermo-galvanometer or a rectifier voltmeter of low range, and is used to read the audio-frequency across the secondary terminals of the output transformer.

Exciter Lamp Tools. A set of two metal studs are necessary to properly adjust the exciter lamp socket. These are listed as stock No. 22978, and serve to align the exciter lamp filament with the axis of the optical system.

Constant Frequency Test Film. A loop of 4000 cycle test film is necessary to properly focus the optical system. Such a film is listed as stock No. 22983, and enables you to obtain the fine slit image necessary for proper high-frequency reproduction.

Offset Screwdriver. An offset screw driver such as stock No. 22107 is necessary due to the exciter lamp socket and optical system mounting screws being inaccessible with ordinary screwdrivers. A capstan head screw is used in later models and a suitable wrench included with the equipment for making adjustments.

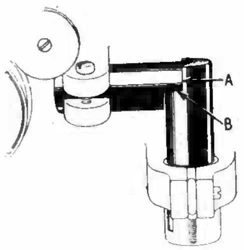


Fig. 9 - EXCITER LAMP SOCKET ADJUSTMENT.

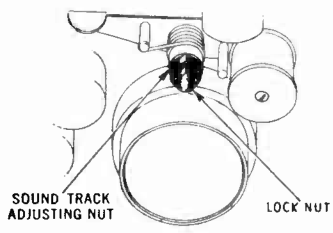


Fig. 10 - PRESSURE ROLLER ADJUSTING SCREWS.

After obtaining the necessary equipment and connecting the output meter, proceed as follows:

1. Remove the exciter lamp socket and insert the lamp so that the snugness of the fit may be checked. If a snug fit is not obtained a new socket must be used.

2. Remove the lamp and replace the socket.

3. Remove the optical system and exciter lamp and insert the steel studs (see Figure 9) in the optical system holder and exciter lamp socket.

4. Adjust the socket by moving up and down and turning until the surfaces A and B are evenly touching. The final check should be made with the sound optical system and the socket clamps tight.

5. Remove studs, clean optical system lenses and replace optical system.

6. Insert the exciter lamp into its socket and check its filament to make sure it is parallel to the optical system face. This will insure that the entire width of the slit is illuminated.

7. Remove the sound take-off drum and clean the reflector mirror. Then see that all the light from the optical system falls on the mirror and that none of it is thrown on the casting instead of going through the hole. If these points are satisfactory, replace the drum.

8. Connect the output meter and turn on the amplifier switch.

9. Thread the constant frequency film with the emulsion side of the film on the outside of the loop into the machine and start the projector. Focus the optical system until sound is heard or a reading obtained in the output meter. Note the reading in the output meter and adjust the volume control so that the deflection is approximately in the center of the scale.

10. Focus the optical system by moving it forward or back until a maximum deflection is obtained in the output meter. This means that the slit image is as fine as it can be and therefore in proper focus, so that the higher frequencies will be properly reproduced. Then carefully tighten the clamp so that the focus does not change. When tightening this screw be sure and not scratch or burr the pressure roller as a "wow" or flutter will result.

(3) WOWS AND FLUTTER

A "wow" (caused by slow variation in speed of film passing the sound optical system) or a flutter (fast "wow") may be caused by any of the following:

1. "Wow" on film. Some films of the 16 mm. variety have "wows" recorded on the sound track. Naturally there are no means of eliminating such defects.

2. Lack of oil on felt pads of sound take-off drum. This drum may be easily disassembled and the pads thoroughly lubricated.

3. Damaged or worn take-up sprocket.

4. Oil or dirt on the idler roller, impedance roller, sound take-off drum, or pressure roller will cause a "wow" or flutter.

5. Binding. Any binding of the rollers mentioned in (4) must be remedied either by cleaning, lubricating or replacing the unit.

6. Improper threading. Unless the proper loop is present in the film after leaving the picture gate a flutter will result.

7. Worn sprocket holes. Worn sprocket holes in the film may cause a "wow."

(4) ADJUSTMENT FOR LOCATION OF SOUND TRACK

An adjusting screw and lock nut are provided for adjusting the pressure roller so that the film sound track is centered on the light slit. The following equipment is necessary:

Open-end wrench, stock No. 22979.

Spintite Socket wrench.

"Buzz" track film loop, stock No. 22980. This has two different frequencies recorded, one on each side of the sound track, but not extending into it. Therefore, if the track is properly aligned with the slit image, the latter will not be acted upon by either of these two frequencies, as the image will "ride" between them and cover neither of them. However, if the film is displaced to either side of the track, the image will be modulated by the corresponding frequency, and thus indicate in which direction the film is out of line.

After procuring the necessary equipment, proceed as follows:

(a) Place the instrument in operation with the "Buzz" track film threaded into the machine. If the pressure roller is properly adjusted no sound will be heard. However if it is not, either a high or low pitch note will be heard.

(b) If the high-pitched note is heard, then the pressure roller must be moved out, if the low-pitched note is heard, then it must be moved in. Usually it is best to move the roller assembly back and forth so that both notes are heard and then lock the assembly half way between. See Figures 10 and 11.

(c) After finding the correct position by means of the adjusting nut, it should be held while the lock nut is securely tightened with a socket wrench.

(5) ADJUSTMENT OF FILM GATE

An eccentric roller and lock screw are provided for adjusting the back shoe of the film gate so that its opening is .007 inches. Improper adjustment of the gate is evidenced by excessive film jump, blurring or undue wear on the sprockets. Also increased background noise will result on the third or fourth showing of the film. An adjustment is made as follows:

(a) A piece of 16 mm. film is .006 inch thick. Split a small piece--4 inches long--so that it may be placed under the gate shoe. The film gate locking screws (Figure 12) should then be loosened and the eccentric roller turned until the strip of film may be easily slipped back and forth under the shoe. There should be no excessive play, also no binding.

(b) The locking screw should then be tightened, being careful not to disturb the position of the eccentric roller.

(6) ADJUSTMENT FOR CORRECT FRAMING

The film gate may be adjusted if proper framing of the picture is not obtained. If such a condition is present, proceed as follows:

(a) Loosen the two screws (see Figure 12) and shift the gate up and then down until both frame lines of the picture are shown on the screen. Proper adjustment is about half way between these two extremes.

TROUBLES: THEIR LOCATION AND CORRECTION

EQUIPMENT COMPLETELY INOPERATIVE. Complete failure of the equipment to operate may be due to any of the following causes:

(a) No power available at the house receptacle. Check this by plugging a floor or table lamp into the socket to be used for the equipment.

(b) A-C line cord not properly plugged into the house receptacle or not making proper contact.

NO PICTURE. If the projector motor will run but the projection lamp does not light, it is an indication that the projection lamp is burned out and should be replaced.

POOR SCREEN ILLUMINATION. If the pictures appearing on the screen do not appear normally brilliant, the trouble may be due to:

(a) Dirty lenses, projection lamp, or projection lamp reflector. Clean the lenses as instructed in the section covering care of lamps, reflectors, and lenses.

(b) Carbonized projection lamp. Replace the projection lamp as described in the section dealing with projection lamp replacement

(c) Abnormally low a-c line voltage.

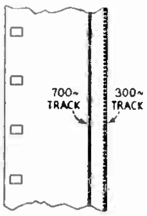


Fig.11 - BUZZ TRACK FILM.

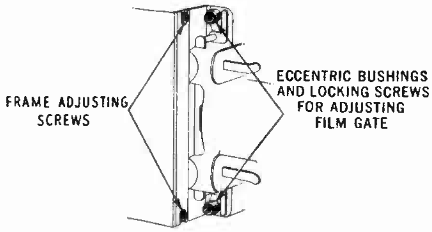


Fig.12 - FILM GATE ADJUSTING SCREWS.

PROJECTOR MISCELLANEOUS TROUBLES. If the take-up belt fails to run, the cause will probably be the improper threading of the belt around its driving pulley. There are two pins, one above and one below the driving pulley, for preventing the belt from jumping off the pulley. The belt must pass between each pin and the pulley in order to rest properly in the pulley groove. See Figure 13.

If the loop is lost above the picture gate, the cause will be the failure to latch properly the pad roller arm at the time of threading the feed sprocket.

If the film is not properly threaded into the picture gate, the intermittent claw will not engage the sprocket holes. This results in the loss of the loop below the picture gate and the continuous movement of the film through the gate. An extremely blurred and streaked picture will result and this picture will not be centered on the screen. Sound will be garbled and distorted if sound film recordings are in use.

If the pad roller arm over the take-up sprocket is not properly latched at the time of threading, the take-up sprocket will not pull the film from the sound head. This will result in the piling up of

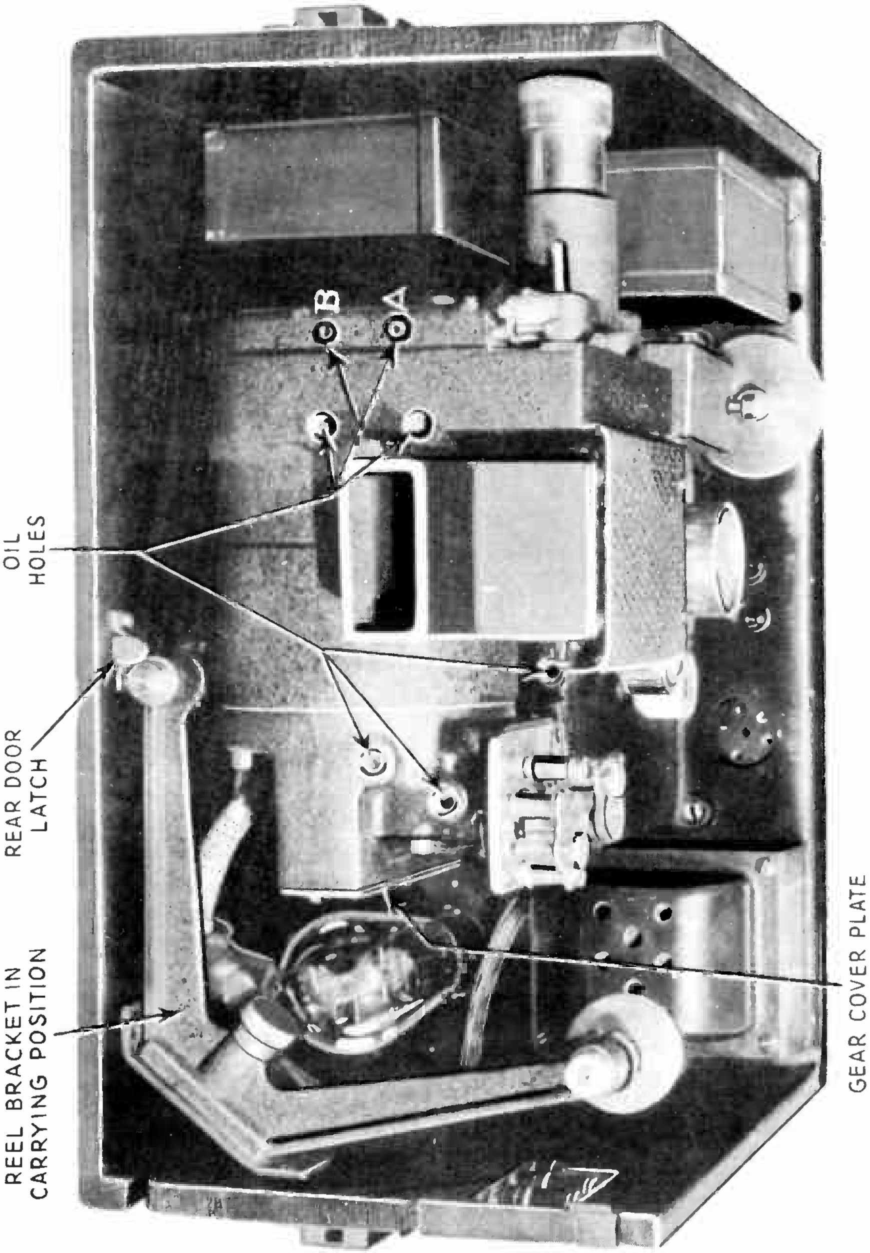


Fig. 13 - TOP VIEW SHOWING COMPACT ARRANGEMENT OF PARTS IN THE HOME PROJECTOR.

the film between the picture gate and the guide roller, together with the complete loss of sound if sound film recordings are in use.

VACUUM TUBES AND LAMPS. No sound, low volume, noisy or intermittent operation, and excessive hum may be caused by old or defective tubes. Defective tubes may also cause the exciter lamp to burn out.

A projection lamp which still lights but which has been used to the point where it has become badly carbonized (blackened) will cause poor screen illumination. An exciter lamp with an improperly suspended filament will cause low volume and poor quality when sound film recordings are in use.

It is advisable to keep a spare projection lamp and a spare exciter lamp on hand for emergency use. The projection lamp and exciter lamp may be purchased from the dealer who sold the equipment.

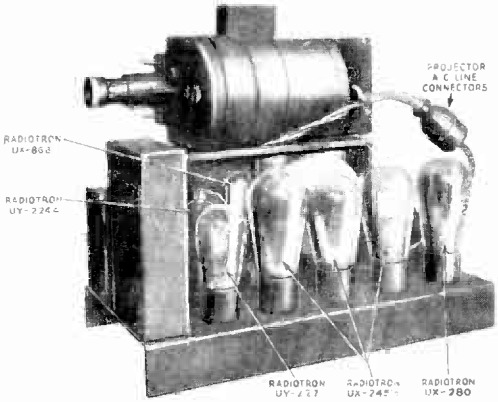


Fig. 14 - TYPE PB-29 PROJECTOR-AMPLIFIER UNIT, SHOWING LOCATION OF TUBES.

NO SOUND. If the projector runs but no sound can be obtained, the first thing to do is to note whether or not the exciter lamp lights.

A. If the exciter lamp does not light the trouble may be due to:

(a) Amplifier a-c line switch not turned on.

(b) Loudspeaker plug not inserted in its receptacle.

(c) One or more of the tubes not in its socket or inserted into the wrong socket. The correct arrangement of tubes is shown in Figure 14.

(d) Burned out exciter lamp or defective rectifier UX-280 or the UX-245 nearest it. Occasionally a serious defect in one of the other tubes may cause this trouble, but this is rare. Replace the exciter lamp by another known to be in good condition. If this lamp does not light, have the tubes tested and replace any found to be unsatisfactory.

B. If the exciter lamp lights but no sound is obtained the trouble may be due to:

(e) Combination volume control and projector switch not turned far enough in the clockwise direction.

(f) Projector not properly threaded. See Figure 15.

(g) No sound on the film or defective film. To determine in this case that the equipment is not at fault, turn on the amplifier and, with no film in the projector, advance the projector switch and volume control knob full "on." Rapidly pass a card back and forth in between the sound optical system and the sound drum. If the equipment is functioning in a normal fashion, a loud "thumping" sound will be heard from the loudspeaker as the card interrupts the light beam.

(h) Grid clip not attached to the cap on the UY-224A.

(i) Sound optical system obstructed by dust, dirt, oil or other foreign material. Turn off the amplifier a-c line switch and clean the optical system as outlined in the section covering the care of the sound optical system.

(j) Defective tubes. Have them tested and replace any found to be unsatisfactory.

LOW VOLUME. Low volume from the equipment may be due to any of the following causes:

(a) Combination projector switch and volume control knob not turned far enough towards its maximum volume setting.

(b) Partially obstructed or dirty sound optical system. Clean as outlined in the section devoted to the care of the sound optical system.

(c) Dirty, oily, or poorly printed film. If some films sound normal while others do not, the film is probably at fault.

(d) Defective tubes. Have all tubes tested and replace any that are found to be defective.

(e) Defective or dirty exciter lamp.

(f) Excessively low a-c line voltage.

POOR QUALITY. Poor quality of sound may be due to any of the following causes:

(a) Improper threading. If the loop between the picture gate and the film guide roller is not fully maintained, poor quality will result.

(b) Dirty, oily, or poorly recorded or printed film. If the sound from some film is normal while that obtained from others is not, the film from which poor sound is obtained is at fault.

(c) Partially obstructed sound optical system. Clean as outlined in the section relating to the care of the sound optical system.

(d) Defective tubes. Have all tubes tested and replace any which are found to be defective.

HUM, NOISES, WHISTLING SOUNDS, ETC. These troubles may in practically all cases be attributed to defective tubes. However, if the projector pedestal rear cover is not properly fitted into place whistling or "motor boating" sounds may result; and if the base prongs of the tubes are dirty, static-like sounds may result. The remedies are, in the case of the pedestal cover, to fit the cover properly into place and, in the case of the dirty tube prongs, to clean the tube prongs with 00 sandpaper, wiping them with a bit of clean cloth before again placing the tubes in their sockets.

GENERAL DESCRIPTION. The type PG-38 portable equipment for reproducing sound motion pictures from 16 mm. film consists of a type PB-29 projector-amplifier unit and a type PL-50 loudspeaker unit. This equipment is completely operable from any 105-120 volt, 50 or 60 cycle, a-c lighting circuit. The total power consumption of the entire equipment is approximately 200 watts.

The projector is equipped with a 115 volt, 100 watt projection lamp, and a 2 inch focal length, f:2, "Ilex," standard 16 mm. projection lens. This combination of lamp and lens projects pictures varying in size from 22 inches wide by 16 inches high at a distance of 10 feet to 67 inches wide by 50 inches high at a distance of 30 feet. The maximum picture size recommended for good illumination is 52 inches by 39 inches. This size is obtained with the 2 inch lens at a projection distance of 23 feet.

The exciter lamp used is a 4 volt, 0.75 ampere, Mazda lamp, and the tubes used in the amplifier are: 1 UX-868 photocell, 1 UY-224A. 1 UY-227, 3 UX-245's and 1 UX-280.

All power for the operation of the type PL-50 loudspeaker is obtained from the projector-amplifier unit.

SETTING UP INSTRUCTIONS

POWER SUPPLY. One standard power supply receptacle should be available sufficiently close to the location of the projector-amplifier unit to allow a connection to it by means of a 6 foot cable. The power available from this socket must be 50 or 60 cycle, 105-120 volt, alternating current. Never connect the equipment to a power supply other than that specified on the name plate as serious damage to the equipment may result.

ARRANGEMENT OF APPARATUS. A suitable screen should be set up in such a position that it is easily visible from all parts of the space to be occupied by the audience and should be so placed as to be perpendicular to the line of projection.

The speaker should be set up beneath and slightly in front of the screen with the screened opening towards the audience, all loose material which may rattle with vibration of the case should be removed, the loudspeaker cable should be uncoiled, passed through the notch at the side of the case and run along the floor to the position to be occupied by the projector. The cover prop may then be raised and the cover tipped back to rest upon it, or the speaker may be operated with the cover closed. Operation with the cover open will result in a decrease in the amount of bass tones reproduced.

The projector-amplifier unit should be placea on a table or stand of sufficient height that there will be no obstacles in the path of the projected light beam. The size of picture obtained may be regulated to suit the screen size by moving the projector-amplifier unit nearer the screen to reduce the picture size, and farther from the screen to increase it.

The RCA Victor Co., Inc., does not recommend the reproduction from the type PG-38 equipment of a picture in excess of the 39 inch by 52 inch size.

When the projector-amplifier unit has been set up, open the top and front of the case, remove the packing blocks and the spare film reel, unscrew the reel bracket thumb-screw and remove the bracket from its

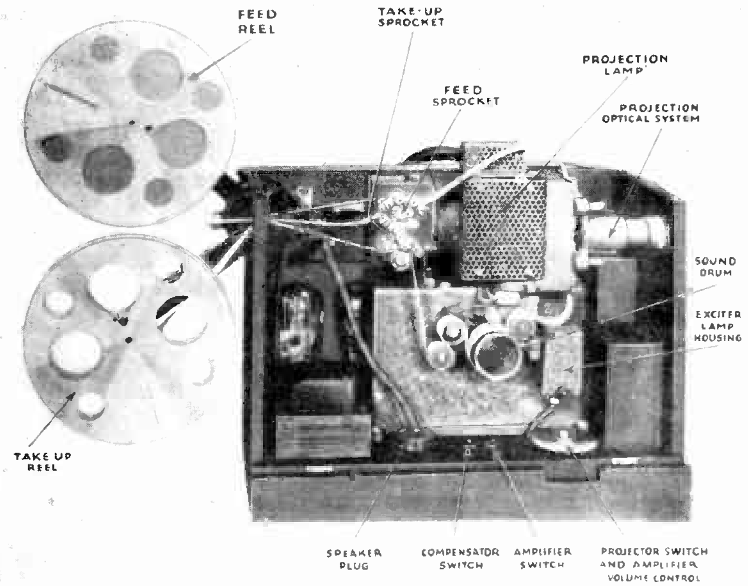


Fig. 15 - TYPE PG-29 PROJECTOR-AMPLIFIER SHOWING LOCATION OF OPERATING CONTROLS. (REFER ALSO TO PHOTOGRAPH ON FRONT COVER PAGE)

carrying position in the case. Attach the reel bracket as shown in Figure 15, with the larger pulley down, being sure that the thumb-screw is snugly tightened. Pass the belt over the take-up pulley on the reel bracket and see that the belt is properly seated in the belt rollers.

Open the rear door of the case after releasing the catch inside of the back of the case, and remove the exposed tubes from their sockets. The back cover of the projector pedestal may then be removed by simply pulling it out. Remove all packing material from the inside of the pedestal. This is important as any obstruction between the photo-electric cell UX-868 and the pedestal light aperture will render the equipment inoperative as far as sound is concerned. Before replacing the pedestal rear cover plate, make certain that the two tubes within the pedestal (UY-224A and UX-868) are securely seated in their sockets and that the clip lead is firmly attached to the cap on the top of the type UY-224A tubes. Remove the packing from the tubes UY-227, UX-245, and UX-280 and insert them into their respective sockets. The proper arrangement of these tubes is indicated by the engraving on the amplifier base beside the tube sockets shown in Figure 14.

In the gear cover plate of some models of the projector is a small screw, painted red, which must be removed before the projector is run. These models should never be turned upside down or set on end, or the oil in the gear case will run out of the screw hole. If the equipment is to be shipped by any carriers who may be likely to turn the unit upside down or on end, the screw must be replaced before shipment. See Figure 13.

See that the amplifier a-c line switch is turned "off" and insert the loudspeaker plug into the receptacle provided in the base of the amplifier unit. See Figure 15.

CAUTIONS. Never turn the a-c line switch "on" unless all the tubes are in their respective sockets. Never remove any tube from its socket without first turning "off" the a-c line switch.

Pass the loudspeaker and a-c line cords out of the projector-amplifier unit through the notch provided for the purpose in the rear of the case. See Figure 13.

Plug the a-c line cord into the most convenient source of 105-120 volt a-c power.

Start the projector by turning clockwise the combination projector starting switch and volume control knob. Bring the aperture image on the screen to a sharply defined focus by screwing the projection lens in or out as required, and center the image on the screen. When a sharp focus has been obtained, turn off the power to the projector by returning the combination switch and volume control knob to its "off" position. It has been found desirable to point out that the focusing adjustment mentioned is only a preliminary adjustment prior to threading the projector. A final focusing adjustment to obtain a sharp, clear, picture image on the screen should be made during routine step (f) outlined in the section relating to routine operating procedure.

To tilt the projector up, an adjustable foot is provided under the front of the projector which is clamped in position by means of a knurled thumb screw projecting through the front of the case. Another type of tilting device is also used in which a knurled wheel at the same position is used to screw the adjustable foot up or down after the fashion of a jack-screw.

HOW THE FILM IS THREADED.

Figure 15 shows how the film is threaded in the projector.

From the upper reel the film passes over the upper feed sprocket and above the associated guide roller. From thence it passes in a long loop over the lamp house and down through the picture gate. The latter can be opened by pressing together the two little projecting levers and then pulling them and the assembly away from the pressure plate. The assembly will thereupon lock in place in the open position. After the film has been threaded through the gate, the latter can be closed by pushing the above two levers apart, whereupon the picture gate assembly will snap into the closed position. It is to be noted that the intermittent claw movement automatically frames the picture. This is so because there is only one sprocket hole per frame, so that when the claws engage their respective sprocket holes, they pull the picture into frame and then move back out of engagement until their cam completes its revolution and causes them to engage with the next pair of sprocket holes and thus pull the next frame into place in front of the picture aperture.

The student will by this time have noticed that the intermittent differs from that employed in the larger standard size projectors. The intermittent used in the latter is too complicated and expensive to be used in the smaller sized projectors, hence a simpler arrangement similar to that used in a moving picture camera is employed.

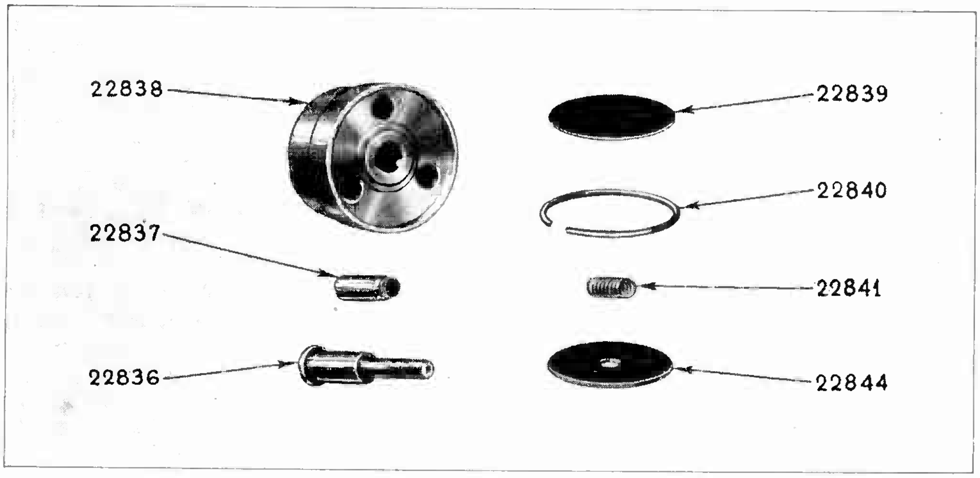


Fig. 16 - SOUND TAKE-OFF DRUM ASSEMBLY.

This can be most simply explained by imagining a pair of claws, or nibs, fastened to a frame, and this entire arrangement caused to move by means of a cam in a circular path in a vertical plane at right angles to the film. It is also to be understood that the frame and claws are always parallel to any other position in their travel. At the top point of their travel the claws are moving towards the film and thus come into engagement with the sprocket holes. Since they are moving in a circle, their main component of motion by this time is downward, so that they pull the film down one frame. Having now reached the bottom of their path, their main component of motion is now away from the film, so that they disengage the sprocket holes and allow the film to remain at rest in the picture gate. During the last quarter of their travel the claws move upward ready to move forward again at the top of their travel to engage the next set of sprocket holes and move the film down another frame.

From the loop below the picture gate the film proceeds in a counterclockwise direction over the pressure roller and thence in a clockwise direction over the sound take-off drum. This quick reversal in film direction, together with the pressure between the pressure roller and the drum, cause the film to "hug" the drum tightly and thus stay in focus for the light slit. The stepped portion of the drum, on which the film rides, is not as wide as the film, so that the sound track on the latter overhangs the drum, and thus allows the light from the slit image focussed on it to pass through onto a 45 degree angle mirror. From this mirror the light is reflected through a 90 degree angle onto the photocell.

Figure 16 shows the sound take-off drum assembly. In the three holes of this drum - #22838 fit three brake shoe assemblies - #22838. Each assembly comprises a brass tube and felt shoe. In the brass tube of each assembly is placed a helical tension spring, which presses the felt shoe against a stationary brake disc - #22844. The other end of each spring presses against a round steel cover plate fastened to the outer side of the drum by means of a steel retaining ring - #22840. The drum rides on a special stud screw - #22836 - fastened to the frame of the projector. It will be noted that the drum is thus restrained from rotating too freely by means of the friction of the oiled felt shoes against the stationary brake disc. This puts enough drag on the film to cause it to wrap itself with sufficient tightness around the drum and the rollers following it.

From the drum the film passes in a counter-clockwise direction over the idler roller and thence over the impedance roller in a clockwise direction. The impedance roller, as you know, is a smooth roller with a flywheel mounted on the other end of its shaft. The inertia of this flywheel prevents the roller and the film wrapped around it from moving at a non-uniform speed over the sound drum, and thus prevents "wows" and flutter in the reproduction.

From the impedance roller the film passes over the take-up sprocket in a counter-clockwise direction onto the lower take-up reel. You will thus notice that the take-up sprocket pulls the film over the sound drum and idler and impedance rollers. If the spring tension and hence friction in the drum damping mechanism is excessive, the pull on the film by the take-up sprocket will be too great, and the sprocket holes will be torn. In such a case the tension springs in the drum must be shortened somewhat to reduce the frictional damping.

The path of the film is shown below in Figure 15. This corresponds to the diagram to be found on the inside of the cover of the unit. The new standard 16 mm. sound film now has a leader, that is, that portion of the film preceding the actual picture. This leader contains: first, between 24 and 30 inches of either transparent film or cream colored film (raw stock); second, 7-1/2 inches or more of transparent film bearing the film title and part number; third, and last, an opaque length of film a little over 15 inches long. These three sections of film leader are known as the protective leader, the identification leader, and the synchronizing leader, respectively.

It is the synchronizing leader which contains the "start" frame and the sound synchronizing arrow referred to above. The "start" frame will be found about 9-1/2 inches from the beginning of this section of the leader. This frame is transparent and bears the word "start" in black letters. The sound synchronizing arrow is a double-headed arrow, transparent against the opaque film background, and will be found exactly 7-1/2 inches from the "start" frame and toward the beginning of the leader. In threading up the projector, see that the "start" frame is exactly in front of the picture gate aperture. The sound synchronizing arrow of the film leader should be on an imaginary line with the centers of the sound optical system and the sound drum. In this way the sound and picture will be synchronized, that is, the action such as the motion of the speaker's lips, will be in time with the reproduced speech.

An important point to be noted is that the loud speaker field constitutes the choke coil in the filter circuit of the power pack. Hence the amplifier should not be operated unless the speaker plug is plugged into the speaker receptacle of the unit, as otherwise a dangerously high voltage will be impressed upon the first filter condenser.

ROUTINE OPERATING PROCEDURE. (SOUND-ON-FILM). Assuming that the equipment has been completely set up as instructed in the foregoing sections, and that all switches are "off," the following routine operating procedure should be used:

(a) Open the top and front of the projector-amplifier case.

(b) Turn "on" the amplifier a-c line switch shown in Figure 15.

(c) Thread the projector as described above.

(d) Check the threading of the projector by turning "on" the projector and observing the passage of about 2 feet of film. If the film tracks its rollers, sprockets and guides properly and the loops above and below the picture gate are properly maintained, turn "off" the projector and close the front and top of the case. To turn "on" the projector for this test, turn clockwise the combination projector switch and volume control knob.

(e) By inserting a finger into the opening in front of the case, move the edge of the combination switch and volume control knob toward the reel bracket end of the case just far enough to start the projector.

(f) As soon as the projector is up to full speed and a picture has appeared on the screen, turn the switch and volume control knob further until the desired volume has been attained.

(g) Just to the right of the amplifier a-c line switch will be found a "Speech Clarifying Switch" labelled "VOICE" and "MUSIC." See Figure 15. When the switch is in the "Music" position, music will sound full, rich, and natural, but speech may in some cases sound muffled. In these cases, it is advisable to set the switch in the "Voice" position, which will result in a reduction of the amount of bass tones reproduced and will thereby render speech more intelligible.

(h) When all of the film has run out, remove both film reels from the reel bracket spindle and place the empty reel upon the take-up spindle. The running of the next reel will be accomplished in the same manner as outlined in paragraphs (c) to (h) inclusive.

(i) When the last reel has run out, turn "off" the amplifier a-c line switch.

(j) At the conclusion of the show, all film may be rewound so as to place the starting end of each reel at the outside of the reel. To do this, transfer the spring belt to the pulley of the upper spindle; place an empty reel on the upper spindle and a full reel on the lower spindle; insert the loose end of film from the lower reel into the hub catch of the empty reel; and start the projector. If the upper reel does not start to rewind at once, start it by hand. Film libraries generally prefer that the film be returned not rewound.

(k) When all of the film has been rewound, slip the spring belt off the reel bracket pulley and place the reel bracket in its carrying position in the case (see Figure 13).

The spring ends need not be disengaged, but the spring loop may be passed around the take-up sprocket and its pad roller arm to hold the loop within the case while it is being carried.

(l) Remove the a-c line plug and the loudspeaker plugs from their respective receptacles and coil the cables into their respective cases.

(m) Film reels and cans may be placed in the storage spaces provided in the loudspeaker case.

(n) Close and latch the cases.

CARE AND MAINTENANCE

PROJECTOR LUBRICATION. The projector should be lubricated in accordance with the following instructions:

(a) All oil holes illustrated in Figure 13 should be filled once with oil every 90 days.

(b) The oil hole marked "A" in Figure 13 should receive several drops of oil after every 30 hours of use. Some models of the projector have an oil hole located as shown at "B" in Figure 13, which should also receive several drops of oil after every 30 hours of use.

(c) The bearings of the idler roller, film guide roller, pad rollers, film guide roller arm, and pad roller arms and latches should receive a drop of oil applied from the oiling pin in the oil can supplied with the equipment once every 90 days. Extreme care should be used when oiling these points to avoid over-oiling or otherwise placing oil on any surface with which the film comes in contact. Oily film results in poor sound.

A handy oil can containing 1 ounce of Texaco Regal "C" oil is suplied with each equipment. No other oil should be used for lubricating the projector. Additional oil may be obtained through the dealer who sold the equipment.

NOTE: Texaco Regal "C" is not an automotive oil and is not available at automobile filling stations. Once every six months the projector-amplifier unit should be returned to the dealer to have the gear box at the back of the projector drained and refilled with new oil.

CLEANING THE PROJECTOR. The picture gate, sound drum, rollers and sprockets should be kept clean at all times.

It is advisable to wipe off the film guide surfaces of the picture gate with a piece of soft, lint-free, cotton cloth before and after the running of each show. If film emulsion is left on the film handling parts, it will harden and become difficult to remove. It may be necessary at times to use a cloth moistened with "Carbona" to remove caked emulsion, grease, or film wax from the guide surfaces, but the use of solvents should be avoided as far as possible.

A soft tooth brush may be used to clean the teeth of the sprocket wheels.

Never use any metallic instrument such as a screwdriver, knife blade, etc., for cleaning any surface with which the film comes in contact. Such instruments will scratch these surfaces and the scratches will in turn scratch the film. Scratched film produces poor sound, even if the scratches are on the uncoated side of the film.

If emulsion is allowed to collect on the sound drum or on the guiding edges of the film guide roller, the film will be thrown out of its normal position, and poor quality of sound will result.

If emulsion is allowed to collect on the guide surfaces of the picture gate, an excessive drag will be put on the film in the gate and there will be considerable danger of the film being torn or broken.

Lint, dust, or other foreign matter should be removed from the edges of the picture gate aperture whenever the edges of the picture on the screen become "cobwebby." Usually, it is only necessary to open the picture gate and blow sharply into it. If this procedure is not successful, remove the projection lens and wipe the aperture with a camel's hair brush or a piece of soft, lint-free, cotton cloth on the end of a stick of wood. Use a piece of cloth long enough to protrude from the front of the lens tube while wiping the aperture or attach a piece of thread or string to the cloth so that it may be retrieved in case it falls back of the aperture. The space back of the aperture contains the shutter and intermittent claw mechanism which may be seriously damaged if the projector is run with such foreign material in this space.

CARE OF LAMPS, REFLECTORS, AND LENSES. All lenses, reflectors, and lamps should be kept clean. The projection lens, condenser lens, projection lamp reflector, and sound optical system lenses and mirror should be wiped with special tissue paper supplied by lens manufacturers for the purpose, or soft, lint-free, cotton cloth. No fluids may be used for cleaning other than water or "Carbona" and these should never be used while the glass is hot.

CARE OF FILM. Special care is necessary in handling sound film to keep it clean and free from oil. Oil, dirt and scratches on the sound track seriously impair the quality of sound reproduction by introducing extraneous background noises. A little care in oiling the projector and in the handling of the film will greatly repay the showman in the continuously good quality of picture and sound reproduction which will result.

PROJECTION LAMP REPLACEMENT. When replacing the projection lamp the following procedure should be used:

(a) Open the top and front of the case and remove the two projection lamp housing cover screws. The lamp housing cover may then be removed readily by slipping it outwards on the two pins which guide it into place at the top of the housing.

(b) The projection lamp base is similar to that of a single contact automobile lamp and the lamp is removed or replaced in the same manner. Simply push downward on the lamp and twist it counter-clockwise until the bayonet pins are released from the horizontal or locking portions of the socket slots, and then pull the old lamp straight upward and out of the socket.

(c) Place a new lamp in the socket, being certain that the loop of wire supporting the upper bend in the filament is toward the rear of the projector, i.e., so that it lies between the filament and the reflector. Push down on the lamp and twist it clockwise until the bayonet pins in its base engage the locking portions of the socket slots.

(d) Carefully wipe all finger marks from the exposed surfaces of the reflector, projection lamp, and condensing lens. It is important that this be done before the projector is turned on for any purpose, as the heat of the lamp would otherwise render it very difficult, if not impossible to remove these marks by ordinary means.

(e) Replace the projection lamp housing cover and cover screws; the equipment is then ready for operation.

EXCITER LAMP REPLACEMENT. The replacement of the exciter lamp is accomplished very simply. To render the lamp accessible for replacement, remove the knurled thumb-nut holding the exciter lamp cover in place and remove the cover. Push down on the lamp while twisting it counter-clockwise until the bayonet pins in the lamp base reach the vertical portions of the socket slots,and then pull the lamp straight up and out of the socket. The new lamp is placed in the socket by a reversal of this procedure and should then be carefully wiped with a soft cloth or piece of lens tissue to remove all finger marks. This must be done before the lamp is lighted for any purpose, as the heat would make it difficult if not impossible to remove these marks by ordinary means. After wiping the lamp, replace the cover and tighten the cover clamping nut.

CARE OF THE SOUND OPTICAL SYSTEM. The optical system lenses and mirror should be kept clean, but no attempt should be made to adjust the optical system and at no time should the optical system clamping screw be tampered with. The adjustment of the sound optical system requires special training and the use of special equipment.

The lens at the exciter lamp end of the sound optical system is set into a recess in the lens barrel. To clean this lens, remove the exciter lamp cover and exciter lamp, wipe the lens with a bit of soft, lint-free, cotton cloth on the end of a toothpick, and pick any dust or lint from the corners of the recess with a sharpened end of the toothpick. Replace the exciter lamp, wipe from it all finger marks, and replace the exciter lamp cover.

The lens at the film end of the sound optical system protrudes slightly from the lens barrel. To clean this lens, pass a short length of soft, lint-free, cotton cloth between the sound drum and the end of the lens barrel, hold the cloth taut against the lens barrel, and move it up and down.

The mirror behind the sound drum may be cleaned as follows:

(a) Open the rear door of the case and remove the tubes from their sockets.

(b) Remove the rear cover from the projector pedestal and remove the photocell from its socket. The mirror is then visible through a hole in the projector pedestal above the photocell socket.

(c) Wrap a bit of soft, lint-free, cotton cloth about the end of a toothpick and with this gently wipe the surface of the mirror.

(d) Return the photocell to its socket and replace the projector pedestal rear cover.

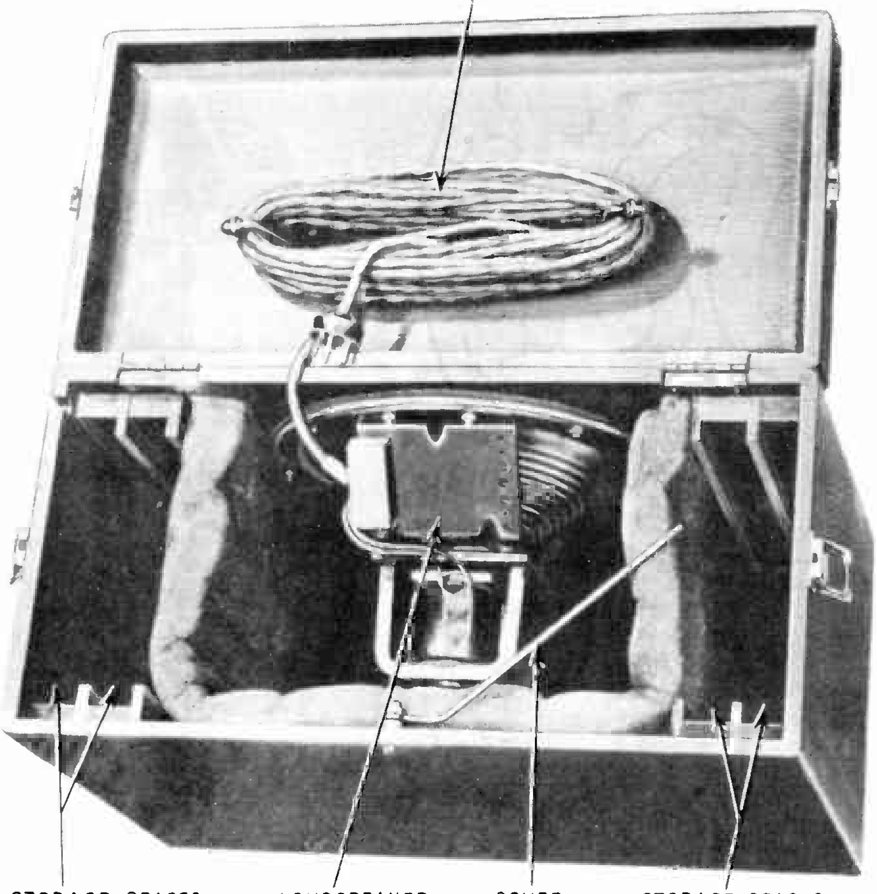
(e) Replace the tubes in their respective sockets as indicated in Figure 14, and close and latch the case rear door.

NOTE: Carbon tetrachloride ("Carbona") applied to the wiping cloths may be used to remove oil from the surfaces of any of the sound optical system lenses or the mirror. No other fluid (except water) should ever be applied, as the cement holding the lenses and mirror in place might be damaged. If "Carbona" is used, polish the surfaces of the lenses and mirror with a dry bit of cloth after cleaning.

This concludes the lesson on 16 millimeter sound-on-film portable projectors in which you have studied the problems involved, how they have been solved in this particular projector and the necessary information for setting up, operating and servicing the equipment in the event you are called upon to do so.

EXAMINATION QUESTIONS

1. What is the speed in feet per minute of 16 mm. film?
2. What is the speed in frames per second of 16 mm. film?
3. What is the picture frame size of 16 mm. film?
4. What two reasons prevent the width of the sound track of 16 mm. film from being materially decreased?
5. Why is the frequency range of 16 mm. film reduced as compared to 35 mm. film?
6. State briefly the number of tubes in the RCA Victor Model PG-38 amplifier and how each is coupled to the other.
7. What part of the equipment constitutes the filter choke?
8. What is the purpose of the sound drum?
9. What is the purpose of the impedance roller?
10. Why is an intermittent claw movement used?



THE INTERIOR OF THE LOUDSPEAKER CASE PROVIDES AMPLE ROOM FOR CARRYING REELS OF FILM.

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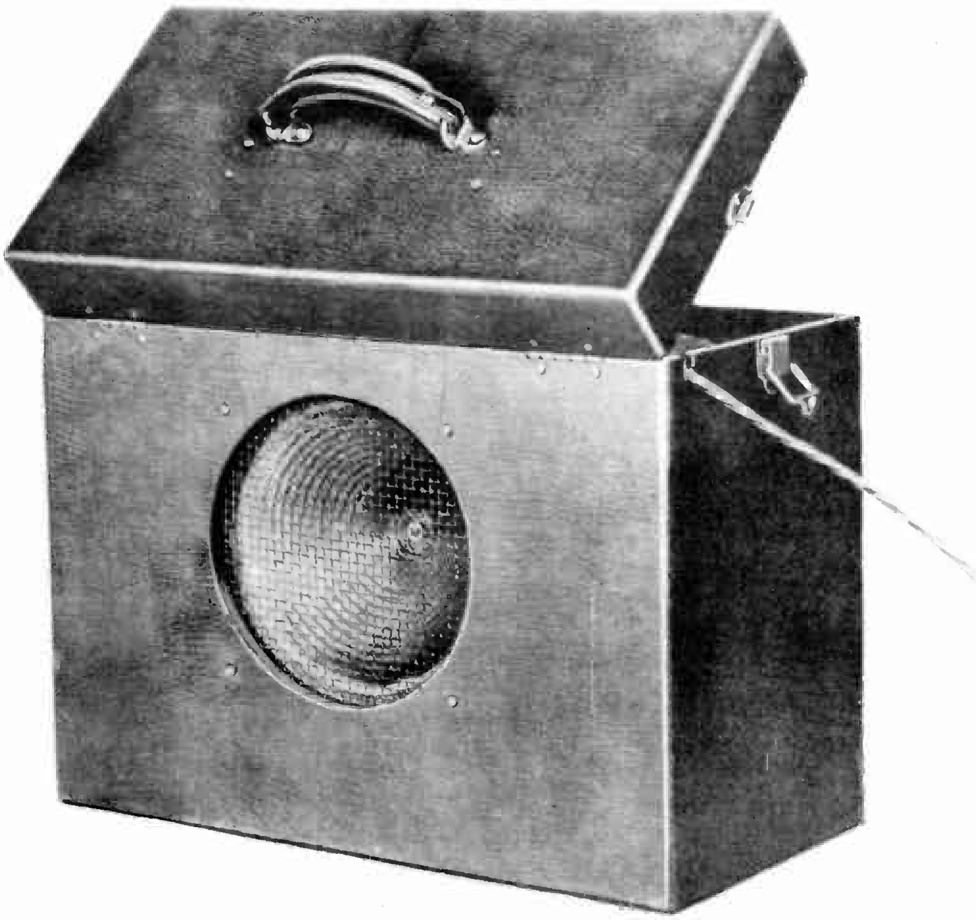

VIEW SHOWING HOW THE SIDES OF THE CARRYING CASE PROVIDE THE EQUIVALENT OF A FLAT BAFFLE FOR THE LOUDSPEAKER.

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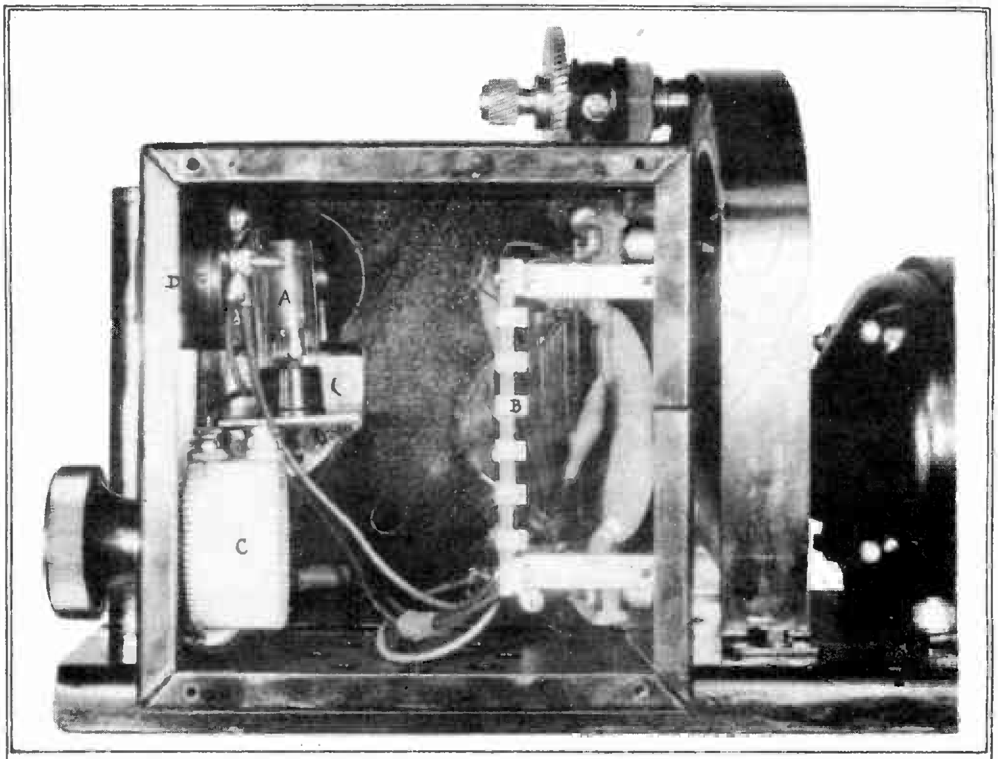
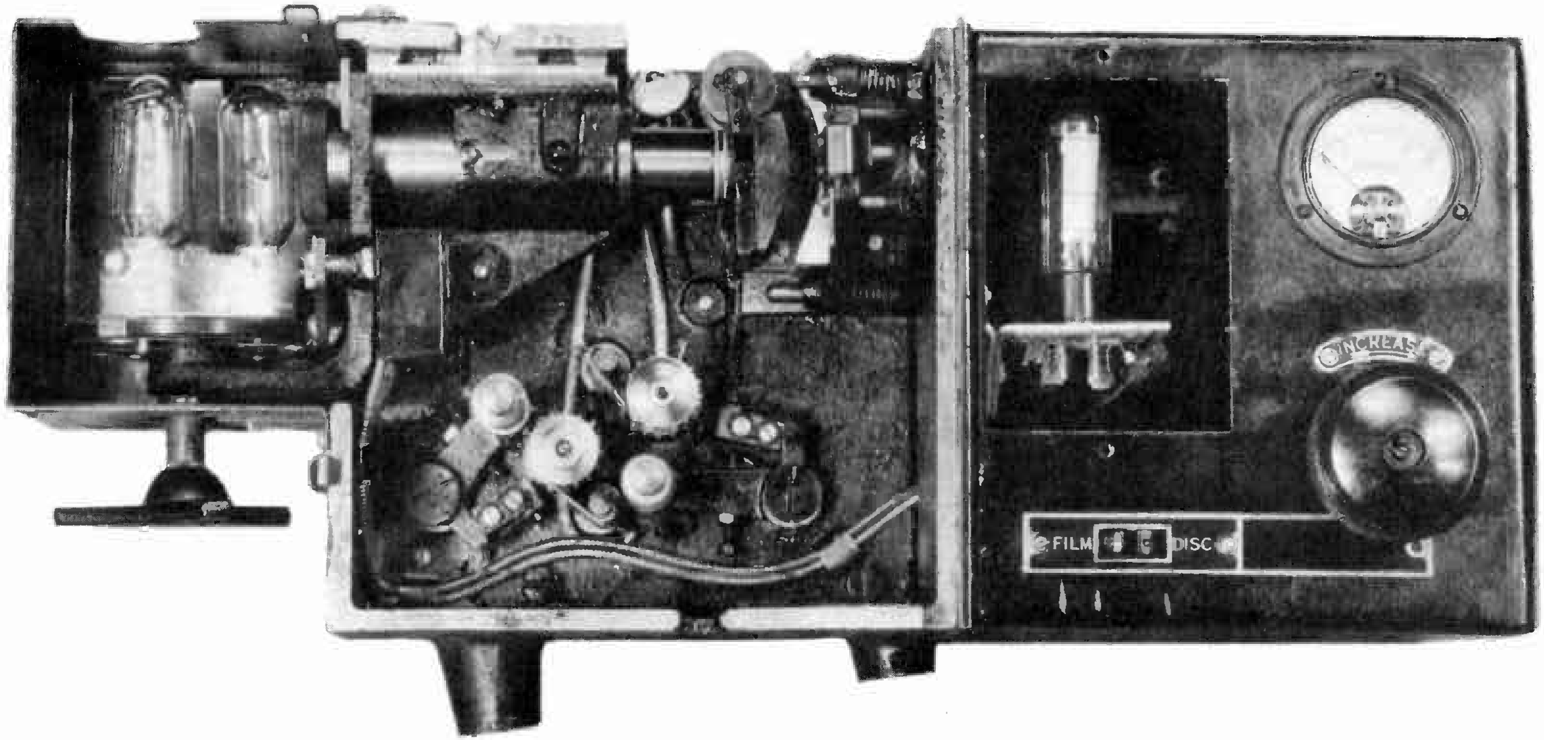


SOUND HEAD FOR SMALL THEATRE EQUIPMENT, MOTOR GENERATOR OPERATED, FOR POWERS PROJECTOR, SHOWING PHOTOCELL, PHOTOCELL TRANSFORMER, EXCITER LAMP RHEOSTAT, AND EXCITER LAMP AMMETER.

Sound Heads Used With Standard Motion Picture Projectors

VOL. 58, No. 3

Dewey Classification R 580



SOUND HEAD FOR ONE TYPE OF SMALL THEATRE EQUIPMENT, BATTERY OPERATED, SHOWING OPERATING SIDE WITH DOORS AND PHOTOCELL COVER REMOVED.

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SOUND HEADS USED WITH STANDARD MOTION PICTURE PROJECTORS

PURPOSE OF SOUND HEAD

The sound head is the unit in the sound system which changes the photographed sound wave, located on the sound track of the film, into variations of an electrical current. This varying electrical current is then amplified until it is of sufficient strength to actuate the loudspeakers to the degree required for adequate sound volume in the auditorium or theatre where it may be used.

In order to translate the photographed sound into a variable electrical current, at least three units are required in the sound head.

1. A source of light and means for shaping it into the form of a slit for scanning the sound track. This unit consists of the exciter lamp and optical system.
2. A means for pulling the film at as uniform a speed as possible past the light slit. This consists of the sound gate, constant speed sprocket, and associated driving means.
3. A means for translating into electrical current variations the light variations produced as the photographed sound more or less obliterates the light passing through the sound track. This translating unit is known as the photoelectric cell.

Each of the above units required in the sound head are described in detail in this lesson.

LOCATION OF SOUND HEAD

Motion Picture Projection Machines and Picture Heads were, of course, in existence long before the advent of Sound Motion Pictures. These machines were costly devices. The problem of the sound apparatus designer was to construct the sound mechanism so that it could be conveniently attached to existing motion picture projectors. The most logical and convenient place for the attachment was immediately beneath the motion picture projection head. Sound Heads are therefore found always mounted in this position. The adoption of the mounting of the sound head immediately below the picture head in the first design resulted in a recording restriction which has made it a hard and fast rule that sound heads must always be mounted in this relative position. The first sound heads were so designed that, when the film was properly threaded in them and in the picture head, there was a linear measurement of film of 14.25" or 19 frames between the picture optical system and the sound optical system. Since both picture and accompanying sound must be projected simultaneously it is obvious that the sound must be recorded on the sound track exactly 14.25" ahead of the picture to which it corresponds. Sound-on-film recordings have therefore been made in this manner from the start and will have to be made so until existing sound projectors are no longer in use. By the same token, correspondingly, sound heads will always continue to be designed and mounted so that there will be exactly the proper length of film between the two optical systems.

Figure 1 depicts a typical sound head and Figure 2 shows a sound head mounted on a standard motion picture projector.

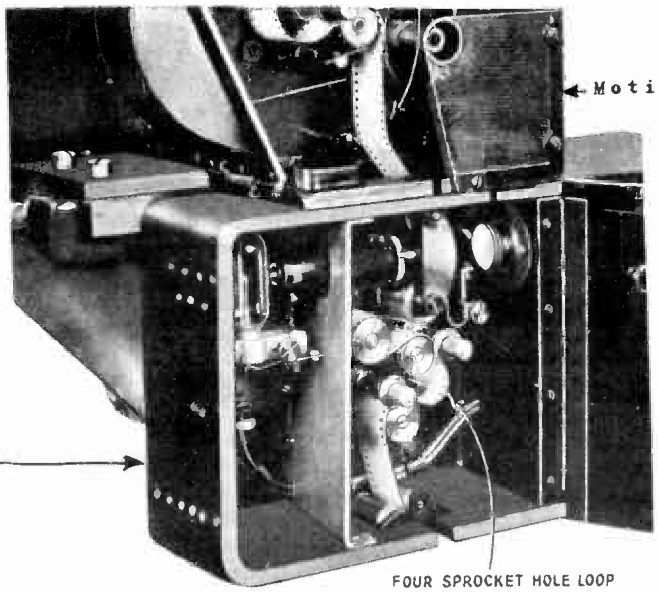


Fig. 1 - TYPICAL SOUND HEAD WITH FILM THREADED IN PLACE.

SOUND HEAD CONSTRUCTION.

The sound head must be of rugged construction. The relationship of the various parts and the delicacy of the adjustments require working tolerances of the order of one thousandth of an inch or less. Weaving or warping of the sound head housing cannot be tolerated and it is therefore always made of heavy pressed metal,or it consists of a unit casting,or of several castings bolted together.

SOUND-ON-FILM RECORDING.

It has elsewhere been noted that sound is a vibration of the air or other medium of such frequency as is capable of affecting the ear and producing the sensation of sound in the brain. The pitch of the sound depends upon the number of vibrations made per second; a note of high pitch corresponds to many vibrations per second and a note of low pitch, to few vibrations per second.

Thus, a 9000 cycle note is one in which 9000 to and fro vibrations are made by the air particles in one second. The light beam of the oscillographic recorder must therefore make 9000 such oscillations per second across the sound track of the recording film (variable area type recording). The speed of the film is 90 feet per minute, or 18 inches per second. Therefore, in 18 inches of film, 9000 to and fro light streaks, hence black lines on the film, must be accomodated. This means that each streak, or "peak" as it is called, and the "valley" between it and the next "peak", must both occupy a space of 18" ÷ 9000 = .002". Hence, the "peak will be .001" wide, and the "valley" will be the remaining .001" in idth.

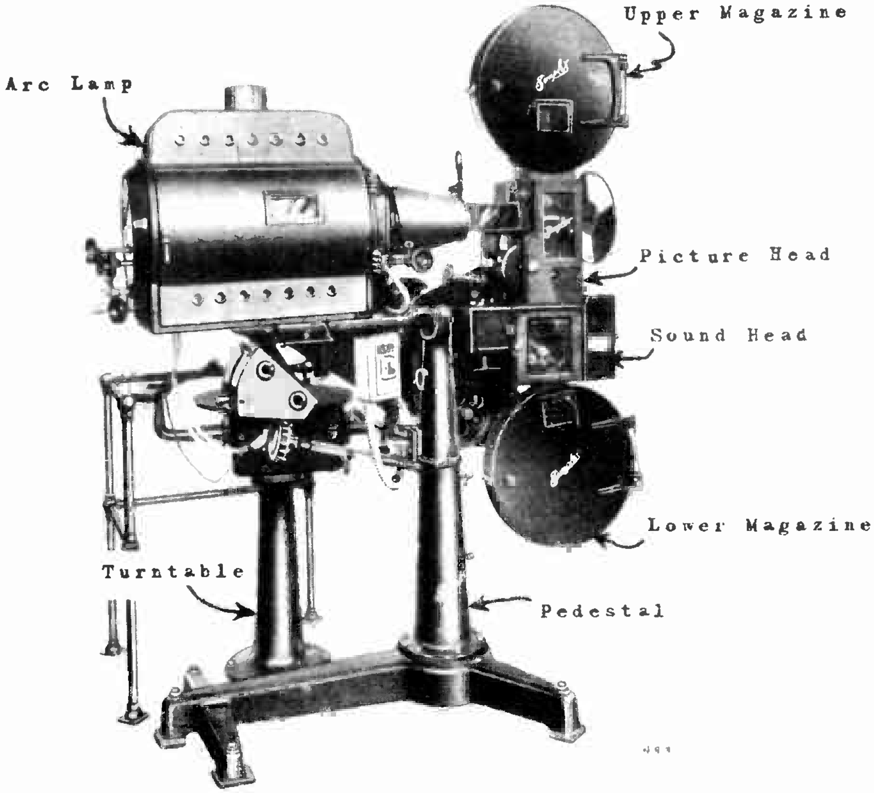


Fig. 2 - SOUND HEAD MOUNTED ON A STANDARD MOTION PICTURE PROJECTOR.

A 100 cycle note, however, can be 18" ÷ 100 = .18" wide, that is, the "peak" and the "valley" will each be .09" in width, or ninety times as wide as that of the 9000 cycle note. This brings out the interesting fact that the higher the frequency, the narrower must be the peaks and valleys representing the photographic recording of the sound on the film, since, for high frequencies, more peaks and valleys must be recorded in the same 18 inches of film per second.

If we wish to record or to reproduce these higher frequencies, it is essential that the light slit scanning these peaks and valleys be comparable to them in width. It can be shown mathematically that a light slit .001" in width will just fail to be affected by an 18000 cycle note. This is about the limit of audibility, but the obliterating effect of even lower frequencies and hence wider peaks and valleys is reduced from 100 per cent modulation or obliteration, i.e., a 9000 cycle note, or even a 5000 cycle note of the same amplitude as a 100 cycle note, will not modulate the light slit as completely as the 100 cycle note.

There will be, consequently, a falling off in response at the higher frequencies, even if the amplifier and loudspeakers were perfect, due to this slit loss in the sound head, and, as explained above, this loss is due to the fact that the slit is finite, instead of infinitesimal in width.

From the foregoing, we perceive the need for a very fine slit to scan the sound track, in order that the finest lines of the recording, (representing the highest frequencies) may produce the maximum variation in the light impinging upon the photocell, and thus be reproduced as strongly as the lower frequencies. In practice a light slit .001" <u>wide</u> (or rather <u>high</u>, as this dimension is termed by recording engineers) by .070" wide, is employed. Such a slit will reproduce even a 6000 or 7000 cycle note without undue loss (attenuation), and consequently is capable of giving good reproduction of sound.

<u>EXCITER LAMP AND OPTICAL SYSTEM.</u>

The exciter lamp produces the light, and the optical system shapes it into the form of a slit upon the sound track of the film. Although a mask could be placed against the film, and the slit placed directly in this mask, so as to allow only a narrow slit of light to pass through the sound track of the film from the exciter lamp, such a means is not usually employed in practice. The reason is that any dirt or oil on the film would quickly deposit and block up the fine slit in the mask, and spoil, if not actually stop, the sound. Moreover, as the film passed over the mask, it would wear it in time, and change the dimensions of the slit.

As a consequence, the mask with the slit in it is not located at the film, but is tucked away in a barrel or metal cylinder where it can be shielded from all dirt and oil. Between this physical slit and the exciter lamp is placed a condenser lens to gather the light rays from the exciter lamp and concentrate them on the slit. Between the slit and the film, i.e., at the other end of the barrel, is placed an objective lens to focus the illuminated slit upon the sound track of the film.

We have thus formed at this latter point an image, or optical slit, which scans the sound track, and as this slit is nothing but focused light, it cannot wear out, nor can any dirt cling to it. Furthermore, by employing well-known principles of optics, we can make this optical slit a reduced image of the physical slit by a suitable choice of objective lens and distances between it and the film on the one hand, and the physical slit on the other hand. Thus the physical slit can be made larger, which allows more light to be passed through it for a given mechanical arrangement, and also enables the slit to be manufactured more accurately, since a given tolerance constitutes a smaller percentage of its dimensions.

the optical arrangement is shown in Fig. 3 . It will be evident from this figure that this system represents in miniature the projection of a picture by the picture head. Thus, the exciter lamp corresponds to the arc lamp, the condenser lens gathers the light and concentrates it upon the slit, which corresponds to a picture frame in the film. Then the objective lens, corresponding to the picture lens, picks up the light from the illuminated slit, and forms an image of it upon the sound track of the film, which corresponds to the picture screen. The main difference is that a magnified image of the picture on the film is produced on the screen, whereas here a reduced image of the slit is formed on the sound track of the film.

As can further be seen from Fig. 3 , the light, after impinging upon the sound track in the form of a slit, passes through to the photocell. In most systems the latter has but a small window through which the light must pass, and as the light beam diverges after focusing on the film, it must be gathered together again by the photocell. Photocells having a large window do not require this second condenser lens.

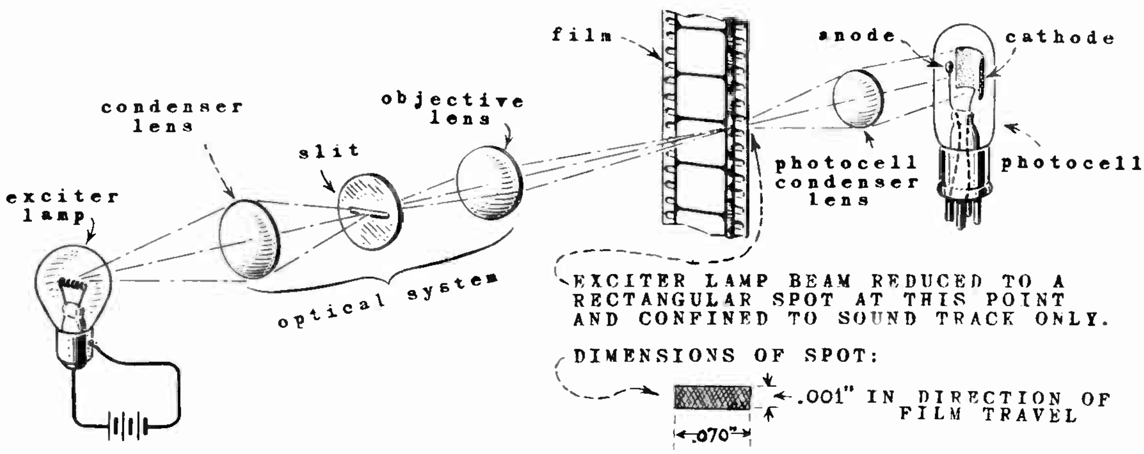


Fig. 3 - OPTICAL ARRANGEMENT AND LIGHT SYSTEM FOR SOUND-ON-FILM REPRODUCTION.

SOUND GATE AND FILM DRIVE.

It is evident from Fig. 3 that the slightest motion of the film toward or away from the optical system will throw the slit image out of focus on the sound track of the film, and thus result in an enlarged, blurred slit image. This will, as explained above, cause marked attenuation of the higher frequencies in the recording and consequently impaired reproduction. In addition, the slightest weaving of the film sidewise will cause the slit image to scan either the sprocket holes or the picture frames of the film. These will modulate the light, and cause unwanted sound in the loudspeakers, since the photocell is incapable of discriminating between sound recording modulation of the light and any other cause of modulation.

Hence the film must be held in place very accurately where it passes the light slit, and for this purpose a sound gate is provided. One form of sound gate is shown in the photograph of the sound head on the inside back cover page. Here a curved sound shoe, or guide plate, is used and in operation the film has a natural tendency to wrap itself around this member and hug it tightly as it passes over it because of its curvature. The action may be compared to that of a polishing rag run over a shoe when polishing it. The film is also aided in keeping to this surface by the tension pad, on which are mounted two tension shoes, like sled runners. The bottom of the one nearest the projectionist can be seen in this photograph of the sound head.

These tension shoes press against the edges of the film, where the sprocket holes are located and hold it against the guide plate. Any wear or scratching of the film occurs at the edges, and not on the sound track or picture, so that these are not harmed by this pressure.

Above the gate are two guide rollers, the forward one of which can be seen just underneath the picture head. These guide rollers function as their name suggests. They guide the film into the sound gate at exactly the right position for the slit image to fall on the sound track, and nowhere else. The forward guide roller cannot move laterally whereas the back guide roller can move against the action of a small spring, which keeps it pressed against the other edge of the film. In this way any irregularities in the width of the film are taken up by the rear guide roller, while the forward one remains fixed laterally, and prevents any shifting of the forward edge of the film, since it is next to this edge that the sound track is placed.

A loop is left in the film above the sound gate, as shown, in order that the sprocket above the loop impart no irregularities to the motion of the film passing through the sound gate. Below the latter is placed the constant speed sprocket to pull the film through the gate. The photograph shows that two smooth rollers are interposed between the gate and the sprocket, their action being explained below.

In passing, it is to be noted that the film touches the guide plate only at the edges, where its sprocket holes are located. The central portion of the plate is depressed below the edges, and does not touch the film. A hole is cut out in this central portion to let the light through onto the film. While this hole need only be slightly larger than the fine slit of light, in practice it has been found advisable to make this much larger, in order that it will not be blocked up by dirt from the film, and thus cut off the light. This may appear like a small detail yet the practical success of the sound head depends upon an unobstructed light slit.

CONSTANT SPEED DRIVE.

Film is very light in weight, and can easily be accelerated or slowed up. Hence, any irregularities in the driving gear are readily imparted to the film, and it is essential that the drive gear be made to turn at an absolutely constant speed. This requirement can be appreciated from the following considerations. In order that the reproduced sound be a faithful copy of the original, it is necessary that the film in the projector move past the light slit in exactly the same way as the recording film negative moved past its light slit in the recording mechanism. The simplest way in which this similarity in motion can be obtained is to move both films at an absolutely constant speed. If one or the other does not, distortion will be the result.

In recording great care is exercised to bring about this condition. In reproducing sound, similar care must be exercised. A brief review of a few of the methods employed for insuring constancy of speed are given in this lesson, however, the mechanical features of these methods are described in detail.

Although the sound is recorded at a film speed of ninety feet per minute, it is not absolutely essential that the film be run through the projector at this particular speed. Thus, film speeds between eighty-eight and ninety-three feet per second are satisfactory, as the difference in pitch is negligible from an aesthetic viewpoint. Indeed, you may have noticed that various pianos are not all tuned to the same pitch, although the various notes of any given piano must be in tune with one another.

Because of these conditions it is perfectly feasible to run the projector by means of an induction motor which, as you know, runs at slightly below synchronous speed. Moreover, slow variations in speed, if the variations occur within a narrow range, will not be noted by the ear, so that it is permissable to have small variations in line voltage, which will vary the speed of the motor to a slight extent.

The prime requisite is to have the film pass the light slit at an absolutely uniform speed — at least, there must be no abrupt change in speed. If the film moves at the rate of 90 feet per minute, any point of it traverses 18 inches in one second, or 0.18 inche , for instance, in one hundredth of a second. It is possible, however, for the film to traverse 0.16 inche in the first hundredth of a second, and 0.20 inche in the second hundredth of a second. The <u>average</u> speed will be 0.18" per hundredth of a second, or ninety feet per minute, yet it is obvious that the film is not moving at a uniform rate of speed. If these variations follow each other very rapidly, we get a modulation of each cycle of sound recorded, and this results in the production of harmonics with consequent harshness of tone. If the variations are of a slower periodicity, the tone sounds "wavery", and this is particularly noticeable in piano music, where each tone dies away after the string is struck by the hammer. These fast "wows", as they are called, cause the tone to die away with a vibrate effect, and so piano music is used as a test for this effect.

From the above it is evident that if the constant speed sprocket below the gate be driven directly through a train of gears by the motor, the gear vibration will be transmitted to the film and result in imperfect reproduction of sound. To prevent this, practically all sound heads have some sort of a flywheel through which the drive is transmitted to the film. The flywheel thus acts as a heavy mass which is coupled to that portion of the film passing through the sound gate, and so loads up the light film to a degree which gives it sufficient inertia to pass smoothly through the gate.

One common form is to mount the flywheel on the same shaft as the constant speed sprocket. Hence, the sprocket and the film meshing with it are constrained to move at a uniform speed. The flywheel is not driven directly through a train of gears by the motor. Instead, it is driven from the driving pinion through a series of springs, which take up the vibrations and thus do not transmit them to any extent to the flywheel. The latter, in turn, has too much inertia to respond to any degree to such vibrations as may come through the driving springs.

However, you will note that the flywheel and springs correspond very much to the balance wheel and hair-spring of a watch and hence, are liable to vibrate in exactly the same way as the balance wheel does when given an impulse. This impulse may be due to various causes, such as a film patch passing over the constant speed sprocket. Such an oscillation would result in "wows" in the reproduction (variations in pitch) and could not be tolerated. Hence some frictional damping means must be employed to prevent such oscillation.

One type of sound head employs a felt washer, lubricated with Alemite grease, to press against the face of the flywheel. The viscosity of the grease acts as a smooth frictional damping means. Another type of sound head employs a dashpot arrangement for this purpose. The dashpot is in the form of a pair of thin brass bellows, from which air can escape, or into which air can enter, through a pinhole in each. As the flywheel oscillates with respect to its driving member, these bellows are distended and contracted, and as they do so, the air is drawn in or forced out, respectively. It is the frictional force of the air passing through the pinhole that serves as the damping means.

A third system employs a smooth roller known as an impedance roller, over which the film passes, and which is caused to revolve due to the frictional contact of the film with its surface. The film thus acts as a drive belt for it. The shaft on which the roller is mounted carries a flywheel on its other end. The latter prevents the roller, and hence the film passing over it, from varying in speed, so that here we have another example of the light film being loaded up with a heavy weight to give it more inertia. In some other models, the constant speed sprocket below the impedance roller is itself driven from the motor through three "V" belts passing around a huge flywheel mounted on the same shaft as the constant speed sprocket. This further insures constancy of speed.

The sprocket following the constant speed sprocket is known as the take-up or hold-back sprocket. Since the pull of the lower take-up reel varies with the amount of film wound on it, and this pull may be very uneven if the reel is bent, it is apparent that a take-up sprocket takes up this pull and prevents it from being transmitted to the constant speed sprocket. This is further aided in most sound head designs by leaving a small loop between the two sprockets.

PHOTOCELL AND PHOTOCELL CIRCUITS.

The photocell is located behind the sound gate, and receives the fluctuating light that passes through the sound track of the film. The photocell has the remarkable property of emitting electrons from its cathode in direct proportion to the amount of light impinging upon the cathode. An ordinary "B" battery then draws these over to a small anode or plate and thence around through the coupling impedance or load and the rest of the circuit.

We thus have an electric current flowing which is directly proportional to the amount of incident light. If the light varies, so will the current, therefore the latter becomes an electrical replica of the fluctuating light and also of the original sound vibrations. The fluctuating or variable current flows through the load impedance and sets up a fluctuating voltage drop in it. This voltage drop can then be applied between the grid and cathode of the first tube in the amplifier, and amplified through the latter, until we obtain from the last stage, or power tubes, sufficient fluctuating voltage and current to energize the loudspeakers and obtain adequate sound.

The photocell has a high internal impedance — in the neighborhood of a megohm or more — depending upon the type of cell used. For proper energy transfer, the load impedance in its circuit must be comparable to it in value. However, if the load impedance is separated from the photocell by any considerable distance, we shall find that the capacity of the connecting leads begins to have a marked and injurious effect. The connecting leads consist of an insulated copper wire and a ground return — usually also of copper wire. The two leads form the two plates of a condenser, of which the insulation is the dielectric. While the capacity of this condenser is small, its reactance at high frequencies becomes comparable to that of the load impedance, and thus it acts as a shunt to the latter. As a result, only a small part of the high frequency currents pass through the load impedance, causing the higher frequencies to be attenuated.

Moreover, a high impedance circuit of low signal level is very sensitive to stray voltages existing in its locality, so that all sorts of "static" from the arc lamps, etc., will be picked up by the circuit. To obviate this, either of two methods is used:

1. Locate the load impedance and a portion of the amplifier close to the photocell, i.e. in the sound head, or...
2. Use a step-down transformer located at the photocell to change from a high impedance circuit to one of low impedance. The latter circuit can then be run for a considerable distance to a step-up transformer located in the amplifier rack, and there the signals stepped-up to their original voltage by means of the latter transformer for application to the grid of the vacuum tube in the first stage of the amplifier.

In the first method, as used by the Western Electric Company and a number of other manufacturers, the load impedance is a resistor of about 1/2 megohm resistance. Since a resistance has the same impedance at all frequencies, it can be less in value than that of the photocell, with the result that although the gain is reduced, the response at the higher frequencies is not appreciably attenuated due to the inter-electrode capacity of the first amplifier tube. This resistor is coupled to the grid of the first tube through a coupling condenser and grid leak; in short, the photocell is resistance coupled to the first tube. The latter is in turn resistance coupled to the second tube, which is connected to a transformer. The latter is of the step-down type, so that the secondary can be connected to a low impedance line running to the fader and thence to the main amplifier located elsewhere in the booth. The pick-up (for disc reproduction) is connected into this low impedance line running to the fader, for the signal output of the pick-up is much greater than that of the photocell, and does not require the two stages of amplification in the sound head.

It will be noted in this arrangement that instead of using a transformer to step-down from the photocell to a low impedance line, two stages of amplification are first employed in the sound head itself, and then the step-down is made to the low impedance line. The advantages are two-fold:

1. The signal is built up so that any noise ("static") picked up is less in proportion to the signal.
2. The vacuum tubes have a much lower impedance than the photocell, so that it is easier to match the transformer primary impedance to that of the plate resistance of the second vacuum tube than it would be to the photocell itself.

The above two-stage amplifier is usually located in the sound head so that the lead between it and the photocell may be as short as possible. Such an amplifier, followed by many more stages in the main amplifier rack, is bound to be microphonic, so that it must be mechanically insulated from the vibrations occurring in the sound head. This is accomplished by mounting the entire amplifier chassis on long coil springs and rubber pads, and care must be exercised to see that the chassis never directly comes into contact with the sound head housing.

The method of coupling a transformer directly to the photocell is used by RCA Photophone in its equipment. This transformer is large in size and made of very high grade material, with its primary wound with thousands of turns of fine wire in order that its impedance be sufficiently high for the photocell. Its step down ratio is 12 to 1, and the secondary impedance is 3500 ohms (except for the PG-30 and PG-28 equipments, for which it is 500 ohms and the step-down ratio correspondingly greater). In either case the impedance is sufficiently low to allow this circuit to be run for a considerable distance to the amplifier rack, which houses all the stages of amplification. Thus, the use of a pre-amplifier in the sound head is obviated, and the only thing present at that point is the above-mentioned photocell transformer. The latter must be mounted on rubber in the sound head, as otherwise the mechanical vibrations would be picked up by its laminated core and thus modulate its electrical output and cause these noises to be reproduced in the loudspeakers. It is also to be noted that it must be located very close to the photocell so that, as in the case of Method 1, the lead joining it to the photocell be as short as possible.

MISCELLANEOUS.

Besides the switching arrangements between the sound-on-film and sound-on-disc circuits and apparatus, the sound head usually carries an ammeter to indicate the current through its exciter lamp, and an exciter lamp rheostat to control this current. Finally, it must be remembered that in all the systems employed, satisfactory results may be obtained with them if properly adjusted and maintained. The variations mentioned above and in the detailed discussion to follow are dictated mainly by design and economic considerations peculiar to each manufacturing company, but as far as results are concerned, excellent sound may be obtained from any of the systems to be described. We shall now make a specific study of sound heads of different manufacture.

SOUND HEAD - WESTERN ELECTRIC COMPANY.

In Figure 4 is shown a Western Electric sound head. At the left we see the exciter lamp bracket, "B", and exciter lamp, "E".

It is to be noted that by turning knurled adjusting screws 1 and 3, the lamp can be moved in the directions shown by the arrows, while turning adjusting screw 2 moves it away from or toward the operator. The reason for these adjustments is that a small exciter lamp filament is used, and fairly accurate alignment of the filament with the axis of the optical system is required in order that the slit be properly illuminated. Moreover, should the filament be too far away from or too close to the slit, the condenser lens will form an image of the filament too close or too far away from the condenser lens, respectively, and thus not in the plane of the optical system. As a result, loss of illumination will occur, as well as distortion, if the slit is not uniformly illuminated over its entire height.

To the right of the exciter lamp is the optical system lens tube or barrel, "L". Window "W" enables the projectionist to check the location of the image of the exciter lamp filament with respect to the

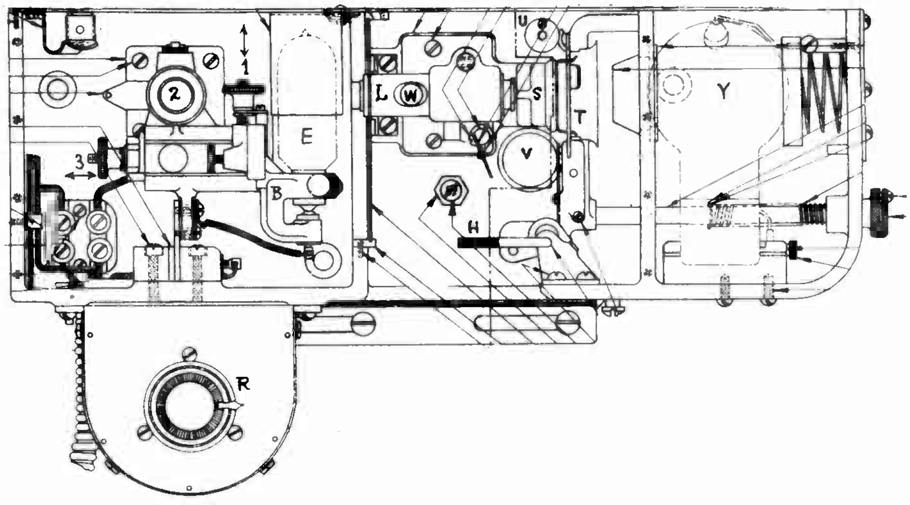


Fig. 4 - SHOWING ARRANGEMENT OF PARTS IN A SOUND HEAD. COURTESY OF WESTERN ELECTRIC CO.

slit. At the right-hand end of the optical barrel is the objective lens for focussing an image of the slit upon the sound track of the film as it passes through the sound gate. The optical system is adjusted and sealed at the factory, and no further adjustments are to be made in the field.

The sound gate is shown at "S". This has a straight guide plate, and above it are mounted the guide rollers "U" for the lateral alignment of the film as it passes into the sound gate. The film is held against guide plate "S" by means of tension pad "T". By moving lever "H" up and to the right, "T" can be pushed back toward the photocell house, i.e., the gate is opened for threading the film through it.

Tension pad "T" can then be removed for cleaning purposes, as emulsion will pile up in the gate after several reels are run through it.

At "v" is shown the constant speed sprocket which pulls the film through the gate. The film thereafter passes over a guide roller (not shown) down a film chute, and over the take-up sprocket, which is located in the lower magazine (not shown). From thence it passes onto the lower take-up reel.

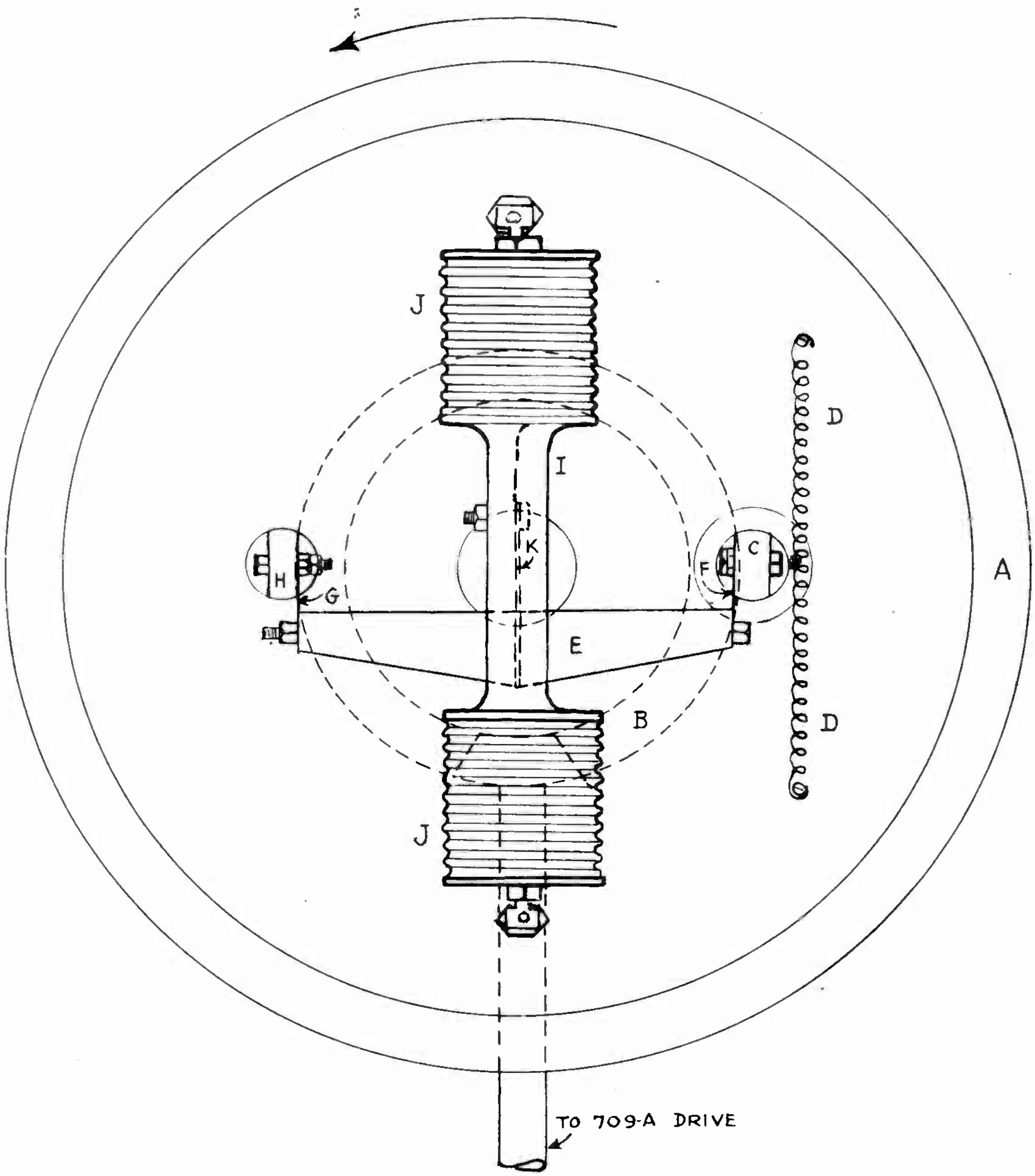


Fig. 5 - MECHANICAL FILTER FOR THE CONSTANT SPEED SPROCKET.

The photocell, "Y", is located behind the sound gate in order to intercept the light passing through the sound gate. It feeds into a resistance-coupled two-stage amplifier located in a compartment below it (not shown).

Finally—"R" is the exciter lamp rheostat to regulate the current passing through it. This current should not exceed 3.9 amperes.

An interesting feature is the method of driving the sound head. Considerable design difficulty has been experienced by the various manufacturers in devising a drive for the sound head attachment, since it has had to be "tacked on" to the picture head, after all, as an afterthought upon the advent of sound. In the case of the Western Electric equipment employing the Universal base, the motor shaft is in the same direction as the length of the base, i.e., perpendicular to the screen. At the rear end it drives the disc turntable through a worm gear. At the front end it drives, at right angles to itself, two vertical shafts. These have universal joints so that one may be aligned to drive the picture head, and the other the sound head. The drive for the latter employs the mechanical filter for the constant speed sprocket as shown in Figure 5. Here, a flywheel "A" is mounted on the same shaft as the constant speed sprocket. It is driven by bevel gear B (shown in dotted lines) through pin"C"and coil springs "DD", whose outer ends are fastened to the flywheel. The hole in the flywheel through which pin "C" projects acts as a stop so that "C" cannot stretch the springs "DD" beyond their elastic limit. This is necessary when starting, as the force required to overcome the great inertia of the flywheel at that time would be too great for the springs to transmit. The pin therefore stretches them until it bears up against the rim of the hole and thereupon accelerates the flywheel by direct contact with it.

Pin "C" also drives a cross bar, "E", through a flat spring "F", as shown, and causes"E" to revolve along with the flywheel. The other end of "E" is fastened to a pin "H" integral with the flywheel through the medium of a flat spring "G", similar to "F". Bar "E" in turn drives a bronze member "I" through the medium of another, longer flat spring "K" (shown in dotted lines). Fastened to the ends of "I" are two thin brass bellows, "J J", whose outer ends are fastened at diametrically opposite points to the flywheel "A".

These bellows have pinholes at their ends through which air can enter or escape, depending upon whether they are expanded or compressed, respectively. They thus act as dampers to the relative motion of the flywheel "A" with respect to driving gear "B". ("B" is driven in turn by means of a bevel gear and vertical shaft from the lower 709A drive.)

To see the action of these bellows, suppose the flywheel moves relative to the pinion "B", in a counter-clockwise direction, as shown by the arrow. Pin "H" will move downward with respect to pin "C", thus tilting the left end of bar "E" downward with respect to its right end. The top bellows will thereupon be expanded, and the bottom one contracted. Thus air will rush into the former, and out of the latter, and the friction set up as the air rushes through the fine pinholes will serve as a damper to this relative motion.

In a similar manner, should the flywheel move in a clockwise direction relative to drive gear "B", the top bellows will be contracted, and the bottom one expanded, and damping again introduced into this system. Thus oscillations of the flywheel with respect to the drive gear "B" are damped out.

The entire mechanism is housed in a recess in the flywheel, and is shielded from dust and dirt and tampering by a cover plate which bolts on the face of the flywheel.

PS-8 SOUND HEAD - RCA PHOTOPHONE.

In Figure 11 is shown one type of sound head manufactured by RCA Photophone, Inc., and known as the PS-8 sound head. To the left are shown three exciter lamps in a turret holder "A." Any one of the three can be rotated into position in front of the optical barrel, "B," by means of the handle below. When this is done, contacts are made to the two terminals of the lamp, thereby sending current through it and lighting it. The current is read on meter "C," and regulated by rheostat "D." The knurled ring at the left of the barrel clamps a pair of condenser lens into place at that end. These focus the light upon a slit in the barrel. The slit is formed in the capped end of a short cylinder within the barrel. There is a slot "E," in the side of the barrel through which a small screw "F" passes, and this screw screws into the side of the cylinder. When the screw is tightened, the head bears upon the wall of the optical barrel, and thus clamps the slit cylinder within the barrel. The slot in the latter permits the screw to be raised or lowered, thus rotating the cylinder (and its slit) within. The latter may thus be adjusted so that its image is perpendicular to the sides of the sound track, a very important requirement for clear, undistorted sound.

Above the optical barrel is shown an arrangement, "G," similar to that of a lathe slide rest. By turning bolt head "H" the whole optical system may be moved forward or backward for the purpose of focussing the slit image upon the film. By turning screw head "I," the optical system may be moved laterally to center the slit image upon the sound track.

The curved sound gate—a feature of Photophone sound heads—is shown at "J," and the guide rollers above the gate at "K." The tension shoe holder, "L," slides along the rods as shown for the purpose of pressing the film against "J" by means of the tension shoes "M." The latter are made of a thin piece of spring steel. The tension shoe holder, "L," can be removed for cleaning. Behind the gate, in the right-hand compartment, is located the photocell, which has a caesium cathode, and is gas-filled to increase its sensitiveness. Behind the photocell is the photocell transformer. This can be seen more readily in the photograph on the front cover page. Here "A" is the photocell, "B" the photocell transformer mounted on sponge rubber, and "C" is the exciter lamp rheostat, while "D" is the exciter lamp ammeter. The spring steel for the tension shoes is shaped like an inverted U.

While the head shown in this photograph is for use with a Powers' projector, the above-mentioned parts are identical with similar parts used in the sound head shown in Figure 11. The photocell transformer, as you will remember from the earlier part of this lesson, is for the purpose of coupling the photocell to the low impedance line running to the amplifier located elsewhere in the booth.

Referring once again to Figure 11, we have the constant speed sprocket "M" with its associated pad roller "N" and stripper "O," while "P" is the take-up sprocket, "Q" its pad roller, and "R" its stripper. The lower magazine is attached to the projections "S" of the sound head, while the picture head (Simplex) is fastened to its top by means of two bolts.

The entire mechanism is driven by a chain meshing with a small motor sprocket and large sprocket wheel mounted on the main drive shaft of the assembly. This main drive shaft replaces the original drive shaft of the Simplex projector, and has two pinions on it, side by side. One drives the Simplex head, as originally, and the other drives the sound head through a gear train.

The constant speed sprocket is driven from one of the pinions of the above gear train through a pair of spiral springs. One end of each spring fastens to a flat in the hub of the pinion; the other end, to a pin on a flywheel, which in turn is pinned to the constant speed sprocket shaft. Thus the pinion drives the sprocket through the spiral springs and flywheel. In Figure 6 we see such an arrangement adapted for a turntable drive. The principles employed, and the design of the mechanism, however, are exactly the same as for the

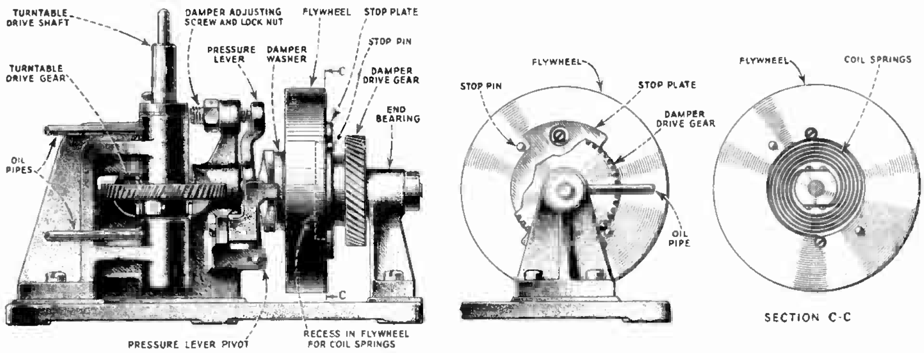


Fig. 6 - SYNCHRONOUS TURNTABLE VISCOUS DAMPING DEVICE.

sound head, so it is advisable to remember this point. It will be noted that the coil or spiral springs fit into a recess in the flywheel.

The application of this viscous damping drive to a sound head is shown in Figure 7 . To increase the damping, lock nut "A" is first loosened, and its screw turned until the felt washer is pressed against the flywheel with the proper amount of force. To feed more grease into the felt washer and hence between it and the face of the flywheel, screw the top of the grease cup into its body, thus forcing the grease out of it through its feed tube into the washer.

In this figure you will also note the drive gear, which is driven from a pinion on the main drive shaft directly above it. The main drive shaft rotates in bearings in the picture head . The sound head drive gear, as you will note, has a pulley on it. This is for the purpose of driving the lower take-up reel by means of a round leather belt. Previously this reel was belt-driven from a pulley in the picture head, but after the sound head was attached it was necessary to substitute for the gear carrying the above pulley in the picture head, a gear without this pulley, as the flange on the latter interferes with the sound head drive pinion mounted on the main drive shaft. Consequently the take-up is now driven by the pulley on the sound head drive gear, which pulley is closer to the lower take-up pulley than the flanged gear in the picture head (previously mentioned) and thus permits a shorter and more direct drive.

PS-1 SOUND HEAD - RCA PHOTOPHONE.

This is an earlier type head manufactured by RCA Photophone, Inc., and is illustrated in Figure 8. It is practically the same as the PS-8 head described above. The main points of difference follow: (1) The slide rest arrangement for moving the optical system is not employed. Instead, the optical holder is bolted by means of three bolts to the underside of the top of the sound head. Two of these bolts can be seen in the photograph. (2) The optical barrel has a vertical illuminator interposed between the slit and the objective lens. This illuminator consists of a piece of clear optical glass interposed in the light beam coming from the slit. This piece of glass

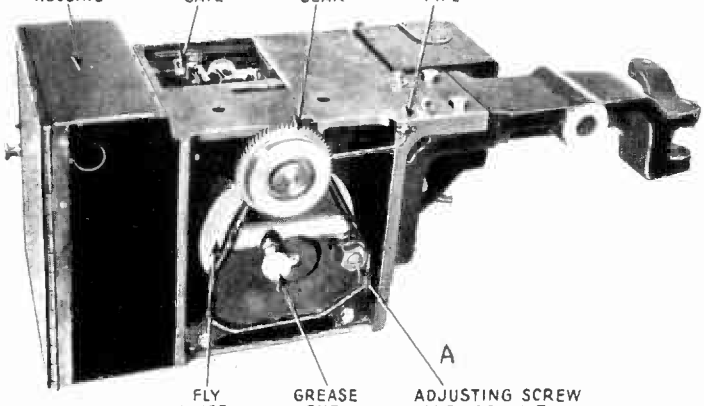


Fig.7 - DRIVE SIDE OF TYPE PS-1 SOUND HEAD.
(PHOTOPHONE TYPES PS-5, 6 AND 8 ARE SIMILAR.)

can be rotated by the knob to which the arrow points in Figure 8. so that it is at an angle to the light beam and thus reflects a small portion of the light coming both from the slit image and from that part of the sound track (illuminated by a flash light from the photocell housing) up through a hole at the top of the illuminator block. A periscope (Gem eye-piece) is inserted into this hole so that the service man may conveniently view a composite view of the frequency peaks on the film and the slit image on it from the front of the sound head. The latter may thus be focussed on and oriented with respect to the sound track. However, other methods for doing this are now employed, so that the usefulness of this illuminator is not particularly marked. (3) No exciter lamp ammeter or rheostat is furnished on the photocell housing of this sound head, as this head was furnished with equipment using an Input Control Panel, on which these units were mounted.

PS-14 and -16 SOUND HEADS — RCA PHOTOPHONE.

Figures 12 and 9 show a PS-16 and PS-14 sound head, respectively. The former is used for a Simplex projector and the latter for a Powers. The only difference between the two heads is in the method of mounting them on the pedestals and to their respective picture heads, and in the drive gear, which is located on the other side of the mechanism. As can be seen from either figure, the film feeds into a sound gate, thence over an idler roller directly beneath it, then it wraps around the free-running impedance roller and thence over the constant speed sprocket. A small loop is left between it and the take-up or hold-back sprocket, and from thence the film proceeds through the fire rollers to the lower magazine onto the lower take-up reel.

The constant speed sprocket is directly driven by a gear train from the motor, and no provision is made to smooth out any vibrations

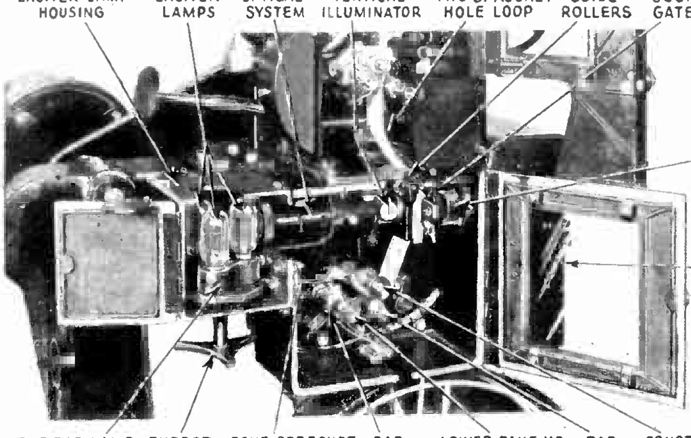


Fig. 8 - OPERATING SIDE OF TYPE PS-1 SOUND HEAD.

(from gears, etc.) that may be transmitted to it. However, between it and the sound gate is interposed the impedance roller, which prevents any of this vibration from being transmitted to the film in the sound gate, as described previously in this lesson. It must be remembered that on the rear of the impedance roller shaft (behind the center plate) is mounted a flywheel to give the requisite inertia to this roller.

In Figure12 you will note that the motor is directly geared to the main drive shaft, instead of transmitting its motion through a chain, as in the PS-1 and 8 heads. The action, however, is exactly the same. In the case of the PS-14 head (for Powers) this main drive gear meshes directly with the sound head main drive gear, but drives the Powers picture head through a series of auxiliary gears, due to the different gear arrangement in this head.

The exciter lamp is mounted in a bracket instead of a turret. The lamp can be adjusted in the bracket for proper illumination of the slit, and then the lamp and bracket removed, and another lamp adjusted in another bracket and used. When this second lamp burns out, the first lamp and bracket can be quickly substituted for the other, so that no appreciable interruption in the show need occur.

The optical system is somewhat different from that used in the other heads. A single condenser lens is at the rear of the lens tube (near the exciter lamp) instead of two lenses as in the other heads, and the slit is located very close to it. The slit may be rotated into proper alignment by means of a little lever protruding through the top of the lens tube. The objective lens (which is partly hidden by the sound gate) may be moved backward or forward for focussing by

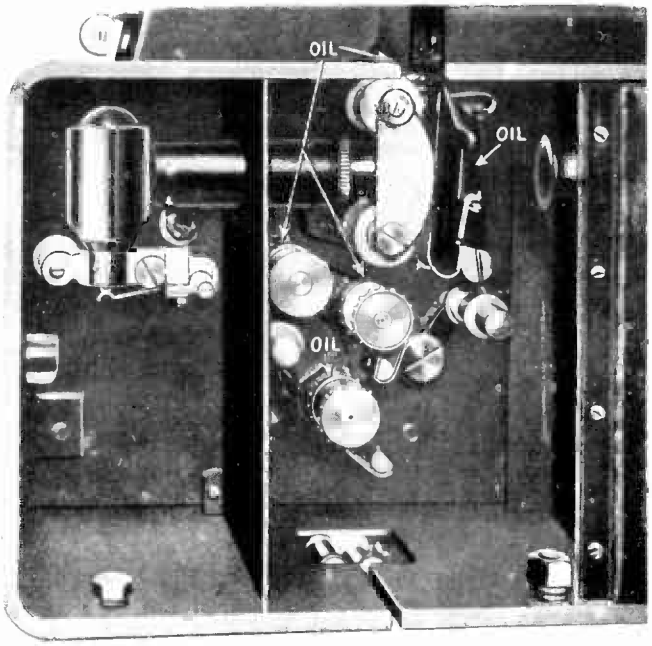


Fig. 9 - FILM SIDE OF TYPE PS-14 SOUND HEAD, SHOWING OILING POINTS AND EXCITER LAMP SHIELD IN PLACE.

turning the knurled ring, which causes it to screw in or out of the lens tube. A strip of metal bears down on this knurled ring, thus locking it sufficiently to prevent it from turning of its own accord.

The sound gate consists of a stamped metal guide plate, and a stamped metal tension pad, on which are mounted the two tension shoes, much like the runners on a sled. These hold the film firmly against the guide plate when the gate is closed. The two guide rollers may be moved sidewise in order to adjust the film laterally so that the entire slit falls on the sound track. In the other heads, you remember that the optical system was moved laterally to accomplish this.

In the PS-20 heads the arrangement is much the same as in the above, except that the constant speed sprocket is directly driven by a flywheel mounted on the other end of the shaft. The flywheel is in turn belt-driven from the motor by means of three V-belts. The photocell is inserted through a hand-hole at the top of its compartment instead of through an opening in the side. Moreover, the photocell transformer has a secondary of 500 ohms impedance, to match the input transformer of the type PG-30 amplifier.

The PS-22 sound head is of simpler construction, and is used in conjunction with the PG-28 small theatre equipment. This sound head dispenses with the impedance roller, and the film is pulled through the sound gate directly by means of the constant speed sprocket. The latter is belt-driven by the motor through a flywheel, in order to insure constancy of speed.

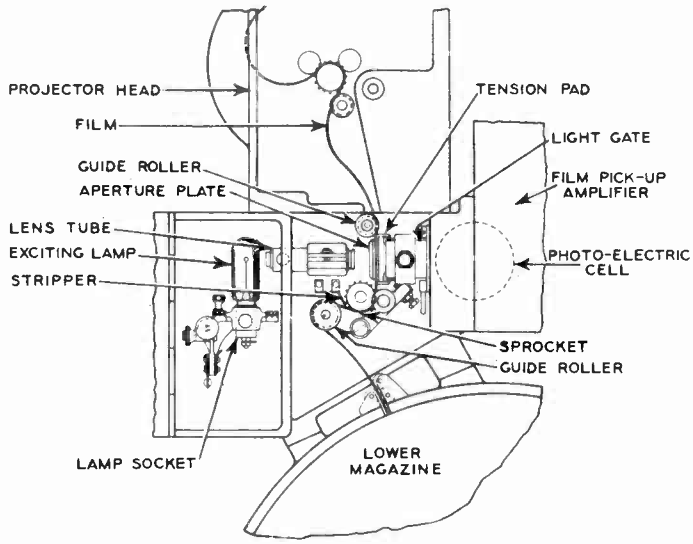


Fig. 10 - A TYPE OF WESTERN ELECTRIC SOUND HEAD.

The drawing in Figure 10 clearly illustrates the relation of component parts in a type of Western Electric sound head.

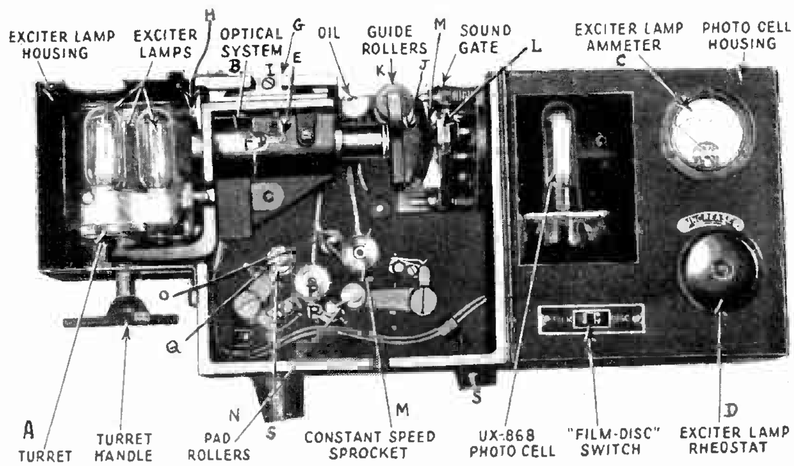


Fig. 11 - FILM SIDE OF TYPE PS-8 SOUND HEAD (PHOTOPHONE TYPES PS-5 AND 6 ARE SIMILAR).

This concludes the lesson on sound heads. In it we have studied various forms of this mechanism, and the functions which it performs. It is one of the most important parts of sound equipment, and upon its correct action depends much of the quality of the reproduced sound.

EXAMINATION QUESTIONS

1 . What are the three fundamental parts of a sound head?

2 . (a). What is the purpose of the exciter lamp?
(b). Of the optical system?
(c). What is the purpose of the sound gate?
(d). Of the constant speed sprocket?

3 . Why is it difficult to pull the film at a uniform speed?

4 . Explain the action of a viscous damped constant speed sprocket.

5 . Explain the action of the Western Electric drive for the constant speed sprocket.

6 . How does the impedance roller function?

7 . What is the purpose of the take-up or hold-back sprocket.

8 . What does the photocell do?

9 . Give two methods of coupling the photocell to the main amplifier.

10 . Why must the light slit be so fine in height?

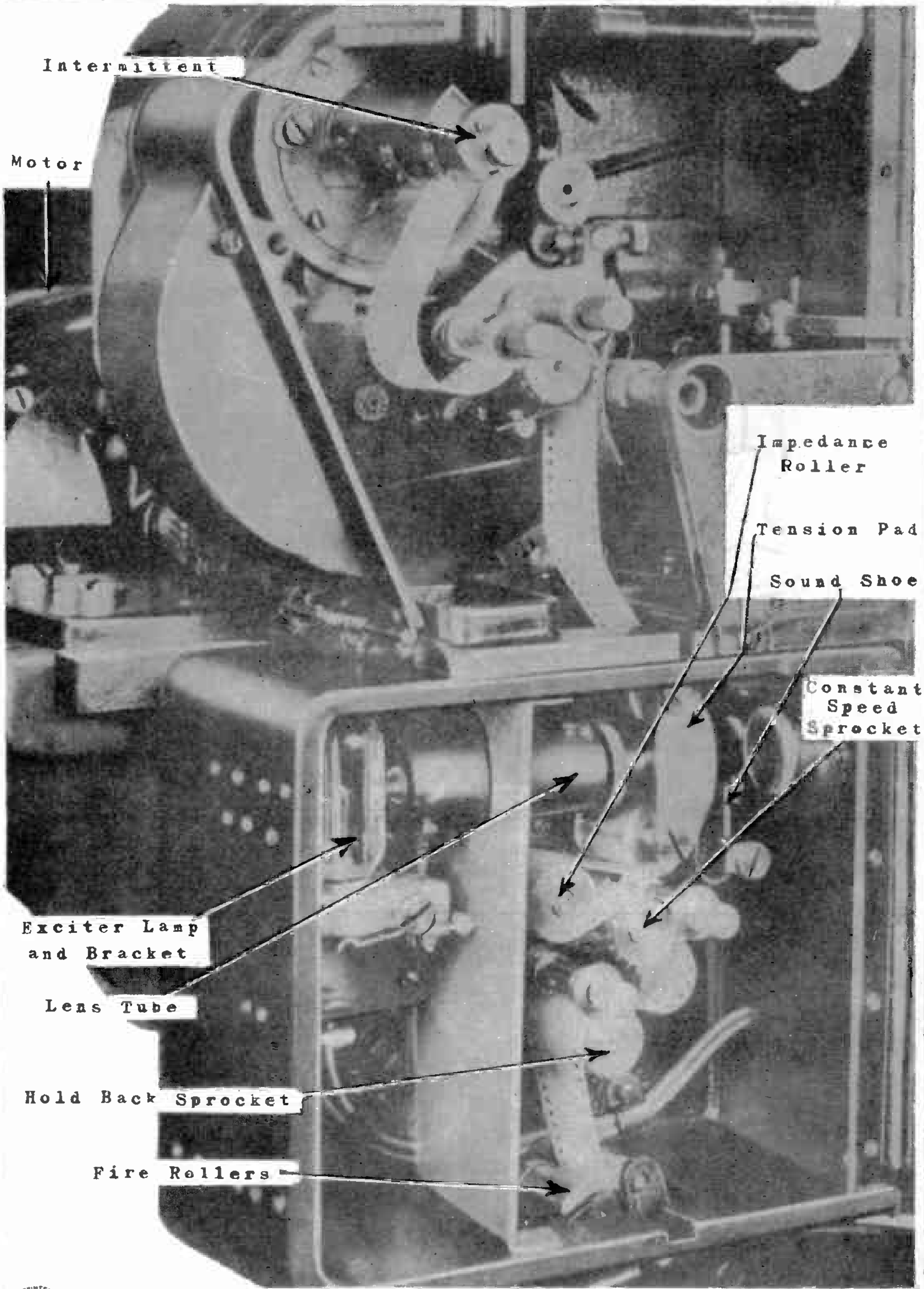
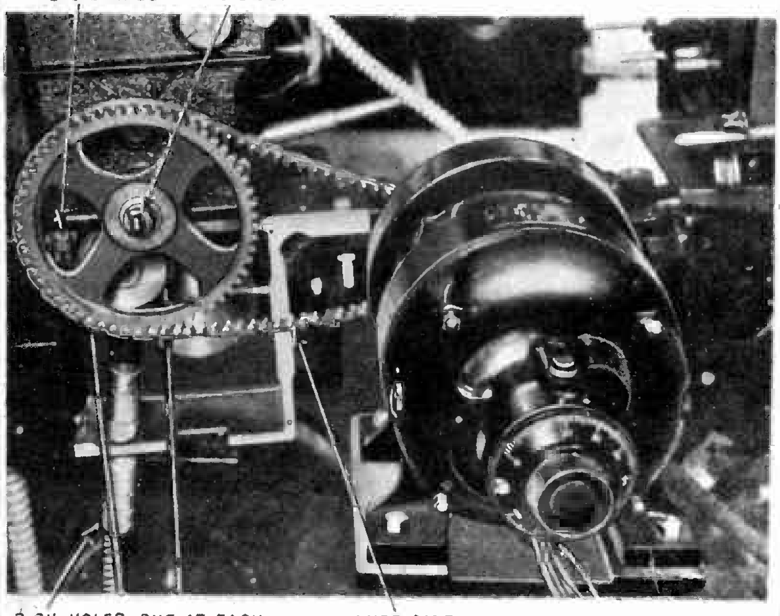


Fig. 12 - FILM SIDE OF PS-16 SOUND HEAD.



OILING POINTS IN DRIVE SIDE OF TYPE PS-16 SOUND HEAD (D-C MOTOR DRIVE).

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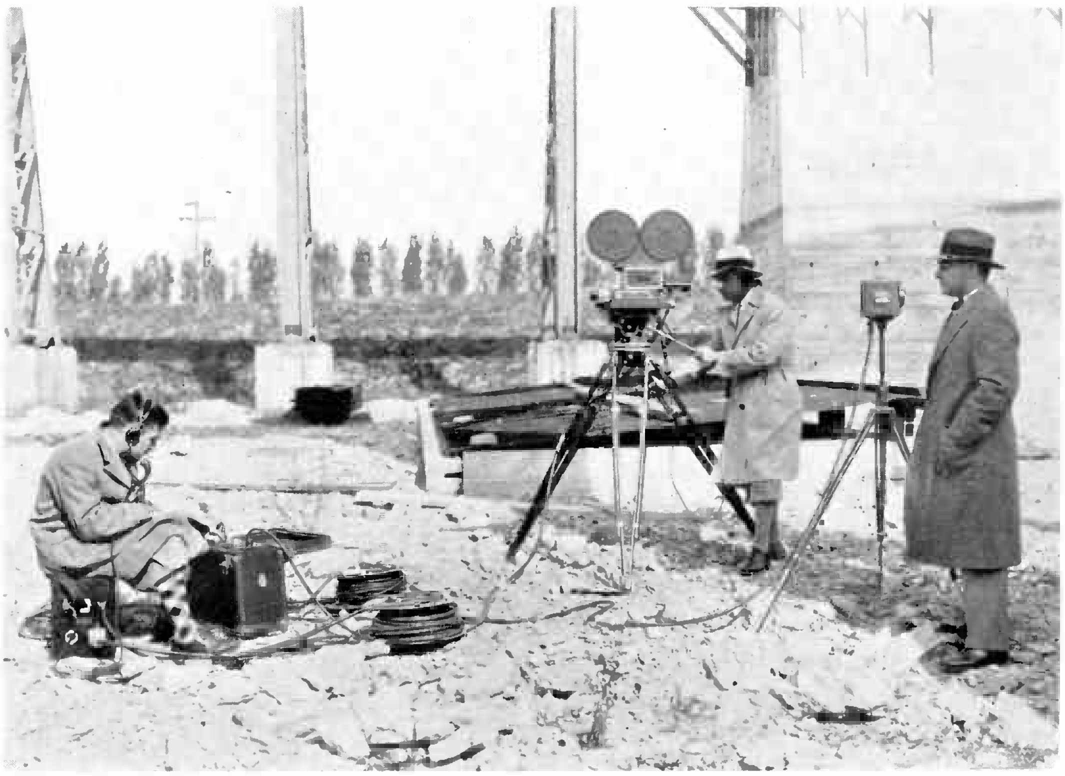

Motion picture camera "on location."

Principles of Photography

Vol. 58, No. 4 Dewey Classification R 580

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Principles of Photography

The Pinhole Camera

A very simple experiment can be performed, as shown in Figure 1, to illustrate a principle of photography. This sketch shows how the rays of light from an object pass through a very small hole in a piece of cardboard to form an image of the object on a piece of white material used as a screen.

Although it is not shown in the drawing in Figure 1 the candle flame is throwing off small pencils or beams of light from every part of its surface, for instance, from the point or apex of the flame, from each side of the flame, from the bottom of the flame and so on, and moreover, there are beams of reflected light being thrown off from the wax of the candle itself. The points just named are the "outside" points of the flame and it follows that the area of the flame in between these points is also composed of thousands of small points each of which throws out rays of light.

Since the rays of light from the object pass through the "pinhole" in a straight line each ray strikes the screen at a point different from any other ray. Thus, the rays from the top of the actual flame pass through the pinhole and appear on the lower part of the screen below the level of the hole in the cardboard. Also, the rays from the bottom of the flame pass through the hole and strike the screen at its upper part which is above the level of the hole. Hence, all points of light between the top and bottom of the flame throw out rays of light that pass through the hole and strike the screen in the same relation to each other that they had as points of light in the flame. This causes a com-

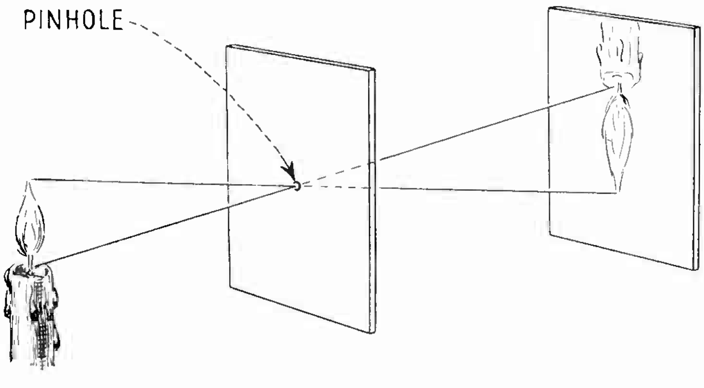

FIGURE 1—*A sharply defined image focused by a pinhole.*

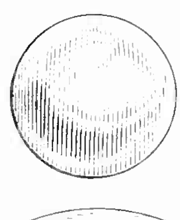

FIGURE 2—*Front and side views of double convex lens.*

pletely reversed image of the object to be formed on the screen, where the top of the flame shows its image at the bottom of the screen and the bottom of the flame shows its image at the top of the screen. Likewise, the left side of the flame shows its image on the right side of the screen and vice versa. If you have ever looked at the ground glass screen of a photographer's camera when focusing for a picture you have seen this "reverse" and "upside down" effect.

The image that is produced by a pinhole camera is always very dim, however, because the small hole allows only a very limited amount of light to pass through. Knowing this fact you might well ask the question, "Why not enlarge the hole and allow more light to pass through to the screen?" But this cannot be done so easily, for you will find that if you try to increase the brightness of the image by enlarging the hole, the image on the screen becomes blurred. This is due to the fact that the beam of light which is thrown off by each tiny point of the flame becomes larger as it travels further away from its source. An effect of this kind is similar to one obtained from a spotlight used in a theatre but on a much smaller scale. In the case of a spotlight the beam of light is about 6 inches in diameter when it starts out from the projection booth high up in the balcony but it gradually spreads and grows larger in size until it appears on the stage as a spot of light about 7 feet in diameter.

Referring again to the image of the candle flame, in Figure 1, let us explain further that the image is made up of many small circles or dots that start out from the candle flame as minute points of light which increase in size until they reach the screen. Now, if these small dots of light are not too large when they hit the screen they will not overlap each other to any considerable degree and, therefore, the image of each dot will show up sharply. All the dots together appear to the eye as a "blend" which gives the effect of "seeing" the candle flame on the screen. You see a demonstration of this power of the eye to "blend" a number of such dots into a single image each time you look at a photographic reproduction or half-tone in either a book, newspaper or magazine. Pictures or half-tones of this kind are made up of numerous dots of ink so closely spaced that the eye does not see them as separate dots but only as the black and white shading or "blend" that forms the picture.

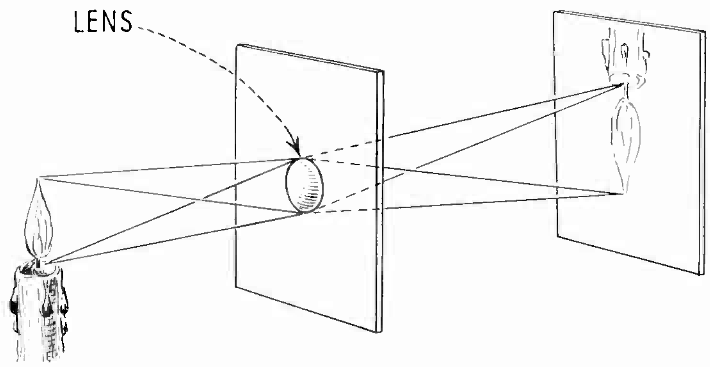

FIGURE 3—*The lens allows more light to be focused on the screen without loss of clarity.*

The Lens

If a larger "pinhole" is used in the pinhole camera experiment the dots on the screen will become so large that they will overlap and lose their sharpness thereby destroying the clearness of the picture. Such a blurred picture is said to be "out of focus". As you will learn later it is necessary to have a certain amount of light pass through the opening in order to produce a picture or photograph. Since it is necessary to have a fairly large opening in order to pass more light and a large opening causes diffusion or a blurr as we just stated then it is obvious that some method must be used which will keep the image clear, that is, prevent it from being blurred on the screen. This is accomplished by the use of a lens like the one pictured in Figure 2. The effect of a lens on the rays of light is shown in Figure 3. Observe from this drawing that each ray of light leaving the candle flame, instead of being allowed to continue its spreading effect until it reaches the screen, is changed upon passing through the lens until all the light thrown off by each point of the flame is "brought to a focus" or reproduced on the screen without overlapping. This results in a good sharp image on the screen. Hence, by employing a lens and inserting it in the opening we find it is possible to in-

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crease the size of the "pinhole" and obtain an increase in the amount of light falling upon the screen without losing the sharpness of the image.

At this point you will notice that we have succeeded in producing a copy of an original object on the screen with the aid of the light rays emitted by the object itself, which in this case is the candle flame. It is well known that when rays of light strike upon any object that reflects the rays then the object itself becomes in effect a source of light rays. Let it be understood, however, that objects can be seen even though they are not sources of light rays in themselves because they reflect or throw back the light from another source.

If the rays of light from the candle fall on an object, such as a person's face for instance, the rays are reflected back from the face and will act on the eye or on a screen in the same manner as though the rays had originated on the face. This property that most objects possess of reflecting light enables us to see things by daylight. The sun is an original source of light but the moon gives us light only by reflecting back to earth the light of the sun that strikes upon it. It is plain, therefore, that it is possible to produce, as on the screen in Figure 3, the image of an object that is not an original source of light by means of reflected light rays. Most images in photography are produced in this way.

Daguerreotypes

There is nothing very permanent about an image made of light rays for if the source of light rays is removed the image disappears. With the image for a guide, one could draw with pencil or ink the necessary lines on the screen to represent the subject but a picture drawn in this way, while more

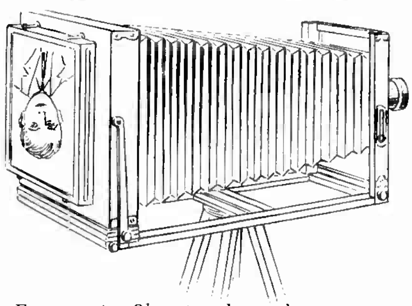

FIGURE 4—*Showing how the image is inverted on the plate of a camera.*

permanent, would be imperfect and not exactly like the original image. Merely making a pencil or ink sketch in this way is not to be compared to the perfected method of preserving images by means of photography as we will now explain.

A man by the name of Daguerre made up a solution that he found would change its chemical composition under the influence of light rays. To make practical use of this discovery he coated thin plates of tin with this solution and constructed what we now call a camera, which was nothing more than a light-proof box with a lens sealed in the front of it. By substituting a coated tin plate, also known as a sensitized plate, for the screen at the rear of the lens in his camera the sharp image of the light rays would fall on the solution. The camera used by Daguerre years ago was practically the same as the one illustrated in Figure 4 which is also typical of those used by professional photographers of the present day for making studio portraits. The lens is shown projecting from the front and a bellows, or light-tight cloth that folds conveniently, joins the lens rack to the plate holder located at the rear. In this sketch a translucent (semi-transparent) screen is shown upon which the image is first brought to a sharp focus by moving the lens nearer to or further away from the screen, this being done before inserting the sensitized plate in the holder.

Daguerre's method of procedure was to place the object to be photographed in the correct position in front of the camera and then by moving the lens to the proper position he would bring the image of the object to a sharp focus on the translucent screen, usually of ground glass. After this he would cover the lens carefully, remove the glass screen from its position and put a holder containing the coated tin plate in its place. When all was in readiness he would again remove the lens cover and the light rays focused from the object would strike the coated tin plate and begin to act on the chemical coating. After being exposed to the light rays for a certain length of time the chemical coating on the plate changed sufficiently so that after proper treatment in a chemical bath there appeared on the surface of the plate all the light and dark shades or areas which bore a similarity to the original subject and, therefore, the picture on the plate was easily recognized.

Owing to the fact that the chemical coating on the tin plate was not very sensitive, that is, it took a great deal of light to complete the proper chemical change, a very long exposure to the light rays was necessary. With this slow process, the subject oftentimes had to hold a certain position for a matter of 10 minutes in bright sunlight.

The necessity for keeping the subject being photographed in exactly the same position during the complete exposure of a tin plate is apparent when you stop to consider that if an object moves so does its image, and were this to occur the light rays would leave off working where they were focused in the first place and start their action on the chemical coating in a new position. Under such conditions the "developed" plate would show an under-exposed image of the moving object for each position it occupied while the picture was being taken.

Daguerreotypes, or tintypes, as these photographic images were called, could not be reproduced. Only one image or tintype picture could be taken at a sitting and, therefore, additional sittings were necessary if more than one picture was needed. The two-pronged head rest, which we often see in old tintype portraits was required because it is obvious that without a support of some kind no one could be expected to hold his head in a steady position long enough to produce a successful Daguerreotype.

Modern Developing and Printing

Years of scientific research taught those in this work how to produce a more sensitive coating for the tin plate so that it was no longer necessary to expose it to the light rays for such a long time. Shortly after this period in the development of photographic plates a method known as the "wet collodion process" was discovered. This method has survived to the present day and is used chiefly by photo-engravers for producing the negatives from which they make the engraved metal plates used in printing pictures. When using the wet collodion process it was necessary for the photographer to make his own plates just before he took the picture. To do this he would clean off a plate of glass, coat it with collodion, which contained iodides and bromides, and then put the plate in a bath of nitrate of silver which formed silver iodide in the collodion film thus making it sensitive to light. The glass plate had to be exposed in the camera while it was still wet, and immediately after exposure it was developed by pouring over it a liquid chemical known as the developer. Next it was treated in another solution, called a fixing bath, and then allowed to dry. All this inconvenience of taking pictures with a wet solution on the glass plate disappeared with the coming of the *gelatin emulsion*, or dry plate process which is the method now in universal use. Moreover, in photographic work the film has largely supplanted the use of glass plates upon which the sensitized coating is placed.

In the dry plate method only one side of a thin, transparent plate of glass is coated with a solution of silver salts contained in a very thin gelatin, called *emulsion*, that solidifies after coating. The silver salts contained in this emulsion change to metallic silver if exposed to the action of light rays and treated in a solution of chemicals called a *developer*. The parts struck by the light that was focused to an image on the emulsion are the only parts in which a change from silver salts to metallic silver takes place and the extent to which this action takes place is governed by the amount of light striking each part.

To cite an example, suppose a photograph is taken of an object composed of three shades which

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are, let us say, white, gray, and black. It follows that the rays of light coming off the white portion of the object will be the most intense and the silver salts on the portion of the emulsion upon which they strike will be turned to a heavy layer of metallic silver. After development this portion will appear black. In the second case where the rays of light are coming off the gray area of the object being photographed they will be about half as intense as those from the white area and will turn the silver salts on the plate to a thinner layer of metallic silver than would the rays from the white portion. After development this portion will appear gray, or lighter than the first portion. In the third case where the rays are coming off the black portion of the object they will be of such low intensity that the silver salts will not be affected at all and during the process of "fixing" will wash off. Thus, after development this portion leaves the emulsion transparent. It can be seen then the shades of light reproduced on the plate will appear to the eye in shades just the opposite of those actually present on the object, that is, the lighter portions of the object will turn out to be the darker portions of the image as shown on the developed plate and so on. Hence a black locomotive will look on the plate as if it were white. A plate of this kind is called a "negative" because everything is reversed in shade as shown in the illustration in Figure 5.

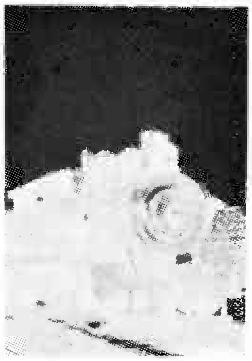

FIGURE 5—*Negative image.*

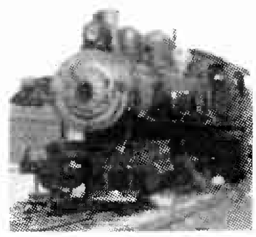

FIGURE 6—*Positive or Print.*

The next step to be considered is how a photograph is produced in which the shadings have again been reversed so that a true image with proper shadings is obtained. Such a photograph is called a "positive" print because the relation between the light and dark shades that form the picture appear like the original subject.

From the foregoing description of the action of light on a silver salts emulsion you can easily understand how a "positive" print can be produced by laying the negative plate over a sheet of photographic paper which was, of course, previously coated with the emulsion. A large amount of light will pass through the negative where the transparent parts of the image lie and this action of the light will turn the silver salts of the emulsion to a deep black. Now suppose only about half the amount of light will be able to pass through the thin layer of metallic silver that represents the gray part of the object. Then this amount of light will be just sufficient to turn the silver salts gray at this place. Or, in other words, where the parts of the negative have a heavy coat of metallic silver practically no light will be able to pass through and consequently this will leave the silver salts on the paper unchanged and after washing this area will appear white.

It is this chemical action that gives us a "positive" image, or a true picture of the original object or subject on the photographic paper. Figure 6 shows a positive print or photograph which was made or "printed" in this manner from the negative plate in Figure 5.

Since a negative must be wound on reels for use in motion picture cameras it is evident that the glass type plate cannot be used for this purpose so a transparent film having an emulsion coating of silver salts is employed instead. Insofar as the action of the chemical coating is concerned and the process of exposure and development they are similar for either a film or glass plate type of negative.

To stop the process of development of either a negative or a positive, when the action of turning the silver salts to metallic silver has gone to the proper stage, another chemical solution called a "fixer" is used. When the negative or positive is immersed in this bath the emulsion is no longer sensitive to light, the process of development ends, and the image is "fixed" in the emulsion. This method works out to a decided advantage because any number of positives can be produced from a negative.

Exposing the Plate or Film

The greatest trouble experienced in photography is in getting the correct "exposure", that is, allowing the light image to fall on the sensitized plate or film so that the best relation of light and dark portions is achieved. The function of "exposure" is to allow just enough light to act on the

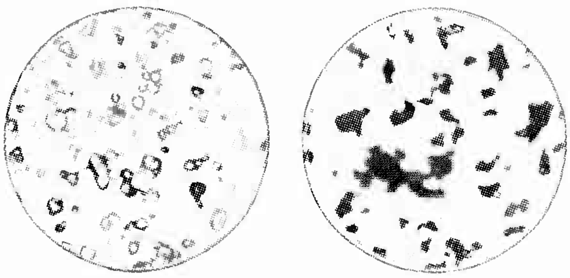

FIGURE 7—*Silver bromide crystals (left) change to metallic silver (right) after development. (Courtesy of Eastman Kodak Co.)*

silver salts emulsion to properly prepare it for the action of the developer. The function of "development" is that of causing the silver salts which have been exposed to light to change to metallic silver.

It is explained that the amount of metallic silver that will be caused to appear by the action of the developer depends on the degree to which the silver bromide was acted upon by the light rays. For instance, the light rays reflected from a white object, which are focused to an image on the photographic emulsion for a certain length of time will affect the silver bromide more than light reflected from a gray object focused on the plate for the same length of time. This follows from the fact that more light is present in the image of the white object than in the image of the gray object.

To obtain a correct exposure consists in allowing enough light to act upon the silver bromide so that in the extreme case of light rays coming from a pure white object, the silver bromide will be affected to such a degree that it will practically all change to metallic silver under the action of the developer. This will produce such a thick layer of silver on the negative that it will appear black and will not allow light to pass through it. In the case of the other extreme, or that of photographing a black object, there is practically no light reflected and, therefore, the image of such an object has no light rays which might act on the emulsion of the negative.

Therefore during development of the negative no metallic silver is produced, the silver salts are washed away during the fixing process and that, part of the plate or film showing the black object is transparent. Objects with colors or shades that reflect varying amounts of light in the range between white and black affect the emulsion differently according to the amount of light each reflects and when the developer has completed its action an image of each object appears in a degree of shading, or "blackness", that corresponds to the amount of metallic silver produced.

Let us see just what crystals of silver bromide look like before and after development. Figure 7 shows the crystals after they have been exposed to light. The left photograph shows the crystals *before* development and the right photograph shows the same crystals *after* development. Before development the crystals are transparent except where they are seen sideways or where their edges appear darker. The photograph on the right shows how crystals which have been exposed to light are changed to black masses of metallic silver by the action of the developer. Bear in mind the fact that the developer changes to metallic silver only those crystals that were struck by the light rays and that when a crystal is so changed it is opaque. These photographs, of course, were taken through a very powerful microscope.

From our explanation it should be clear that after development we have an image in metallic silver corresponding to the light image which was focused on the emulsion by the camera and that the darkness of this metallic silver image is determined by the amount of light that was reflected from the object to the emulsion during exposure.

Figure 8 shows how the number of crystals changed to metallic silver varied for four different

FIGURE 8—*The longer the silver bromide crystals are exposed to the light the greater will be the number change to metallic silver. (Courtesy of Eastman Kodak Co.)*

exposures, each exposure being four times as long as the preceding one. In view "A" only a comparatively few crystals were changed to metallic silver. As each succeeding view indicates the number increases rapidly with each increase in exposure time, until a rather heavy deposit of metallic silver occurs as in view "D". The latter film was exposed 64 times longer than the one in view "A". These views of crystals in different stages of chemical change give a good idea of why there is more opacity produced in the emulsion for long exposure to light and why a negative shows black where the most light fell on it during exposure. Figure 9 is a view illustrating the appearance of an emulsion, after exposure and development, when magnified 900 times. The black areas are where the most light from the image was focused on the emulsion.

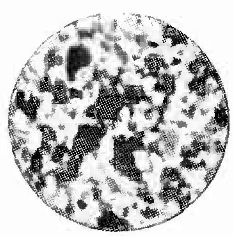

FIGURE 9—*Emulsion as it appears after development—magnified 900 diameters. (Courtesy of Eastman Kodak Co.)*

The term "density" is used to indicate the degree of "blackness" which results from varying amounts of metallic silver deposited on the film. In Figure 10, use is made of this term in computing a "characteristic curve" of an emulsion. The heavier the deposit of metallic silver, the greater is the "density" of the negative and consequently, the amount of light which may be passed through it is inversely proportional to this density, that is, $D = 1/T$, where D is the density and T is the "Transmission", or amount of light passed.

Light and Time

Inasmuch as it is the amount of light falling on the emulsion that determines whether or not the "exposure" is correct it is easy to reason that a correct exposure may be obtained either by letting a small amount of light act on the emulsion for a long time or by letting a larger amount of light act

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on it for a shorter time. However, the fact remains that for any particular emulsion there is a certain exposure that produces the best possible effect in its action on the silver bromide, and, therefore, emulsions are made in various sensitivities for various purposes. Whether this optimum or ideal exposure is in the form of a large amount of light for a short period of time or a small amount of light for a correspondingly longer period of time makes no difference, generally speaking. Each emulsion has what is known as its "characteristic curve", which is only another way of saying that its silver bromide is affected a certain amount by each variation in the amount of light falling upon it. You will meet the term "characteristic curve" a number of times throughout this course and although it has a highly technical sound you will find it is exceedingly simple in meaning and one of your best friends if you really make an effort to know it well.

Let us go through an explanation of the "characteristic curve" of a certain emulsion as depicted in the graph in Figure 10. Across the bottom of the graph there are numbers showing exposure to light marked off in seconds beginning at 1 sec. at the left and ending at 524,288 secs. at the right.

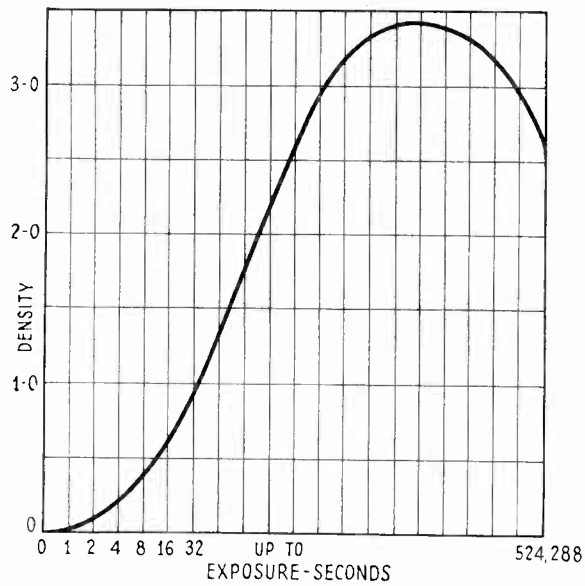

FIGURE 10—*Showing the relationship between exposure time and density.*

Running up on the left side or vertical axis can be seen a scale marked from 0 to 3½. These numbers on the left side represent arbitrary units, that is, they indicate only the density or proportion of silver deposited after development for the different time exposures in seconds as indicated by the bottom set of numbers or, 0, 1, 2, 4, 8, 16, and so on up to 524,288. In other words, the number 2.0 on the left side scale does not indicate any definite amount of silver deposited but only that there is twice as much deposited for any point on the horizontal line drawn to the right of 2.0 when compared with any point on the horizontal line drawn to the right of number 1.0. For instance, for an exposure of 192 seconds the curve is seen to cross the horizontal line marked number 2.0 while for an exposure of about 40 seconds the curve crosses the horizontal line marked number 1. Therefore, we gather from this chart that an exposure of 192 seconds will cause twice as much silver to be deposited as an exposure of 40 seconds. Inasmuch as a deposit of twice the amount of silver means the plate or film will be twice as opaque with the greater amount of exposure as with the lesser amount, a correspondingly smaller amount of light will be allowed to pass through to the "positive" when it is printed.

Let us again repeat that a photograph is nothing more than a series of light and dark areas of varying density arranged on the positive according to their relative positions on the subject originally

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photographed. In this lesson we have considered both negatives and positives but it can be mentioned now that the ultimate end of practically all photography is in the production of the positives. The negative is only a means to that end and its greatest use lies in the fact that positives can be made from it in almost unlimited quantities.

Referring again to Figure 10, note the rather strange behavior of the curve at the extreme right of the chart which shows that after we increase the length of exposure up to a certain point instead of a further increase in opacity there is a decrease. This condition, of course, represents tremendous overexposure and could not possibly produce a good picture.

If a picture is to be true to life it must faithfully reproduce the various degrees of shading that are present in the original subject, hence, in order to accomplish this only periods of exposure represented by the steepest and straightest part of the characteristic curve can be used. This is so because the increase in density is directly proportional to the increase in exposure only along that part of the curve. In order to achieve the same differences in shading in the photograph as are present in the original, it is necessary that for each vertical line to the right the exposure time moves up an even distance as you will notice upon examining the course travelled by the curve depicting this relation. In other words, this means that for each doubling of exposure time the opacity of the silver deposit must increase in even "steps" of the same amount. Therefore, it is apparent that in order to produce a photograph that has the proper values of shading, a very close watch must be kept to see that the exposure is correct or on the straight portion of the characteristic curve. When the exposure is either on the lower or upper portions of the curve the increase in opacity is not proportional to the increase in exposure (light intensity) and "distortion" results.

A vacuum tube also has a characteristic curve and when operated on the lower or upper bend instead of on its straight portion distortion results. Distortion, however, in the case of photography, is a lack of true reproduction of value in shades, whereas, distortion in a vacuum tube results if the characteristics of the electrical output of the tube are not a faithful copy of the electrical characteristics in the input circuit.

Putting Knowledge into Practice

You may have had some experience with photography in your own home, for many of us in these days of widespread use of the camera have developed and printed pictures which we have taken. If you have not had the interesting experience of performing all the operations necessary to produce a finished photograph or "positive" it will be well worth your while to obtain the paraphernalia of an amateur photographer and acquire the knowledge that comes from doing the actual work. You should first of all learn how a negative is correctly exposed and second, how to obtain the proper development and fixing of the positive. There is no doubt but that the knowledge you gain in this way will give you a clearer insight into one of the problems of workers in the sound picture field.

A vast amount of research work is going on every day in the never-ending search for better sound motion pictures and good photography plays a very important part in this field of research. Improvements are constantly being sought after not only in the "taking" of the picture but in new and better methods for "photographing" the sound vibrations on the film itself.

There are at the present time a number of film companies recording the sound on discs or "records" which are geared to run in time or synchronism with the machine which projects the picture on the screen, but this type of recording is gradually losing favor due to the number of factors that are frequent sources of trouble.

By far the greater part of all films now produced are "sound-on-film" recordings and it is generally predicted that the time is not far distant when all sound recording for motion pictures will be done in this manner, that is, the sound parts of a sound motion picture reel will be placed on the edge of the film by photographic means.

According to this commercial trend we may conclude that certain important processes in sound picture work are becoming increasingly photographic in nature and, therefore, a good fundamental knowledge of photographic principles is essential to a good understanding of this subject. Bear in mind that whether these photographic processes are being applied to the taking of the scene or to the photographing of a "sound track" on the edge of the film, the principles involved are the same. If you are interested in actually developing and printing pictures it is suggested that you obtain the book "How to Make Good Pictures" published by the Eastman Kodak Company at Rochester, N. Y.

Knowing how to take, develop, and print "still" pictures, provides a good foundation for the future work in sound motion picture photography, whether it applies to sound recording or to picture recording as we have previously stated. Since motion picture photography is in reality the "taking" of many "still" pictures per second one should carefully study the principles just covered in this lesson on how "still" pictures are taken, developed, and printed. Later we will take up motion picture photography and you will find it very interesting because it represents ingenuity of the highest order in taking advantage of a natural faculty of the human eye known as "persistence of vision". This faculty comes into play only during the later projection of the photographed scene on to the screen in the theatre but the photographing of the scene and the making of the films used later in the theatre must be done in full accord with this principle of persistence of vision.

In the lessons which follow on the photography of objects in motion you will study subjects such as motion pictures in color, wide film, and stereoscopic or three dimension pictures. Also, the various forms of the art as it has been developed up to the present with forecasts of the possibilities and needs for the future are included in the discussions.

EXAMINATION QUESTIONS

1. Is it necessary to have a lens in a camera in order to take a good picture?
2. What is the chief function of a camera lens?
3. (a) What are the three main parts of a camera? (b) Explain the function of each part.
4. What name was given to the first photographs?
5. Name one great difference between the early process of photography and modern photographs?
6. What is the principal chemical ingredient used in emulsions?
7. Discuss the action of light and developer upon a film emulsion.
8. What stops the process of "development?"
9. How may a positive be distinguished from a negative?
10. How many positives can be "printed" from one negative? Give reasons for your answer.

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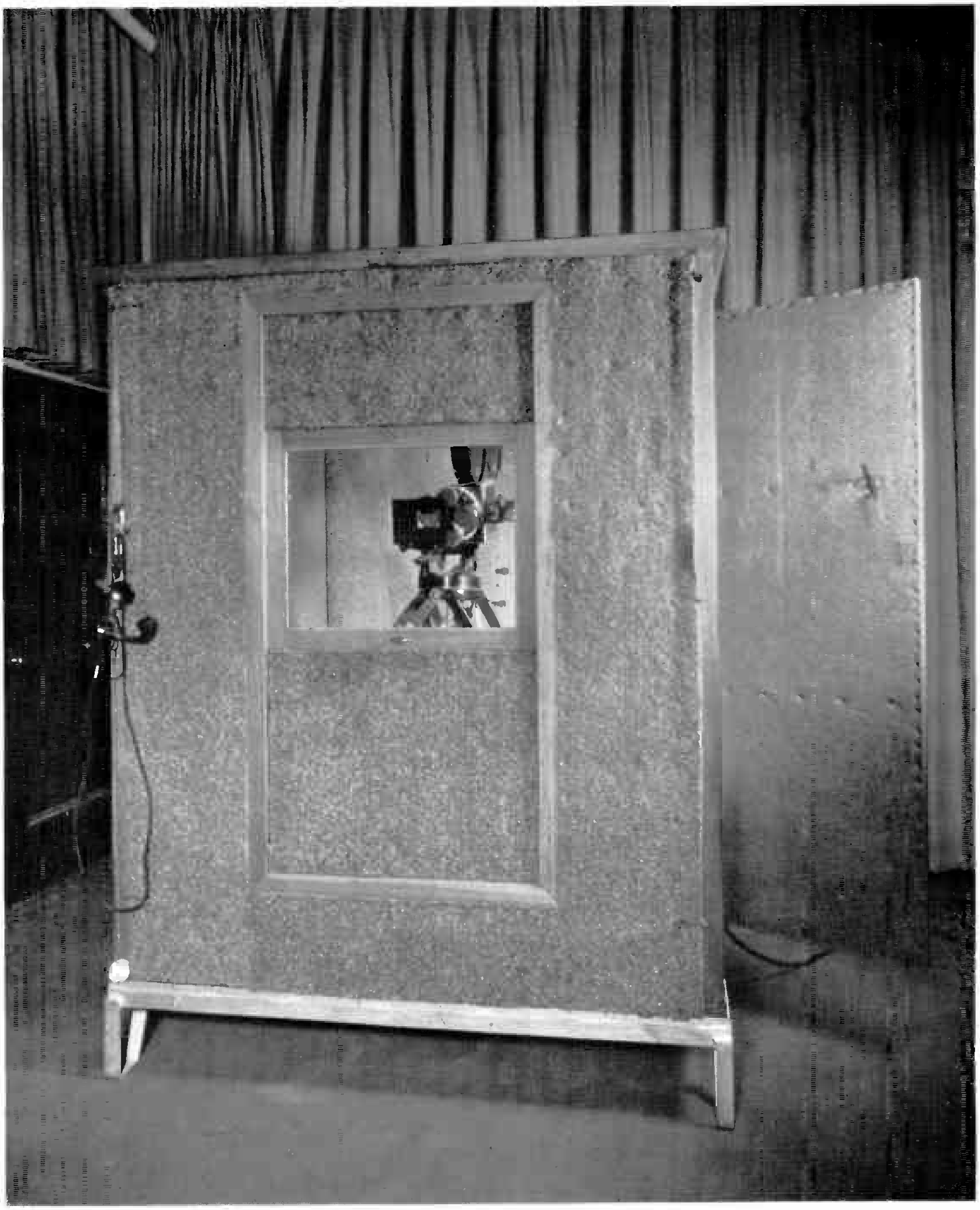
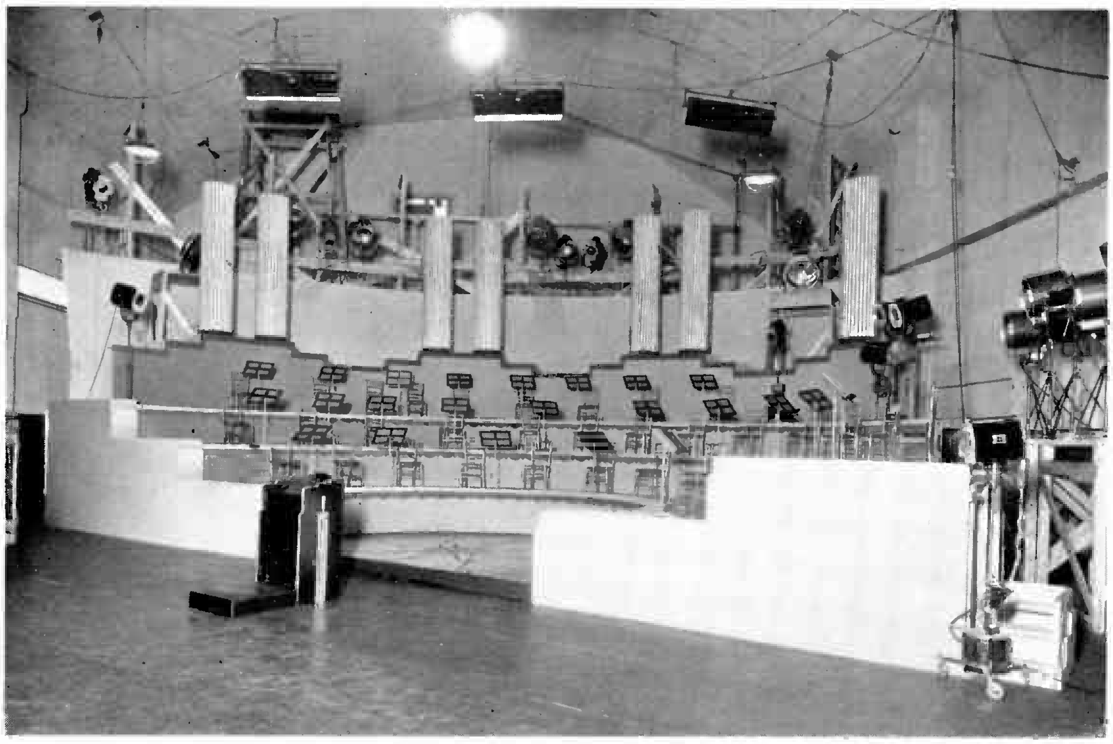
NOTES

NOTES



Motion picture camera in sound-proof booth.



Interior set for photographing and recording an orchestra.

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Vol. 58, No. 4

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Portable camera and recorder for News reel work

"Seeing" Motion Pictures is due to Persistence of Vision

VOL. 58, No. 5

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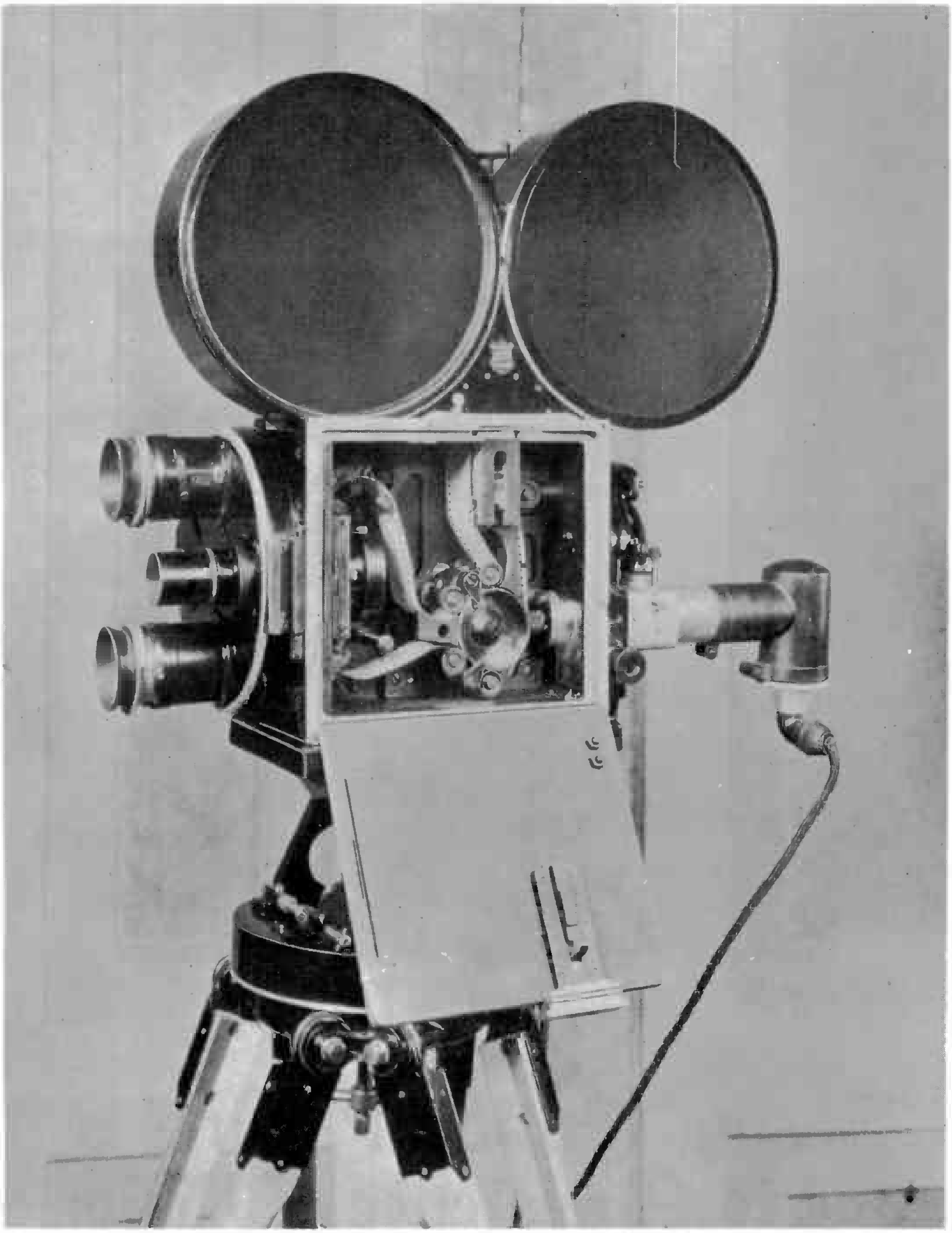


Sound picture camera using Aeo light method of sound recording.

"SEEING" MOTION PICTURES IS DUE TO PERSISTENCE OF VISION

PERSISTENCE OF VISION

Did you ever stop to consider that the illusion of motion which we get when looking at a moving picture on a screen is possible only because our eyes possess the peculiar faculty of being able to "see" an object for a fraction of a second after the object has been removed from view? We are able to test this property of the eye in many ways, some of which are so common in our experience that we do not even question the causes which bring about certain effects. For instance, most of us can recall having seen a boy in the act of rapidly whirling a tin can or "firepot" filled with small pieces of lighted wood. This fast movement causes the air to rush through holes punched in the can and fan the lighted wood into a roaring flame. Now the thing about this action that holds our attention is the fact that as the pot of fire is whirled in a circle we do not actually see the can and burning wood, but instead it appears like a continuous circle of brilliant flame or smoke, and the outline of the can seems very indefinite. Figure 1 shows how the flaming circle would naturally appear to the eye due to the property of persistence of vision. If it were not for this property of the eye we could clearly see the pot with its burning wood at any particular point as it moved in the circle.

Another familiar demonstration of the principle of persistence of vision is a propeller in rapid motion. As shown in the picture drawing in Figure 2, the propeller appears to be a hazy, transparent disc instead of a set of long narrow blades. The action of persistence of vision in the case of either the whirling firepot or the revolving propeller blades, of course, is to cause the eye to continue seeing the object in one position for a short time even after it has passed to a new position, and to blend these impressions into a whole figure.

A simple experiment to test the effect of persistence of vision is to look at any object for a moment and then quickly close your eyes. You will find that an image of the object looked at still remains with you for a fraction of a second after shutting your eyes. It has been definitely decided that this natural function called persistence of vision takes place not in the eye, but in the nerves which convey visual impressions to the brain, or in the brain itself.

Whether or not the ancient people on our earth possessed any knowledge concerning motion pictures probably will never be known, because the records of man's activities so many years back have thus far been lost to us, but we do learn that as early as the year A. D. 130 a Greek geographer and astronomer, named Ptolemy, demonstrated the phenomenon of persistence of vision by means of a simple piece of apparatus consisting of a disc with spots on it, which was made to revolve. The first record of anything suggesting the general scheme of modern pictures is found in the Zoëtrope or Wheel of Life, patented by W. G. Horner in 1833. His device consisted of a hollow cylinder which turned on a vertical shaft. On the inside of the cylinder there was an arrangement of slots, which permitted a series of pictures to be inserted in a certain sequence so that each pic-

Figure 1

ture would show a successive stage in some movement, for example, a horse in the act of galloping. As one looked through a hole in the cylinder the picture on the inside of the cylinder directly opposite the hole came into view, and as the cylinder continued its rotation successive holes and consequently new pictures rapidly followed one another. Persistence of vision caused these individual pictures to blend together and produce the effect of a horse in motion. Figure 3 gives a general idea of the appearance of a Zeotrope. At first the Zeotrope pictures were drawn by hand but later photography was used to produce them.

You may have seen the application of the Zoetrope principle in a very simple form which was merely a small booklet or tablet of blank paper on the pages of which were drawn a series of pictures, each one being slightly different from the other and in proper sequence, so as to depict some action. When thumbing through the book the pages would follow one another in quick succession and if approximately 16 pictures per second were flashed before your eyes, persistence of vision would come into play and cause the pictures to blend into one picture giving a fairly clear effect of the object in motion. This method of showing a moving picture was used by Leonardo da Vinci, the great artist and inventor, to amuse the people of his time.

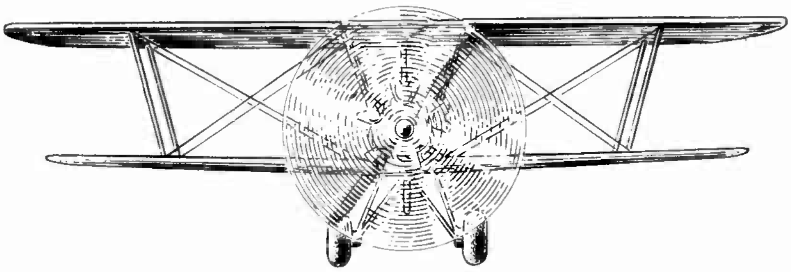


Figure 2

The pictures used in early attempts to produce the illusion of motion pictures were merely sketches or drawings made by an artist and even to this day we have "comics" in the movies, or animated pictures of cats and other animals that are made up of a series of drawings. However, regardless of whether the pictures are drawn or are actual photographs, so long as each succeeding one is slightly different from the preceding one and in correct sequence; and the series is flashed before your eyes at the proper speed; the effect of "seeing" the picture in motion is always due to your "persistence of vision."

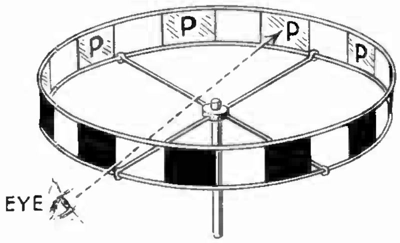


Figure 3

EARLY ATTEMPTS AT PHOTOGRAPHY

The first attempt to produce successive pictures of an action by photographic means was made in the year 1872 by an Englishman named Edward Muybridge. He made these photographs at the request of several race-horse owners who had come to a heated discussion regarding the gait of their favorite horse. At this time wet collodion plates were used in photography. Muybridge set up twenty-four cameras in a row at the side of a race track and stretched a thread from the shutter of each camera across the track so that the horse, when running, would break each thread in turn and open and close the shutter of each camera in succession. With this arrangement 24 separate pictures were taken with each one showing the horse in a position slightly in advance of the preceding picture.

The first attempt to obtain photographs of a galloping horse was not a success because the wet collodion plates were not sensitive enough to get a fully exposed photograph in the short time required for the horse to pass by the lens of each camera. The problem connected with obtaining a good picture of an object in motion when using a short exposure time was greater then than it is today, because of the older types of lenses and shutters in use at that time.

EXPOSURE TIME

If we carefully consider how a camera operates it is easy to understand that if an object should move while actually being photographed then the image of this object focused on the plate in the camera will also move. This fact makes it rather difficult to obtain a sharp picture of a moving object at any particular instant unless the proper exposure is made as we will explain.

Let us consider an extreme case where an object moves across the field of vision of a camera lens from the extreme right to the extreme left and, likewise, the image of this object moves across the sensitized plate from left to right because we assume the shutter of the camera is left open during this time. We can be sure that the silver salts of the emulsion will be affected in every portion of the plate by the light rays of the image as the rays pass over the emulsion on their journey across the plate and upon development a blurred outline of the image will show up extending clear across the plate making it unfit for use as a negative. To avoid this difficulty in photography we must do something that will give the effect of "stopping" the motion momentarily. By the expression "stop motion" in photography we mean that the light image reaching the plate from a moving object should be permitted to remain on the emulsion for only an extremely short time, or a small fraction of a second, so that for all practical purposes a sharply defined image will be obtained in one place on the negative after development.

It is quite plain that strictly speaking there is no such thing as "stopping the motion" of an image on the plate if the object is actually moving. Therefore, regardless how short may be the time allowed for light from an object being photographed to pass through a lens, if the object moves in that time the image will also move a certain distance on the plate, as already explained.

The best we can hope to do in trying to cope with a situation of this kind is to allow light to come through the lens for only a small fraction of a second so that although the image may have moved a little during this short exposure, yet the movement is relatively so small that the developed image on the negative will appear to be sharp and clear.

Then, in order to "stop motion" on the plate only a very short exposure time should be used. The part of a camera that controls the time of exposure is called the "shutter." It is made of an opaque material, for example sheet metal of some kind, and is mechanically arranged to open and close the path of the light rays through the lens in varying amounts of time; certain types of shutters can be regulated to provide an exposure as fast as 1/10,000th part of a second. It is important that with a short exposure time there must be a sufficient amount of light allowed to enter the lens to focus on the plate or film to fully expose or act on the silver bromide in the emulsion.

According to the limitations just outlined for photographing any object in motion a simple line of reasoning tells us that in order to take photographs with very short exposures it is necessary to provide any one of certain conditions as follows:

(1) There should be a great deal of reflected light from the subject to be photographed, or

(2) A very large lens in proportion to the size of the plate should be provided so that a large amount of light may enter and strike the plate, or

(3) An emulsion should be used that requires very little light to become fully exposed. An emulsion made for this purpose is said to be "fast" emulsion, whereas, one that requires a strong light for proper exposure is called "slow."

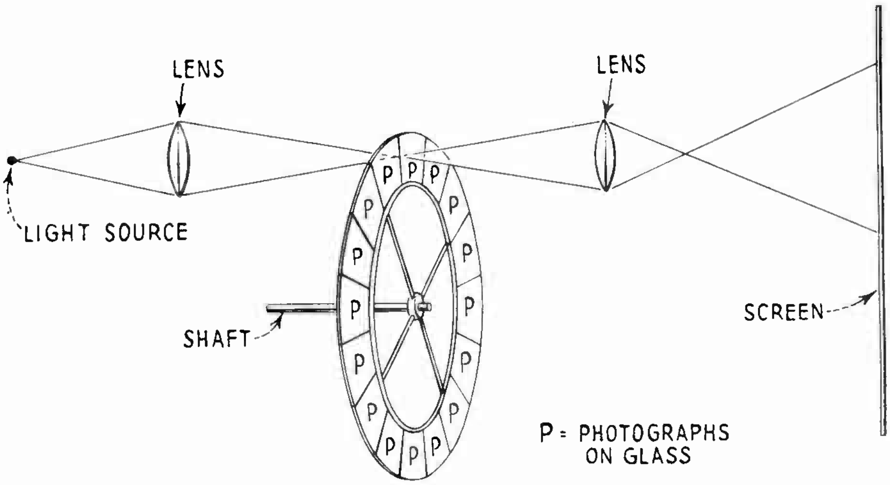


Figure 4

Now that you understand what "stopping motion" means and the need for proper values of time and light for a given exposure, let us return to the race track discussion where Muybridge had his cameras set up to take 24 separate and slightly different views of a horse in motion. He found after developing his wet collodion plates they were too "slow" to produce a good image, so he conceived the idea that the amount of light falling on the plates could be increased if the legs of the horses were painted white. He was sure the white would reflect more of the brilliant sunlight which shone upon the horse, and in turn more light rays would enter the lens to properly expose the emulsion.

After obtaining a good set of 24 photographs taken by this method

Muybridge proceeded to build a machine for projecting them on to a screen to give the illusion of motion. He called the apparatus a Zoopraxoscope, probably because it was the customary thing in those days to make scientific names sound as impressive as possible. The machine consisted of a large glass disc that revolved in a vertical plane with 24 photographs set in proper sequence along its outer edge. A limelight was set up with a lens that projected the pictures on to the screen and so, when the wheel was revolved each picture came into view for a moment and was quickly replaced by another. With this crude method the photographs projected on the screen were quite blurred, nevertheless they gave the effect of a horse in motion, and all because of that quality which the human eye possesses — persistence of vision. This was the first time moving pictures were ever produced on a screen. Figure 4 is a drawing of Muybridge's Zoopraxoscope.

INTRODUCTION OF THE SHUTTER

As just explained, the images on the screen were so blurred by the movement of the photographs as they passed in front of the light beam it was necessary for Muybridge to devise a shutter that allowed light to pass through the photograph only for a very short interval of time,or precisely at the moment the photograph came into place before the lens. This shutter eliminated the blurred effect and the same principle is still in use today as you will learn. When the shutter on a modern motion picture projector gets out of adjustment you instantly see the same blurring effect in the form of white lines racing up the screen.

It is interesting to note that the idea of "talking pictures" was in Muybridge's mind as early as the year 1888 for at that time he went to Thomas A Edison who had invented the phonograph and asked whether the Zoopraxoscope could be connected in some way to Edison's phonograph so as to make it appear that the people shown on the screen were speaking or singing as the case may be. Mr. Edison would not consider the project because the phonograph at that time was not loud enough to be heard by a large audience. In 1893 at the Chicago World's Fair, Muybridge, due to his efforts in this field, won recognition as the father of Motion Pictures. The thing that was holding back the practical development of motion pictures however, was the difficulty experienced in obtaining satisfactory photographs on glass plates when the exposures had to be taken in quick succession.

For years scientists and inventors in various countries continued to struggle with the problem presented by the use of glass plates. The most successful of these workers was a man named Donisthorpe who patented a mechanism for taking photographs on plates at the rate of 8 per second. These photographs were printed on a continuous strip of paper which was used in the Zoopraxoscope, and with this improvement the movements of persons, animals, etc., could be reproduced on the screen with more lifelike effect to the eye of the observer than had heretofore been possible. Donisthorpe made a very entertaining moving picture by taking a series of photographs of buds opening into flowers, with long intervals between each picture, and then by showing these photographs in rapid succession he produced in a matter of seconds the effect of buds unfolding into flowers.

CELLULOID FILM MADE MOTION PICTURES PRACTICAL

Dr. Marey who was carrying on experiments in Paris was the first to use flexible sheet celluloid for taking a series of photographs. At the same time two men in England were using paper film for a similar purpose and, also, Thomas Edison in America began work on the production of motion pictures. In fact these inventors and many others bent their efforts toward producing moving pictures, not for projection on a screen, however, but particularly for use in coin operated machines where only one person could view a picture at a time. Some of these machines still survive in the "penny arcades" of today.

It is probable that the first public showing of a motion picture was given by C. Francis Jenkins in 1894. The mechanism which he used to take the photographs can be said to be the first camera employing methods corresponding to present day motion picture photography. A significant fact in this connection is that Jenkins used the same machine for both photographing and projecting his pictures. When taking a picture the film was fed from a roll or reel mounted on a ratchet-rotated drum which drew one picture at a time past the lens opening where it was exposed, and from there the film was rewound on another reel ready for the development room. To show or project the picture an oil lamp was so placed that its light passed through the film and then through the lens which focused it on the screen.

THE "GATE" AND "INTERMITTENT"

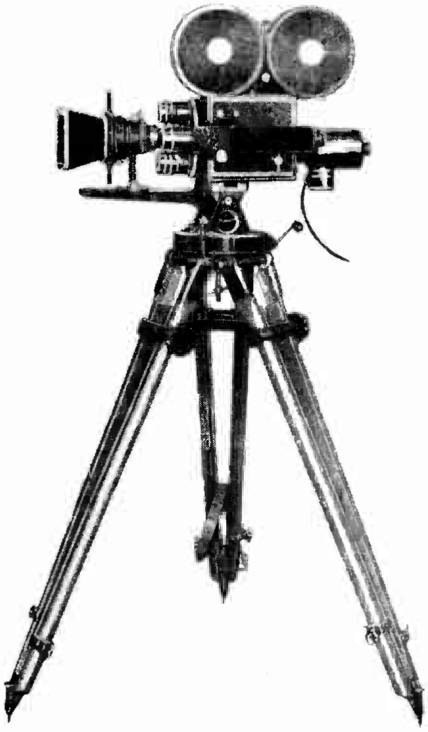
In the foregoing paragraphs we covered some of the principles of motion picture photography with descriptions of the first attempts to produce moving pictures, and now we will pass on to present day practices of the motion picture industry with particular reference to the "gate" and "intermittent" mechanism of a motion picture camera.

Figure 5 is a photograph of a modern silenced motion picture camera of the type used in sound picture work. It has a felt and leather padded hood which encloses the working parts in a sound proof chamber and is different in several ways from the old type cameras used in taking silent "movies". The main difference is in the internal construction, where working parts that were sources of noises in old machines are now made to run so silently that the cameras may be located quite close to the microphone without any danger of running sounds being picked up, or vibration sounds being recorded on the sound track.

Figure 6 is an illustration of a widely used non-silenced type of camera made by Bell and Howell for use in motion picture work where sound is not to be recorded. A comparison between the silenced and non-silenced cameras in Figures 5 and 6 respectively shows that the main difference so far as external appearance is concerned is the addition of the padded hood on the silenced camera for sound picture work. The circular metal housings on top are for the feed reel and the take-up reel. Before a machine is ready for service the operator must place a reel of fresh, unexposed film in the feed reel housing and thread it through the camera mechanism to be rewound on a reel in the take-up housing. The schematic view in Figure 7 shows the interior of the camera pictured in Figure 6, where "A" is the feed reel and "B" the take-up reel.

Figure 5

While in operation the film is pulled from the feed reel by a large sprocket wheel which revolves in a counter-clockwise direction, and then through an arrangement of gears and sprockets the film is fed to the "gate" which holds it firmly in place in front of the lens. Associated with this part of the machine is a mechanism known as the "intermittent movement". It consists of a claw-like arrangement which pulls down the film three-quarters of an inch at a time, allows it to rest in front of the lens opening "C" for a fraction of a second, and then repeats the operation by pulling the film down the same distance to allow the next unexposed section of it to come into place before the lens. The film then passes to the lower portion of the sprocket wheel and is fed by it to the "take-up" reel, which rewinds the exposed film preparing it for the development room.



Courtesy Bell & Howell Co.

Figure 6

Refer to Figure 7. The following paragraphs give the sequence of operations within the machine when photographing just one of the pictures on the film during the taking of a movie scene. We will start out with the assumption that this is to be a "silent picture", that is, without sound, and the photographs are to be taken by the camera at the rate of 16 per second. This rate is standard for silent film and is based on the duration of our persistence of vision. From experience it has been determined that at least 16 separate images must be projected on a screen each second in order to have them blend into an illusion of a continuous picture in motion. To begin the explanation suppose the film is threaded into place in the camera and at this particular instant the intermittent movement has just ceased to move. The image of the scene being photographed will then pass through the lens in the form of light rays which focus on the sensitized film only for this instant, or while the film is stationary before the lens opening. As in the taking of any photograph the light rays of the focused image strike upon the silver bromide of the emulsion with which the film is coated and prepare it for the action of the developer which is used later in making the negative. After this exposure the intermittent movement starts operation and with a swift downward motion it pulls the film three-quarters of an inch by means of claws or sprocket teeth.

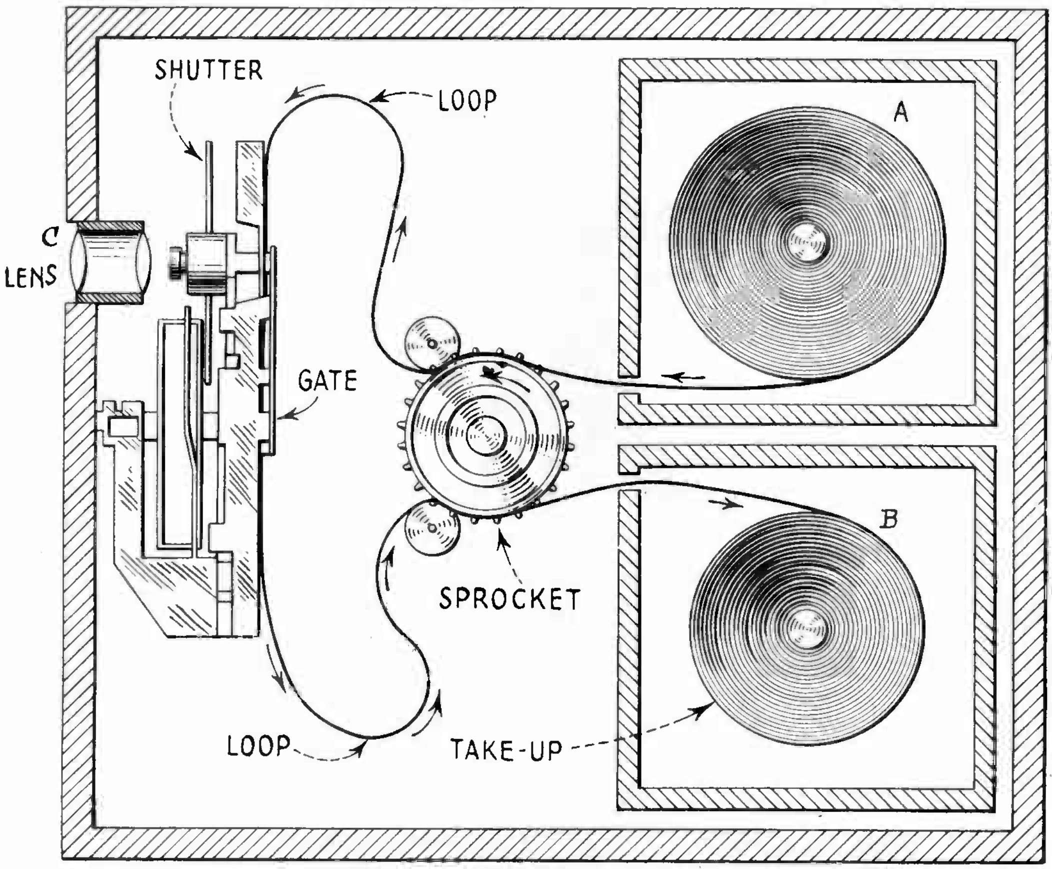


Figure 7

While the film is in motion it is necessary to shut off the light rays coming through the lens so that the image will not then be focused on the film and obviously, the emulsion will not be affected. We know the light rays must be cut off at the proper moment that is, before they are allowed to move to any great extent, or otherwise a blurred negative will result. A very ingenious shutter arrangement is used to cut off the light from the film while it is in motion. As Figure 8 shows, the shutter is in the form of a circular disc with a segment cut out, thus leaving a large opening in one portion of it; a shutter of this general type is also used on the projector when the picture is shown in the theatre.

By referring again to Figure 7 it can be seen that the shutter is located between the lens and the gate. This is the end view of the shutter, the front view of the same shutter being shown in Figure 8. During the running of the machine the shutter revolves continuously making one complete revolution for each picture taken. It is to be understood, of course, that the cut-away portion of the shutter comes in front of the lens only while the film is at rest. This allows the light from the object being photographed to pass first through the lens, next through the opening in the shutter, and then to the emulsion on the film. In this manner one picture is "taken" or, as we say, one exposure is made. After this exposure the intermittent starts to pull the film down and in another fraction of a second a fresh, unexposed portion of the film is pulled into place before the lens ready for the next picture or exposure to be recorded.

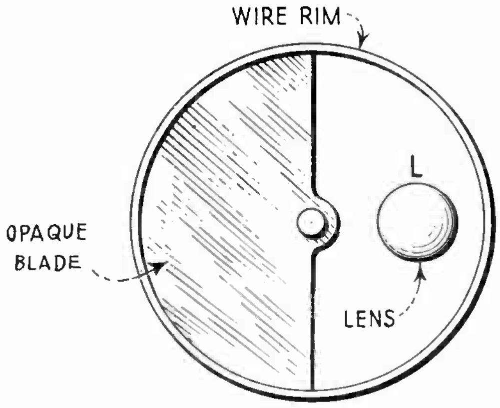


Figure 8

At the instant the intermittent starts to move the film the shutter begins to turn, its cut-away portion is taken away from the lens, and the solid or opaque part comes into place before the lens to cut off the light while the film is in motion. When the intermittent ceases its movement the film remains stationary before the open segment of the lens for a fraction of a second and during this moment another exposure is taken. This sequence of operations continues at the rate of 16 per second so long as the camera crank is turned, or in the case of a motor-driven camera so long as the current is turned on.

The normal operating speed for silent picture photography is 16 pictures per second, for sound pictures 24 per second, but as many as 200 pictures per second can be taken with most standard cameras by means of special adjustments provided. The size of each separate picture taken with a standard motion picture camera is 1 inch by 3/4 inch. Figure 9 shows a strip of film with dimensions indicated.

Figure 10 is a section of film illustrating a simple form of motion. A man is shown in the act of raising his arm from one position to another. As will be observed each succeeding picture shows his arm slightly higher than the preceding one so when these pictures are projected on a screen in rapid succession our persistence of vision causes a blending of each picture with the next to produce the effect of continuous motion. The action of a motion picture camera, after all, is to "break up" the moving object being photographed into a series of pictures where each one shows the action taking place a 24th of a second later than the preceding one.

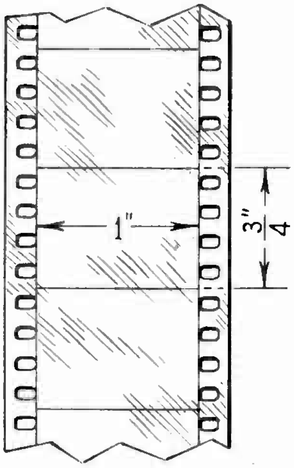


Figure 9

FAST AND SLOW MOTION.

We have already mentioned how a motion picture camera is capable of producing effects which cannot be seen with the unaided eye. Two of these effects may be produced either by taking the pictures very slowly or very quickly. An illusion of a very slow movement in actual life that is speeded up for a moving picture is the blossoming of a bud. On the movie screen, before one's very eyes, we see a series of pictures run off in a matter of minutes that actually were taken at the rate of a few pictures a day. To obtain such a picture the camera is placed before the bud and left there for the required time with an exposure being made at the rate of one per hour or at even longer intervals. When the completed strip of pictures is thrown on the screen the viewing of all the pictures that took days to record is over in several minutes and in this manner any slow motion can be speeded up tremendously.

The other extreme is the case where it is desired to produce a motion picture of an action too fast for the unaided eye to follow. For instance, an action as fast as the flight of a bullet has been successfully photographed. When reproduced on the screen every opportunity was presented to observe the bullet as it floated gracefully across the field of vision and struck objects which were placed in its path. The method of producing such an illusion is just the opposite as in the case of the blossoming bud.

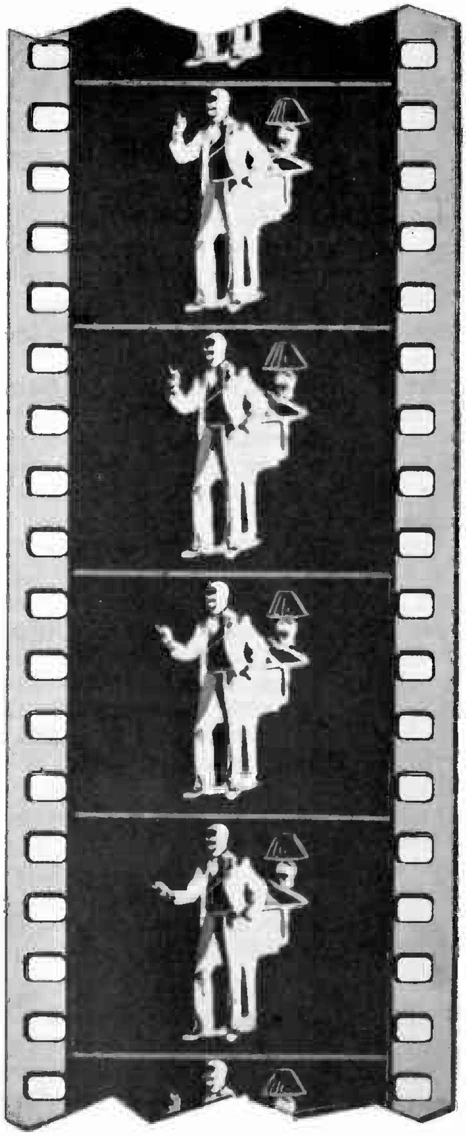


Figure 10

As many as 200 pictures per second may be taken by the standard camera to produce this "slow motion" effect and special cameras have been designed which will take thousands of pictures per second. Suppose the successive photographs of the bullet in flight were taken at very short intervals, say 1/2000th of a second, then when they are reproduced on the screen at the rate of 24 per second the bullet will appear to move across the field of vision at only about 1/83rd of its actual speed, or in other words the actual speed of the bullet is 83 times greater than it appears on the screen.

From your study of exposures and emulsions it is easy to understand that a difficult problem arises in special cases to get enough light to the emulsion for proper exposure at terrific high speed and extremely short exposure time. This problem is solved by a combination of a "fast" emulsion and a "fast" lens. "Speed" in an emulsion means its sensitivity to light and "speed" in a lens is its ability to pass a large amount of light to the film in a short space of time.

HOW THE FILM RUNS THROUGH THE CAMERA.

A standard motion picture film is perforated with holes equally spaced along each edge so that the claws and sprockets in either a camera or projector may have something to catch hold of in the process of moving the film through the machine and pulling it down into place to expose succeeding "frames" of the film.

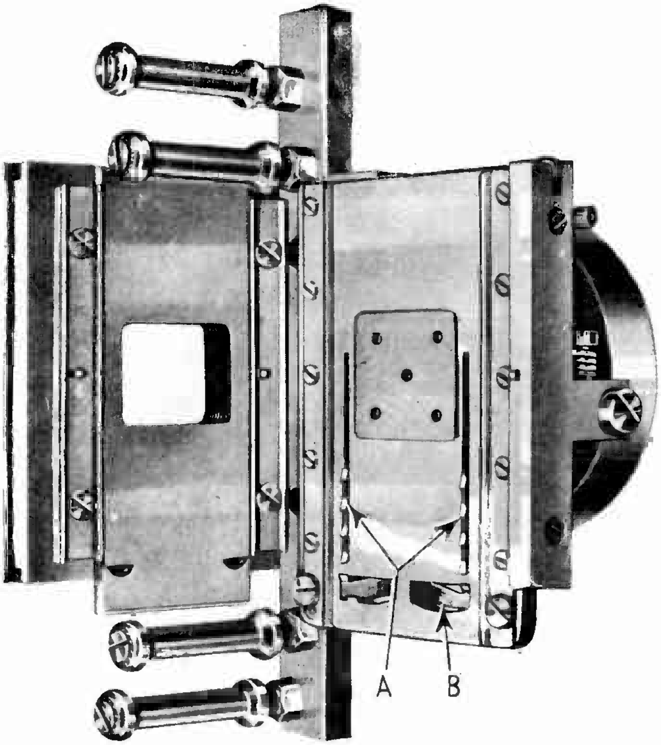
It was explained in the first part of this lesson that the film is held tightly against the aperture in front of the lens by friction springs shaped like tiny sled runners. These flat, thin springs press the film up against the opening before the lens but exert pressure on the edges only where the sprocket holes are located. This serves to keep the film flat and in the proper place for a sharply focused image of the light rays from the object or movie scene.

While the camera is in operation the film is pulled downward in short, sharp jerks by means of the claws, which engage the sprocket holes in their action of pulling successive frames in place before the aperture. To prevent the claws from tearing the sprocket holes out by the suddenness of this jerking action against the friction of the steel springs, a well-designed camera will have a set of 4 claws on each side of the aperture plate which engage 8 sprocket holes in the film at one time. The 8-claw movement in Figure 11, known as super-speed film movement, has two sets of claws, marked "A," sunk in the gate. The gate is shown open as it actually would be if a film were being threaded through the machine. The film would go between the two top rollers and down past the aperture, which is the oblong hole through which light passes to expose the film, and then through the lower rollers back to the take-up reel.

During operation the claws, which are shown at the bottom of the stroke in the illustration, sink into the guide slots, and after rising to the top of the slots they come forward and engage with the sprocket holes in the film. After this the claws move downward with a quick motion pulling the film with them and thus a fresh section or frame of film is placed before the aperture; this action is repeated over and over again. In Figure 11 the part marked "B" is called the "check pawl." When the film comes to rest this part moves out of its slot and engages with the two sprocket holes, which causes the film to be held firmly in place during exposure and while the 8-claw movement is rising to engage a new set of sprocket holes.

Of course, when the film is in place and these operations are in progress the two halves of the mechanism, shown in Figure 11, are closed together like a book thus providing a pathway through which the film passes during operation of the camera. If the shutter were mounted in place in this photograph it would be located just on the other side of the aperture and beyond that would appear the lens system.

A more detailed view of a standard camera is seen in Figure 12 where the film can be traced coming from the reel at the left, passing down to the sprocket wheel which engages the sprocket holes of the film,



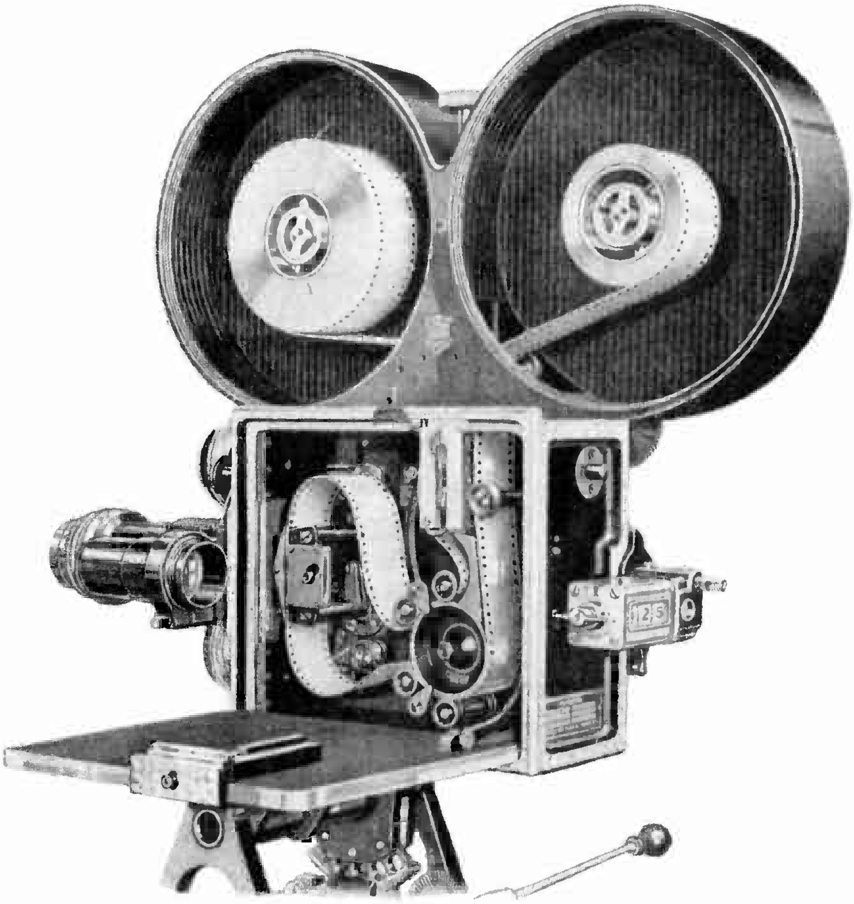
Courtesy of Bell & Howell Co.

Figure 11

then to the gate where it passes before the aperture and lens, and thence to the bottom of the sprocket wheel and back to the take-up reel which is shown at the right. The four small rollers pressing the film up against the sprocket wheel cause the sprocket teeth to make a positive engagement with the sprocket wheel.

As viewed in Figure 12 a modern motion picture camera is seen to consist of first; a lens (a number of lenses are shown on a revolving mount at the left which is the front of the camera); second, a revolving shutter which cannot be seen in this photograph but which is mounted between the lens and aperture, and third; a gate which includes the aperture and intermittent movement.

The sprocket wheel is simply a device for feeding in and taking away film from the gate. The two reels at the top are provided for storing two films, one for unexposed film and the other for exposed film. The feed reel at the left requires no driving power to actuate it because this reel simply unwinds when the film on it is pulled by the sprocket wheel. However, the take-up reel at the right is driven by a slipping clutch arrangement that enables it to take up the exposed film as fast as it is fed by the sprocket wheel. We know that all



Courtesy of Bell & Howell Co.

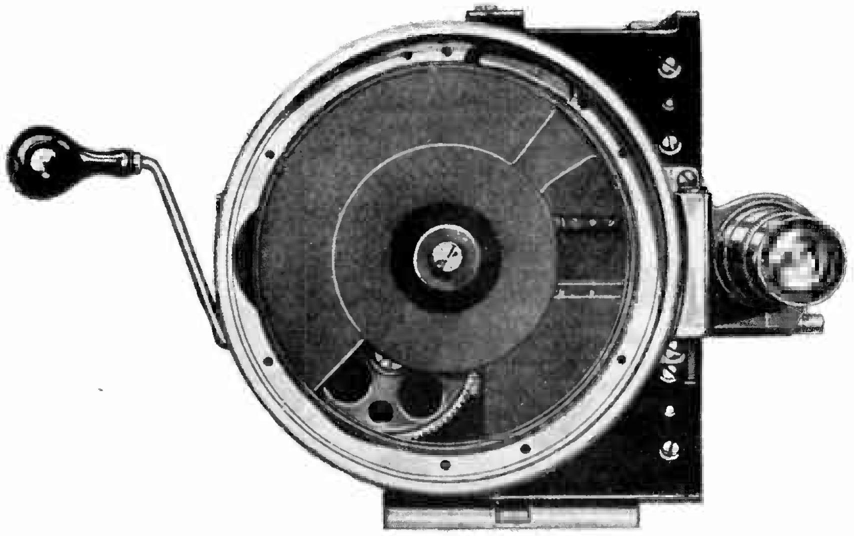
Figure 12

the film is fed evenly to the intermittent movement by the sprocket wheel yet the film moves through the gate in quick jerks of 3/4" sections to expose the frames one at a time. To allow the intermittent enough free film so that the film may be jerked down freely when in operation it is necessary to provide a certain amount of slack film in two loops, one over and one below the gate.

Figure 13 is a front view of the camera with the turret plate removed to show the shutter and aperture. The shutter on this model is semicircular in shape and in the illustration it occupies the position it takes just before it closes off the light from the aperture or oblong opening seen at the right of the circular shutter housing.

The lens barrel at the right is the "finder" or "viewing lens" by means of which the cameraman is able to see the scene exactly as its image appears on the film. Looking through the finder from the rear he is able to follow the action of the scene perfectly so that he knows at all times just what is being photographed on the film. This finder serves the same purpose as the finder found on ordinary cameras with which you are doubtless familiar.

On modern motion picture cameras there is a device known as the "dissolve mechanism." This is an additional shutter about the same size as the regular shutter and is so constructed that it allows the opening in the circular shutter to be closed gradually, thus slowly cut-



Courtesy of Bell & Howell Co.

Figure 13

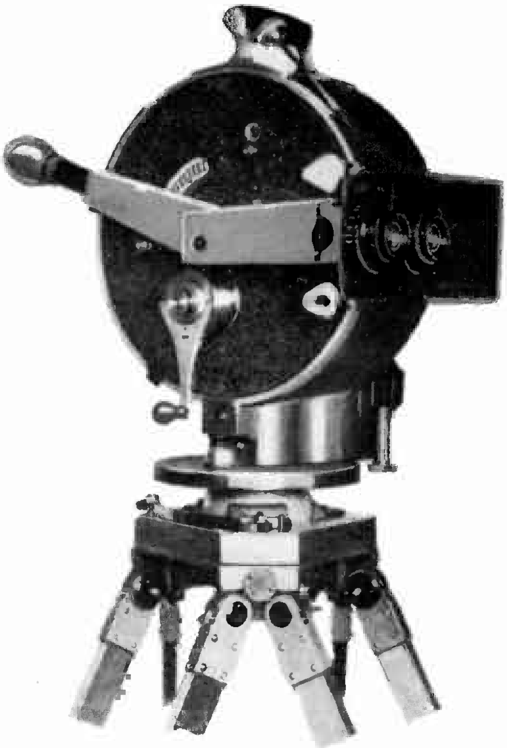
ting off all light entering the camera. This shutter can be made to operate automatically by the cameraman so that if it is desired the amount of light entering the camera may be cut down from maximum to no light by the time 5 feet of film have passed through the camera. A dissolving shutter will close the opening in the regular shutter from 170 degrees (nearly half the circle) to zero, or completely closed. This gradual closing off of the light through the lens gives the effect of the scene gradually fading out of view when shown on the screen in the theatre. By reversing the process a scene may be made to come slowly into view.

CAMERAS FOR SPECIAL PURPOSES.

Generally speaking the internal mechanism of various types of cameras are of such design that they perform similar functions in the taking of a film. The Akeley camera, in Figure 14, is ruggedly built for the use of explorers and hunters. Another type, the Mitchell camera in Figure 15, is made for studio and location work. The term "on location" is used in motion picture work to designate the photographing of scenes away from the studio, for instance in canyons, deserts or places where the natural scenery is used for background instead of using studio "props."

On the front of cameras used in "studio" and "location" work there are a number of lens barrels mounted on a vertically revolving table or mount which permits various types of lenses to be selected and placed before the aperture of the camera. Each lens combination has a distinct quality which makes it most suitable for photographing a certain subject or scene. For instance, the situation is frequently met where a "close-up" of the subject to be photographed is desired as in the case where a person's face is to fill a whole picture; a close-up of this kind requires a certain lens combination.

On the other hand, for the opposite extreme condition or one where an object is located at a great distance and appears as a small speck with an ordinary lens, we must enlarge or bring the object closer by using a "telephoto" lens. This lens combination acts on the image



Courtesy of Akeley Camera Co.

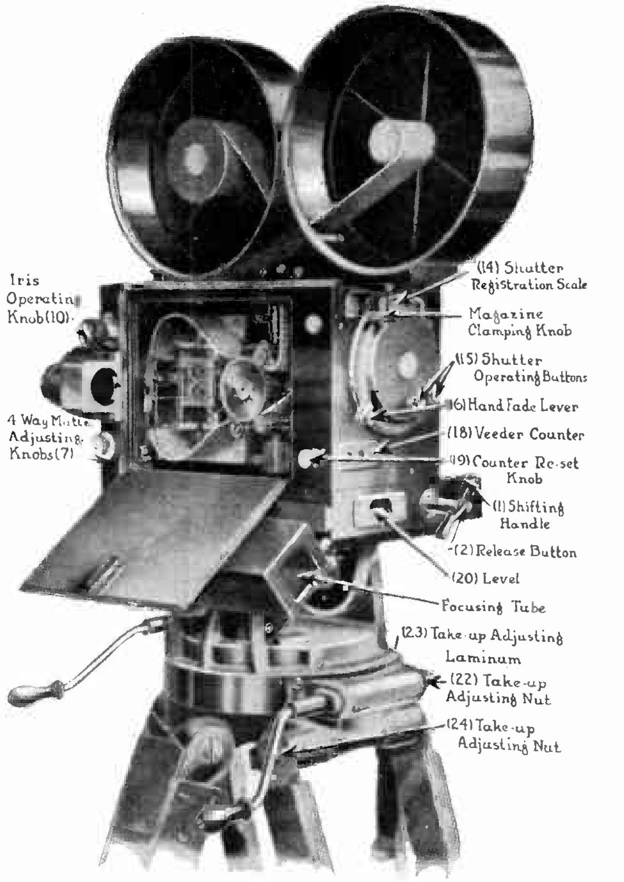
Figure 14

that it focuses on the film in the same way a telescope acts on an image to bring it close to the eye, that is, a distant object is made larger and appears as being much closer when using either a telescope or a telephoto lens.

The set of lenses in Figure 16, made for the Akeley camera in Figure 14, includes a much greater range of lenses than is used on cameras with the revolving lens mount. This range is provided for meeting the unusual conditions encountered by explorers and big game hunters who at times must take pictures under adverse conditions where lighting and distance cannot be arranged as in studio and location work. Alongside of each lens barrel is seen a small tube containing the "finder" through which the cameraman can see any scene exactly as it is being photographed on the film as already explained. A more complete discussion about lenses and their properties is given in another lesson.

DEVELOPING AND FIXING OF FILM.

After a film has been "exposed" it is taken to the laboratory for development and fixing, and the "negative" thus produced is used later for printing "positives."



Courtesy Mitchell Camera

Figure 15

To obtain good photographs, cameramen must be sure to obtain the correct exposure time which is determined by the lens and emulsion used and the light conditions. The principles volved in the development and printing of films are similar but in the matter of the apparatus required for this work we meet various types used by the different companies engaged in this work. For example in some plants the film, after exposure, is wound upon round wooden racks which are immersed in large tanks of developing solution for the required length of time.

A rack with its film would next be transferred to a tank of water for washing off the developer and from there it would go to a tank of "fixing" solution, usually hyposulphite of soda, which acts to definitely stop the development process and "fix" the images on the film.

After succeeding processes of washing and drying of a film it is ready for the film "editor" and the cutters who take the different parts of the complete picture and cut and splice them into a continuous reel of negative from which are printed the final "positives" that are distributed to the theatres.

Another laboratory method employed for finishing a film makes use of an automatic developing plant. This machinery carries the film over rollers that cause it to dip in and out of a tank of developer; from there the film is run through a tank of water, next through the fixing solution and then through another tank of water where it gets the final wash; after which it is wound on racks for drying.

Courtesy of Akeley Camera Co.

Figure 16

A continuous printing machine is used to make a positive. A machine of this kind feeds the exposed positive film and the finished negative together past the light source in such a way that the proper amount of light will pass through the negative to the positive which

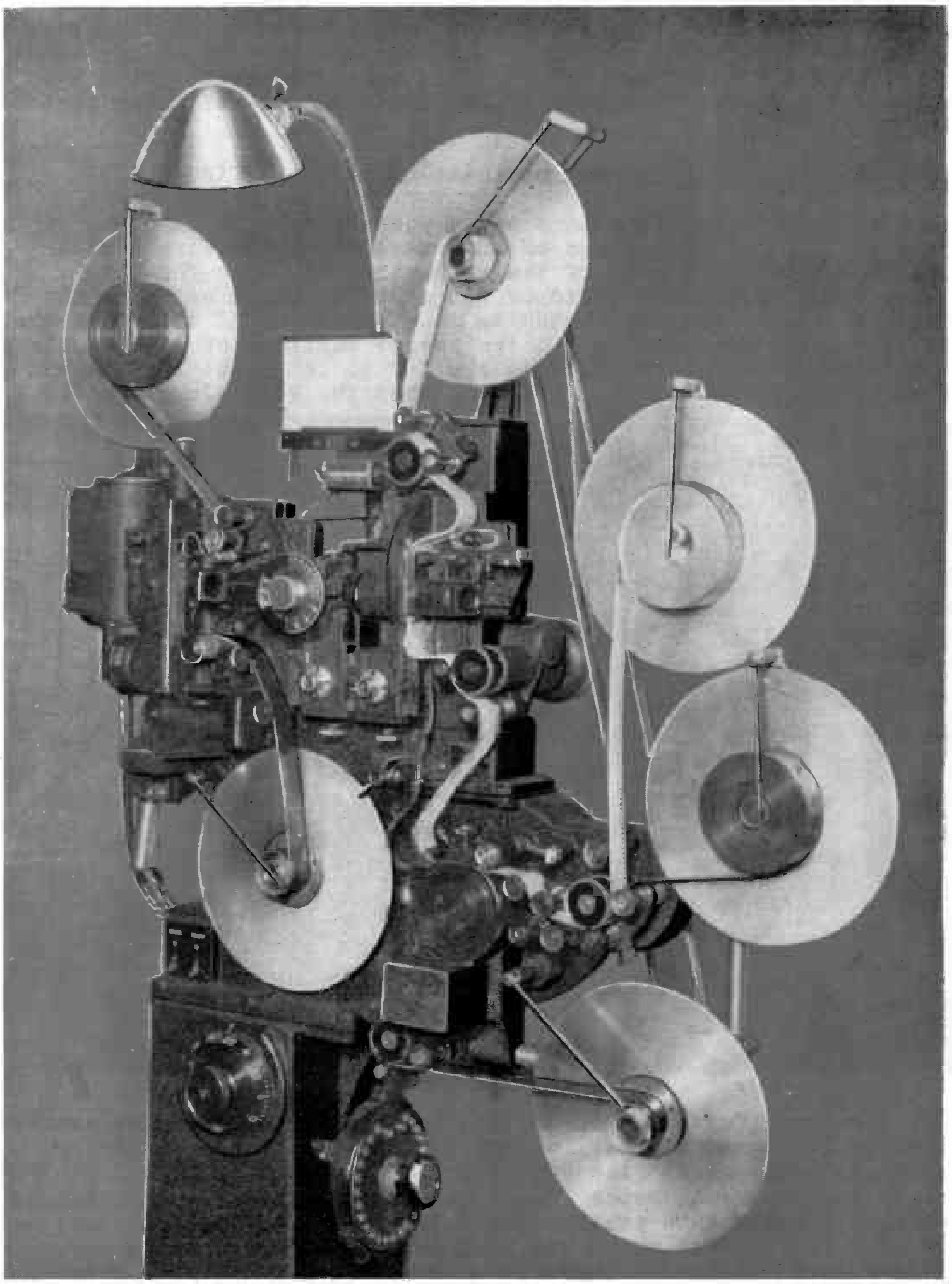


Figure 17

is run underneath. Both films during the process are run in close contact with each other in the oblong opening where the light is focused. After the positive film has been exposed to the light by this method it is developed and fixed in much the same manner as was the negative film from which it was made. A modern printing machine which prints the sound track simultaneously with the picture shown in Figure 17.

A close-up of an intermittent movement is shown in Figure 18.

A late type portable Photophone sound picture machine is shown in Figure 19. A special feature of this machine is the fire shutter which is mounted as a part of the revolving shutter. The fire shutter has openings and solid or opaque parts which are like the revolving shutter and the mechanism is so constructed that when the film is running at normal speed the opaque portions of both shutters are in line and act like a single shutter to let light through and cut off light periodically. However, when the film slows down or

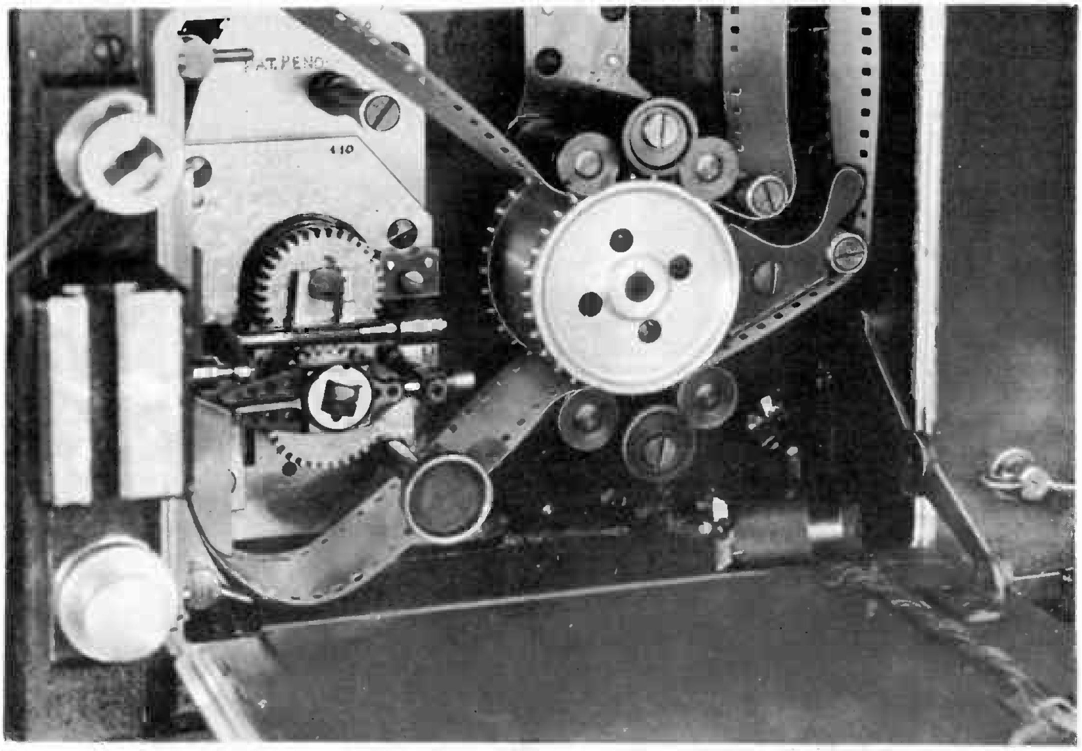


Figure 18

stops the centrifugal action on the fire shutter causes this shutter to change its speed and fall out of alignment with the revolving shutter with the result the opaque portions of both shutters do not line up together and, hence, are like a solid disc with no openings presented for light to pass to the film. Also, in this machine the gate is fixed through which the film is threaded and, therefore, does not open and small shoes press the film against the aperture. A 1000-watt incandescent prefocused lamp is used as the light source. The term "prefocus" means that the plane of the filament is parallel to the plane of the condenser lens when the lamp is inserted in the socket. It has a reflector and condenser lens.

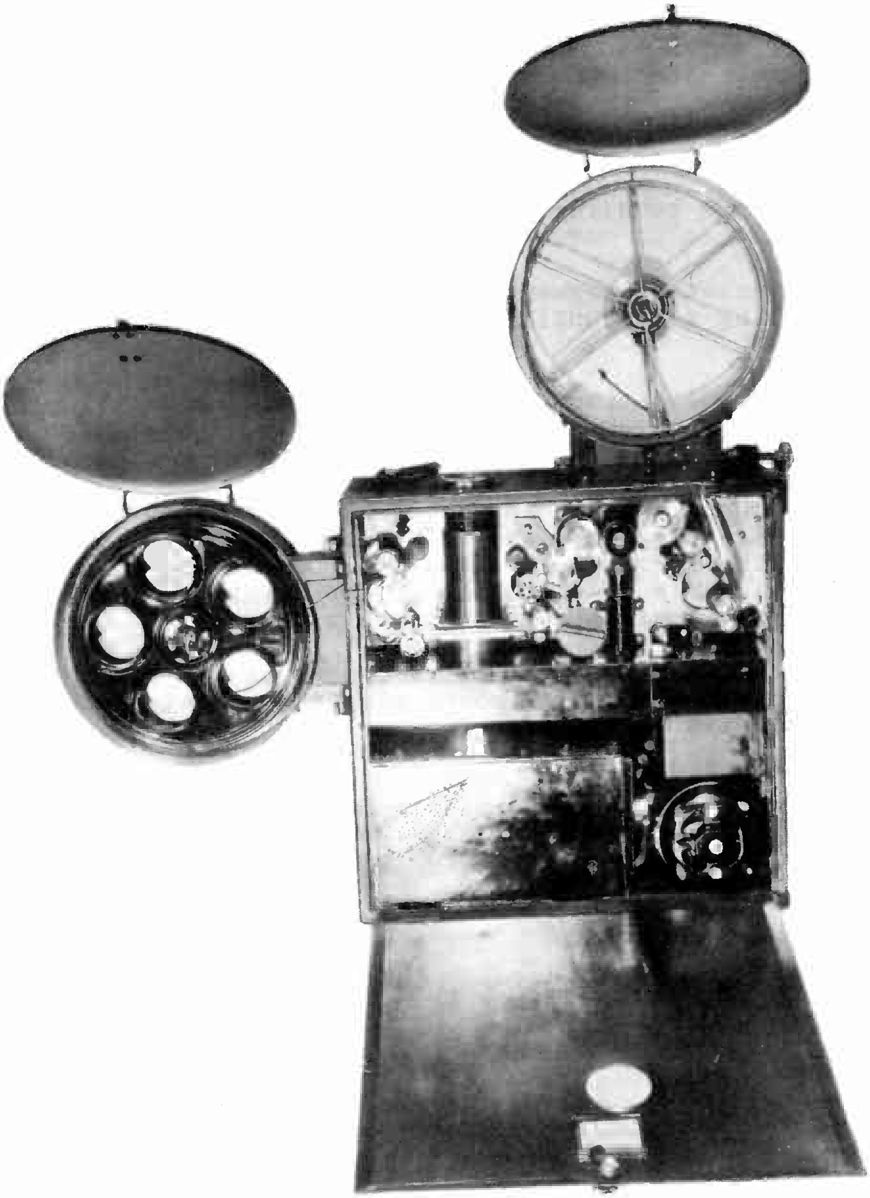


Figure 19

EXAMINATION QUESTIONS

1. What are the dimensions of a single picture or frame on a motion picture film?

2. Is the picture taken by a motion picture camera a "negative" or a "positive?"

3. What piece of mechanism in a motion picture camera moves the film into place before the lens and how does it function?

4. What piece of apparatus cuts off the light while the film is in motion?

5. Explain about the peculiar property of the human eye upon which the illusion of motion pictures depends.

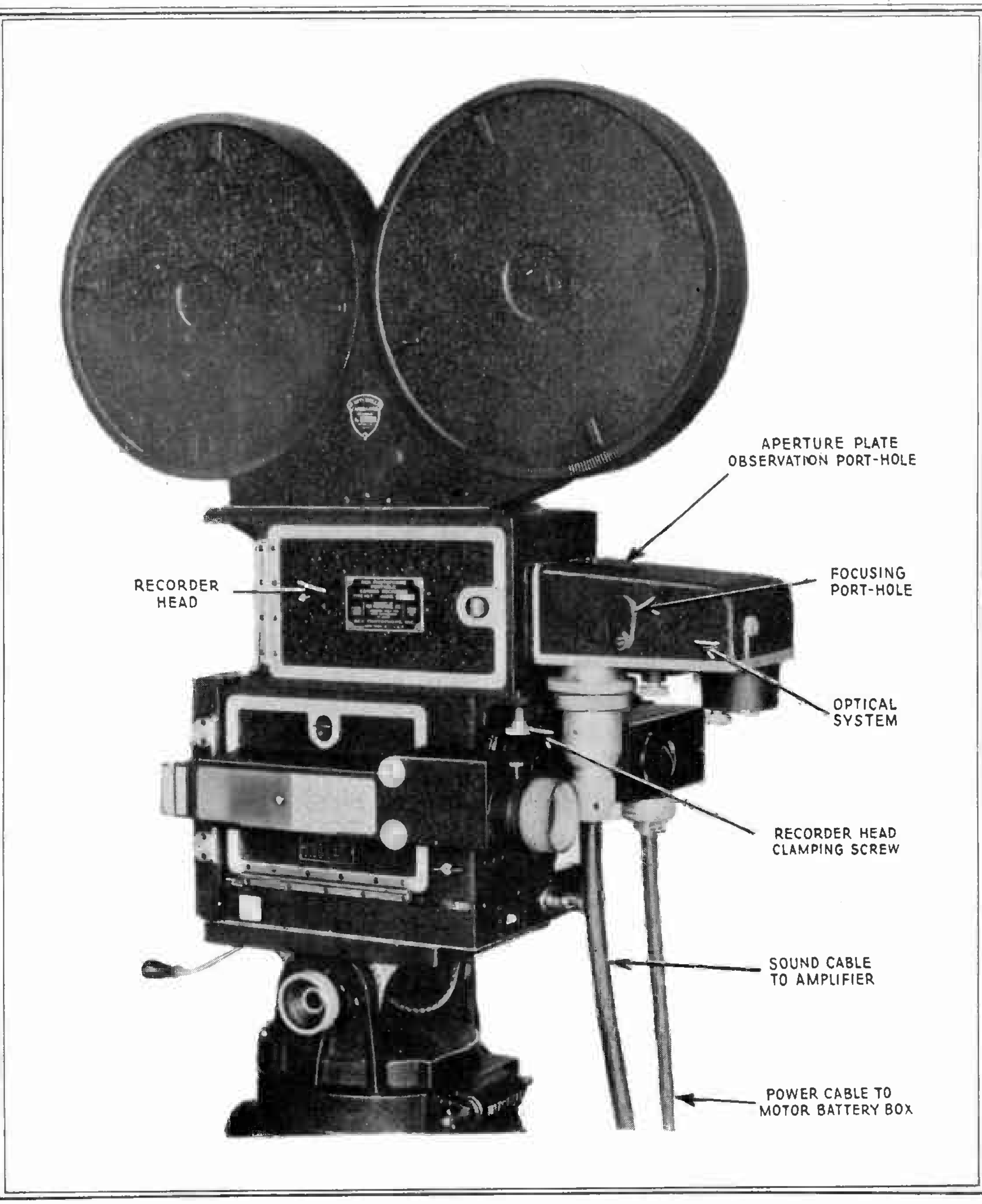
6. Give the sequence of operations of a film from the time the picture is being taken until the film becomes a finished "positive."

7. While taking sound motion pictures a film will pass through the camera at the rate of 90 feet per minute. How many pictures are taken per second?

8. Suppose pictures are taken of an object which is moving too fast for the eye to follow and by means of motion pictures we can see this object in flight on the screen. Explain whether the pictures are taken or projected at the greater speed to make them visible on the screen.

9. An important change in motion picture cameras was brought about by the introduction of sound pictures. What was the change and why was it necessary?

10. Is there any limit as to the number of "negatives" and "positives" that can be taken with a motion picture camera of a given production or scene? Explain.



Sound picture camera with recording head.

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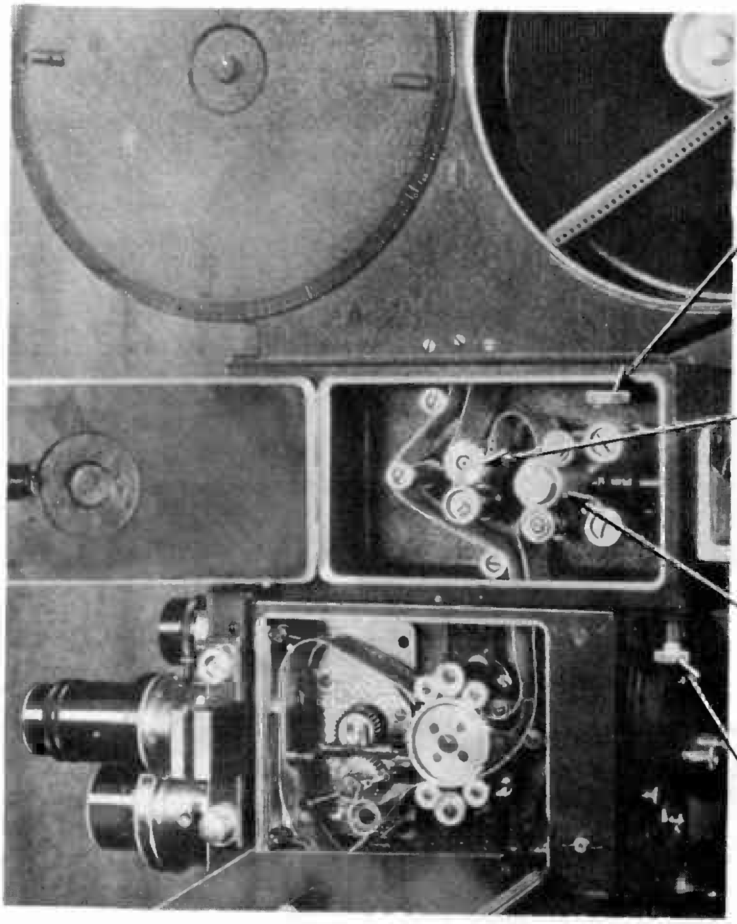

Interior of sound picture camera and recording head.

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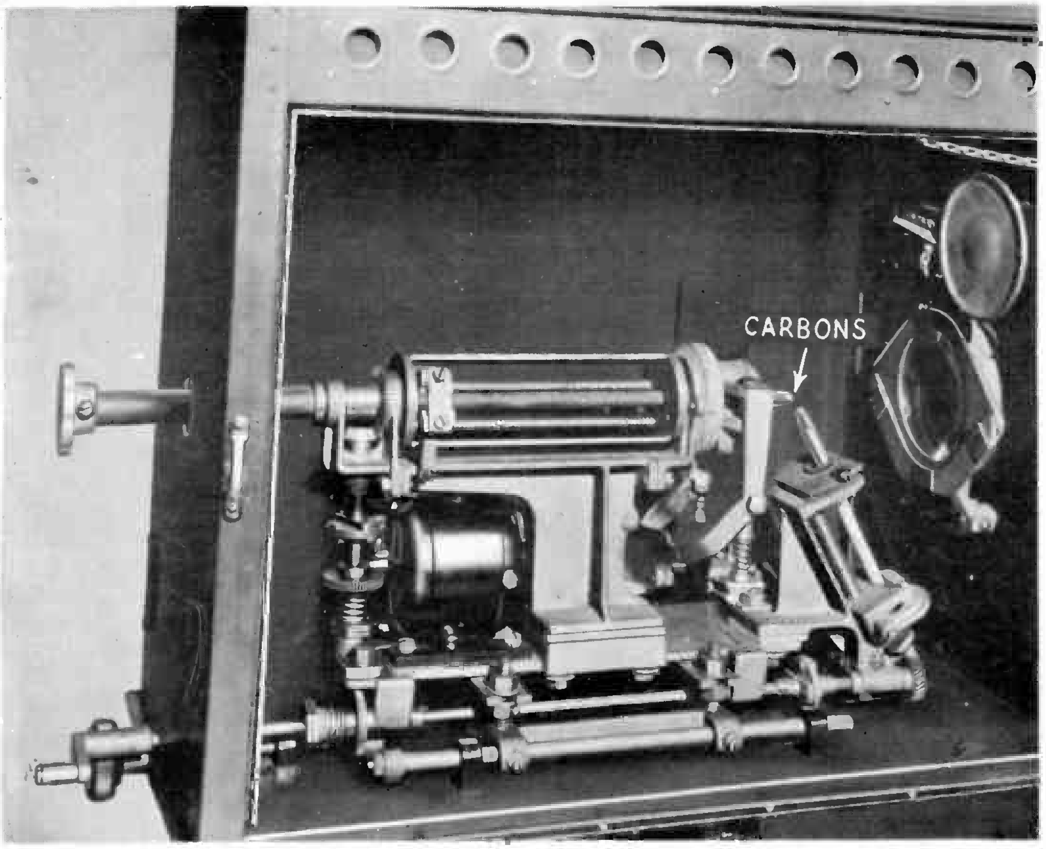
HOME OFFICE
75 Varick Street, New York

Making adjustments and oiling parts of sound equipment.

Feeding the Film by Intermittent Action in Motion Picture Cameras

VOL. 58, No. 6

Dewey Classification R 580



When in operation a brilliant flame is produced at the two carbons of an arc lamp.

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FEEDING THE FILM IS BY INTERMITTENT ACTION IN MOTION PICTURE CAMERAS.

In the days when only silent motion pictures were shown the requirements for projection were not quite as rigorous as they are at the present time due to the introduction of sound along with the picture. This applies particularly to film speed, which averaged sixteen pictures per second for silent projection. It is to be understood, however, that by means of a special variable speed mechanism on the projector the film could be run as fast as thirty pictures per second.

When sound effects accompany a picture it is necessary to run the film at the same speed as that at which it was recorded, if the tone quality and tempo of the speech and music are to be the same as that of the original. Otherwise we would possibly hear a distorting effect which would be quite unnatural. From considerations of sound frequencies it was considered best practice to operate the film at a speed of ninety feet a minute. This is equivalent to twenty-four "still" pictures being flashed in succession on the screen each second. These separate pictures appear to the eye as a single moving picture due to the faculty of persistence of vision.

THE PROJECTOR

In Figure 1 is shown a complete Simplex projector with high intensity carbon lamp equipment. This type is used quite extensively in the sound motion picture field. The projector consists of three main parts as follows: (A) the lamphouse which contains the carbon arc mechanism that supplies the light for projection of the picture, (B) the "picture head" that contains the lens and the mechanism for moving the film into place before the light beam, and (C) the pedestal that supports and furnishes the means for tilting the lamphouse and picture head equipment so that the beam of light may be accurately placed on the screen.

The first part of our study will deal with the subject mentioned in the foregoing paragraph under (A), or the lamphouse and its associated equipment that produces the brilliant light source which is focused on the film as it passes through the sound head.

SOURCE OF LIGHT

The carbon arc has been found by experience to furnish the best supply of light in the large quantities so necessary in motion picture projection. The great light-giving property of a carbon arc is due to the fact that carbon will not melt or vaporize unless subjected to a temperature of a very high order. For example, when a pure carbon arc is in operation the temperature of the "crater" is maintained at over 3,700 degrees Centigrade. Figure 2 shows a carbon arc in operation consisting of two carbons, marked "A" and "B" and known respectively as "positive" and "negative" carbons. Notice that the "crater" is located at the point marked "A" on the positive carbon. While the positive carbon "A" is burned away in a "crater" or hollowed out form, the negative carbon "B" burns away in pointed form. It is the "crater" of the positive carbon that produces the greatest source of light and for that reason you

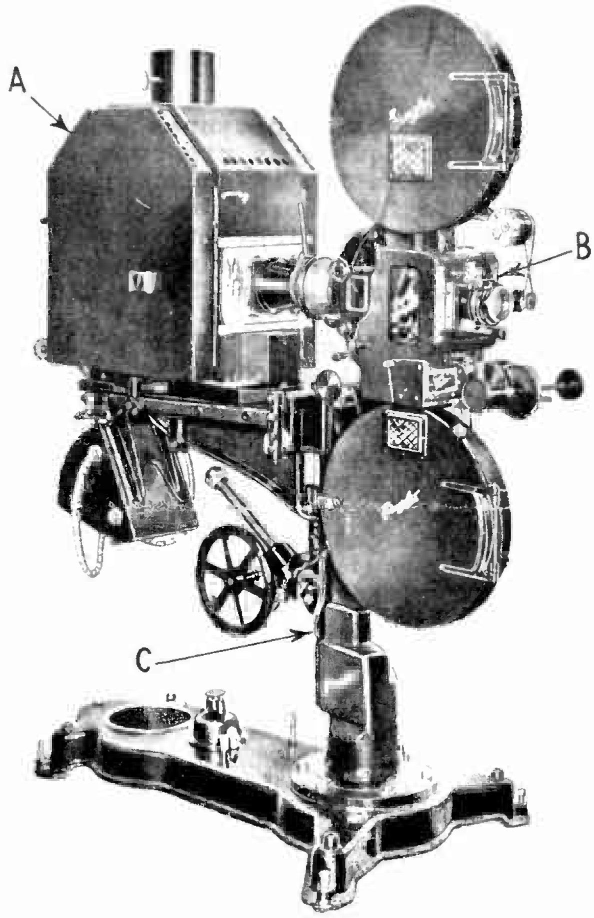

FIG. 1 — A COMPLETE SIMPLEX PROJECTOR.

will find all lamphouses which are not of the reflector type so designed that the crater of the positive carbon is kept pointed toward the lens that focuses the light on the film.

The relative positions of the carbons and the lens are seen in Figure 3, where "A" indicates the lens, which is known as a condenser lens, while "B" shows the position of the arc directly in front of the lens. Although Figure 4 illustrates the appearance of two halves of a condenser lens, it is to be understood that in many machines only one of these halves is used.

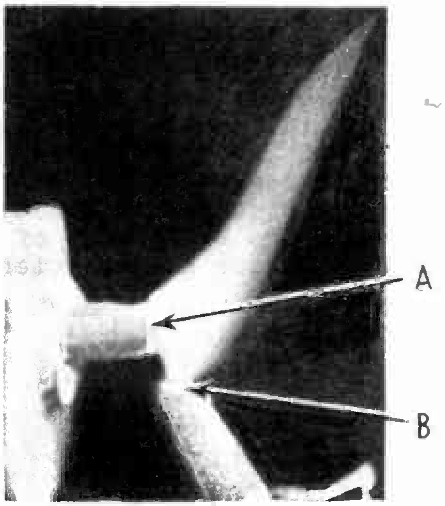

FIG. 2 A CARBON ARC IN OPERATION.

The name "condenser lens" is given to this type because it gathers a considerable amount of light and condenses it to a small spot of great brilliance on the film aperture. In Figure 5 is seen a graphic illustration of how a condenser lens "gathers" a large number of light rays and focuses them to a small and very bright spot of light on the picture aperture projection.

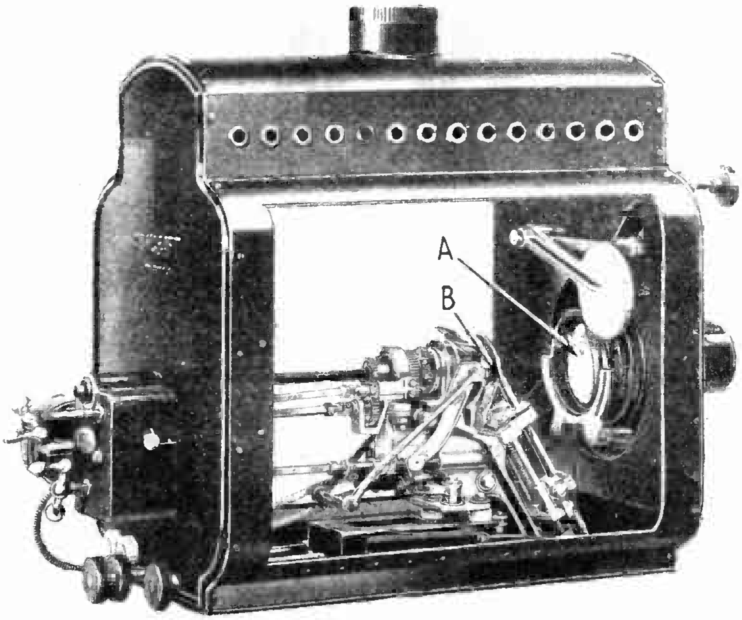

FIG. 3 — SHOWING RELATIVE POSITIONS OF CARBONS AND LENS.

The brilliancy of the crater in a pure carbon arc is of the order of 160 candle power for every square millimeter. One millimeter is equal to 1/100th of a meter, and a meter is equal approximately to 39.37 inches. Knowing that this degree of brilliancy was the upper limit that could be obtained by vaporizing a solid substance, such as carbon for example, an investigation was made of vapors and gases in a search for more efficient light sources. It was found that if a pure carbon rod used to produce the positive crater were replaced by a carbon which was cored or drilled through from end to end and filled with a chemical material that produces gas when heated, a brilliancy of from 500 to 900 candle power per square millimeter could be obtained and, of course, this is considerably greater than the 160 c.p. of an ordinary solid carbon positive. The only other source of light that exceeds the brilliancy of this new high intensity arc is the noon-day sun which has an intensity of about 920 candle power per sq. mm.

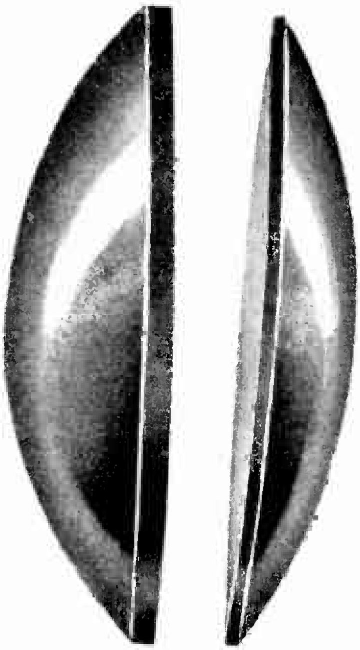

FIG. 4 — TWO HALVES OF A CONDENSER LENS.

Figure 6 shows how the gas from a cored negative carbon strikes the crater of the cored positive carbon and by keeping a certain amount of the gas from leaving the positive crater causes it to become even more brilliant. It is understood, of course, that the heating of the arc is caused by electric current. In operation the current is turned on by means of the arc switch seen under the lamphouse in Figure 1, the carbons are then caused to touch each other for a fraction of a second and then to be drawn quickly apart. At the instant of contact the current surges from the positive to the negative carbon and the carbon melts and vaporizes because the resistance of the path to the current is very high where the carbons come together. When the carbons are drawn apart the carbon vapor furnishes a path of comparatively high resistance to the current which travels through it to the negative carbon and as long as current flows the vapor is kept heated to incandescence. If the gap between the two carbons becomes too wide the vapor will in turn become very thin causing the resistance of the vapor path to increase

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to such an extent that the current will cease to flow and the arc will be extinguished or, as we say, the arc will "go out". To start the arc going again the carbons must first be brought together and then drawn apart as just explained.

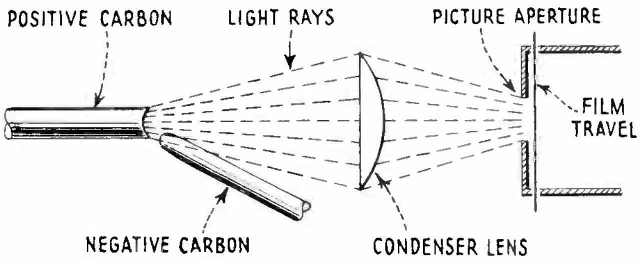

FIG. 5 — LIGHT RAYS ARE CONCENTRATED BY A CONDENSER LENS.

It is evident that inasmuch as the carbons continue to burn away slowly during normal operation the gap separating them will increase in width and in time the gap will become so long that the current cannot travel across it and eventually the arc will "go out". In the early days of the motion picture industry the mechanism by which the carbons were "fed" together was operated by hand which

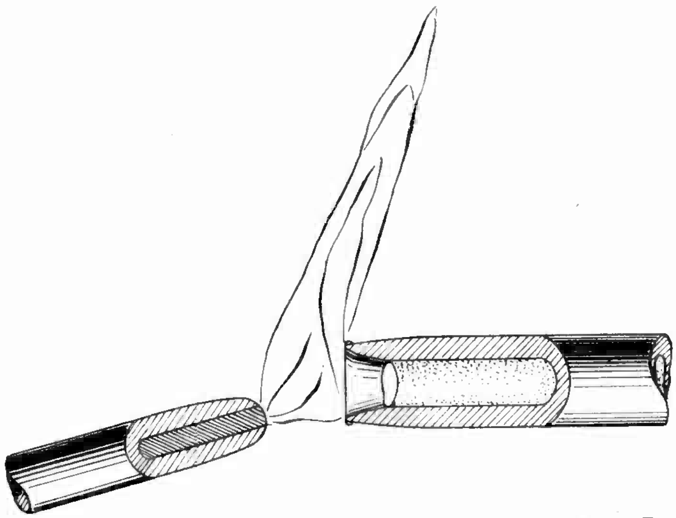

FIG. 6—FLAME PRODUCED FROM CARBONS WHICH ARE CORED

meant that a sharp watch had to be kept on the adjustment by the projectionist lest he "lose his arc" during the running of the film. In modern lamphouse construction, however, this feeding of the carbons is done automatically by means of an electric motor geared to the carbons holders. When the gap between the carbons becomes a certain predetermined length the motor starts up and moves the carbons together slowly until the proper distance between them is obtained at which time the motor stops. This operation is repeated again and again as the carbons burn away to the point where the mechanism has reached the limit of its motion and cannot further bring the shortened pieces of carbon together for the proper gap distance.

In Figure 7 is seen another type of lamphouse in which both carbons are mounted horizontally with a reflector used to collect the rays of light in back of the arc and transfer them to the condenser lens, where these reflected rays join the direct rays of light from the arc, thus increasing the total amount of light passing to the condenser lens to be focused on the picture aperture. Referring to the photograph, "A" indicates the position of the arc proper where the two carbons are brought together, "B" is the parabolic reflector, and "C" the condenser lens. In this particular case you will note from the illustration that the positive (thick) carbon is at

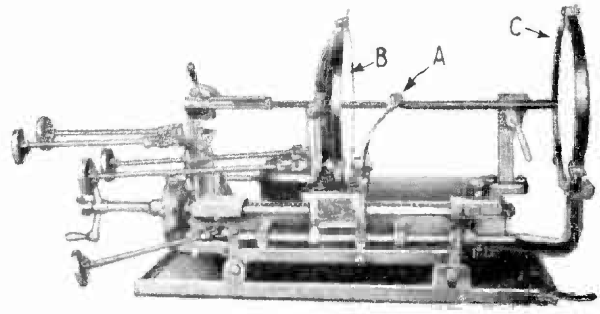

FIG. 7—THE CARBONS HERE ARE MOUNTED HORIZONTALLY.

the right nearest the condenser lens instead of at the left or furthest side from the lens. With this relative position of the carbons in the lamphouses, without a reflector, it would be necessary to have the crater of the positive carbon pointed at the condenser lens so that the greatest number of light rays would strike the lens and be focused to a "spot" on the aperture. However, in

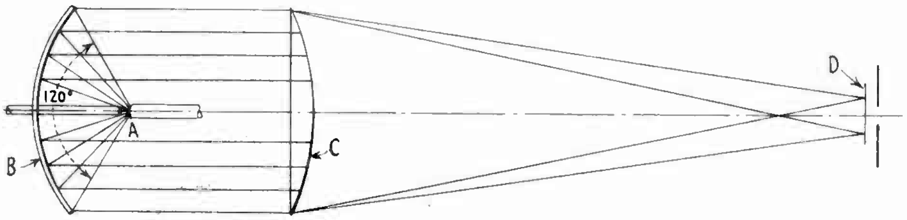

FIG. 8 THE COURSE TAKEN BY LIGHT RAYS.

the type of lamp we are now studying, called the Reflector Arc Lamp, instead of causing the rays of light from the crater to strike directly on the condenser lens, the crater is pointed towards the reflector which gathers the light rays and reflects them to the condenser lens. By this method the light rays from the positive carbon crater of the arc are sent through the condenser to be focused on the aperture.

FOCUSING THE LIGHT

Figure 8 shows the course of light rays as they travel from the arc to the reflector, thence to the condenser lens and finally to the aperture. The arc crater of the positive carbon is shown at

"A", the parabolic reflector at "B", and the condenser lens at "C". The aperture of the picture head on the projector is shown at "D" and it can be seen that all the light collected by the reflector and condenser lens is focused to a spot just large enough to "cover" the aperture, which is the size and shape of one picture or "frame" of the film. It is quite important that this "spot" be of sufficient size to cover the aperture for if it is too large, light will be wasted and if too small the edges of the picture on the screen will not be illuminated.

Figure 9 demonstrates three conditions of the "spot" on the aperture. In these three conditions the black oblong represents the aperture past which the film moves during the course of projection, the aperture being only slightly smaller than a single picture or "frame" of film. The circle around each black oblong area represents the size of the spot of light which can be focused by the condenser lens on the aperture. Spot "A" wastes 81% of the light since only 19% can pass through the aperture, the rest being thrown on the "cooling plate" of the picture head. Spot "B" is a spot of practical size but even in this case 57% of the light is lost on the cooling plate. However, this waste cannot be overcome due to

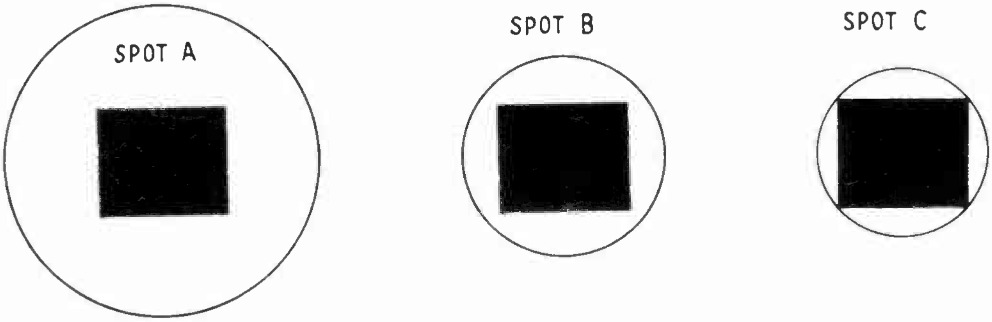

FIG. 9—RELATION BETWEEN SIZE OF SPOT OF LIGHT AND APERTURE OPENING.

the fact that bringing the spot to a smaller diameter as in spot "C" is liable to cause dark corners to appear in the picture on the screen, and also color fringes may show due to "chromatic aberration" caused by the condenser lens. We shall learn more about the term "aberration" under the subject of "lenses". As can be seen by the three illustrations most of the light loss is due to the fact that the spot of light is round and the aperture is oblong. If it were possible to have a combination where both the spot of light and the aperture were oblong it is obvious that a much higher efficiency could be expected from the arc system.

THE ARC CONTROLS

There are two main controls used in arc lamp equipment of the reflectorless type, shown in Figure 3. First is the mechanism which moves the arc back and forth in relation to the condenser lens and which governs the size of the spot on the aperture, and second, the "arc striking" mechanism which is used to bring the two carbons together and quickly draw them apart. We have learned that this operation is necessary to start the arc and is known as "striking the arc". After this operation has been completed the "automatic feed" mechanism comes into play to maintain the proper distance between the carbons. Means for additional adjustments are provided allowing the arc to be accurately centered in front of the condenser lens.

In this type of lamphouse a "pinhole" is provided in the casing so that an enlarged image of the arc crater is thrown on the wall of the projection booth enabling the operator to see the condition of the arc at all times. This is a practical application of the principle of the pinhole camera.

The Reflector type lamp has two adjustments which are not provided in the non-reflector type. These adjustments are used to tilt the reflector up and down and sidewise so that the rays of light it collects will be reflected without loss to the condenser lens. Again referring to Figure 7 and noting the knobs at the left of the lamp, the upper two are used to center the negative carbon on the

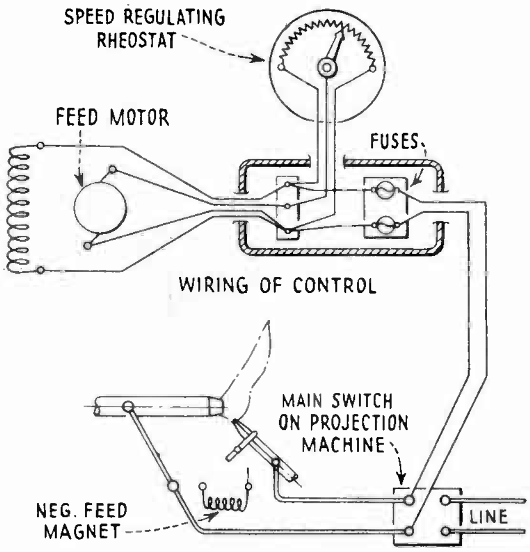

FIG. 10—CIRCUIT THAT CONTROLS SPEED OF MOTOR.

positive carbon which is held rigid, the next two knobs down are for reflector tilting, the next handle down is the arc striking bar, and the lower knob moves the whole assembly back and forth in relation to the condenser lens thus allowing for focusing of the correct size spot on the aperture.

The automatic feeding of the arc is accomplished by using a small motor which is geared to the carbon holders so that as the motor runs the carbons are slowly moved together. A schematic diagram of the circuit that controls the speed of the motor is shown in Figure 10. It will be seen that one side of the line connects to the positive (thick) carbon while the other side connects to the negative (thin) carbon. Two wires lead from the main switch on the projection machine to the motor and rheostat.

The theory of operation is that when the gap between the carbons is small it is comparatively easy for the current to pass across the gap over the carbon vapor path but as the carbons burn away and the gap widens it takes more voltage to force the current across the gap. When this greater voltage is on the arc it also affects the armature of the feed motor causing it to speed up, thus feeding the carbons together faster. When the gap is thus shortened the voltage returns to normal and the motor slows down so that the feeding of the carbons is also slowed down back to the normal rate once more.

Figure 11 shows a widely used make of lamp that eliminates the condenser lens by causing the arc crater to be focused on the picture aperture by the reflecting mirror. It is known as the Strong lamp and is made by the Strong Electric Corporation. In Figure 11 this lamp is shown with the reflector swung out of operating position for inspection. The path of light rays in a lamp using both reflector and condenser lens was shown in Figure 8.

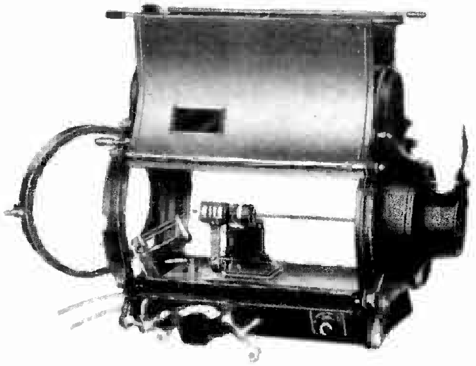

FIG. 11— MECHANISM OF A "STRONG" LAMP.

Figure 12 is a sketch showing the path of rays from arc to aperture when only a reflector is used. This path is shown by the solid lines. The dotted lines indicate the path of rays when it is desired to use the arc for projecting lantern slides. By moving the reflecting mirror forward the light rays are caused to leave the reflector in straight horizontal lines instead of converging to a small spot at the picture aperture. By swinging a small condenser lens into place a portion of these parallel rays are picked up and converged so that after passing through a lantern slide they enter the projection lens. This lens as we shall see later projects the image to a sharp focus on the screen.

To sum up the various points about the arc lamp: It is a brilliant source of light by means of which the picture is projected to the screen on the stage after passing through various lens combinations. The arc is started into operation first by throwing the "table switch" under the lamphouse to the operating position and second by bringing the carbons together and separating them slightly by means of the "arc striking" handle. From this point on the arc control motor goes into action and separates the carbons to provide the proper gap distance between them. If the necessary adjustments of the reflector and arc position mechanisms have been previously made, the light from the arc will be focused to an intense spot just covering the aperture. The "douser" (a metal plate placed on the lamphouse between the aperture and the condenser lens opening which cuts off the light from the aperture and confines it to the lamphouse) is then closed. We are now ready to proceed to the study of the picture head through which the light passes on its way to the screen.

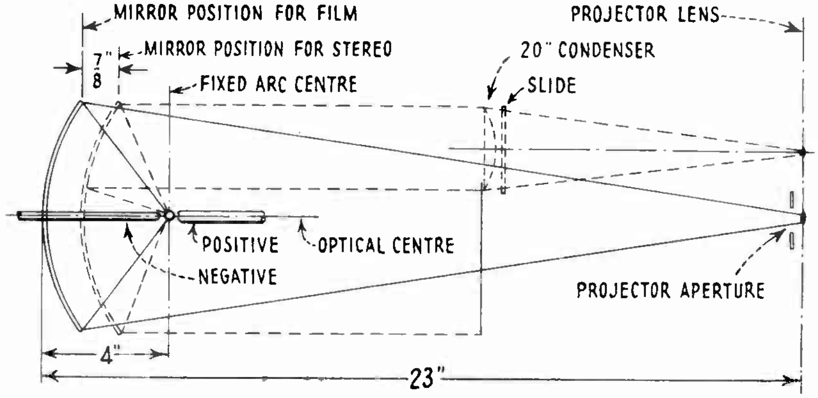

FIG. 12—PATH OF LIGHT RAYS FROM ARC TO APERTURE.

TYPES OF PROJECTORS

There are several manufacturers of picture projection head equipment and in some cases different models are made by the same company. For instance, the International Projector Corporation has two models which are in wide use, namely, the Standard Simplex and the Super-Simplex. The Enterprise Optical Company manufacturers a picture head which is known as the Motiograph. This company also makes a complete sound motion picture projector in which the picture head, sound head, lamp, and base are all made into a single unit. This method is different from the usual procedure because other leading companies in the field make only the picture projection equipment with provisions for adapting the sound projection apparatus to their motion picture machines.

OPERATION OF THE PROJECTOR

We will study the Powers projector first, not because it is in wider use than either the Simplex or Motiograph machines, but its open-type mechanism permits a clearer explanation and illustration of the principles of motion picture projection and the action taking place during each step in the progress of the film through the picture head.

Figure 13 is a photograph of the complete Powers projector including lamphouse, picture head, upper and lower magazines, pedestal, and motor drive. "A" shows the maximum angle at which the machine can be set. It is necessary to vary the angle of tilt in different theatres according to the height of the projection booth in relation to the screen, this slope being known as the "projection angle". "B" shows two handles for controlling the "douser". In all cases where two handles are provided for controlling a piece of mechanism it is only done to make operation easy from either side of the machine.

The parts are identified as follows: "C" is a condenser lens spacing used to space the two halves of the condenser lens to obtain the best focus of the "spot" on the aperture; "D" is the ruby glass eye shield which keeps the glare of the spot out of the projectionist's eyes; "E" is a film footage counter that tells how much film has been run off; "F" focuses the image sharply on the screen; "G" is a speed control for the motor; "H" is the speed control adjustment; "K" is the motor switch which starts the machine; "L" is the "table switch" for starting the arc; "M" indicates the upper and lower magazines; "O" is a hand wheel for changing the projection angle; "P" is used to lock the angular adjustment, and "R" is the motor. The machine as it is shown in Figure 13 is used for projecting silent pictures. When adapted to sound projection a "sound head" is installed between the picture head and the lower magazine

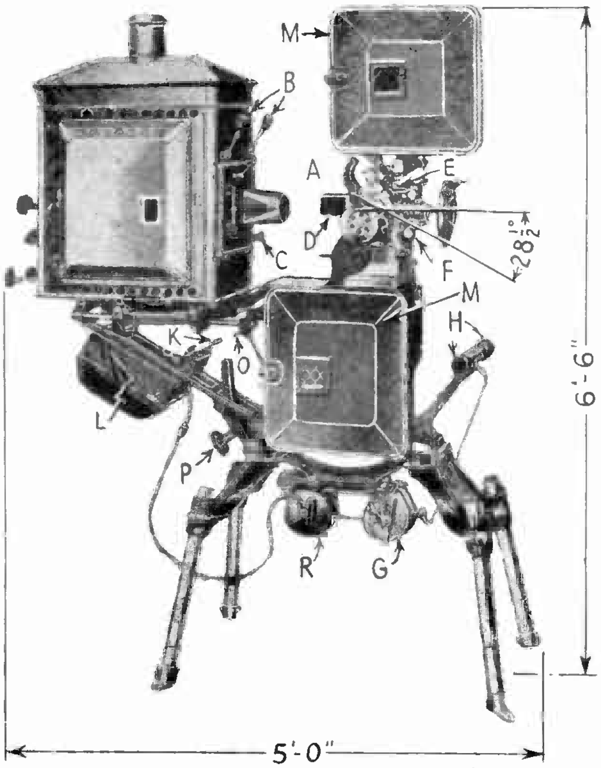

FIG. 13—VIEW OF A COMPLETE POWERS PROJECTOR.

as will be seen later. Figure 14 shows the picture head with part of the upper and lower reels included.

By comparing Figure 14 with Figure 15, which shows the same picture with film threaded into place ready for operation, you will be able to follow the action which takes place in the picture head at each important point in the course of the film's journey through it as we will now explain. Starting from the top magazine where a full reel of film is in place the film passes down through two steel rollers which press snugly against each side of the film. This is called the "fire trap" and should the film catch fire its purpose is to prevent the flame from getting into the upper magazine and setting fire to the upper reel of film. From the fire trap rollers the film passes to the upper feed sprocket "A" the sprocket holes in the film being held in place on the sprocket teeth by "roller" "B". The film then passes down through the "picture gate" "J" shown open in Figure 14 and closed in Figure 15. The picture gate contains the aperture through which the arc light passes on its way to the screen. The film is held snugly in place as it passes through the gate by the "film guide roller" "K" and the spring strips, known as tension shoes, which are shown on each side of the aperture in Figure 14. It is understood that when the film is passing down in front of the aperture and the light of the arc is focused on the aperture the image of the picture will be produced on the screen providing the lens is in proper adjustment. The purpose of the feed sprocket "A", as we have seen, is to draw the film down from the

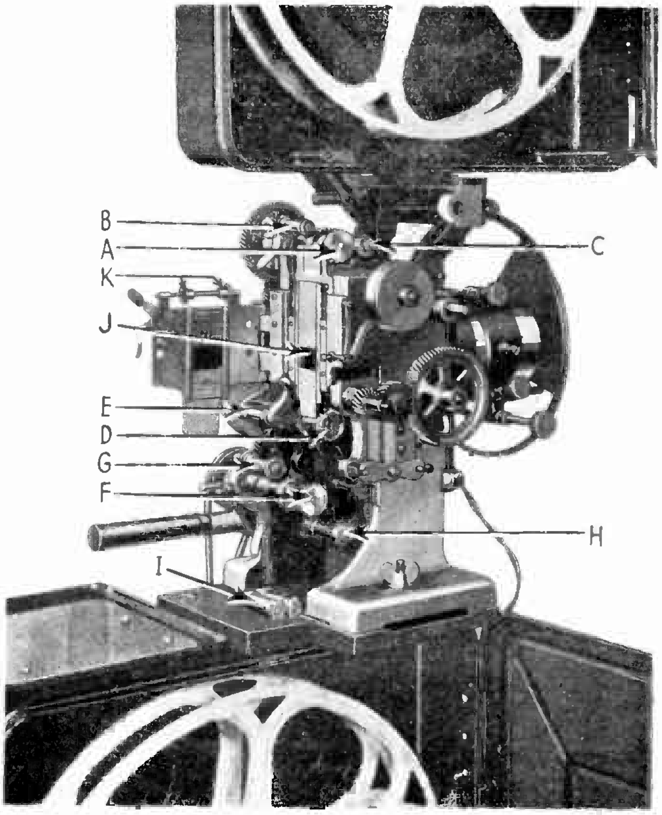

FIG. 14 — CLOSE-UP VIEW OF POWERS PROJECTOR.

upper reel and feed it to the picture gate. In order that the film may then be passed through the picture gate in such a manner that each picture or frame on the film will be at rest for a fraction of a second in the aperture before it is moved on, a toothed wheel called the "intermittent sprocket" comes into play. This sprocket is shown "D" where the film is being held in place over its teeth by the small roller "E" shown in the opened-out view of the picture gate in Figure 14. The intermittent sprocket works in short jerks, that is, it pulls the film down approximately three-quarters of an inch (one picture or frame) and rests a fraction of a second, pulls the film down another "frame" and waits, repeating this operation at the rate of 24 pictures per second.

The film is prevented from moving, due to its inertia, after the intermittent sprocket stops, by the friction in the picture gate. Tension shoes must be adjusted for the proper pressure to produce just enough drag or friction, but not too much,as otherwise the sprocket holes would be torn by the intermittent sprocket in short time, and the sprocket teeth would wear out prematurely. The light of the arc, therefore, is passing through 24 separate and distinct pictures and projecting 24 images on the screen every second while the machine is in operation. We have already explained that when the eye sees this number of pictures per second on a screen and each picture is slightly different from the other and in proper sequence, our persistence of vision produces the illusion of motion pictures.

After passing through the picture gate and intermittent sprocket, the film forms a loop around a roller called the "loop setter" marked "H" (this roller is not used for sound picture projection with certain types of sound heads,) and from there it continues on to a sprocket wheel "F" which feeds the film at a steady rate of speed to the lower reel. Roller "G" holds the film snugly against sprocket "F" causing the sprocket holes in the film to mesh with the

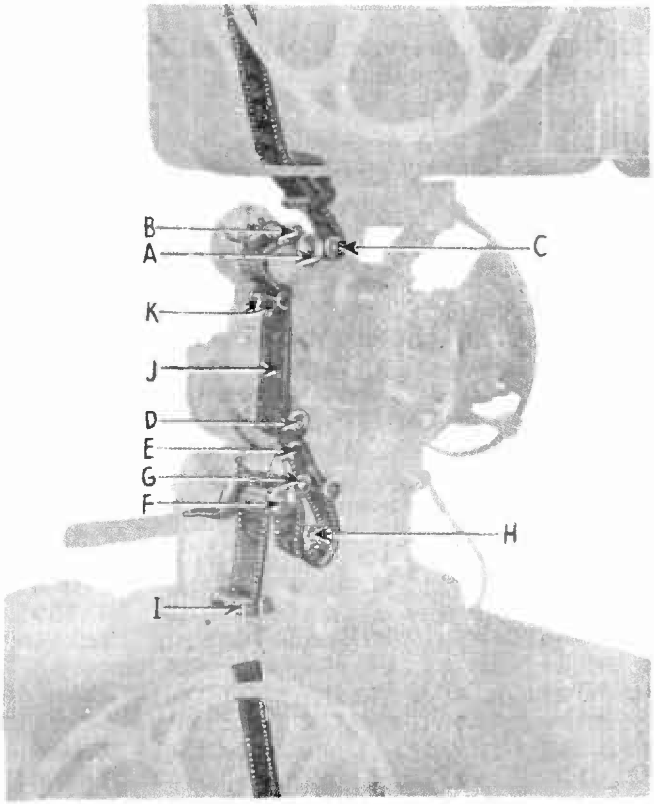

FIG. 15—A FILM THREADED IN PLACE.

sprocket teeth. You will see that the lower magazine is also supplied with a fire trap "I" similar to the one in the upper magazine.

THE INTERMITTENT MOVEMENT

Although the intermittent sprocket "D" pulls the film the same number of feet per minute through the picture gate, we know from our study of the action of the intermittent sprocket that this pull is not uniform but intermittent in action. That is, it pulls one frame or picture into place in front of the aperture, allows it to rest there for a fraction of a second and then quickly pulls that picture down out of the aperture and replaces it with the next picture on the film. This operation takes place at the rate of 24 pictures per second which allows the machine to project 24 "still" pictures on the screen every second. Since 24 pictures per second are fed to the picture gate by the upper sprocket it can be seen that the intermittent must move very quickly in order to pull the same number of "frames" per second through the gate intermittently and allow each picture to rest for a short time in the aperture.

The intermittent sprocket moves five times as fast as either the upper or lower sprockets which means that it passes the same amount of film in one-fifth the time. If the loops were not provided there would be no spare film to draw on and the intermittent would tear out the sprocket holes in its quick downward motion. The upper feed sprocket keeps a supply of film in the loop for the intermittent to draw upon and the intermittent takes it up in jerks and feeds it to the lower loop from which it is taken away by the lower feed sprocket. It should be borne in mind, however, that all the sprockets pass the same amount of film per second which figured from 90 feet per minute is one and a half feet per second.

THE TAKE-UP REELS

Before passing on to a detailed examination of the Powers intermittent movement we will discuss the mechanism that allows the lower or "take-up" reel to take up the film as it comes from the upper feed sprocket. The upper reel has no driving power other than the pull of the film as it is drawn down through the fire gate by the upper feed sprocket "A" in Figure 15. This causes the reel to revolve and as the reel is locked on the shaft in the magazine the shaft also revolves. The shaft has a simple spring friction mechanism located on the outside of the magazine, that gives a slight resistance to its turning and thus prevents the shaft from continuing rotation should the machine stop for any reason. If this friction were not provided there would be a tendency for the reel to continue revolving even after the pull on the film had ceased, causing the reel to unwind several layers into the magazine.

The lower reel must be provided with a driving mechanism of such design that it will take up the film fed to it by the lower feed sprocket under all conditions. You can easily realize that the lower reel cannot be driven at constant speed because it winds more film during one revolution when it is full than when nearly empty due to the greater circumference of a full reel of film. For instance, when the machine is starting to project a new reel most of the film is on the upper reel and only a few turns are on the lower reel. The diameter of the "pulling circle" of the film in this case is little more than the hub diameter of the reel itself but as the machine continues to run and more film is wound on the lower reel its diameter increases until at the end of the run it is about twelve inches in diameter although it measured only about four inches at the start of the run. Therefore, a reel with a large diameter will wind up more film during a given number of revolutions than will a smaller one. Inasmuch as the lower sprocket feeds the film to the reel at a constant speed of 90 feet per minute and yet the reel must wind up all the film fed to it, then some device must be provided that will allow the take-up reel to wind up all of the film fed to it no matter whether its diameter is small, as at the beginning of a run, or large as at the end.

The device that enables the take-up reel to properly wind up the film is a slipping clutch arrangement such as pictured in Figure 16 and consists of the following: "A" is a pulley which is belt driven from a pulley in the picture head and drives flange "B" through three pins; part "C" is a friction disc faced with leather and is attached to the shaft "F" which carries the take-up reel inside the lower magazine; "D" is a coil spring that presses the flange "B" against the leather facing of the friction plate "C" and which can be adjusted to give more or less pressure by means of the knurled nuts on the end, and "E" shows the shaft bearing fastened in the magazine bracket.

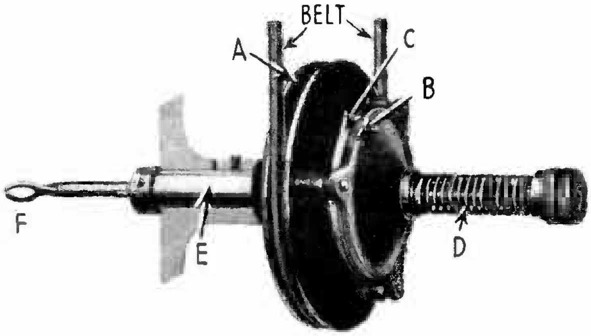

FIG. 16 - A SLIPPING CLUTCH AIDS IN WINDING UP FILM.

In operation, the path of the driving force is through the belt to the pulley, through the three pins to the flange which is free to move in and out on the pins, and thence from flange to friction plate which turns the shaft or spindle upon which the reel is mounted. The speed of the shaft without slippage is great enough to allow the reel to take-up the film when the film is at the beginning of the run and the reel of film has the smallest diameter. Since the diameter of the wound film becomes greater during the run, the slippage between the flange and the friction disc increases as the reel must run slower due to the fact that its increased diameter enables it to wind up the same 90 feet of film per minute with less revolutions. It is in this manner that the film is taken up as quickly as it is fed down by the lower feed sprocket. This sprocket is also referred to as the holdback sprocket because it holds back the film from the lower reel when it tries to wind the film faster than 90 feet per minute. The tension on spring "D" must not be too strong as it is liable to cause tearing of the film sprocket holes at the holdback sprocket.

Figure 17 shows a cut-away picture of the take-up mechanism. "A" is the pulley; "B" the shaft attached to friction disc "C"; "D" is a key which fits in a keyway in the reel hub; "E" is shown in its turned position to keep the reel from sliding off the end of the shaft; "F" are ball bearings; "G" is the tension spring; "H" is the tension adjusting nut, and "I" the locking nut.

In Figure 15 the roller "H", called the "loop-setter", is a special Powers feature and serves to keep a sufficient supply of film in the lower loop. In normal operation the lower loop encircles the loopsetter and does not touch it but should the loop grow smaller, which would occur if there were broken sprocket holes in the film and the intermittent did not move the film down as it should, the loop would then tighten around the loopsetter and lift it up as it is free to move on a lever. On the other end of the lever is a clutch arrangement that throws the lower sprocket out of gear with the driving mechanism thus stopping its motion until the loop reforms or grows to a size large enough to allow the loopsetter roller to drop back to normal.

This calls to mind the fact that both the intermittent and the lower sprocket are dependent upon the sprocket above each for a sufficient supply of film to maintain the loops upon which these parts draw, and the failure of any of the sprockets to deliver film brings about a condition that may develop into serious trouble. The most frequent causes of trouble of this kind are broken sprocket holes in the film and insufficient tension on the "pad rollers" that hold the

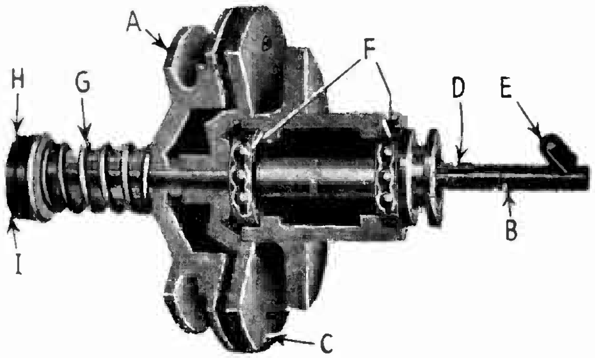

FIG. 17— CUT-AWAY VIEW OF TAKE-UP MECHANISM.

film in close engagement with the sprocket teeth. If the film "rides over" the teeth and does not pass along properly it results in shortening or losing one of the loops. If either of the loops is lost the quick motion of the intermittent, having no loop to draw upon or feed into, causes tearing out of the sprocket holes and the film is liable to become damaged. Therefore, when threading film through a projector care should be taken to see that loops of the proper size are left above and below the intermittent. This is even more important when using sound film with record reproduction as loss of synchronism may be caused by "improper threading".

ROLLER PIN INTERMITTENT

A type of intermittent, known as the "roller pin" movement is used in the Powers projector. A picture of this intermittent is shown in Figure 18 and sketches illustrating four different stages in its operation are given in Figure 19. In both Figures 18 and 19 the part marked "W" which is known as the "pin cross" has four rollers attached to it. "X" is the intermittent sprocket which is on the other end of the shaft to which the pin cross is attached while the part called the "diamond" and marked "Y" and the "locking ring" marked "Z" both together make up the "cam".

Referring to Figure 19-A the operation of the intermittent is as follows: Both the cam and the pin cross revolve in a clockwise direction, or as the hands of a clock move. The teeth of the sprocket are shown engaged with the sprocket holes of a short strip of film, one picture or frame of which being indicated between the black lines. In Figure 19-A the four rollers of the pin cross are shown engaged with the locking ring "Z" of the cam, rollers 1 and 2 being outside of the ring and 3 and 4 inside. The ring is free to revolve between the four rollers but the pin cross cannot move because it is securely locked in place by the locking ring. Thus, while the pin cross, sprocket wheel, and film are at rest one picture or frame is projected to the screen.

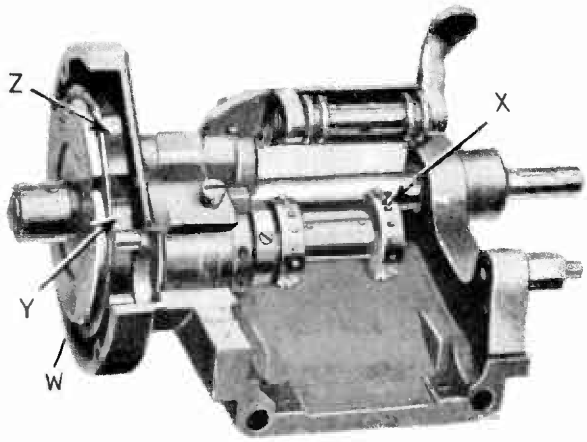

FIG. 18—"ROLLER PIN" MOVEMENT OF POWERS PROJECTOR.

In Figure 19-B the end of the locking ring "Z" is shown passing out from between the four rollers. The "diamond" of the cam then begins to engage roller 1. At this moment the forward slot "F" comes into place beneath roller 2, and the rear slot "G" above roller 4. Consequently, as the diamond pushes roller 1 forward and downward, roller 2 passes down into slot "F" and roller 4 up into slot "G". At the same time roller 3 moves over in a direction opposite to roller 1, since all four rollers are mounted on the same pin cross support. This is shown in Figure 19-C.

After the highest point of the diamond has passed roller 1, the motion is continued by the pressure of the end "H" of the locking ring against roller 4, and the bottom of the diamond against roller 2, so that the pin cross continues its motion until it has made one-quarter turn. The rollers are now in the position shown in Figure 19-D. Locking ring "Z" is now ready to slide once more between the four rollers, thus locking them and the intermittent sprocket.

Since the intermittent sprocket has sixteen teeth on its circumference, it has moved through four teeth in its one-quarter revolution. Since there are four teeth to each frame, it is evident that in one-quarter revolution the film has moved one frame.

Thus for one revolution of the cam, the film has moved one frame after the diamond has actuated the pin cross, and the locking ring now holds the pin cross, intermittent sprocket, and film stationary while the frame is projected upon the screen.

The sequence of operations described above constitute one "cycle" of the intermittent movement. In sound motion picture projection, there are twenty-four such cycles per second, so that projection is at the rate of twenty-four pictures or frames per second, which is equivalent to ninety feet of film per minute.

The particular intermittent described above has a high ratio of time when the film is stationary to that when it is moving. This is desirable in that during most of the cycle the film is stationary and therefore in a condition to be projected upon the screen, and only a very short interval of time is required to move the film for the projection of the next frame. Hence, as will be explained in the succeeding paragraph, the light need be cut off for only a very

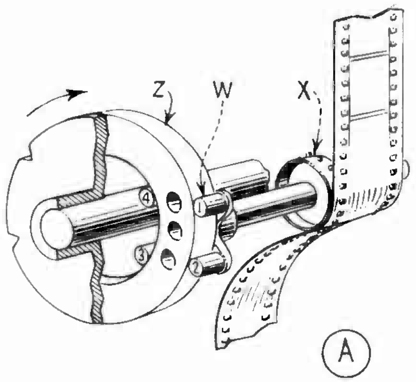

FIG. 19-A — INTERMITTENT ACTION WHEN PIN CROSS, SPROCKET WHEEL, AND FILM ARE AT REST.

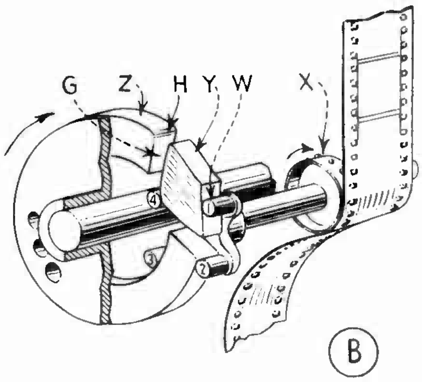

FIG. 19-B — LOCKING RING "Z" PASSES OUT FROM BETWEEN THE FOUR ROLLERS.

short interval of time while the film is moving, and so less light is wasted.

An ideal intermittent would be one that moved the film one frame in an infinitesimally short space of time, so that light could be shone through the frame during the entire cycle. In practice, difficulties arise in utilizing too rapid an intermittent in that the parts of the movement and the film must be accelerated at too rapid a rate, thus causing undue wear both on the intermittent movement, intermittent sprocket teeth, and film sprocket holes.

Moreover, once the film has been set in motion by the intermittent sprocket, it tends to keep moving due to its inertia, even after the intermittent is locked in the stationary position. To offset this, the pressure of the tension shoes in the picture gate must be increased, which results in greater drag on the film, and consequently increased wear.

The intermittent just described represents about the fastest movement practicable in motion picture projection and has proven to be a thoroughly reliable movement for this purpose.

THE SHUTTER AND ITS PURPOSE

We stated previously that while the film is in motion past the aperture it is necessary to cut off the light from the screen or white lines, called "travel ghost", will be seen racing from bottom to top on the screen. The apparatus used to cut off the light is called the "revolving shutter" and in the Powers projector it is located on the front part of the picture head.

Figure 20 shows the shutter in place as it appears when looking at the front of the picture head or when looking from the screen side. This part is made of thin metal and has three vanes or opaque "wings" and three openings in between the vanes. In this illustration a portion of the lens may be seen through one of the openings.

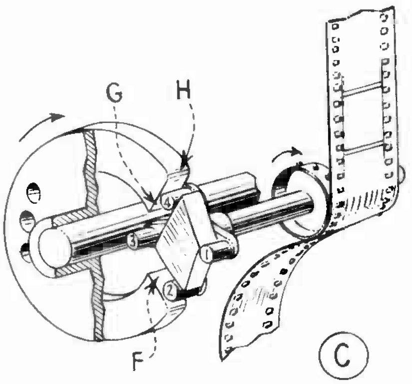

FIG. 19-C — PRESSURE EXERTED BY "H" CONTINUES THE INTERMITTENT MOTION.

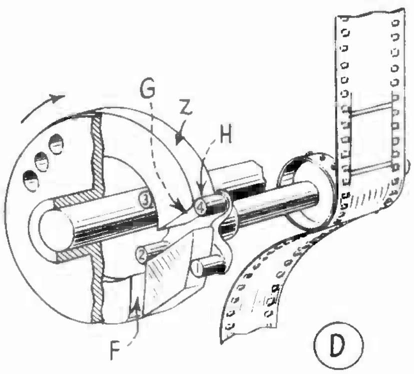

FIG. 19-D — LOCKING RING "Z" IS NOW READY TO SLIDE BETWEEN THE FOUR ROLLERS.

Figure 21 shows an edgewise view of the shutter as seen from the right-hand side or "operating side" of the projector. The same handle seen in each of these photographs is used only for making adjustments and is removed if the machine is to be operated by motor drive. Referring again to Figure 20, the revolving shutter makes one complete revolution during each movement of the intermittent which means that while one frame or picture is being moved into place and projected to the screen the three vanes and the three openings in the shutter pass successively before the lens. Accordingly, there must be three interruptions of the beam of light while each separate frame or picture is being projected. At this point you might well wonder why three vanes or blades are provided on the shutter and the beam of light is interrupted so many times inasmuch as we stated before that in order to eliminate "travel ghost" it is merely necessary to cut the light from the screen while the film is being moved by the intermittent and it is obvious that this can be accomplished by one of the three blades. Therefore, it follows that the extra two blades act to cut off light while the film is at rest in the aperture and, hence, they are not provided for the purpose of eliminating travel ghost.

To explain the use of the extra blades we must consider another natural quality of the human eye in regard to effects caused by quick flashes of light. This is commonly known as "flicker" and is the effect we would get if the light passing through the film were interrupted at too slow a rate.

We know that due to persistence of vision 16 pictures per second will blend into a continuous single moving picture but when it comes to flashes of light they must occur at a rate of from 50 to 60 per second in order to appear as steady flickerless illumination on the screen. It should now be clear why three blades are required on the shutter.

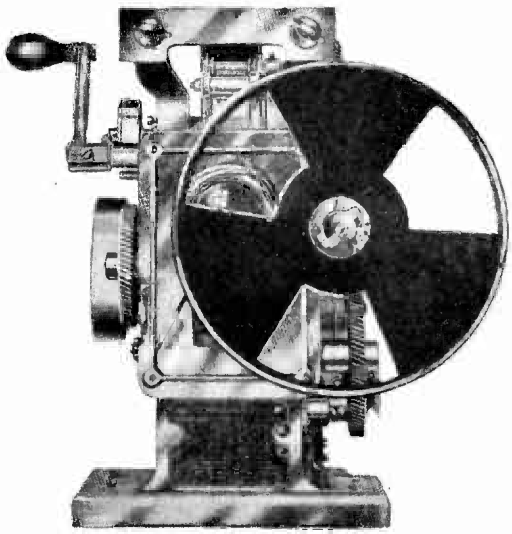

FIG. 20—FRONT VIEW OF POWERS HEAD.

The blade that cuts off the light while the film is moving past the aperture is called the "master" blade because it prevents "travel ghost", while the other two are known as "flicker blades" because their only function is to reduce flicker.

More than 50% of the light which would otherwise pass to the screen is intercepted by the blades of the revolving shutter and therefore is lost to useful work. This loss represents a considerable amount of actual money that must be spent for electric current and larger lamphouses required to produce the extra light needed to properly illuminate the screen. However, the steady, flickerless illumination received in return is worth the extra expense in view of the fact that flickering is not only annoying and tiring but in extreme cases it is harmful to the eyesight. By proper adjustment of the shutter the rotation of the blades may be timed so that the light will be entirely cut off from the screen by the master blade before

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the intermittent starts the film moving in the aperture and will remain cut off until the film comes to rest. This adjustment must be made before showing a film or otherwise varying degrees of travel ghost will result. The adjustment on the driving mechanism of the shutter that allows it to be accurately "timed" to correct a condition of travel ghost is made by merely turning a hand screw until the effect on the screen disappears.

PROTECTION FROM FIRE

Another feature incorporated in the picture heads of modern machines is the automatic fire shutter. One type, shown in Figure 22, is composed of the following units: An automatic fire shutter governor "A", a lever "B" attached to the governor, a curved rod "C" attached rigidly to the shutter itself, and a piece of sheet metal "D" hinged at the top so that when closed, as in the position shown, it entirely covers the picture aperture.

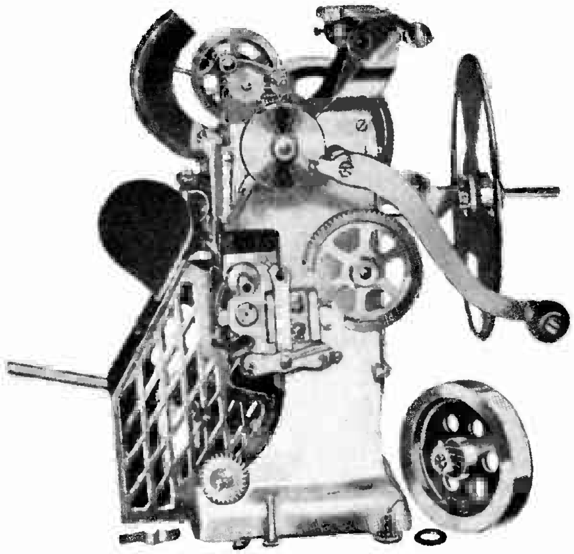


FIG. 21-OPERATING SIDE OF POWERS HEAD.

The sole purpose of the fire shutter is to prevent the film from catching fire in the event the machine stops running or even slows down to a speed that allows less than 40 feet of film to travel through per minute. A device that furnishes this protection is absolutely necessary because the heat rays as well as the light rays of the arc lamp focus to a spot on the aperture and are so intense at this location that the film will catch fire almost immediately if it stops or even slows down too much. Providing a film continues to move fast enough past the aperture no part of it remains in the heat area sufficiently long to catch fire. To prevent any possible trouble from this course the fire shutter is made so that when the machine is at rest or coming to rest the aperture is covered by flap

"D", thus, when the flap is down the film is shielded from the light and heat of the "spot". When the machine is started flap "D" remains down for a time, or until the speed of the film past the aperture is up to 40 feet per minute and after this point the governor

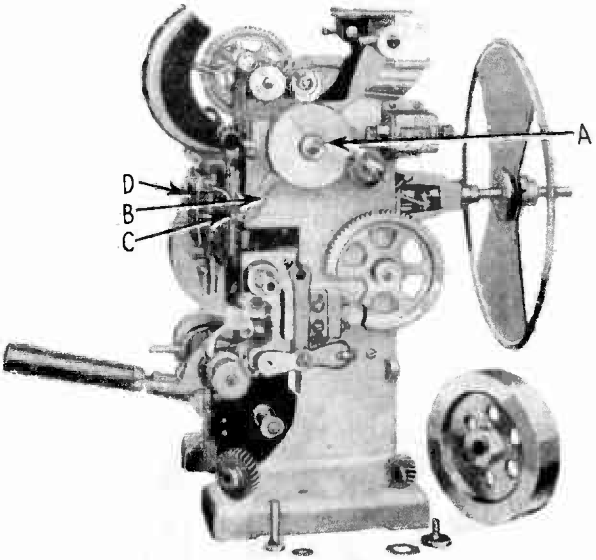


FIG. 22 AUTOMATIC FIRE SHUTTER PROTECTS FILM.

lever "B" pushes on the curved rod "C" and raises the flap. With the flap in the raised position the aperture is open to the light rays which are free to pass through the film, the lens, and the shutter openings to the screen. On the other hand if for any

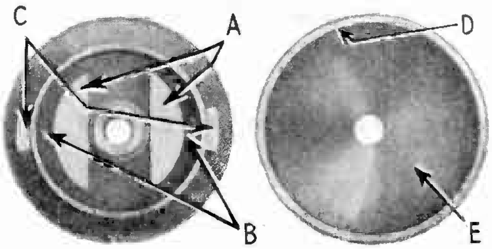


FIG. 23 GOVERNOR OF AN AUTOMATIC FIRE SHUTTER.

reason the projector slows down to less than 40 feet of film travel per minute the lever "B" moves back and causes the flap to fall down over the aperture and cut off all light and heat from the film.

The internal construction of the governor "A" is shown in Figure 23. Its mechanical operation is as follows: Two governor weights "A" revolve with the casing in which they are contained and connect with two friction shoes "C" through two spiral springs "B". As the governor weights come up to speed they move outward against the springs and transmit pressure to the two friction shoes. When assembled, the cover "E" fits over the casing that contains the governor weights and the friction shoes "C" bear outward against the inside of the rim "D". Note that while in operation the casing and cover are closed together like a book. When the outward pressure of weights "A" (as applied through springs "B" to shoes "C") is great enough due to the projector coming up to speed, the friction of the shoes on the inner surface "D" turns cover "E" and since the latter is attached to the flap it raises the flap and the aperture is left open to admit the light rays.

THE FRAMING DEVICE

Projectors are also equipped with a framing device. Framing is necessary to keep an entire frame or picture in place before the aperture instead of allowing parts of adjoining pictures to be shown simultaneously on the screen. The handle of a framing device is shown sticking out from the rear of the picture head in Figure 14. By raising or lowering this handle the intermittent sprocket and the film in the picture gate between the upper and lower loops may be moved up or down until the position is found where only a single picture is accurately "framed" in the aperture. This adjustment can be made while the projector is running. Although the mechanical features of various projectors may differ the principle of "framing" remains the same, that is, the film is moved to a position where one complete picture at a time is placed exactly in the aperture by the movement of the intermittent.

The remaining very important feature of motion picture projectors, the lens, is taken up under the subject of "Light and Lenses".

EXAMINATION QUESTIONS

1. Name the three main sprocket wheels in a projector head and give use of each.

2. Why is a master blade used in a revolving shutter and when does it come into action?

3. What part of a carbon arc is the source of the most intense light?

4. Name any blades other than the master blade of a revolving shutter and explain their purposes.

5. What happens when a picture becomes "out of frame", and how is the condition remedied?

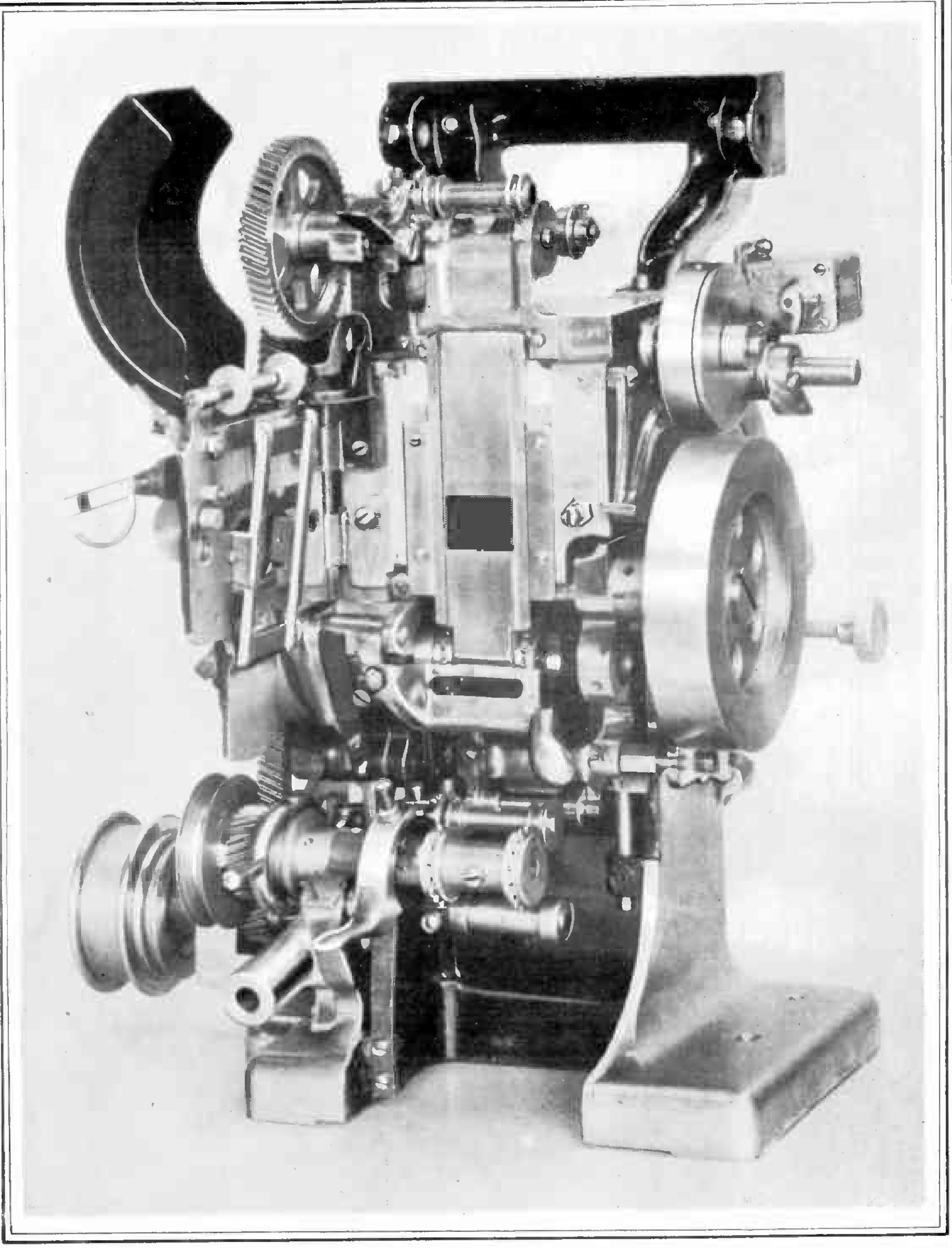
6. (a) What mechanism pulls a film into place in the aperture?
   (b) What type of mechanism is employed in the Powers projector for this purpose?

7. What mechanism comes into play if the projector slows down or stops?

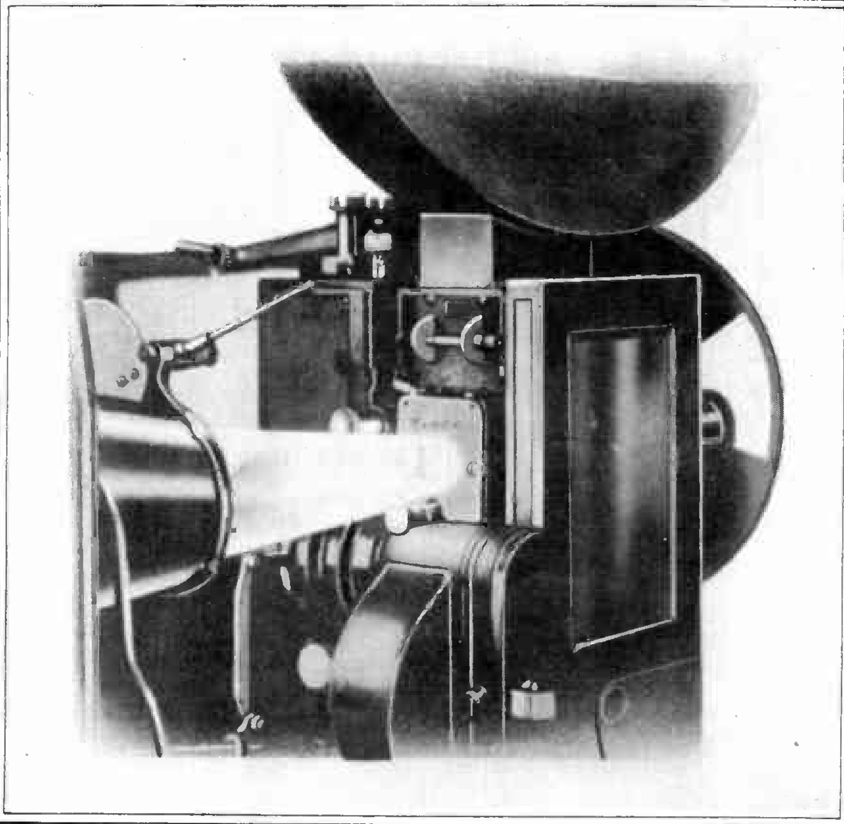
8. Why are loops of film provided above and below the intermittent movement?

9. What does the term "striking the arc" mean?

10. How many times per second is the light beam cut off when a three-bladed revolving shutter is used?



Powers picture head showing aperture, picture gate and sprockets.



A light beam as it appears in its travel toward the picture head aperture.

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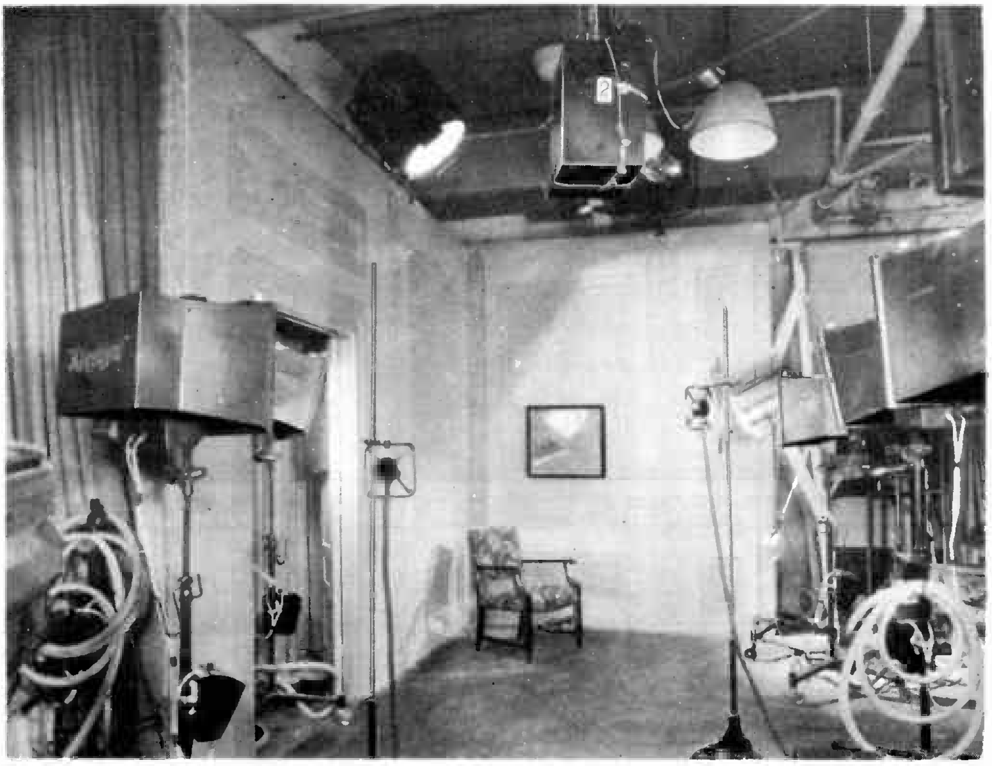
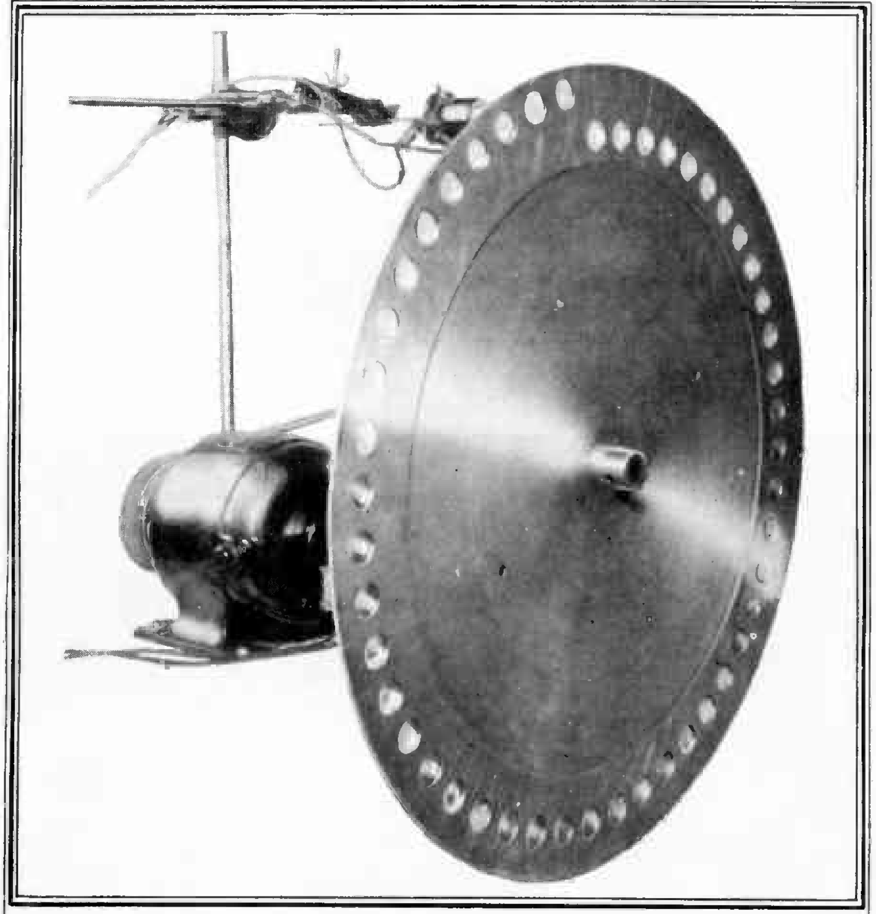


The lighting arrangements are carefully planned for photographing this "corner set."

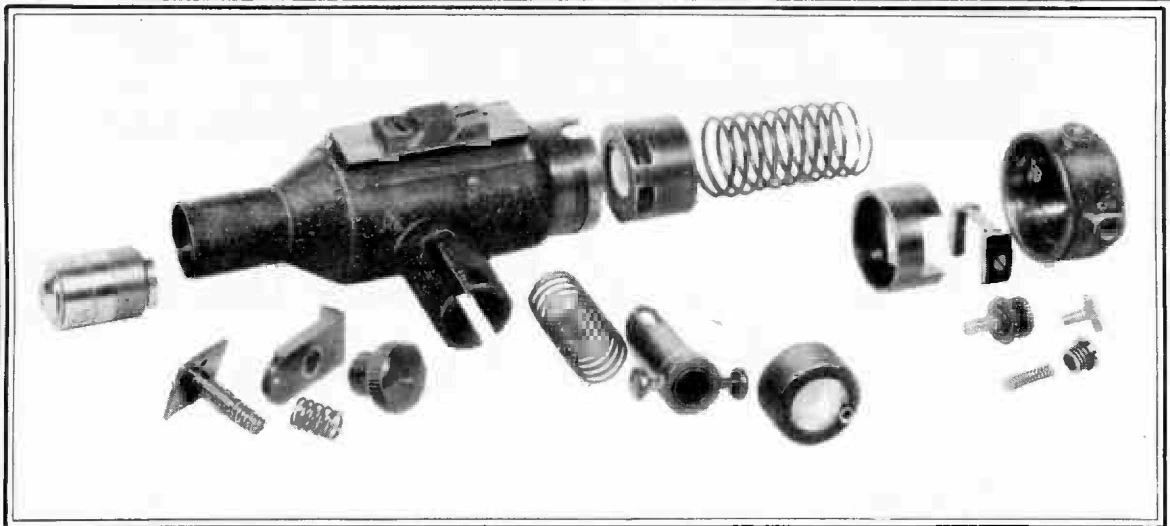
A Study of Lenses used in Sound-Pictures

VOL. 58, No. 7

Dewey Classification R 580



Lenses are used on this scanning disc of television equipment.



Exploded view of lens tube for recorder.

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LIGHT AND SIMPLE LENSES

VELOCITY OF LIGHT. Study of the action of light and lenses is quite necessary in a course on Sound Motion Pictures because light is used, not only in the projection of the picture on the screen but also in the recording and reproduction of sound by means of the sound-on-film system. Also, a knowledge of lenses and their function is essential because of their extensive use in sound-on-film recording and reproduction, which is rapidly replacing the sound-on-disc method.

Years ago, before the time of Roemer the scientist, it was thought that light travelled instantly from place to place because at that time there was no method known by which the speed of light might be estimated. One of the first steps toward the measurement of light speed was taken by Roemer in the year 1675 when he made certain observations and deductions, from which he concluded that light travelled about 186,000 miles per second.

Figure 1 illustrates how he made use of the movements of heavenly bodies to determine the speed of light. "S" is the sun around which our Earth "E" or "E'" revolves once a year. Its path is shown by the circle around the sun. "J" and "J'" represent the positions taken by the planet Jupiter which revolves around both Earth and Sun in a larger path or "orbit." "M" and "M'" are the positions of a moon which circles around Jupiter about every 45 hours. The dark cones are shadows made by Earth and Jupiter whose lighted halves face the sun. Let us explain that "E," "J," and "M" show the relative positions of Earth, Jupiter, and its moon at one certain time, whereas "E'," "J'," and "M'" show the positions of these bodies six months later.

It is apparent that as the small moon "M" circles around Jupiter "J" it plunges into the shadow of Jupiter. This causes an "eclipse" of "M" and it will not be visible again from Earth until it comes out from the other side of the shadow. After observing a number of these eclipses Roemer found that the elapsed time between them was always the same. Therefore, he predicted the time that a certain eclipse would take place six months later when the Earth reached "E'." He found that it actually took place 16 minutes and 36 seconds, or 996 seconds later than he predicted. He concluded that the delay of 996 seconds was the time required for light to travel across the diameter of the Earth's circular path around the Sun, and since this distance was estimated to be 186,000,000 miles he divided this value by 996 seconds and thus found the velocity of light to be about 186,000 miles per second. Later methods used to determine the speed of light proved that Roemer's method gave an approximately correct result.

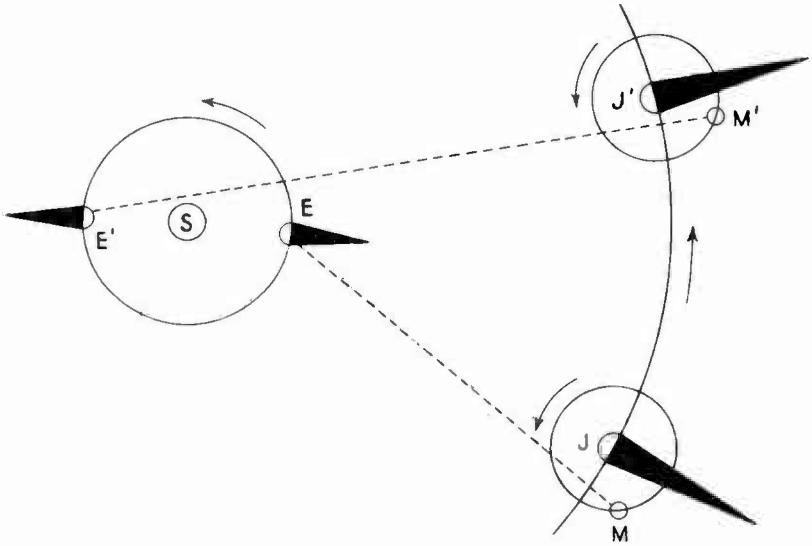

Figure 1

ABSORPTION — REFLECTION — TRANSMISSION OF LIGHT. Light, we know, will pass through many substances. It goes through certain substances without much loss while in other materials considerable light is lost as it passes through,and only a small portion of the rays which enter one side come out on the other. This is called "absorption."

When light rays strike a substance or material another action takes place which cuts down the amount of light which otherwise might pass through. This effect is called "reflection" and is best illustrated by mirrors which are capable of taking a large part of light rays which strike upon them and turning these rays in other directions. This effect is often noticed in our homes where a ray of sunlight is reflected by means of a mirror and we see the sun spot on the wall or ceiling. We may say then, that when light strikes any material part of it is reflected, part absorbed, and part goes through. It may seem that the last condition mentioned does not exist with every material, yet it is a fact that light has power to enter even metals to a certain depth. For instance, if light is allowed to strike on a very thin sheet of iron it can readily be seen from the other side, which demonstrates that some of the light actually passes through the metal.

Figure 2 shows the three conditions mentioned above when light strikes a piece of plate glass. "A" is the light ray which strikes plate glass "B." In our study of light and lenses, we use the expression "incident to" instead of saying the light ray strikes the glass. A part of the light is reflected in the direction shown by the dotted line "C." Another part of the original light ray is absorbed by the glass at "E." The remaining part of the ray passes out on the other side of the glass as at "D." Observe that lines "A" and "D" are parallel but slightly displaced from the position they would normally take if they formed a continuous straight line. The reason for this displacement will be taken up under "refraction."

We have said that all materials act on a ray of light in all three ways at the same time, that is, we have reflection "C," absorption "E," and transmission "D" taking place at all times. Materials, therefore, are classed according to which action takes place in the greatest amount. To explain, suppose we coat the under side of plate glass "B" with silver, it will reflect by far the greater proportion of the "incident" ray "A" and the glass will be classed as a reflector of light. However, if a piece of "dark" material such as black velvet is substituted for the glass then the greater proportion of the light striking upon it will be absorbed. Thus, black velvet may be classed as a good absorber of light. Any clear substance, such as glass, allows light to pass through without much loss and in this case it is classed as a transmitter of light.

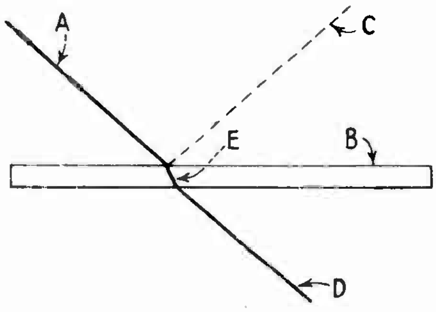

Figure 2

If a material allows no light to pass through, it is called "opaque;" if it allows light to pass through but so scatters or "diffuses" the rays that an object cannot be seen through it, the glass is said to be "translucent;" and if the glass allows light to pass through without diffusion so that objects can be seen clearly through it, it is "transparent." For example, the fire shutter on a motion picture projector is "opaque" and therefore when it drops down over the aperture it cuts off all light from the arc to the film. Of course, it also cuts off the heat rays which is its main function. A piece of oiled paper and ground glass are both translucent because they allow a certain amount of light to pass through although an object cannot be seen clearly when looking through either of these materials. Glass, water, and air are examples of transparent substances for they not only transmit light, but objects can be seen clearly through them.

In sound picture work use is made of the reflector principle as explained under the subject of lamphouses. Glass is used to gather and transmit light by means of the condenser lens, which is located in the lamphouse. The image we see on the screen in a theatre is reflected to our eyes by the reflecting power of the screen, although in some cases a translucent screen is used. Examples of the use of translucent screens are to be found in the theatres in Europe where the motion picture projector is placed on the opposite side of the screen from the audience, or back-stage, the same feature being used by the Trans-Lux theatres in America. Enough of the light passes through the translucent screen to produce a satisfactory picture before the audience. Other examples of translucent screens are the so-called "daylight projectors" that one sees in store windows which are used for advertising purposes.

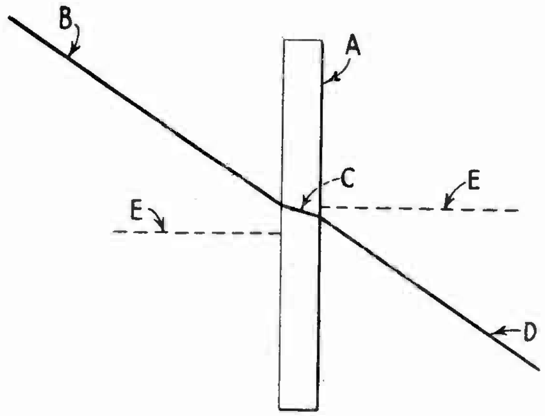

Figure 3

Speed of Light varies for Different Mediums. The velocity at which light is said to travel, or approximately 186,000 miles per second, is considered to hold good only for the medium of air or space through which it passes. If light passes through a medium or material which is denser than air or space medium its velocity will be decreased. In this respect light is similar to a bullet for example which will travel faster through air than through water, because water is approximately one-third more dense than air, or stated the other way around, air is about three-quarters as dense as water. The densities of various materials are as follows, air being taken as unity, or 1.00.

Water	1.33	Crown Glass	1.53
Alcohol	1.36	Flint Glass	1.67
Turpentine	1.47	Diamond	2.47

It will be seen from this chart that a diamond is almost twice as dense as water and considerably more dense than glass.

REFRACTION. One rule to remember is that light rays entering a dense material from a lighter one will be slowed down by the denser medium. This fact accounts for the action of a light ray when it strikes a medium of different density from that through which it has been travelling, as for instance, when it enters glass after travelling through air. If it enters the second medium at an angle to its surface the light ray will be bent out of its former straight course and will follow a new straight course upon leaving it. "A" denotes the glass, "B" the entering ray, "C" the course of the light through the glass, "D" the ray after leaving the glass, while the dotted line "E," called the "normal" of the surface is an imaginary line drawn perpendicular to the surface of the glass. Since both faces or surfaces of the sheet of glass are parallel then "E" is normal or perpendicular to both surfaces. This is shown in the sketch in Figure 3.

It will be seen from this sketch that the incident ray of light "B" is bent upward as it enters the glass thus tending to go more in the plane or direction of the normal "E." This illustrates a law of optics which states that a ray of light in passing from a rare to a more dense medium is bent or "refracted toward the normal." The course of the ray is straight in the new medium, which is glass in this case, but upon leaving the glass the ray is bent once again, this time in a downward course as shown by "D." The latter condition indicating that the new direction of the ray is away from the normal demonstrates the truth of another law of optics, namely, a ray of light going from a dense to a rarer medium is "refracted away from the normal".

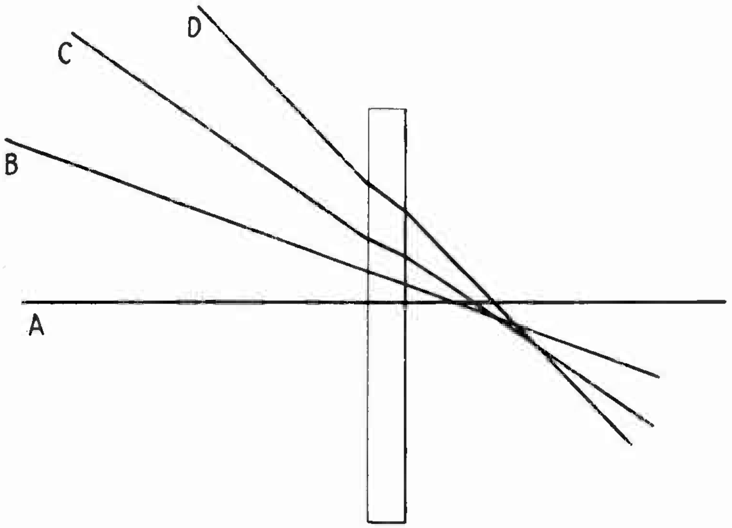

Figure 4

The course of the incident ray "B" is parallel with the course of the emergent (taken from the word "emerge" meaning "come out") ray showing that there was the same amount of refraction or bending of the ray when it left the glass as there was when it entered. This refraction of light takes place only if the ray enters the new medium at an angle to its surface. However, if the ray comes from such a direction that it enters the glass perpendicularly or on the line of the normal then no refraction takes place and its course would be as shown by "A" in Figure 4. The greater the angle of incidence (angle between incident ray and normal) at which the ray enters the new medium the greater will be the refraction. This is demonstrated by rays "B," "C," and "D," where a greater refraction takes place on entering and leaving the plate glass.

REFRACTION IN PRISMS. In leading up to a study of the effect of a lens on light rays we next come to a consideration of the effect of a prism of glass on light refraction. Figure 5 is an edge view of a prism "A" (a prism being a solid, in this case a column of glass, whose bases are equal and parallel and whose faces are parallelograms) with a light ray incident upon its surface, as at "B", from a source of light "C". Here again we have the principle of a light ray which upon entering a denser medium at an angle is refracted or bent toward the normal of the surface of the new medium, the normal being designated by the dotted line "D" which is perpendicular or at right angles to the left surface of prism "A". The refracted ray "E" is shown passing through the glass in a straight line to the right surface of the prism, where it is again bent or refracted, but this time away from the normal "F" of the new surface, taking a downward course "G".

The action of the light ray from the source "C" to the point "H" has followed each law of optics thus far explained. When the light ray entered the glass prism (a dense medium) from the air (a lighter medium) it was refracted toward the normal "D" of the left surface of the prism and as it left the denser medium, glass, and entered the lighter medium, air, it was bent away from the normal "F" of the right surface.

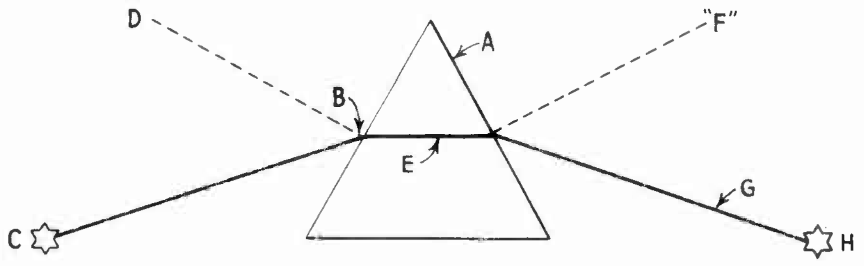

Figure 5

REFRACTION IN A CONVEX LENS. Suppose, this time we place another prism like the one in Figure 5, with its base or broad part up against the base of the first prism. We will then have an arrangement as shown in Figure 6. The appearance of the prisms is very much like the edge view of the double condenser lens used in a lamphouse. It will be seen that rays "A" and "B" both starting out from the same source of light "C" each arrive at the same point "D" after having been refracted by prisms "E" and "F." In this sketch "E" and "F" represent an edgewise view of a lens, like the lens in a camera for instance, that would appear round if it were viewed from the front or back. In this illustration only two rays of light are used to simplify the explanation but it should be realized, of course, that the source of light "C" sends out millions of such rays which enter the lens at every point on its surface and these are refracted in the same way as rays "A" and "B." This causes each point of light leaving source "C" to be gathered together again at point "D" by the action of the lens, thus producing an "image."

We know that if the source of light were a candle flame for example, the image also would take the shape of a candle flame when brought to a "focus" on a screen. Refer to Figure 6 at the location "D" which marks the point where the image is brought to a "focus." This point is called the "focal plane" of the lens because all the rays of light which left the plane of source "C" are brought to a focus in such relation to each other that a true image of the source is formed at the focal plane or "D" in a reversed position, that is to say, the image is upside down and with the left side of the source of light occupying the right side of the image and vice versa.

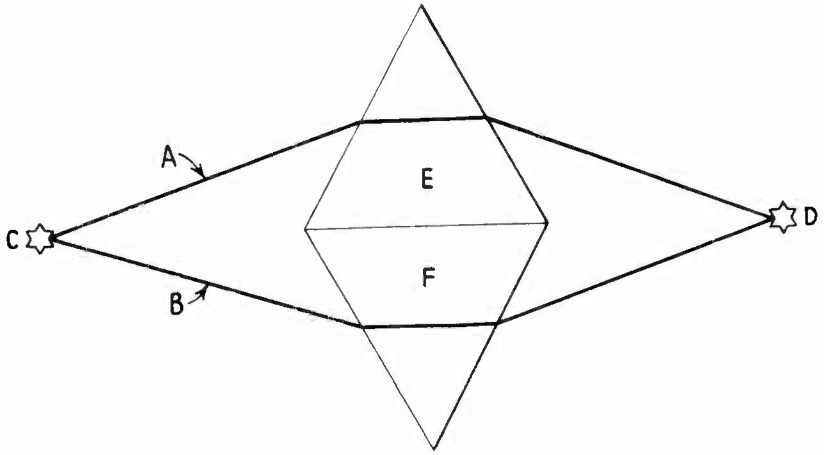

Figure 6

It can be seen from Figure 7, that the focal plane of the arrangement shown in Figure 6 can only be in one position for if (refer to Figure 7) the screen is placed at the focal plane "D" where the light rays originating at "C" are brought together, a true image of "C" will be obtained. Then if the screen be moved to either "G" or "H" the image will be out of focus because the points of light leaving the object "C" will not be brought together in proper relation but will be spread out over a greater surface as marked by X, Y, or X', Y' and consequently the image will be blurred or indistinct. In this drawing outlines of the two prisms are shown in dotted lines, but in Figure 6 these lines are filled in to form an edge view of a true lens.

LIGHT WAVES — WAVE FRONT. The action of light as it enters a dense medium will be our next topic. Light waves, like water waves or air waves, have a wave front. The wave front of a water wave is circular in form as shown in Figure 8. This is the effect that is seen when a stone is thrown into a pond or other body of water, and consists of rings or circles of disturbed water which are more often referred to as "waves" or "ripples." This disturbance starts at the point where the stone strikes the water and expands rapidly into circles which become wider and wider as they move outward until finally the resistance or inertia of the water reduces the amplitudes of the waves until they die down and are no longer visible. All of the circles as they travel outward are called the wave front, likewise each small segment of any individual circle is also known as the wave front of that part of the wave, as for instance that portion between lines "A" and "B." A moment after the stone touched the water that part marked "a b" on the sketch was a segment of the wave front; but a short time later we find "a'b'" is the new position of the same segment of the wave front; and finally the wave front arrives at "A-B" thus indicating the movement is always progressing outward toward "X." From this explanation it is apparent that as section "a b" moves out from the center of the disturbance the direction of travel of the wave front, or any part of it is at right angles to the wave front itself.

Light waves also follow this rule, and therefore the wave front of a ray of light travels in a direction at right angles to the plane of the wave front. There is a difference, however, between water waves and light waves in that water waves move over the surface of the water as expanding circles, whereas light waves travel in the shape of a sphere or ball in all directions from their source. Now, since it is a law of light that rays always travel at right angles to or perpendicular to their wave front, then it must be true that if the direction of the wave front is changed, the rays will also change their direction of travel.

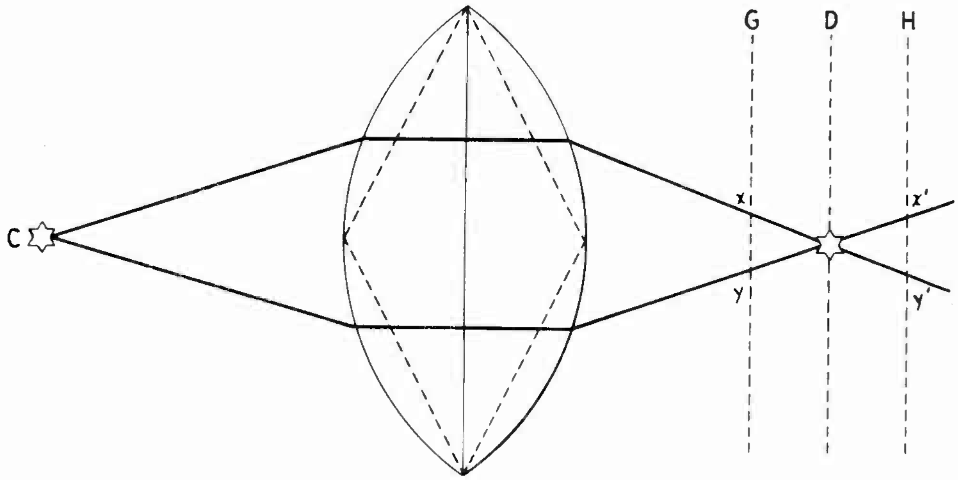

Figure 7

This change in the direction of a wave front is exactly what happens when light enters a new medium, as shown in Figure 9 where a wave front of light "A" travelling in the direction "B" strikes a body of water "C" at an angle. The lines 1, 2, 3, 4, 5, and 6 denote sections of the wave front and are used merely to allow us to give a clearer explanation of the sketch. Assuming that air is the medium through which the light is travelling before it reaches the surface of the water, then that part above the line marked "C" represents air while the part below the line represents water.

Any section comprising the wave front of light must always take the shape of a curve because all sources of light send out waves in spherical form. Of course, if a source of light is many miles away, as for instance the sun, then by the time the wave has expanded sufficiently to reach the people on Earth the curvature of the wave at this great distance is so slight that it may be considered to be a straight line, or "plane wave" as shown by "A" in Figure 9. Wave "A" travels at the same velocity along its entire front from 1 to 6 so long as the medium through which it passes enters the water, however, the part marked 1 of the front in striking the denser medium first is slowed down for the reason as already explained that the

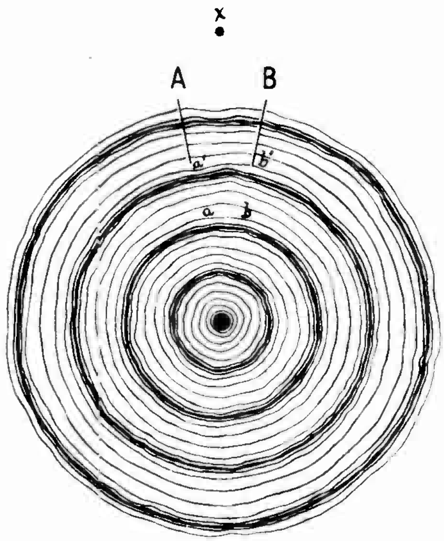

Figure 8

velocity of light is less through a dense medium like water than through a lighter medium like air. Although part 1 of the wave front is shown travelling in the water, part 2 is still in air but about to enter the water, while parts 3, 4, 5 and 6 of the front are considerably further away from the surface of the water and are trav-

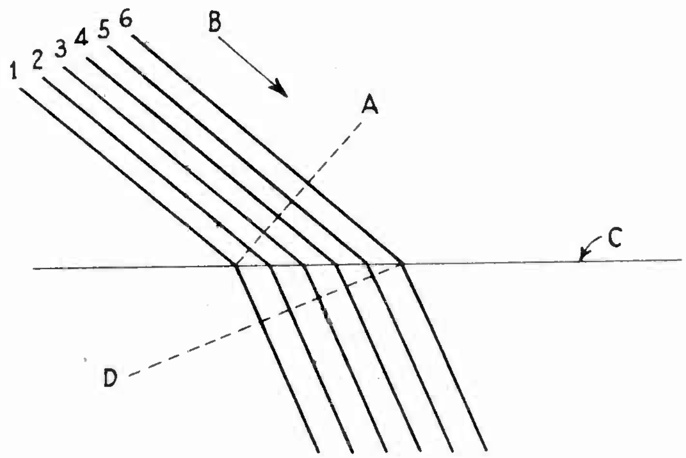

Figure 9

elling at the speed of light in air. It is evident that the end of the wave front indicated by number 1 is held back by the density of the water while the wave end toward number 6 travels at the greater speed of light in air. This difference in velocity will cause the wave front "A" to swing toward the horizontal until the time comes when the number 6 part of the front has just entered the water. The wave front "A" will have reached the position shown by the dotted line "D" which is the new front of the wave as it travels through the water. Inasmuch as the direction of travel of light is always perpendicular or at right angles to its wave front, and the wave front in the water is different from what it was in air, it follows that the direction of travel or "propagation" changes to suit the new wave front, and the light travels in a new direction through the water.

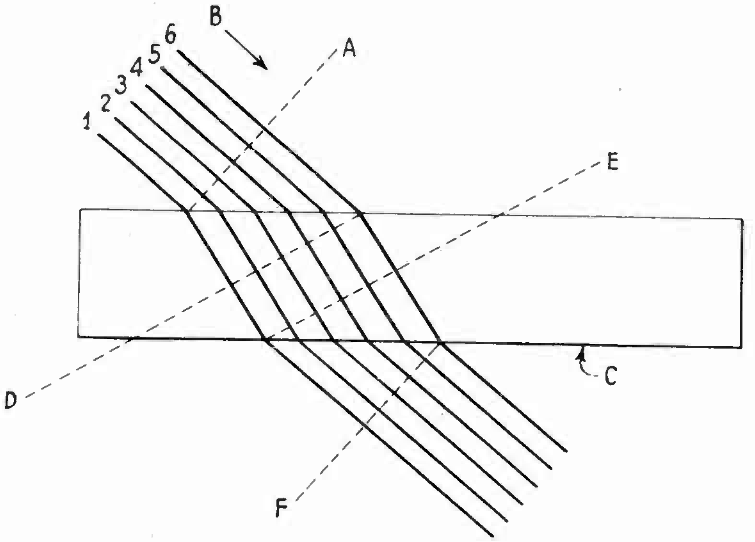

Figure 10

Glass and water both influence light rays in the same way, the difference being that the effect caused by glass is more pronounced because of its greater density when compared to water. By substituting a thick sheet of glass for the body of water in Figure 10, the same action is seen to take place as shown in Figure 9, but in Figure 10 we have also indicated how the light rays again change their direction when they leave the dense medium, glass, and enter the lighter medium, air. Referring to Figure 10 it will be seen that the wave front entering glass "C" was changed toward the horizontal until it reached the new position "D", much the same as it changed when entering the water, as indicated in Figure 9. The wave front "D" in Figure 10 continues in the same direction until part 1 of the front reaches the air underneath, whereupon it immediately increases its velocity to equal that of light rays in air, while at the same time that part of the wave from 2 to 6 is still passing through glass, and naturally the velocity of the rays through the latter or denser medium is much slower. This gives part 1 of the wave front a chance to catch up with part 6 which is still moving in the glass, until the time comes when part 6 has also reached the air, then part 1 will have advanced to the position shown at "F" which denotes the new wave front as it travels in air. Observe that wave front "F" upon leaving the glass is parallel to wave front "A," and so we learn that while light travels in the same direction as it did before it entered the glass, its path is slightly displaced from its original path. Also notice that when the two surfaces of the glass are parallel the light rays are refracted the same amount upon leaving as upon entering the glass and therefore although the rays are moving in parallel directions on both sides of the glass they are slightly displaced.

We previously mentioned that if rays of light entered a "double convex" lens, as the lens in Figure 7 is called, the rays would "converge" or come together at some point on the other side of the lens. It was also stated that the greater the angle from the normal at which the incident ray enters the lens, or the greater the angle of incidence, the greater will be the refraction or bending of the ray.

From the foregoing facts we know that the normal of a plane surface, such as a piece of plate glass, is at right angles to its surface, but in the case of a curved surface, as for instance the surface of a condenser or convex lens, a different procedure must be followed to locate the normal as will now be explained.

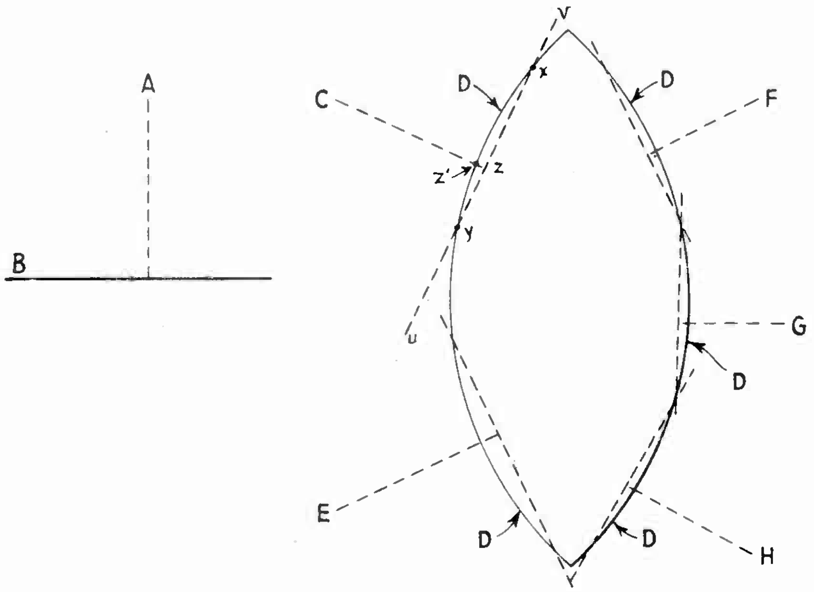

Figure 11

FOCAL LENGTH OF CONVEX LENS. Figure 11 shows the normal "A" to a plane straight surface "B." Dotted lines "C," "E," "F," "G," and "H" are also normals of curved surfaces "D" at various places on a double convex lens. The normal to a curved surface is found as follows: Draw a straight line cutting the curved edge of the lens in two places as at "U" and "V" in Figure 11. Locate point "Z" on this line half way between the two points where the straight line cuts the curved edge "D." In the drawing "X" and "Y" are the points where "U" and "V" cut the curved line "D," and "Z" is located half way between "X" and "Y." The line "CZ" is then drawn perpendicular to "UV" and is normal to the edge "D" at "Z."

From this illustration it can be seen that for a given convex lens the thicker it is at its center when compared with its edge the greater will be the angle (angle of incidence) at which light strikes its curved surface and therefore the more it will be refracted. If it is refracted more it will come to a focus closer to the lens on the other side, and thus the lens is said to have a short focal length. The focal length of any convex lens is the distance between the center of the lens itself, and the point where parallel rays of light, entering the lens, are brought to a focus. Figure 12 shows this difference clearly where "A" is a thin lens and "B" a thick one, and although parallel rays of light from a distant source enter each lens alike, yet they are brought to a focus at different distances from the respective lenses. It can readily be seen that the focal length "C" of the thin lens "A" is twice as great as the focal length "D" of the thick lens "B."

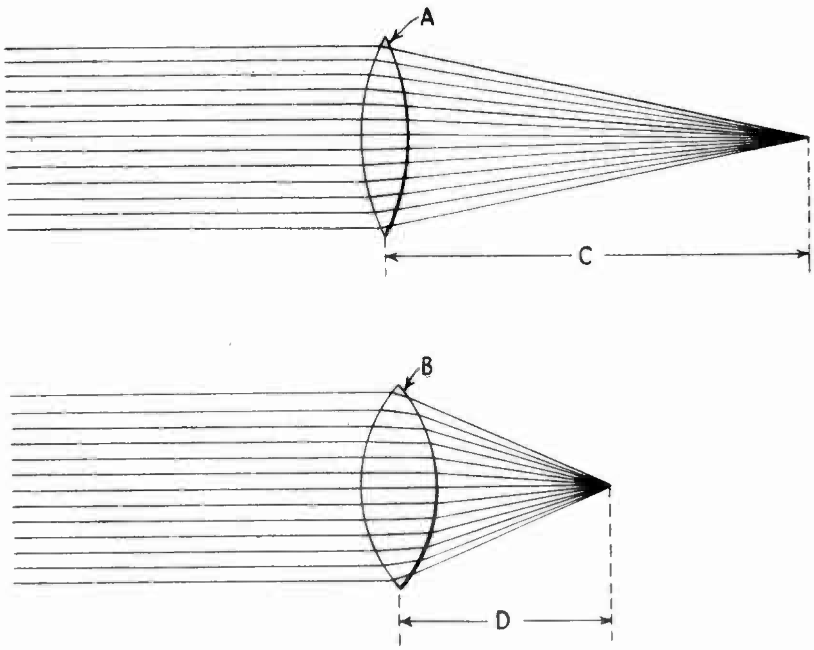

Figure 12

If you wish to find the approximate focal length of any convex lens it is only necessary to hold the lens up so that rays of light from any distant object, such as a building for example, will shine through it to a piece of white paper. When the image of the object is distinct and clear on the paper it is properly focused.

By measuring the distance from the center line of the lens to the paper you will get a close estimate of the focal length of that particular lens. Bear in mind, however, if the source of light is very near, or only a few inches or feet away this method will not prove accurate for the rays of light in this case will not be parallel. In fact, when the source of light is near the lens the focal point will change noticeably as the source is moved closer to, or farther away from the lens. Let us repeat that the focal point is the point where all rays of light passing through a convex lens are brought together or to a focus.

This action can best be explained by using the wave front method of demonstration as shown in Figure 13, in which "L" is a convex lens, "S" a light source, and "F" the focal point of the lens where an image of the source "S" is formed by the converging wave front of light rays indicated at the right of the lens. At the left of the lens, or between the light source "S" and the lens itself, can be seen the curved lines of the diverging wave front of the rays from the source. The wave front is, of course, circular in form, as shown near the source "S" but only that portion of the front that strikes the lens is of interest in this case. The wave front between the source and the lens is said to be diverging, because unless it is changed in form so that it curves in the opposite direction, the rays which left the source will never come together again to form an image of the source. The convex lens is able to change the form of the wave front, however, by holding back the middle of the wave as it passes through the dense glass medium. This allows the ends to catch up with the middle and then to speed ahead so that as the wave undergoes a change and as it passes out of the lens on the opposite side it becomes a converging wave which brings all the rays to a focus at "F."

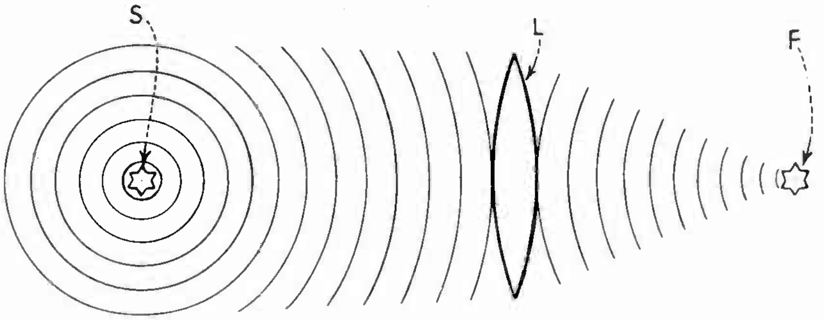

Figure 13

It should now be easy to understand why a thick lens has a shorter focal length than a thin one simply because its thicker center holds the middle of a wave back even more than a thin lens and thus allows the ends of the wave to get further ahead. Thus, a wave front of sharp curvature (short radius) is produced. With a short radius the wave front converges to a point more quickly than it would if it came from a thinner lens and so produces the image closer to the lens. This demonstrates that a convex lens always slows up the middle of a wave and the thicker the lens with relation to its edges the more it holds back the middle of the wave and the more the ends are able to catch up, as it were.

Suppose this time we move light source "S" close to the lens, as in Figure 14. This is actually what we do at times in order to focus the light of the arc to a proper spot on the aperture of the motion picture head. Moving the light source is also necessary when focusing the light beam on the sound track of the film in the sound head of a sound motion picture projector. Referring to Figure 14, we find that the wave front is more curved now when it strikes the lens because it is closer to the source and as we explained in the case of the light from the sun the farther a wave extends from its source the less curved it becomes, until at very great distances the wave front is practically in the same plane and the rays are travelling in parallel lines.

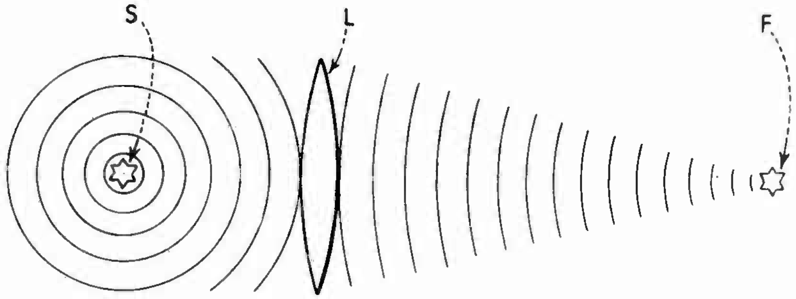

Figure 14

We found from a study of Figure 13 that the lens held back the middle of the wave to such a degree that not only was it straightened out but it actually reversed in form, so that where the middle of the wave formerly travelled ahead of the ends, the ends travel ahead of the middle after passing through the lens. This action changed the wave front from a "diverging" form on the left of the lens to a

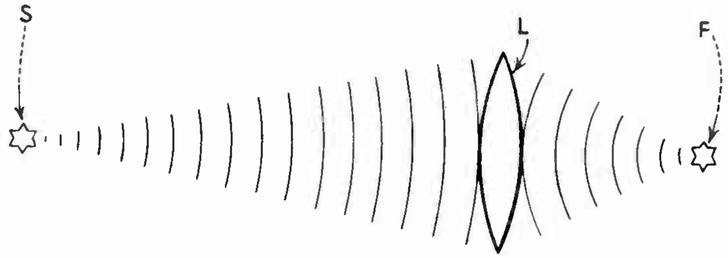

Figure 15

"converging" form on the right side, and the light came to a focus at "F." In both Figures 14 and 15 the lenses are the same and therefore each holds back the middle of a wave by exactly the same amount. In the case of Figure 14, however, the wave striking the lens is more curved, and even after the lens holds back the middle of it by the same amount as for the wave in Figure 13, it will be seen that in Figure 14 the ends are not as far ahead of the middle when the wave comes out of the lens as is the case in Figure 13. This means that the wave leaving the lens in Figure 14 is less curved than the wave leaving the lens in Figure 13 and, furthermore, the center of its curvature, or focal point, as in Figure 14, is farther away from the lens than it was under the conditions pictured in Figure 13.

If the source of light were moved farther away from the lens in either Figures 13 or 14 the opposite condition would be brought about, or one where the image would be focused at a point nearer the lens than in either of the previous cases. This condition, as shown in Figure 15, is due first to the fact that waves which strike the lens from a more distant source are "flatter" or less curved, and second, because the lens in slowing up the middle of such a wave by the same amount as in the other two cases puts a sharper curve in the flatter wave that passes through it. All of this results in bringing the image of the source to a focus nearer the lens.

To demonstrate another point suppose we turn Figure 15 upside down and place it over Figure 14. We have almost an exact copy of Figure 14 which shows that if a source of light, as for instance "S" in Figure 15, is focused to an image at "F" through a lens "L" and the source of light is then moved to the point "F," the image will be focused at the place where the source was formerly located, or at "S." In other words, "S" and "F" are interchangeable for if the source of light be located at either place the image will be brought to a focus at the other. It is apparent from this fact that the mechanism of a lamphouse, or sound head used in sound motion pictures, which permits the source of light to be moved closer to, or farther away from the lens, enables the rays of light from the source to be brought to a focus at the point desired, whether in the aperture in the picture head in one case, or in the sound head in the other. Of course, moving the lens while the source of light remains fixed would accomplish the same result but in sound picture work it is found more practical to move the light source and permit the lens to remain fixed.

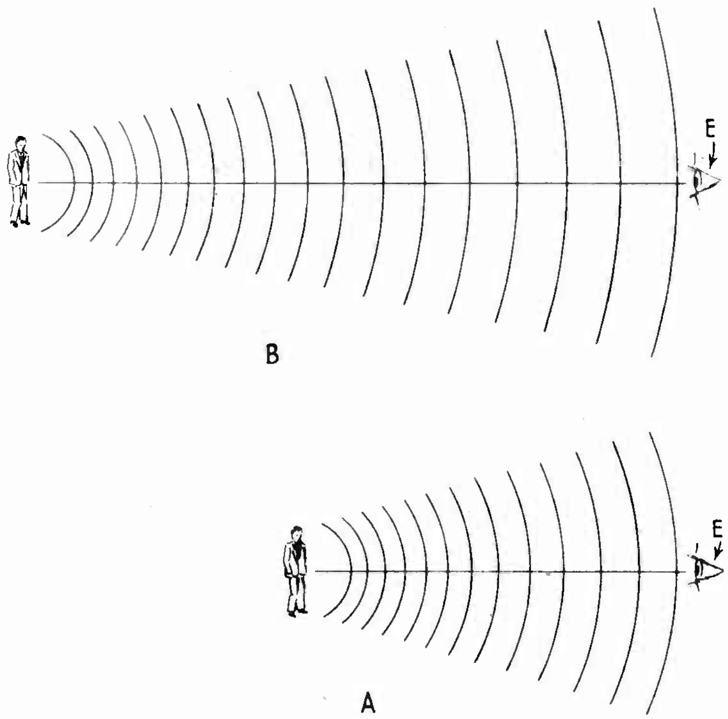

Figure 16

<u>HOW THE EYE JUDGES DISTANCE.</u> When a small section of light wave strikes the eye, the eye "sees" to the center of the curvature of the wave, that is, it sees the object as being at the center of a circle whose circumference is a continuation of the small section that enters the eye.

Figure 16 illustrates this idea, "A" showing waves from a nearby object entering the eye and "B" waves from an object farther away. The waves that reach the eye "E" in sketch "A" have considerable curvature to them as you will observe and since the small section of the wave that enters the eye causes it to see to the center of a circle of which it is a part, the object will appear large because the center of the circle is near the eye. On the other hand in sketch "B" the waves reaching "E" are much flatter and have less curvature and the eye "seeing" to the center of this larger circle registers the object as being smaller.

Many persons can judge with a fair degree of accuracy how far away a certain object might be through knowing its comparative size with another object which is close by. For instance, experience has taught us that most men are about alike in general size and, therefore in a case where two men are standing some distance apart instead of believing what our eyes tell us, that the man nearest us is larger, we know that the man nearest only seems to be larger. For more accurate judging of distance we call upon both eyes to work together to produce what is known as binocular vision wherein each eye sees the object at a slightly different angle and by this means we appreciate the depth of a scene and object. We study this faculty of the eyes in the subject dealing with stereoscopic or third dimension motion pictures.

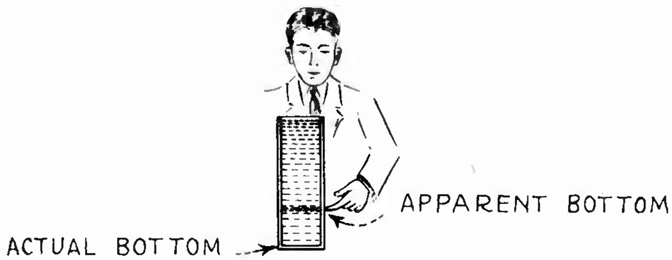

Figure 17

If the light wave which leaves the object is changed in form by passing through a different medium before it reaches the eye, the object will seem to be at the center of the new curvature into which the wave was changed by its passage through the new medium. This is best demonstrated by looking at an object in water and then trying to touch the object. It will be found to your surprise that the object is down a greater depth than it appears to be, that is, your eye tells you the object is located higher in the water than its actual position. Figure 17 shows where the bottom of a container of water appears to be when viewed from above and no doubt you would actually touch this spot if told to put your finger on the place where the side and the bottom of the container meet. Observe that the point where the bottom appears to be is about one-quarter of the total height of the water above the actual bottom.

Again using the wave front method of demonstration, refer to Figure 18 where "A" is an object under water, "W" is the surface of the water, "E" is the eye looking directly down into the water, and "E'" is the eye looking into the water at an angle to its surface. The wave front of light from source "A" passes upward becoming less curved as it gets further away from the source and if it continued travelling in water when it reached the point marked in the drawing it would have the shape or curvature represented by the dotted line. The middle part of the wave, however, speeds up as soon as it leaves the dense medium water and enters the lighter medium air, so that while the ends of the wave may still be travelling in water at this moment, the middle gets ahead of the ends and bulges the wave upward thus producing a wave front of greater curvature.

The newly-formed wave front now proceeds upward in air until a section of it enters the eye. The eye in receiving a wave of this curvature, sees to the center of the curve, and since the center is at "B" instead of "A" the object appears to be at "B" when it is actually at "A." To the eye at "E" the apparent object "B" is in a line with the actual object "A" but when the eye views the object from point "E'" the apparent object "B" appears above the actual object "A." It is quite evident that if object "A" were a fish in the water and a man stands at "E'" and tries to spear it, he should aim at a point below where he sees the fish.

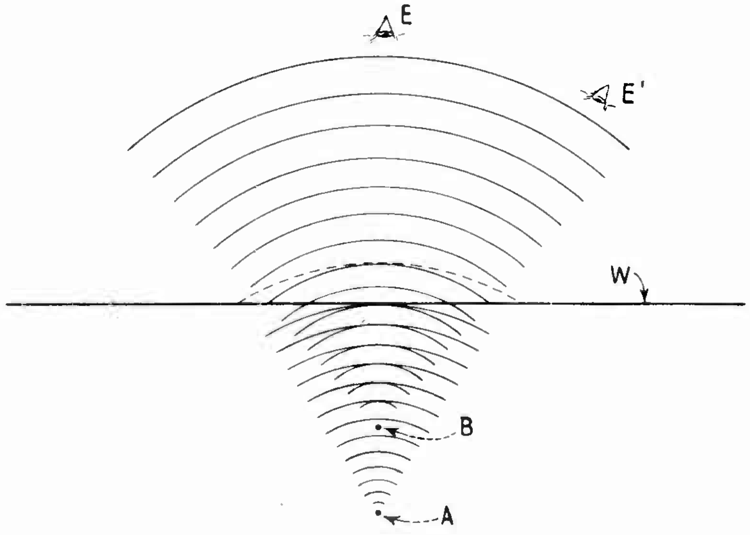

Figure 18

Thus, we see that all objects under water, when looked at from a point not in the water appear nearer than they actually are and this peculiar effect is attributed to the fact that the velocity of light is greater in air than in water.

Remembering from Figure 17, that the bottom of the container appeared to be located at a point about three-quarters the actual distance below the surface of the water we can reason that the velocity of light in water is about 3/4 that of light in air. If we assume the reverse of the situation shown in Figure 18 and consider that the eye is placed under water, then all objects outside of the water appear to be further away than they actually are. This can be demonstrated by drawing the wave front as coming from a source above and placing the eye beneath the surface of the water. In this case, the curvature of the wave front will grow flatter or less curved when it strikes the water and the source will appear further away than its actual position.

CONCAVE LENS. The lens we have studied in the foregoing paragraphs is the convex lens. One type in use in lamphouses is the plano-convex lens, which is flat on one side and curved out on the other. Another type is the bi-convex or double-convex lens, which is rounded out on both sides and can be made from two plano-convex lenses with their flat or plane sides placed together. Another type of lens used in motion picture optical work is the concave lens.

A "convex" lens is always thicker at the center than at its edges, but a "concave" lens is just the reverse, or thinner at the center than at the edges. Figure 19 shows edgewise views of four types of lenses, "A" being a plano-convex, "B" a bi-convex or double-convex, "C" a plano-concave, and "D" a bi-concave or double-concave. The face or front view of each lens when viewed in this manner is similar and, of course, would appear like "E."

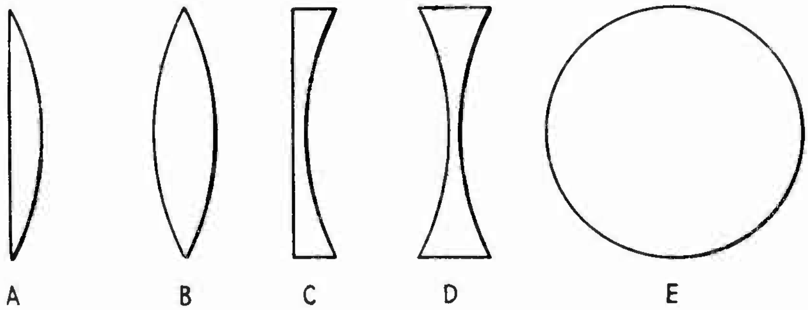

Figure 19

We found in our study of the convex lens that a cross section of such a lens could be divided into two sections each of which resembled a cross section of a prism as shown by the dotted lines in Figure 20. The dotted line "x" forms the base of both the upper and the lower triangular prisms, the points of such prisms being called the "apexes." As may be seen in "A" of Figure 20 one apex is located at the top of the upper prism and another at the bottom of the lower prism. Light rays in passing through these prisms are refracted toward the base or center line and are brought to a focus on the center line of the lens as shown in "B" of Figure 20. If we take a cross section of a double-concave lens and divide it in the middle we will have roughly two prisms somewhat like those obtained after dividing a convex lens cross section. However, in the case of the concave lens the two prisms, instead of having their bases together, will have their apexes together or point to point as shown in sketch "A" of Figure 21 where the top half is shown as a prism with the point or apex down, and the bottom half is shown as a prism with the apex up. Here it is seen that the "base" of the upper imaginary prism is at the top while the "base" of the lower imaginary prism is at the bottom. The "bases" of the imaginary prisms thus become the edges of the concave lens. Refer to "A" in Figure 21.

Light rays in passing through these prisms, according to the law of refraction, bend toward the "bases" or away from the center line. This law states that the rays bend toward normal on entering a denser

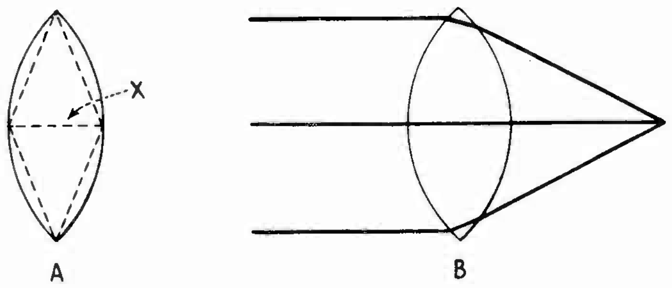

Figure 20

medium and away on entering a less dense medium. Since light rays entering a concave lens are not brought to a point on the opposite side, but are refracted away from the center, then no image of the source can be brought to a focus after the rays pass through the lens. In drawing "B" of Figure 21 the course of parallel rays of light from a distant source are shown as they pass through a concave lens.

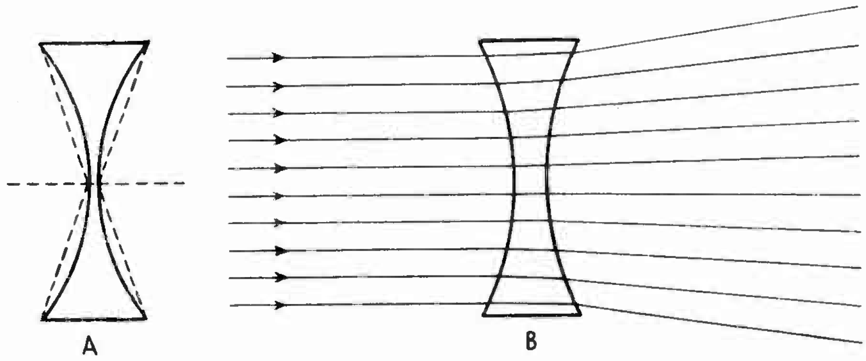

Figure 21

The action of a concave lens on light rays can be easily explained by again making use of the wave front method shown in Figure 22, where the circular wave front from a near source of light upon passing through a concave lens is changed in form, it being understood that in every case the front becomes more curved by its passage through the lens. Contrary to the action of a convex lens, the wave front cannot be reversed by a concave lens. Referring to Figure 22, the source of light "S" sends out a curved wave front which after passing through concave lens "L" is held back at the ends by the thicker glass at the edge of the lens. The ends being held back allow the middle, which is still travelling in air, to get even further ahead of the ends than before or previous to the time the wave front entered the lens.

This gives the wave front a greater curvature as it comes out of the lens and the eye "E" receives a section of the altered wave front. Source "S" appears to the eye to be at the point "F" or the center of curvature of the altered wave front, which is called the "focal point." It can be seen that while the focal point of a convex lens is on the opposite side of the lens from the source, in the case of a concave lens the focal point is on the same side as the source. Another big difference between these types of lenses is that the image formed at the focal point of a convex lens is an "actual" image, that is, all the rays of light striking the lens from the source are gathered or focused to a spot that can be seen on a screen, whereas the rays from a source that pass through a concave lens are "diverged" or spread, instead of being gathered and therefore cannot form an actual image on a screen. The image formed by a concave lens, as at "F" in Figure 22, is called a "virtual" image because it can be seen by the eye which receives a small section of the wave front and sees the image of the source at the center of this wave front.

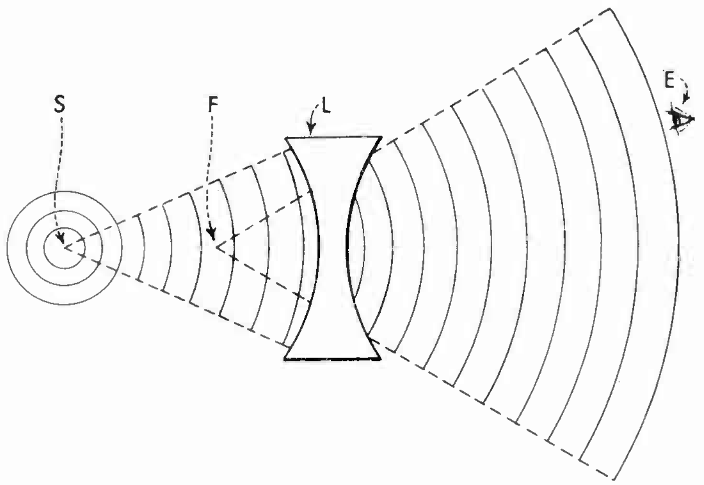

Figure 22

Moreover, using the wave front idea we see that if the source is moved closer to the lens the virtual image is formed closer to the lens and likewise if the source of light is moved further from the lens the image is formed further away from the lens. In every instance, however, the image is closer to the lens than the source of light. Quite the opposite effect takes place in the case of a convex lens because with this type the closer the source is to the lens, the further away will be the image formed and vice-versa. The focal length of a concave lens is the distance from the center of the lens to the point where the virtual image is formed, when the rays entering the lens are parallel.

This type of lens is used in sound motion picture apparatus for correcting troubles in lenses known as spherical aberration and chromatic aberration. Concave lenses are used with convex lenses where such corrections are necessary. These combination lenses are known as corrected lenses and are used as follows: 1st, in the picture head of a projector to throw a true image on the screen; 2nd, in the optical system of the sound head, or the sound-on-film recorder, to project a true image of a slit of light on the sound track of the film; and 3rd, in the motion picture camera to form a true image of the scene being photographed on the sensitized film.

TOTAL REFRACTION. Another property of a prism known as "total refraction" is explained in the following paragraphs. By this term is meant that a prism has the power to take all the light it receives and turn it in a direction at right angles or 90 degrees to its original direction. Mirrors are also able to change the direction of travel of light waves but their efficiency is much lower than glass prisms in doing this because less light is lost in a prism by absorption. At first thought it seems strange that a piece of clear glass is able to turn a light ray to such an extent but a more detailed study of the refractive effect of water on light than is given in the early part of this lesson will show that the action is easy to understand. For this explanation refer to Figure 23, which shows the surface of a body of water "W" with rays of light "A," "B," "C," "D," and "E" coming from a source of light "S" under the water and striking the surface at different angles. Note that ray "A" leaves the

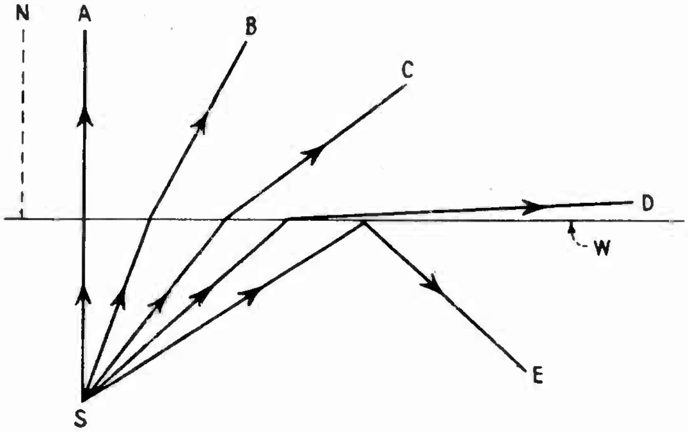

Figure 23

water along the line of the normal "N" and is therefore not refracted but continues on unchanged in direction into the new medium, which is air in this case. In obeyance of the law that light passing from a dense to a lighter medium is bent away from the normal we find that ray "B" bends outward as shown. Another law of optics previously given states that the greater the angle of incidence the greater will be the angle of refraction; this law explains why rays "C" and "D" upon leaving the water at greater angles to the normal are refracted even more than ray "B." Ray "D" has been refracted to the extent that its course lies practically along the surface of the water. When the angle of incidence becomes greater, as in ray "E," the refraction is then so great that the ray does not leave the water at all but is bent back again and it is obvious no light from this ray enters the air. Glass, being a dense medium exhibits this characteristic, known as "total refraction," in a more pronounced manner than water.

The principle just explained is used commercially in binoculars as shown in Figure 24, and also in sound picture work where so-called periscopes are used for adjusting optical systems in recorders and

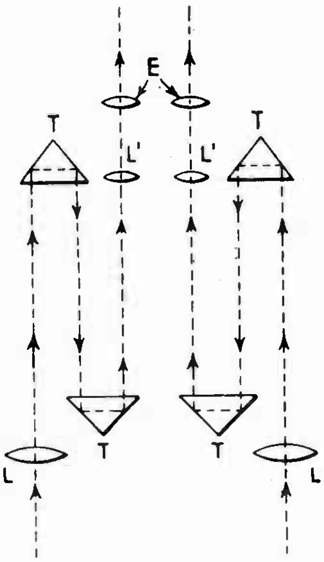

Figure 24.

sound heads as Figure 25 illustrates. In Figure 24 the light enters lenses "L" at one end of the binoculars and is totally refracted twice in each barrel by the glass prisms "T," after which the light enters the eye pieces "E" at the opposite end, which are held to the

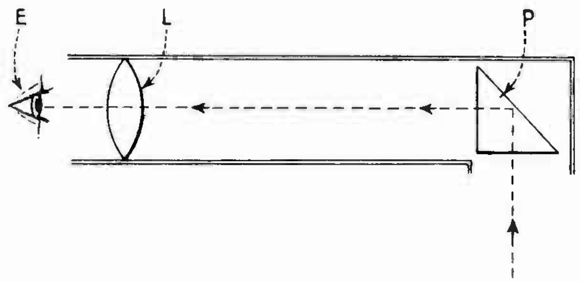

Figure 25

eyes when the instrument is in use. The main reason for using prisms is to provide a longer distance of light travel between lenses "L" where the light enters the instrument and lenses "L'" where the light enters the eyes. The magnifying power of a telescope or field glass is dependent to a large degree on this distance between lenses.

By the use of prisms, the same length of light travel can be obtained in comparatively short binoculars as in straight tubes or telescopes which are several times longer.

The "periscope" shown in Figure 25 makes use of a prism merely to take the beam of light from an "exciter" lamp and turn it at right angles, so that the sound service man may in effect see around a corner. Referring to the drawing, the light first enters the glass prism "P," next it is refracted at right angles through the tube of the periscope and then passes through lens "L" to the eye "E."

Another lesson dealing with combination lenses used in motion picture projectors, cameras, and sound-on-film recorders includes in addition the subject of mirrors and laws of reflection.

EXAMINATION QUESTIONS

1. Draw a bi-convex lens showing path of rays from a point source through the lens, to the focal plane.

2. Show by a sketch how the wave front of parallel rays is changed passing from air to water at an angle.

3. Has a convex lens with a comparatively thick center a longer or shorter focal length than a lens with a thinner center?

4. Draw a sketch of a double-concave lens showing path of light rays through it from a point source.

5. What kind of image does a convex lens form? A concave lens?

6. Show by the wave front method why moving the point source of light nearer the lens changes the location of the image.

7. How may you quickly determine the focal length of a convex lens?

8. What type of lens is used in the lamphouse of a projection machine?

9. Draw an edge view of a convex lens and a concave lens, showing in dotted outline how each can be roughly divided into two prisms.

10. How does the eye judge distance or comparative size?

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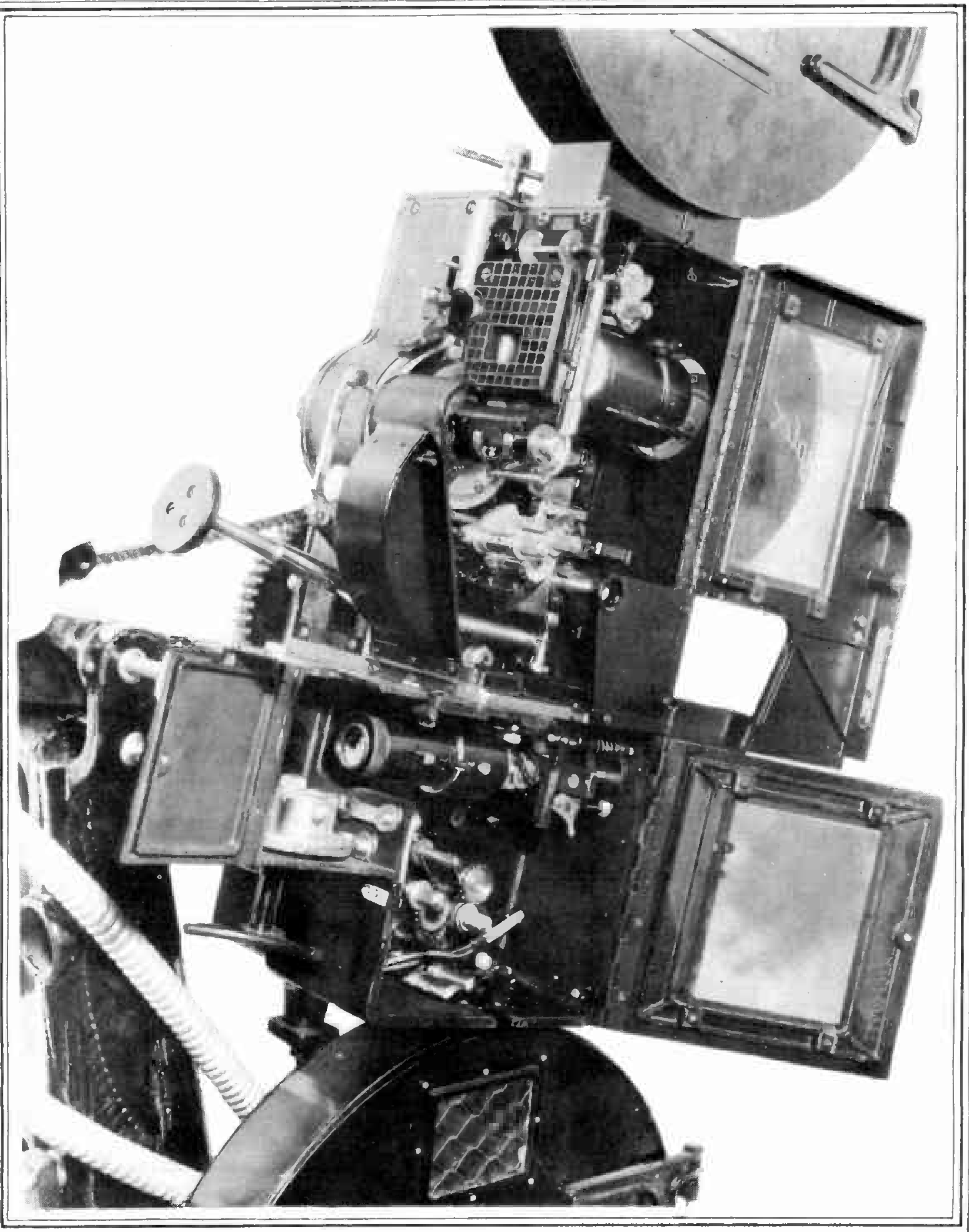

Sound head compartment with door open showing lens tube.

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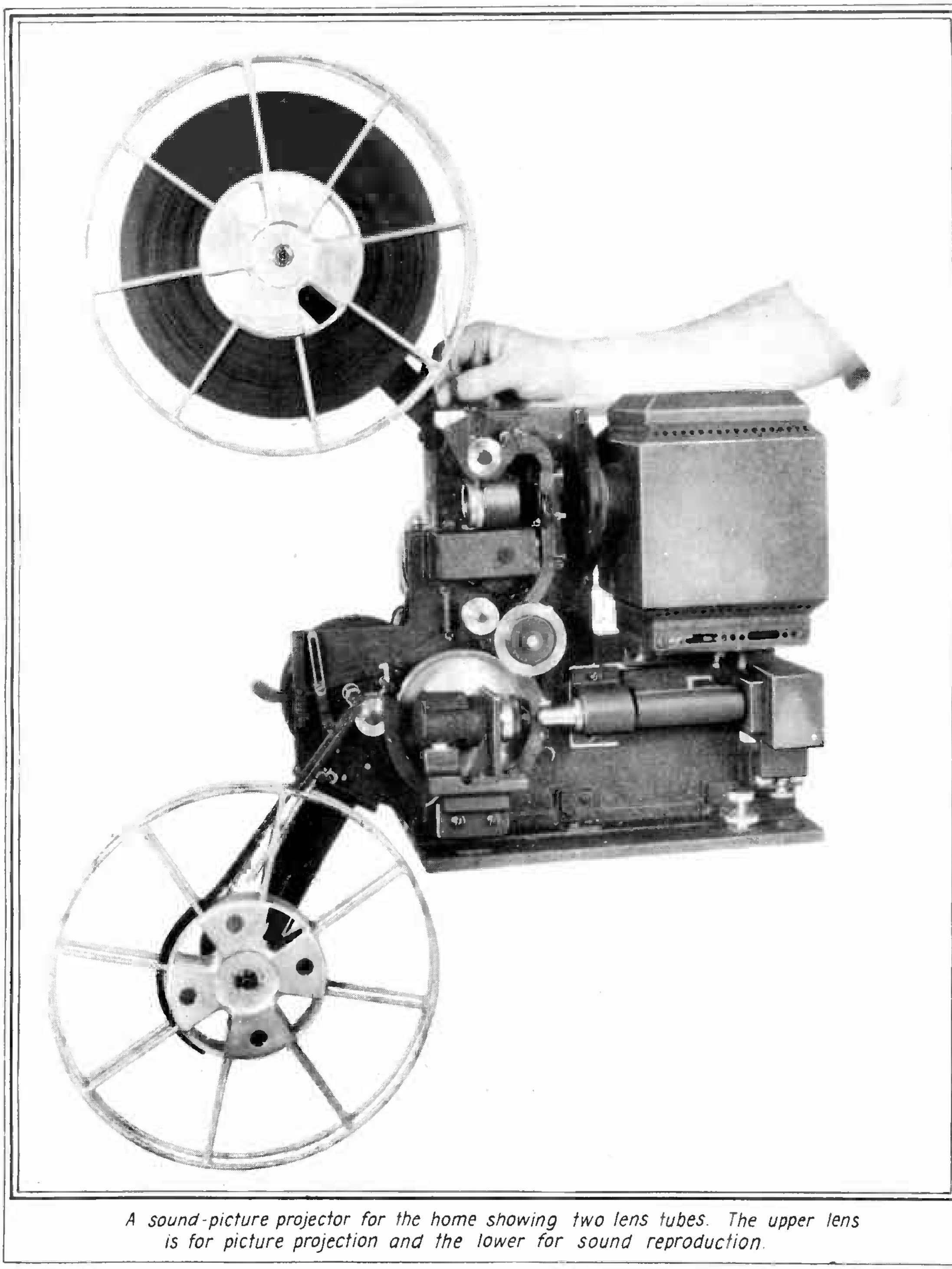

A sound-picture projector for the home showing two lens tubes. The upper lens is for picture projection and the lower for sound reproduction.

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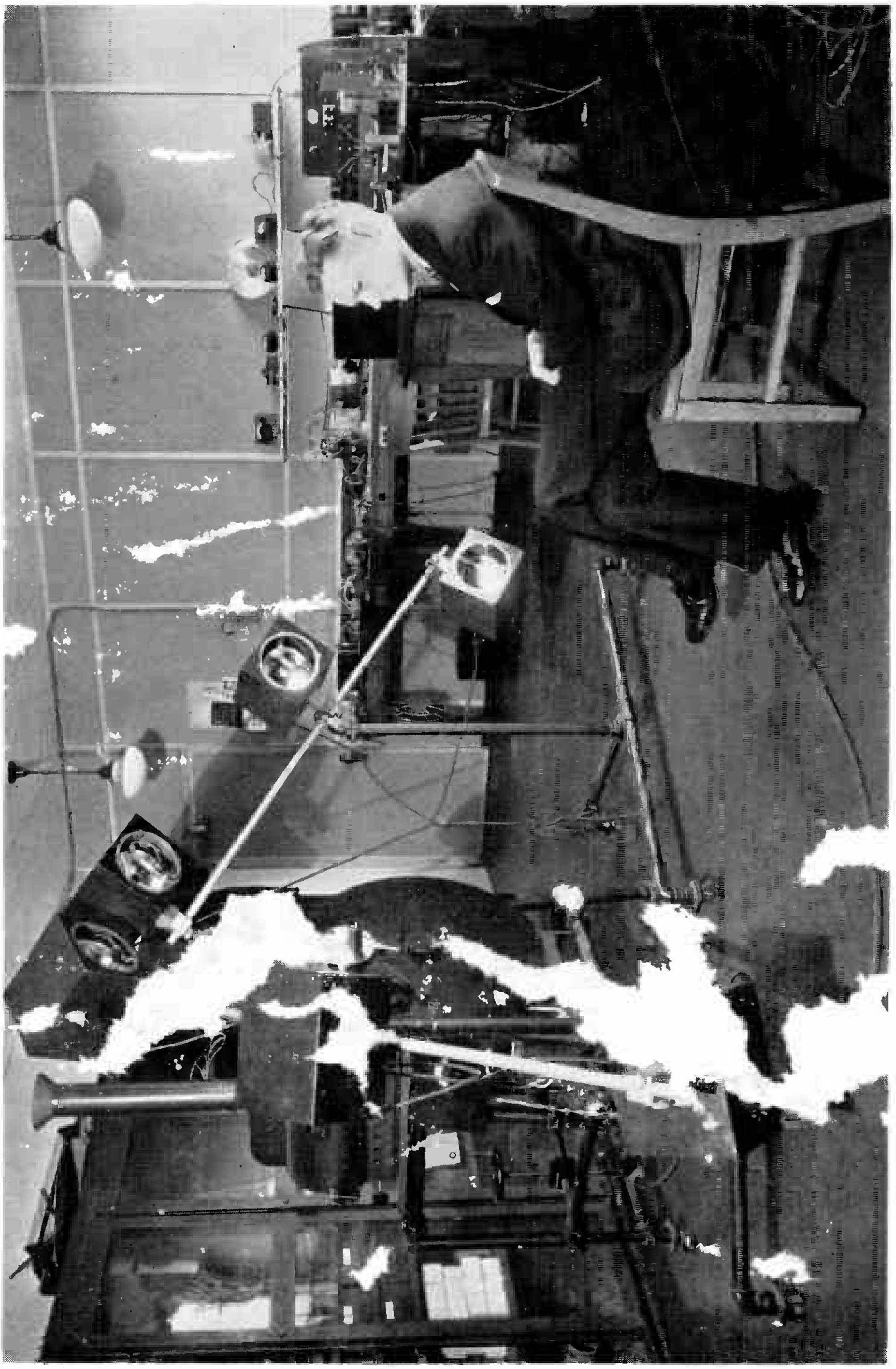
The reflector on each lighting unit prevents waste of light by directing light rays on the scene being photographed.

Combination Lenses and Reflectors

Vol. 58, No. 8

Dewey Classification R 580



A battery of six reflectors gather light from the television subject and direct it to the photoelectric cells

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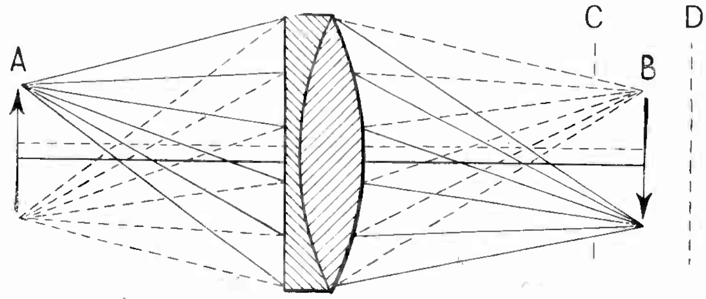
Combination Lenses and Reflectors

Distortion in Lenses

The table of comparative densities of various materials in another lesson showed that different transparent materials or mediums through which light travels have different densities. For examples of this peculiarity we have water which is denser than air, and glass which is denser than water. An examination of this chart shows further that even different kinds of glass have different densities. For instance referring to the chart it will be noted that flint glass is more dense than crown glass. At this time we wish to point out the fact that different mediums have densities of varying degree and the greater the density of any particular medium the more will it refract or bend light rays. As an



FIG[illegible]—*How a true image is formed b*[illegible]*ns.*

illustrat[illegible] flint glass ha[illegible] power than crown glas[illegible] kinds of glass just mention[illegible]d ex[illegible]ing combination or [illegible]rected lense[illegible] they a[illegible]apable of correct[illegible] ma[illegible]istortion present in sing[illegible] uncorrected len[illegible] namely, spherical aberration [illegible] at[illegible]ration.

Spherical Aberration

Spherical aberration is the distortion of an image caused by the failure of a simple or uncorrected lens to focus all the rays of light passing through it at the same distance from the lens. We know that in order to produce a true image of an object a lens must gather rays of light from every point of the obj[illegible]nd focus them on a plane surface, l[illegible] a screen, in proper relation to each other, or in other words the rays must have the same relation to each other as they had when leaving the object.

Figure 1 shows how a true image is formed by a corrected lens and it can be seen that the rays of light leaving each point of the object "A" is brought to a focus at the same distance from the center of the lens. These many points of light form an image "B" of the object in reversed form the image being clear and sharp only because the points are in focus at the focal plane of the lens. If some of the points of light came to a focus at "C", some at "B", and others at "D", they would not form a true image of the object.

Figure 2, shows how an uncorrected lens focuses the rays passing through its center at a greater distance from the lens than the rays passing through the edges of the lens, and it can be seen that at no place are all the rays brought to a point. This fault of uncorrected lenses is due to the fact that near the edges of the lens the light rays are refracted out of proportion to those passing through points nearer the center. We know that at the exact center there is no refraction at all, because the rays of light passing through at this point are on a line with the normal of the lens surface at which place no refraction occurs. Figure 2, shows that the rays from various parts of the lens are focused at different distances from the lens or on different planes, as on planes "A" and "B". It should be realized that each part of an uncorrected lens from the center out to the edge has a different focal plane although only two points have been shown in Figure 2 to simplify the diagram.

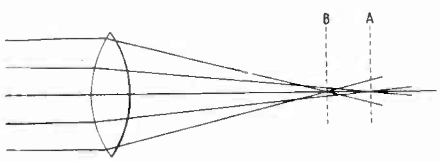


FIGURE 2—*An uncorrected lens does not focus all rays to a single point.*

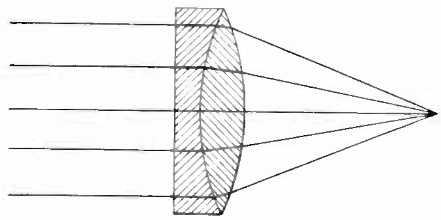


FIGURE 3—*Construction of a corrected lens.*

It is known that if the rays of light passing through the lens between the center and the edge are made to focus at a point further away from the lens, then all the rays can be brought to a focus at a single plane, as for instance to a plane "A" in Figure 2. The method employed in the manufacture of a lens is based on this fact and a corrected lens becomes an improvement over a simple lens by using two kinds of glass each having a different density and form as shown in Figure 3, the two kinds of glass used in most lenses being crown glass and flint glass. The rays that would be focused too close to the lens in an uncorrected lens are now caused to change their courses and come to a focus at a single focal plane by the different refractive powers of these two materials when used together.

Chromatic Aberration

Many different forms of this type of corrected lens are found in actual practice but the purpose of each of them is the same, to correct distortion and produce a clear, sharp image of the source with the least possible loss of light. The other form of distortion, chromatic aberration, mentioned in the first paragraph of this lesson, is caused by the fact that a simple, uncorrected lens separates the various colors which together make white light and focuses each color at a different focal plane. Thus, a beam of white light striking upon such a lens will have that part of it which passes through the lens nearest its edges, separated into the various colors which make up the "spectrum", the light being focused at various distances from the lens, the violet color coming to a focus nearest the lens, and the red color furthest away from the lens.

This chromatic aberration is always present in the type of condenser lens used in the lamphouse of a motion picture projector and inasmuch as the lens produces a ring of color on the outside edges of the spot of light thrown on the aperture of the picture head, we now see more clearly that the spot of light must not be allowed to become too small or some of the colored light will pass through the aperture and appear on the motion picture screen. Occasionally, this color is seen by the audience when the arc sputters for a moment, changing its position and throwing the edge of the spot on the aperture, thus passing the color through to the screen. Figure 4 shows how the various colors of the spectrum are focused at different planes by an uncorrected lens, such as a convex condenser lens. The dotted line "V" is the plane at which the violet rays are focused, "B" the blue, "G" green, "Y" yellow, "O" orange and "R" red. By correcting the lens as shown in Figure 3, the various colored rays are caused to come to a focus at the same plane and the colors joining each other produce white light. A very conclusive demonstration that these various colors, when joined, will produce white, is to make a cardboard wheel and paint or chalk in segments of these colors shaped like pieces of pie. When the wheel is revolved rapidly persistence of vision causes the colors to blend so that the entire wheel or disc appears white.

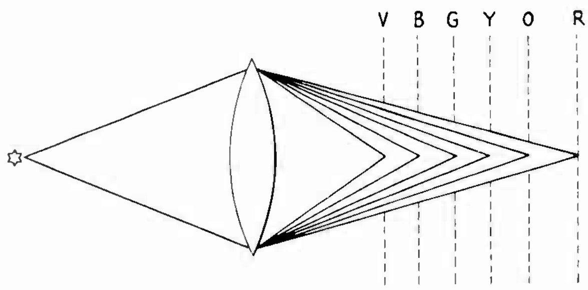


FIGURE 4—*Separation of white light into colors.*

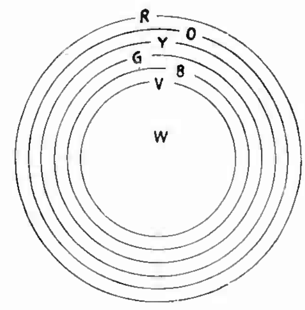


FIGURE 5—*Showing the projection of the light of Figure 4 on a screen.*

In Figure 4 only the rays of light from the source that strike the edges of the lens are shown because it is at the edges of a lens that the distortion or aberration is most marked. The color rings shown in Figure 4 would appear in the positions shown in Figure 5 if they were projected to a screen. The colored rings from the inside out are violet, blue, green, yellow, orange, and red, while the circle in the center "W" is white due to the fact that the white light from the source, passing through the central area of the lens is not separated into colors. Therefore, in motion picture work usually when color shows up on the screen it is because the light of the arc is focused to too small a spot on the aperture and instead of passing only the white center of the beam through the aperture, a part of the colored edges of the spot is also getting through to the screen. It is evident that when this condition occurs the appearance of the picture on the screen is damaged by this rainbow of colors drifting around the edges of the screen. While corrected lenses in the picture head prevent chromatic aberration of the light delivered to them at the aperture, if the light is already colored by condenser lens distortion then the screen will show colored light. The remedy in this case is to enlarge the size of the spot so that only the white center of it passes through the aperture, while the colored edges are cut off by the cooling plate of the picture head.

Combination or Corrected Lenses

Figure 6, shows a modern combination lens, made by Zeiss, used in photography, the focal length of which is 4 inches which means that parallel rays of light converge as shown at the focal plane "F", or principal focus which is located 4 inches from the lens. This plane "F" is where the film is placed in a motion picture camera and the image of the scene being photographed is brought to a sharp focus in order to expose the sensitive emulsion on the film. As can be seen in Figure 6, the path of the rays through the different combinations that make up the complete corrected lens changes as it passes through so that when the rays finally emerge or come out of the lens they are free from spherical and chromatic aberration and come to a sharp, clear focus at the focal plane "F".

The two kinds of glass used in this lens, namely, crown and flint, are shown by diagonal lines running in a certain direction in one case and in an opposite direction in the other. The part of the lens combination on the right is made up of two kinds of glass cemented together so that no air space separates them and since the cement being used is balsam cement, which has a density about equal

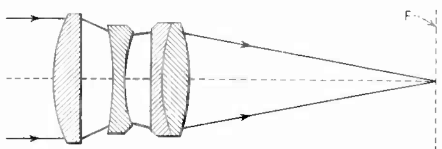


FIGURE 6—*A combination or corrected lens.*

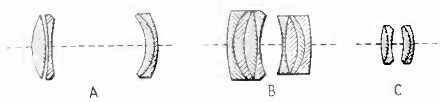


FIGURE 7—*Lenses (a) Tele Tessar (b) Universal (c) Wide Angle.*

to glass there is therefore no refractive effect as the light passes from the glass to the cement or from the cement to the next glass surface. Inasmuch as there is no air space between the two sections of glass the only refraction that occurs is due to the difference in density between the crown glass and the flint glass. This lens is known as an extra-rapid lens because it will allow a large amount of light to pass through in a short time thus permitting very rapid exposures of short duration to be made as in the case of high speed motion picture photography which was discussed in a previous lesson.

Other types of Zeiss lenses are designed for various purposes several combinations of which are shown in Figure 7. "A" is known as the Tele Tessar and is a long focus lens for use in "bringing distant objects closer". As a telescope when held to the eye enlarges distant objects to the vision, so in like manner a Tele Tessar lens makes a distant object appear much closer on the film. "B" is known as a universal lens because it is not necessary to focus on objects at different distances from the lens in order to get a sharp image at the focal plane or film. The lens is fixed at a certain distance from the film and all objects beyond a certain distance from the lens will be in focus. "C" is a wide angle lens used to photograph interiors where a large scene is to be taken but where it is not possible to get the camera back far enough to get the whole scene with an ordinary lens. This lens is also used for outdoor panorama scenes where it is desired to take a picture of a large section of scenery. All of these combinations are made of glass material of various densities cemented together.

Lenses are held in place in the proper position by means of lens mounts, which are metal tubes that can be screwed into the camera front. In the case of motion picture cameras the various lens combinations used for different purposes are mounted on a vertically revolving turret which allows any lens to be rotated to a position before the camera aperture, as we saw in the illustration of a

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standard motion picture camera in a previous lesson. Figure 8 shows the lens combinations which were described in Figure 7 mounted in lens tubes. "A" is the Tele Tessar, "B" the Universal, and "C" the wide angle combination.

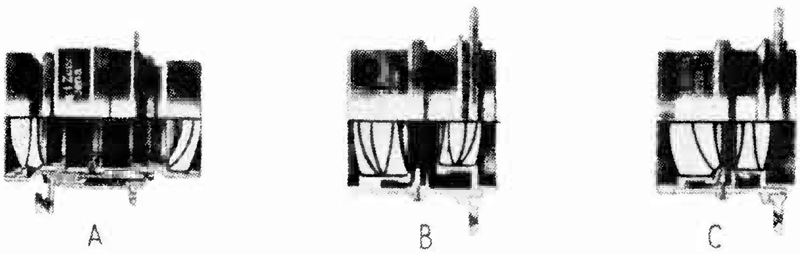

FIGURE 8—*How Zeiss Lenses are mounted.*

Use of Lenses in Motion Pictures

The action of a lens used in a motion picture projector is in certain ways quite the opposite of a lens in a camera. For instance, the lens in a camera focuses the light coming from the object to a small image on the film, in other words the object is usually larger than the image. This is more clearly seen in Figure 9 where "A" is the camera lens, "B" a large arrow which represents the object to be photographed, and "C" the image of this object focused on the film in the camera. If we turn this sketch around and add a source of light, shown passing through the condenser lens "E" in Figure 10, we have an arrangement that shows how the object, in this case the arrow on the posi-

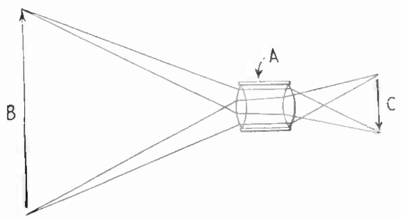

FIGURE 9—*Small image of large object produced by a lens.*

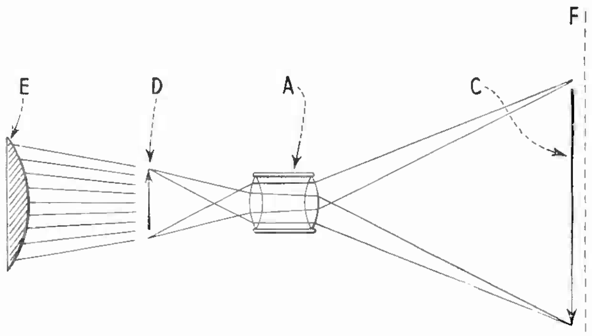

FIGURE 10—*Projection of film image to screen by projector lens.*

tive film in the aperture of the motion picture head, is projected to the screen as an enlarged image. With the aid of Figures 9 and 10 it is possible to show the paths of light rays from the taking of the picture by the camera, to its projection on the theatre screen.

Referring to Figure 9 first, the object "B" to be photographed reflects rays of light which enter the camera lens "A" and are focused to an image "C" on the sensitized negative film in the camera. The action of the light rays aided by chemical development later in the process, produce an image of the arrow in metallic silver on the negative film which is used to "print" a "positive" on another strip of film. This positive is threaded into a projector in the operating booth in the theatre and the light from an arc lamp is focused by the condenser lens "E" in Figure 10 on the positive film "D" as it passes through the aperture of the picture head. The light passing through the film enters the projector lens "A" and is focused to an enlarged image "C" on the screen "F". The arrow in these illustrations is used merely to make the sketch clearer and in all cases of actual practice the arrow would be replaced by a scene or a person or whatever the scenario called for in the way of photography. The fact that a lens may be used either for taking or projecting a picture is taken advantage of by some makers of amateur movie equipment, inasmuch as they make cameras which not only take pictures but are also able to project pictures with the aid of an additional light source.

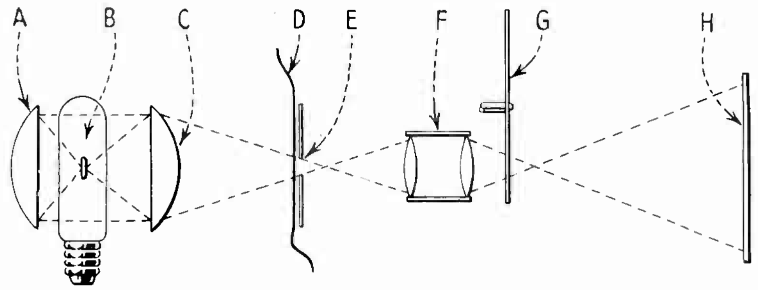

FIGURE 11—*Incandescent lamp and projecting devices.*

The necessary optical elements for motion picture projection are shown in Figure 11. In this illustration, instead of showing an arc light as a source of illumination, an incandescent filament lamp of high candlepower is used. This form of light source is seldom used in theatre projection unless the theatre is extremely small. In general its use is confined to private home installations and to portable projectors such as those made by R.C.A. Photophone and Electrical Research Products, Inc. 1000 watt filament lamps are generally used in these portable projectors and by their use a source of light is secured that is strong enough for the purpose of short range, small screen projection, and yet is more simple in operation and less liable to fire risks than an arc lamp.

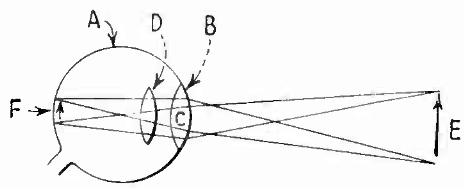

FIGURE 12—The human eye.

Referring to Figure 11, "A", which is a parabolic mirror, reflects the light from the incandescent filament "B" to the cendenser lens "C", which focuses the light to a spot on aperture "E" and the film "D" running before it. The light rays then are received by the projection lens "F" or "projection objective" as it is called, and focused to an enlarged image on the screen "H". The revolving shutter "G" whose action we studied in the lesson on projection, serves to cut the light from the screen at certain intervals to eliminate "travel ghost" and aid persistence of vision.

The Eye

One seldom thinks of the eye as an ingenious arrangement of lenses, yet it is, and moreover in certain respects it functions like a camera as Figure 12 attempts to illustrate. The eye has a lens which takes the rays of light falling upon it from an object, and focuses them to an image on the retina which is an expansion or spreading out of the optic nerve at the back of the eyeball. This retina can be compared to the sensitized film in a camera but, obviously will not keep a permanent record of the

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image focused upon it as would a camera film. The retina will transmit to the brain objects or scenes only while in view and for a brief moment after removal from view, as explained in our study of persistence of vision.

Observe that in Figure 12 the eyeball "A" has the "cornea" "B", the "aqueous humor" "C", and the "crystalline lens" "D", all of which act as a single lens and focus light from an object "E" on the retina "F". It should be borne in mind that the apparent size of an object seen by the eye depends on the size of the image formed by the lenses of the eye on the retina and for this reason the man in

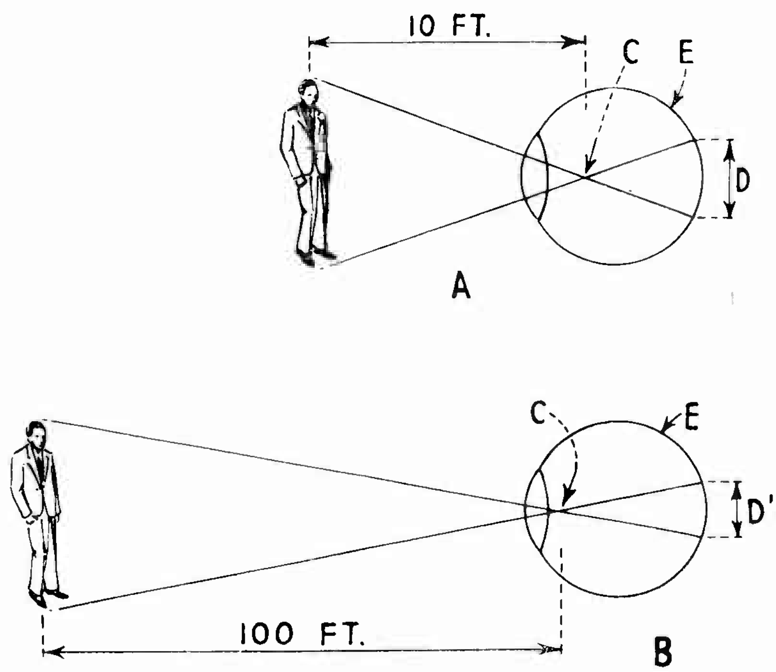

FIGURE 13—*Apparent size of an image depends on the visual angle.*

sketch A, Figure 13, appears in actual life to be ten times as large when he is ten feet away than he appears when he is 100 feet away. This is because the image on the retina of the eye is 10 times as large in "A" as in "B". From experience, however, we have learned that no man is ten times as large as another man and thus we say that one man only "appears" so much smaller than another because he is farther away. In Figure 13 "A" and "B", "E" is the eyeball, "C" the center of the lens system, and "D" the size of image on the retina. The distance "D" in Figure 13A is supposed to be 10 times as long as the distance "D" in 13B. An interesting feature of the lens in an eye is that it focuses objects at different distances, by changing the shape of the lens through muscular movement, thus making a thicker or thinner center of the lens at will. This action is called accommodation and results in a changed focal length of the lens which we know brings the image to a focus at a different place. In order to produce the same effect in cameras the lens is moved back and forth in relation to the film thus bringing the image to a sharp focus no matter what distance the object is from the lens.

Telescope and Microscope

The magnifying power of a telescope is due to the fact that the front lens or objective shown at "O" in Figure 14, forms an image in front of the black lens or eyepiece "L". The rays of light "R" from a distant object in Figure 14 are focused by lens "O" to an image just in front of lens "L". Lens "L" changes the wave form of the light rays so that the eye seems to see the object at "I", as a virtual image in enlarged form.

The microscope works on somewhat the same principle as the telescope, as it forms an enlarged image directly before the eyepiece which is then changed in form by the eyepiece so that an enlarged virtual image is seen by the eye. Figure 15 illustrates the action of a microscope where "O" is the object, "J" the objective lens, "I" the image formed by the objective lens, "L" the eyepiece lens. "E" is the enlarged image which the eye sees in inverted form as was illustrated by "E" in Figure 14.

The microscope is used in sound motion picture work to examine the groove cut into the wax disc as sound is being recorded. The grooves are only 1/100 of an inch apart, that is, there are 100 grooves to the inch along the radius of the wax disc so that in order to see whether the recording is being done properly it is necessary to use a microscope which magnifies each groove so that each

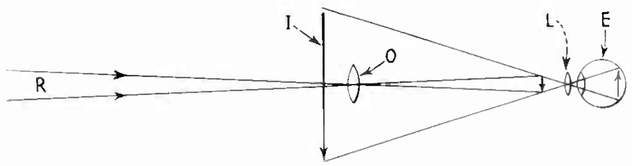

FIGURE 14—*The principle of the telescope.*

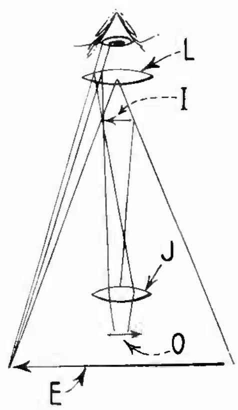

FIGURE 15—*The compound microscope.*

small "wave" cut into it by the recording stylus or needle is clearly visible to the eye. In a following lesson on recording, the microscope will be seen swung into place over the recorder turntable so that the recording engineer can check the operation of the equipment.

Care of Lenses

Lenses, as used in sound motion picture equipment, are expensive and easily damaged, therefore great care must be exercised in handling them. In order to get the best results from lenses it is necessary that they be kept clean, for if oil or fingerprints are allowed to remain on the surface, the sharpness of the image focused by the lens will be seriously affected and what is known as "poor definition" will result. Oil on a lens also causes some of the light to be reflected instead of being transmitted through and this is an undesirable condition because loss of light means a dimmer picture will be found on the screen. Loss of light also means that there is a waste of light and power which may prove expensive. In cleaning a lens only soft, clean, chamois skin or soft cotton material should be used and the surface of the lens should not be rubbed too hard for fear that grit may scratch the glass. A good cleaning fluid for a lens is about half a pint of alcohol diluted with the same amount of water. The lens surface should be washed with this solution and then quickly polished while still wet. Occasionally lens assemblies should be taken apart and the interior surfaces of the various lenses cleaned. In reassembling the lenses in the lens mount special care must be taken to see that they are put back in proper relation to one another.

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Projection or Objective Lenses

Projection lenses are usually made up of a combination of four lenses as shown in Figure 16. "A" shows them unmounted and "B" shows them assembled in a lens mount. The two lenses at the left of each illustration are known as the "back factor" of the combination and are nearest the film, while the other two are called the "front factor". It will be seen that the safe rule to follow in assembling a lens is to have the sides with the greatest convexity toward the screen. The back factor has an air spacing between its two lenses while the lenses of the front factor are cemented together with balsam cement.

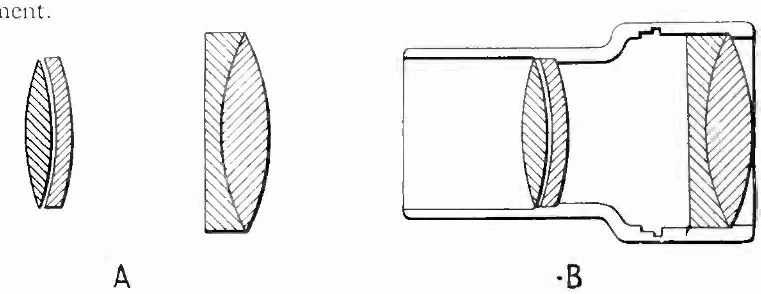

FIGURE 16—*Projection lens (a) Unmounted, (b) mounted.*

The diameter of the lens used in projection is important for if the diameter is too small a large loss of light will result since a small opening will cut off a great deal of light that would reach the screen with a larger lens. However, the smaller the lens opening becomes, the sharper will be the focus of the picture on the screen and the narrower will be the beam of light where it is cut by the revolving shutter; a condition that is desirable. If the projection lens is not of large enough diameter to receive all the light that passes through the aperture from the condenser lens, it will be impossible to evenly distribute illumination over the entire surface of the screen. In this case, the center of the screen will be brighter than the edges and the picture will not be so pleasing to the eye because of the loss of "depth" as this peculiarity is called.

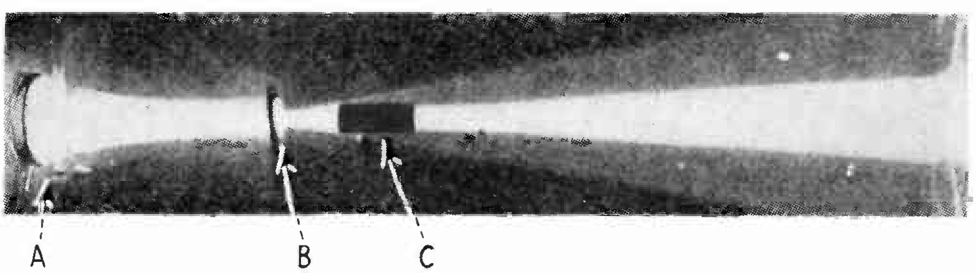

FIGURE 17—*The effect of too small a projection lens.*

This effect of "depth" which gives the impression that the objects in the picture are at different distances from the spectator in the theatre even though the screen as we know is flat, is obtained by proper reproduction on the screen of the light and shadows in the film. The best example of this illusion is seen in stereoscopic pictures of which we shall learn more later. A certain amount of "depth illusion" is possible by the use of (1) proper lighting during the photography of motion pictures and (2) evenly distributed illumination when the picture is projected on the theatre screen.

The effect of too small a projection lens to receive the full beam of light from the aperture is shown in Figure 17 which is an actual photograph of the course of light rays from the condenser lens of a projector, through the aperture and thence through the projection lens. The aperture "B" is the oblong opening that frames each single picture as it is pulled into place by the intermittent movement. The condenser lens "A" focuses a spot of brilliant light from the arc on this aperture, and if the spot is of the right size and properly focused the whole of the picture on the film that is framed by the aperture will be evenly illuminated. If *all* the light from the aperture passes through the projection lens which is shown at "C", then the lens will focus an evenly illuminated image of the film on the screen. Under the conditions shown in Figure 17, however, some of the light coming through the film at the edges of the aperture is not entering the projection lens and therefore is lost as far as the screen is concerned. This means that pictures projected through an optical train like this will have bright centers and dimmer edges which will lessen the depth effect and the enjoyment of the picture by the audience even though they cannot definitely account for the reason. Figure 18 is an illustration of an optical train that will project the picture at the aperture with evenly distributed illumination on the screen, for it can be seen that the entire beam of light from the condenser lens "A", passing through the film at the aperture "B", is received by the projection lens "C" which focuses the light to an image on the screen.

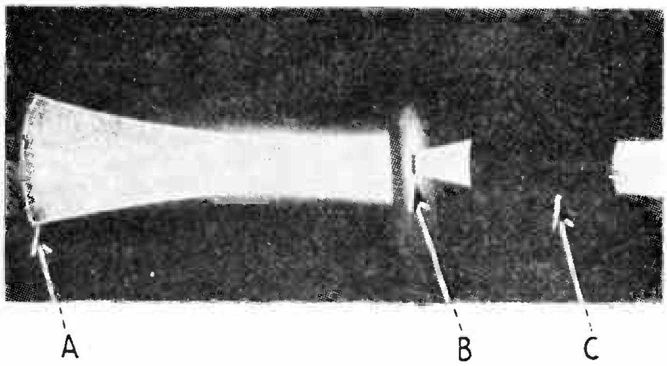

FIGURE 18—*Larger diameter projection lens and its effect on uniform screen illumination.*

Commercial objective, or projection lenses may be obtained in two standard sizes, the "quarter" size or Number 1 lens which has a "free aperture" or opening of about $1\frac{1}{2}$ inch diameter and the "half-size" or Number 2 lens which has a free aperture of about $2\frac{1}{2}$ inch diameter. These lenses, when of good make, usually have the characteristics of: (1) no spherical aberration, which means good definition with no distortion of the image; (2) flatness of field, which means that the image will be equally sharp over the entire surface of the screen; and (3) freedom from chromatic aberration, which means the absence of color fringes in the image. In addition to the above the Number 2 lens gives brilliant screen illumination due to its larger free aperture or opening.

The focal length of the objective lens determines what the size of the picture will be for a certain "throw" or distance between the center of the objective lens and the screen. In the study of single convex lenses we used the term "focal length" to express the distance from the lens that parallel rays of light from a distant source were brought to a single point or focus. The focal length of the lens shown in Figure 19 is five inches because the parallel rays "A" pass through convex lens "B" to a point "C" which is just five inches from the center of the lens. In an objective lens, however, we are dealing with a number of separate lenses that are assembled to form the complete lens combination, so instead of an objective lens having a focal length the assembly has what is called an "equivalent focus" which means that its focus is the same as a single lens of that focal length. To make this clearer look at Figure 20 which shows an objective lens which has an equivalent focus equal to the focal length of the single lens in Figure 19. In Figure 20, however, the equivalent focus is measured from a point somewhere between the front and back factors of the lens, called the "optical center", to the place where the rays of light are brought to a focus, or the "focal plane". "A" shows the parallel rays of light passing through the objective lens "B" which brings them to a focus at "C".

Selection of Objective Lenses

It must be realized of course that while in Figures 19 and 20 the incident rays are parallel, in the actual use of the lens in a projector the "front" of the light rays passing through the film aperture is very curved. From what was learned earlier in the course we know that when the incident wave front is curved the focal plane is removed further from the lens and in the case of motion picture projection the lens is so designed that it brings the image of the picture in the aperture to a focus on the screen many feet away. This brings us to a place where we can discuss how to select the right lens for a certain sized picture screen and a certain "throw". In other words, the problem arises where a picture house is of a certain length and the screen is a certain distance from the projection booth. If an objective lens with the proper equivalent focus, often abbreviated to E.F., is selected the picture can be made to appear on the screen in any desired size within limits. For instance, let us take a theatre with a throw, or distance from lens to screen of 100 feet. If a lens with an equivalent focus of 2″ is used, the size of the picture on the screen will be approximately thirty-four by forty-five (34 x 45) feet. This is a very short focus lens and gives a large screen picture for a given distance while an extremely long focus lens gives a much smaller picture at the same distance, for instance an 8″ E.F. lens throws a picture only 8½ x 11½ feet at the same distance.

Figure 21 is called a lens table of film projection, because with a given size of aperture which is about ¾″ by 1″ in standard motion picture projection, it gives the size of the picture thrown by

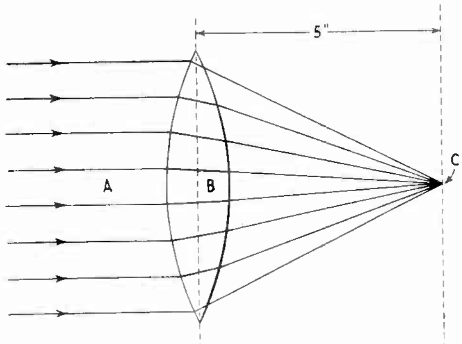

FIGURE 19—*Convex lens with focal point 5 inches from center of lens.*

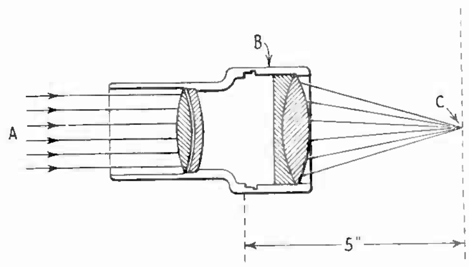

FIGURE 20—*Lens assembly with 5 inch equivalent focus.*

lenses of various E.F. at different distances of throw. Referring to the table, the lefthand column indicates equivalent focal lengths of lenses from 2″ to 8¾″. The top row of figures running from left to right denotes various distances from film to screen, ranging from 15 feet to 116 feet. The rest of the columns indicate the sizes of pictures at various equivalent focal lengths and distances of throw. It will be noticed that in each column opposite an equivalent focus number, there are two figures, the smallest at the top and the largest just below it. The top one of each pair of figures is the measurement in feet from top to bottom of the projected pictures or the height, and the one below it is the width, or left to right measurement of the picture. The proportions of the two measurements are as ¾ is to 1 because the picture on the screen is just an enlarged image of the aperture which is approximately ¾″ by 1″. In using the table to find the proper lens needed to project a picture of a certain size on a screen a known distance from the film, find the distance of throw in the top row of figures and glancing down that column find the size of picture desired. At the extreme left of that row the equivalent focus of the lens needed will be found.

Let us take an example and find the lens needed to project a picture about 15 x 20 feet in size on a screen 90 feet from the projector. Selecting the column with the figure 90 at the top of it we find that running down that column seventeen figures we find the figure 15.24 and directly under it figure 20.31. These are the nearest dimensions to 15 x 20 feet we can find so looking at the number

Lens Table of Film Projection

Distance from Film to Screen

F. F.	15	20	25	30	35	40	45	50	56	60	64	70	76	80	84	90	96	100	104	110	116
2	5.04	6.74	8.44	10.14	11.84	13.54	15.24	16.93	18.97	20.33	21.69	23.73	25.77	27.13	28.49	30.53	32.57	33.93	35.29	37.33	39.36
	6.72	8.99	11.25	13.52	15.78	18.05	20.31	22.58	25.30	27.11	28.92	31.64	34.46	36.17	37.99	40.71	43.42	45.24	47.05	49.77	52.49
2¼	4.48	5.99	7.50	9.01	10.52	12.03	13.54	15.05	16.87	18.07	19.28	21.09	22.91	24.12	25.32	27.14	28.95	30.16	31.37	33.18	34.99
	5.97	7.98	10.00	12.01	14.03	16.04	18.05	20.07	22.48	24.10	25.71	28.12	30.54	32.15	33.76	36.18	38.60	40.21	41.82	44.24	46.55
2½	4.02	5.38	6.74	8.10	9.46	10.82	12.18	13.54	15.17	16.26	17.34	18.98	20.61	21.70	22.78	24.42	26.05	27.14	28.22	29.86	31.49
	5.36	7.17	8.99	10.80	12.61	14.62	16.24	18.05	20.22	21.67	23.12	25.30	27.47	28.92	30.37	32.55	34.72	36.17	37.62	39.80	41.97
2¾	3.65	4.89	6.12	7.36	8.59	9.83	11.06	12.30	13.78	14.77	15.76	17.24	18.73	19.72	20.70	22.19	23.67	24.66	25.65	27.13	28.61
	4.87	6.52	8.17	9.18	11.46	13.11	14.76	16.40	18.38	19.70	21.01	22.99	24.97	26.29	27.61	29.59	31.56	32.88	34.20	36.18	38.15
3	3.34	4.47	5.61	6.74	7.87	9.00	10.14	11.27	12.63	13.54	14.44	15.80	17.16	18.07	18.97	20.33	21.69	22.60	23.50	24.86	26.22
	4.46	5.97	7.48	8.99	10.50	12.01	13.52	15.03	16.85	18.05	19.26	21.07	22.89	24.10	25.30	27.12	28.93	30.14	31.35	33.16	34.97
3¼	3.08	4.13	5.17	6.22	7.26	8.31	9.35	10.40	11.65	12.49	13.33	14.84	15.84	16.67	17.51	18.77	20.02	20.86	21.69	22.95	24.20
	4.11	5.50	6.90	8.19	9.69	11.08	12.48	13.87	15.54	16.66	17.77	19.45	21.12	22.23	23.35	25.02	26.70	27.81	28.93	30.00	32.27
3½	2.86	3.83	4.80	5.77	6.74	7.72	8.69	9.66	10.82	11.60	12.38	13.54	14.71	15.48	16.26	17.43	18.59	19.37	20.14	21.31	22.47
	3.81	5.10	6.40	7.69	8.99	10.28	11.58	12.87	14.43	15.46	16.50	18.05	19.60	20.64	21.68	23.23	24.78	25.82	26.86	28.41	29.96
3¾	2.66	3.57	4.47	5.38	6.28	7.19	8.10	9.00	10.09	10.82	11.54	12.63	13.72	14.44	15.17	16.25	17.34	18.07	18.79	19.88	20.97
	3.55	4.76	5.97	7.17	8.38	9.59	10.80	12.00	13.46	14.42	15.39	16.84	18.29	19.26	20.22	21.67	23.12	24.09	25.06	26.51	27.96
4	2.49	3.34	4.19	5.04	5.98	6.74	7.59	8.44	9.46	10.14	10.82	11.84	12.86	13.54	14.22	15.24	16.25	16.93	17.61	18.63	19.65
	3.32	4.45	5.59	6.72	7.85	8.98	10.12	11.25	12.61	13.52	14.42	15.78	17.14	18.05	18.95	20.31	21.67	22.58	23.48	24.84	26.20
4¼	2.34	3.14	3.94	4.74	5.54	6.34	7.14	7.94	8.90	9.54	10.18	11.14	12.10	12.74	13.38	14.34	15.30	15.94	16.57	16.52	18.48
	3.12	4.19	5.25	6.32	7.38	8.45	9.52	10.58	11.86	12.72	13.57	14.85	16.13	16.98	17.83	19.11	20.39	21.25	22.10	23.38	24.66
4½	2.21	2.97	3.72	4.48	5.23	5.99	6.74	7.50	8.40	9.01	9.61	10.52	11.42	12.03	12.63	13.54	14.44	15.05	15.65	16.56	17.47
	2.95	3.96	4.96	5.97	6.98	7.98	8.99	10.02	11.21	12.01	12.82	14.03	15.23	16.04	16.85	18.05	19.26	20.07	20.87	22.08	23.29
4¾	2.09	2.81	3.52	4.24	4.95	5.67	6.38	7.10	7.96	8.53	9.10	9.96	18.82	11.39	11.96	12.82	13.68	14.25	14.83	15.86	16.54
	2.79	3.74	4.70	5.65	6.61	7.56	8.51	9.47	10.61	11.38	12.14	13.28	14.43	15.19	15.15	16.23	17.32	18.05	18.77	19.86	20.95
5	1.98	2.66	3.34	4.02	4.70	5.38	6.06	6.74	7.55	8.10	8.64	9.46	10.27	10.82	11.39	12.21	13.03	13.57	14.12	15.02	15.75
	2.64	3.55	4.45	5.30	6.27	7.17	8.08	8.98	10.07	10.80	11.52	12.62	13.70	14.42	14.78	15.84	16.90	17.61	18.32	19.38	20.44
5¼	1.89	2.54	3.18	3.83	4.48	5.12	5.77	6.42	7.20	7.72	8.23	9.01	9.79	10.30	10.82	11.60	12.38	12.89	13.41	14.19	14.96
	2.51	3.37	4.24	5.10	5.96	6.83	7.69	8.55	9.59	10.28	10.97	12.00	13.04	13.73	14.42	15.46	16.49	17.18	17.87	18.91	19.94
5½	1.81	2.42	3.04	3.66	4.28	4.89	5.52	6.13	6.87	7.36	7.86	8.60	9.34	9.83	10.33	11.07	11.81	12.31	12.80	13.54	14.28
	2.40	3.22	4.05	4.87	5.70	6.53	7.35	8.17	9.16	9.82	10.47	11.46	12.45	13.11	13.77	14.76	15.73	16.40	17.07	18.06	19.04
5¾	1.72	2.31	2.90	3.49	4.08	4.67	5.27	5.86	6.57	7.04	7.51	8.22	8.93	9.40	9.99	10.59	11.29	11.77	12.24	12.95	13.66
	2.29	3.08	3.87	4.65	5.44	6.23	7.02	7.81	8.75	9.38	10.01	10.96	11.90	12.53	13.16	14.11	15.06	15.69	16.32	17.26	18.21
6	1.64	2.21	2.77	3.34	3.91	4.47	5.04	5.60	6.28	6.74	7.19	7.87	8.55	9.00	9.46	10.14	10.82	11.27	11.72	12.40	13.08
	2.19	2.95	3.70	4.46	5.21	5.97	6.72	7.48	8.38	8.99	9.59	10.50	11.40	12.01	12.61	13.52	14.42	15.03	15.63	16.54	17.45
6¼	1.57	2.11	2.66	3.20	3.75	4.29	4.83	5.38	6.03	6.46	6.90	7.55	8.20	8.64	9.07	9.73	10.38	10.81	11.25	11.90	12.55
	2.10	2.82	3.55	4.27	5.00	5.72	6.45	7.17	8.04	8.62	9.20	10.07	10.94	11.52	12.10	12.97	13.84	14.42	15.00	15.87	16.74
6½	1.51	2.03	2.56	3.08	3.60	4.12	4.65	5.17	5.80	6.22	6.63	7.26	7.89	8.31	8.72	9.35	9.98	10.40	10.82	11.44	12.07
	2.02	2.72	3.41	4.11	4.81	5.51	6.20	6.90	7.74	8.39	8.85	9.69	10.53	11.08	11.64	12.48	13.31	13.87	14.43	15.27	16.10
6¾	1.45	1.95	2.46	2.96	3.46	3.97	4.47	4.98	5.58	5.98	6.38	6.99	7.59	8.00	8.40	9.00	9.60	10.01	10.41	11.02	11.62
	1.94	2.61	3.28	3.95	4.63	5.30	5.97	6.64	7.44	7.98	8.52	9.32	10.13	10.67	11.20	12.01	12.81	13.35	13.89	14.69	15.50
7	1.40	1.89	2.37	2.86	3.34	3.83	4.31	4.80	5.38	5.77	6.16	6.74	7.32	7.71	8.10	8.68	9.27	9.65	10.04	10.62	11.21
	1.87	2.52	3.16	3.81	4.46	5.11	5.75	6.40	7.17	7.70	8.21	8.99	9.77	10.28	10.80	11.58	12.36	12.87	13.39	14.11	14.94
7¼	1.35	1.82	2.29	2.76	3.23	3.69	4.16	4.63	5.19	5.57	5.94	6.51	7.07	8.44	7.82	8.38	8.94	9.32	9.69	10.26	10.82
	1.80	2.42	3.05	3.67	4.30	4.92	5.69	6.17	6.92	7.42	7.92	8.67	9.43	9.93	10.42	11.17	11.93	12.43	12.93	13.68	14.43
7½	1.30	1.75	2.21	2.66	3.11	3.57	4.02	4.47	5.02	5.38	5.74	6.28	6.83	7.19	7.55	8.10	8.64	9.00	9.37	9.91	10.45
	1.74	2.34	2.95	3.55	4.16	4.76	5.37	5.97	6.69	7.18	7.66	8.39	9.11	9.59	10.08	10.80	11.53	12.01	12.50	13.22	13.95
7¾	1.26	1.70	2.14	2.58	3.01	3.45	3.89	4.33	4.86	5.21	5.56	6.08	6.61	6.96	7.31	7.84	8.36	8.71	9.07	9.59	10.12
	1.68	2.26	2.85	3.43	4.02	4.60	5.19	5.77	6.48	6.95	7.42	8.12	8.82	8.29	9.76	10.46	11.16	11.63	12.10	12.80	13.50
8	1.22	1.64	2.07	2.49	2.92	3.34	3.77	4.19	4.70	5.04	5.38	5.89	6.40	6.74	7.08	7.59	8.10	8.44	8.78	9.29	9.80
	1.62	2.19	2.75	3.32	3.89	4.45	5.02	5.09	6.27	6.76	7.18	7.86	8.54	8.50	9.44	10.12	10.80	11.25	11.70	12.38	13.06
8¼	1.18	1.59	2.00	2.42	2.83	3.24	3.65	4.06	4.56	4.89	5.22	5.71	6.21	6.54	6.86	7.36	7.85	8.18	8.51	9.01	9.50
	1.57	2.12	2.67	3.22	3.77	4.32	4.87	5.41	6.07	6.57	6.95	7.61	8.27	8.71	9.15	9.81	10.47	10.91	11.35	12.01	12.66
8½	1.14	1.54	1.94	2.34	2.74	3.14	3.54	3.94	4.42	4.74	5.06	5.54	6.02	6.34	6.66	7.14	7.62	7.94	8.26	8.74	9.22
	1.52	2.05	2.59	3.12	3.65	4.19	4.72	5.25	5.89	6.32	6.74	7.38	8.02	8.44	8.88	9.52	10.16	10.58	11.01	11.65	12.20
8¾	1.11	1.50	1.88	2.27	2.66	3.05	3.43	3.82	4.29	4.60	4.91	5.38	5.84	6.15	6.46	6.93	7.40	7.71	8.02	8.48	8.95
	1.48	2.00	2.51	3.03	3.55	4.06	4.58	5.10	5.72	6.13	6.65	7.17	7.79	8.20	8.62	9.24	9.86	10.27	10.63	11.31	11.93

FIGURE 21—NOTE: This chart applies to standard apparatus

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opposite, in the left hand column we find 4 which is the focal length of the lens needed. As another example, let us assume that we have a "throw" of 110 feet and we wish a picture 9 x 12 feet in size. Running down the column headed 110 we find near the bottom the figures 9.01 and 12.01 and at the left in the E.F. column opposite is found 8¼ which is the proper lens for this condition.

It is evident that the lens table can be worked the other way around also and that the size of the picture for a certain throw can be found if the E.F. of the lens is known. It should be realized here that the larger the picture the less brilliant will be its illumination providing the light source remains the same. Therefore, it is only reasonable to expect that if a larger picture is desired more light must be provided at the lamphouse, and this is usually done by using larger carbons and higher current in the arc. That is why houses with large screens use arcs of upwards of 135 amperes current consumption when a smaller house with a smaller screen may use as low as 35 amperes on the arc. There are other factors which also govern the amount of light needed to project a satisfactory picture, such as screen surfaces, shape of the theatre, etc., which will be taken up at a future time in the course.

Reflection of Light

When light rays strike a polished surface, such as a mirror, regular reflection takes place. For example, in Figure 22 consider "A" as a source of light. The light from "A", upon striking the surface of the mirror "M", will be turned away, that is, reflected in a certain definite direction. The

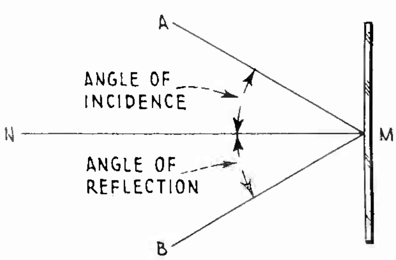

FIGURE 22—*Reflection of light from a plane mirror.*

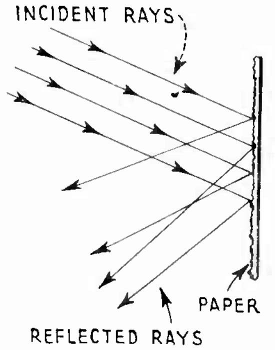

FIGURE 23—*Irregular or diffused reflection.*

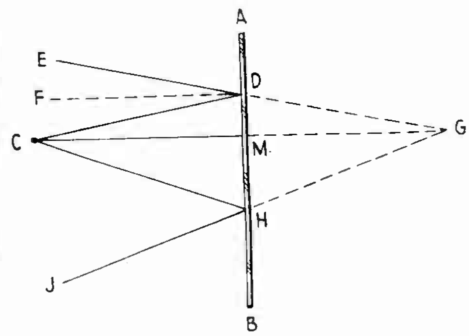

FIGURE 24—*The image of C appears behind the mirror at G.*

law that determines the direction the reflected ray will take is as follows: "*The angle of reflection is equal to the angle of incidence and the two angles thus made will be in the same plane*". Thus we learn that light striking the mirror at "M" will be reflected in the direction "M B". "A M" is called the incident ray, "M B" the reflected ray and "M N" the normal, which is drawn perpendicular to the surface of the mirror. Angle "A M N" is called the angle of incidence, and angle "B M N" the angle of reflection.

Boys often apply this principle in the school room, catching a sun beam on a small pocket mirror and then, by changing the position of the mirror, causing the reflected light to dance across the blackboard and perhaps into the eyes of a student.

Diffused Reflection

Now if we replace the mirror by a non-polished surface, such as a sheet of white paper as suggested in Figure 23, another condition becomes apparent. No longer do we obtain regular reflection because the rough surface of the paper acts as hundreds of small mirrors, the placement of which have no orderly arrangement. The light, therefore, is reflected in all directions. Reflection of this nature is called irregular or diffused reflection and enables us to see other planets and stars as they become illuminated by the sun, the diffused reflection from them traveling to the earth. Daylight, as we call it, is the sunlight repeatedly reduced in strength by an uncountable number of reflections from many surfaces, such as dust particles, the ground, shrubs, trees, houses, buildings, and so on. Now that we are familiar with some of the terms used in the study of reflection and diffusion we can proceed to the study of mirrors which will bring out facts concerning the reflection of light rays.

The Plane Mirror

An ordinary flat mirror, better termed a plane mirror, is a plate of glass having a smooth surface which, after being cleaned, is coated on one side with a solution of silver nitrate, ammonium hydroxide, and some reducing agent such as formaldehyde. This film of silver adheres to the surface of the glass and, after drying, it is varnished to prevent the air from reaching the metallic coating of silver. The coating of silver furnishes a good reflecting surface for light rays.

Assume that "A B", Figure 24 is a plane mirror fastened to the wall. Point "C" is a source of light producing a ray of light "CM" normal to the mirror. "CD" is any other ray striking the mirror at "D". The ray "CM" is reflected back upon itself but the ray "CD" will be reflected along the line "DE" in such a way that the angles "C D F" and "E D F" are equal. Now go back of the mirror and prolong the line "E D" and "CM" by dotted lines until they meet at point "G". We now have two triangles "C M D" and "G M D" which are similar and which make line "M G" equal to "M C". In the same way a third ray "C H" striking the mirror at "H" will be reflected in a line, the prolongation of which, if extended back of the mirror, will cut the line "C M" at "G". From this we are able to understand a peculiar fact concerning a reflecting surface such as a plane

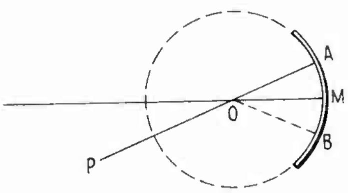

FIGURE 25—*Principle of the concave mirror.*

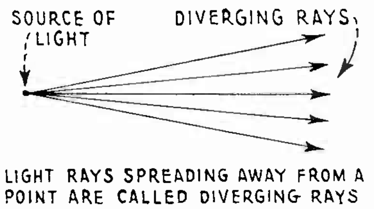

FIGURE 26.

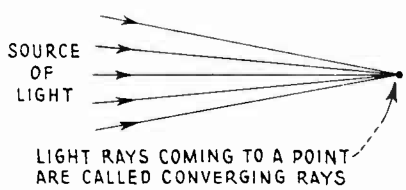

FIGURE 27.

mirror. If you stand anywhere in front of this mirror light rays will strike the eye and appear as though they were originating at "G" instead of at "C" and you will have produced for yourself an optical illusion, for an image of the light source "C" will appear to you as being situated at point "G".

It was previously stated that (1) an object to be seen must first be illuminated, which is true; and also that (2) light travels in straight lines. Furthermore, if an object is to be seen there must be no obstruction between the eye and the illuminated object that will act as a barrier to the light rays. By using a mirror, however, we can see around corners or view events taking place behind us, but this does not alter the law that light travels in straight lines because, between the object "C" and the mirror, there must be no obstruction for the light ray, neither can there be a barrier between the mirror and the eye. When you look into a mirror the objects you see appear to be located at some distance behind the mirror, as though you were looking through an opening in the wall. The eye sees only an image of the objects because the light from the objects are reflected light rays striking the eye from the direction of the mirror, and since the eye sends an impulse to the brain only of the direction from which light enters it, the object appears to be in that direction. If the frame of a mirror could not be seen and the reflecting surfaces were not detected the eye would not be able to distinguish the difference between the real object and its image in the mirror.

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Concave Mirrors

Mirrors of spherical or parabolic shape are employed in motion picture work, a small portion of the spherical surface of the mirror being capable of reflecting light. A mirror of this type shown in Figure 25 is called a concave mirror because it reflects light toward what would be the center of the mirror if it were completely circular as suggested by the light dotted circular lines. To explain the terms necessary to understand the reflecting properties of spherical mirrors let "A B" be a section of a circular mirror made by a plane drawn normal to the surface of a sphere or ball which is not shown. Point "O" of this surface will be the center of the mirror and the point shown at "M" will be the "vertex". A straight line drawn between "O" and "M" is given the name "Principal Axis". Any other line, such as "P A", drawn through "O" is called a secondary axis, and an axis, regardless of whether it is principal or secondary is always normal to the surface of the mirror. (Remember that the surface of the spherical mirror is not shown although the section "AB" represents a portion of it.) The angle formed by the lines "B O A" is called the aperture of the mirror.

Principal Focus

Figures 26 and 27 illustrate what is meant by focus. *A focus is a point from which light rays may diverge or a point toward which they may converge.* In Figure 28 assume that light rays from the sun, for example, are moving toward a concave mirror in a path parallel to the principal axis of the mirror. On striking the reflecting surface of the mirror they will be reflected very nearly to

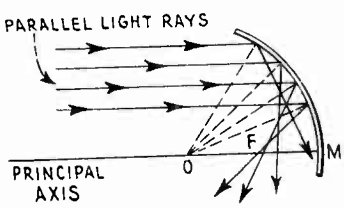

FIGURE 28—*Parallel light rays are concentrated at F by means of the concave mirror M.*

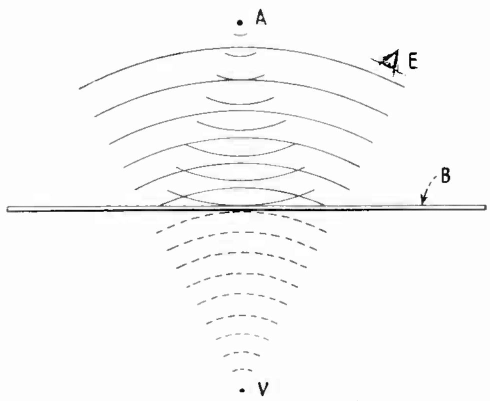

FIGURE 29—*Effect of a plane mirror on a wave front.*

point "F" midway between the vertex "M" and the center of the mirror "O". Those striking the reflector near its edge however will not be reflected to a point very near "F". This is called spherical aberration. The point "F" is called the "principal focus" of the mirror, and the distance from this point to the mirror is called the "focal length" of the mirror. Concentration of light rays from the sun in this manner can be so intense that a sheet of paper placed at the principal focus will promptly have a hole burned through it.

Applying the wave front method to demonstrate the effect of mirrors on light, Figure 29 shows how a wave front from a point source of light "A", striking a plane mirror "B", is reversed in form so that when it strikes the eye at "E" after reflection it is diverging in form and causes the eye to see the virtual image of the source at "V" which seems to be behind the mirror. The reason the source of light seems to be at "V" is that the small section of the light wave that is reflected from the mirror to the eye at "E" is of such curvature that its center is at "V" and the eye "sees" the object as being at this center. The actual path of the wave front is from the source "A" in ever-widening circles to the mirror, where the middle of the wave striking the mirror first is sent back toward "A", being followed by the ends a fraction of a second later. This reverses the direction of curvature of the wave front so that it goes back toward the source "A" in diverging rays and the eye at "E" sees a virtual image of the source "A" just as far in back of the mirror as the source is in front of it.

Focal Point and Center of Curvature

Let us now examine the effect of a concave mirror on a plane wave front as shown in Figure 30. There are two points in relation to concave mirrors, the location of which must be thoroughly understood. One is the "focal point", which is the place where parallel rays striking the mirror, are brought to a focus. The other point is the "center of curvature" of the mirror and is the point at

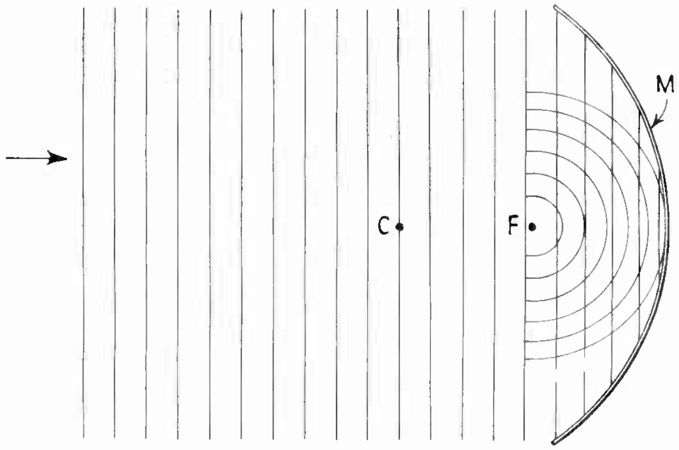

FIGURE 30—*Concave reflector changing curved wave front into plane waves.*

the exact center of the sphere or globe of which the concave mirror is a part. The focal point "F" is always half way between the mirror "M" and the center of curvature "C". Now, if the focal point "F" is the place where parallel rays of light striking the mirror are brought to a focus then if a source of light be placed at "F" the mirror should change the curved wave front into a plane wave front. Figure 30 can be used to illustrate both cases, that is, the first case where a plane wave front

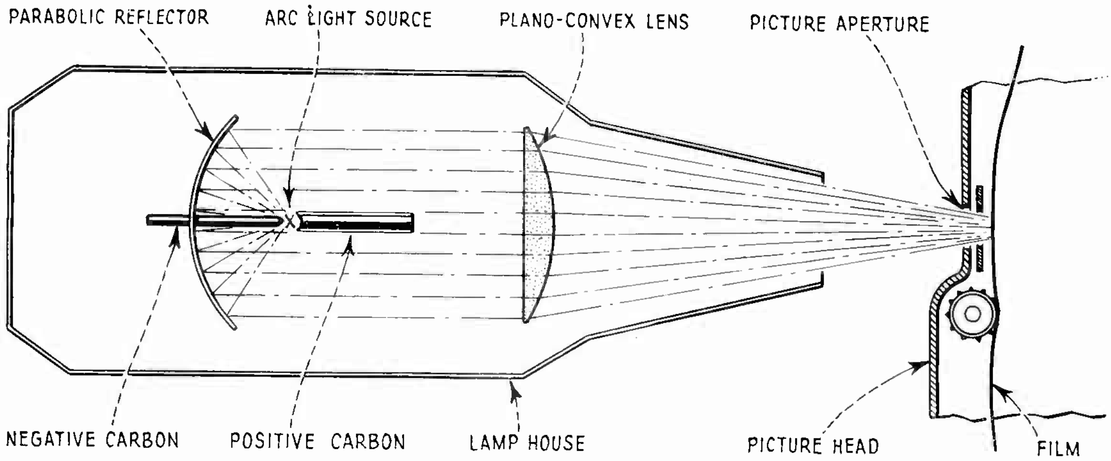

FIGURE 31—*Illustrating general relation of parts in lamp house and picture aperture.*

is travelling from the left of the illustration, in vertical lines and upon striking the mirror "M" is changed to a curved front which comes to a focus at the focal point "F", and the second case where the source of light is assumed to be at the focal point "F" and is changed by the mirror to a plane wave front travelling to the left.

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A practical application of the use of a "concave type" mirror is the reflector arc lamp where a parabolic mirror is used to reflect the light from the arc in parallel rays to the cendenser lens which focuses them to a "spot" at the aperture as shown in Figure 31.

The effect of a concave mirror on a curved wave front from a near source of light is illustrated in Figure 32 where an image "I" of the object "O" is brought to a focus between the center of curvature "C" and the principal focus "F". If the source of light or the object were to be placed at "I" then the image would be produced at "O". The changing of the shape of the wave front when the object is at "O" is caused by the ends of the wave hitting the mirror before the center of the wave reaches it, thus giving the wave more curvature as it is reflected, and causing it to focus the image at a new center of curvature "I". In the case where the light source is between points "C" and "F", the middle of the wave strikes the mirror before the ends reach it, resulting in a flatter wave front which converges to a new center at "O". If the source of the light at "O" is moved toward the mirror the image "I" moves away from the mirror until the two points "O" and "I" come together at "C" which is the center of curvature of the mirror. The reason the object and the image coincide at "C" is that the curved wave front from the source of light, located at "C", strikes

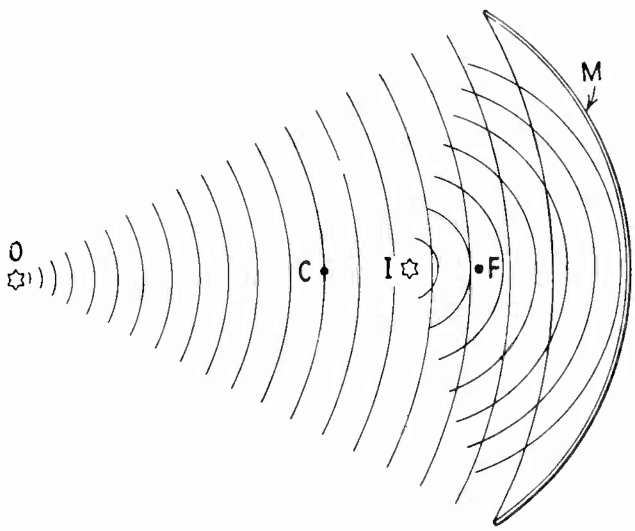

FIGURE 32—*The effect of a concave mirror on a curved wave front from a near source of light.*

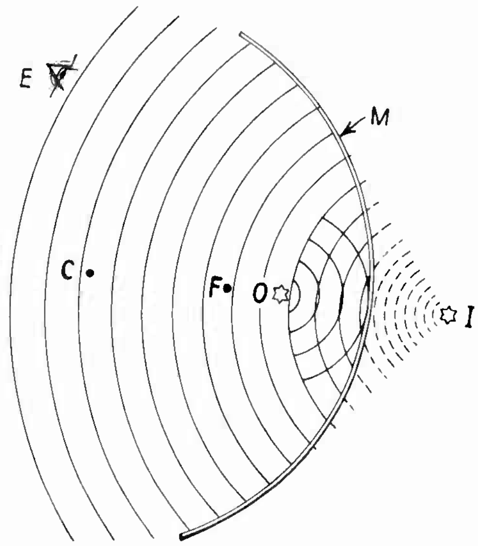

FIGURE 33—*A virtual image in a concave mirror.*

the mirror at all places at the same time and the reflected wave starts back in the same shape it had when it struck the mirror. Thus it comes to a focus at the starting point which is the same as the center of curvature of the mirror.

Another possible condition is that the object or source of light may be placed so close to the mirror that it is between the mirror and the principal focus "F". It has been shown that the wave front reflected from the mirror when the light is beyond "F" is converging, and that the wave front is flat or plane when the light is at the principal focus "F". Similarly it can be shown that the wave front reflected from the mirror when the light is between "F" and the mirror is a diverging one. We learned that a diverging wave front produced a virtual image that could be seen when a small section of this wave front entered the eye. This condition is shown in Figure 33 where "O" is the object, "C" the center of curvature of the mirror, "F" the principal focus and "I" the virtual image, which in this case appears to the eye "E" as if it were behind the mirror. The positions of images are the same with mirrors or with lenses for *real images are always formed by converging rays and are reversed or "upside down"* while *virtual images are produced by a section of a diverging wave entering the eye and always appear erect or "right side up"*. Another form of mirror is the convex mirror

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shown in Figure 34, the images formed by it are virtual images. "O" is the object, "M" the mirror, and "I" the image seen by the eye "E". There are lamphouses that do not make use of a condenser lens, but use a properly located concave reflecting mirror which directs a powerful spot of light of the correct size on the aperture. While there are advantages to this type of lamphouse, such as the absence of the condenser lens with its liability to breakage and the loss of light it causes due to absorption, most of the commercial arc lamps make use of the collector lens (condenser lens).

Motion Picture or Aerial Image

The image projected by a motion picture projector is called an "aerial image" because the image itself is actually in the air at a certain distance from the lens, this distance being the point at which that lens brings the image of the object (film positive in this case) to a focus. In actual practice we place a motion picture screen at this point and the image becomes visible to the eye but whether a screen is there or not the image is at focus in space at that point even though we may not be able to see it. For instance, a picture machine might be projecting an image outdoors in clear air and nothing would be seen of it but if a cloud of dust particles or smoke or steam should suddenly fill the air at the focal point, the image would immediately become visible right in the air, so to speak. This effect

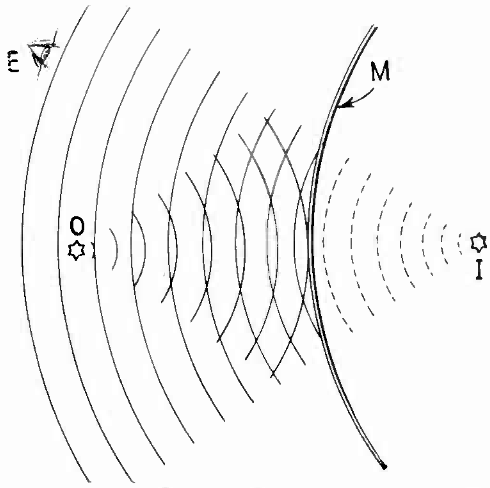

FIGURE 34—*A virtual image formed by a convex mirror.*

is often seen in the case of a searchlight on a clear night when the light it projects becomes visible only as it strikes clouds high overhead. With a powerful enough light source a motion picture could be shown with clouds as the screen.

EXAMINATION QUESTIONS

1. What two forms of distortion are produced by an uncorrected lens?
2. Using the "Lens table" find the proper lens to use if a picture 9 x 12 feet is desired with a "throw" of 50 feet.
3. Does a convex mirror produce a "virtual" or a "real" image and where is the image located in regard to the mirror?
4. Is the light from a picture screen seen by "regular" or "diffused" reflection?
5. How are "corrected" lenses made and what two kinds of glass are used?
6. In what part of a motion picture equipment is a concave type mirror used?
7. How is it possible to find, roughly, the equivalent focus of an objective lens?
8. Show by diagram a concave mirror. Put a cross at the center of its curvature and another at its principal focus.
9. What size picture will a lens with an "E.F." of 5″ form with an 80 foot "throw"?
10. Draw a diagram of a modern Zeiss objective lens, indicating front and back factors.

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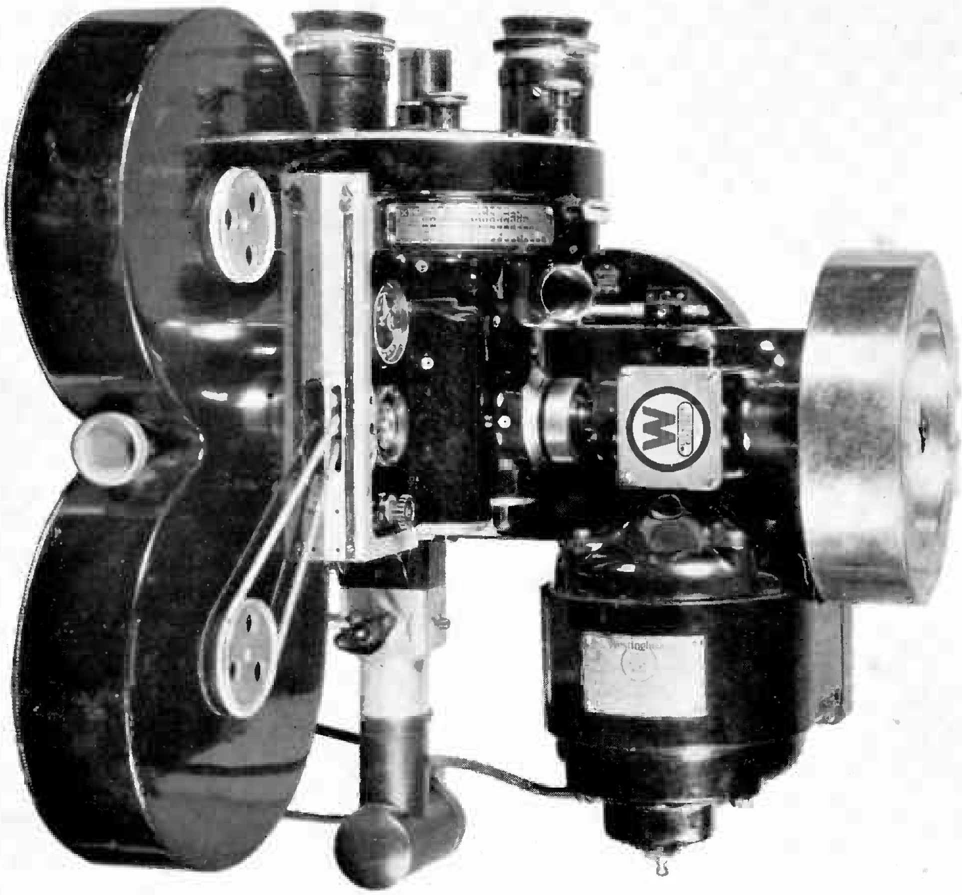
NOTES

NOTES

Typical lighting equipment used by a small size sound picture studio.



Looking down on a sound picture camera, showing various lens combinations, any one of which may be quickly rotated into place.

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Vol. 58, No. 8

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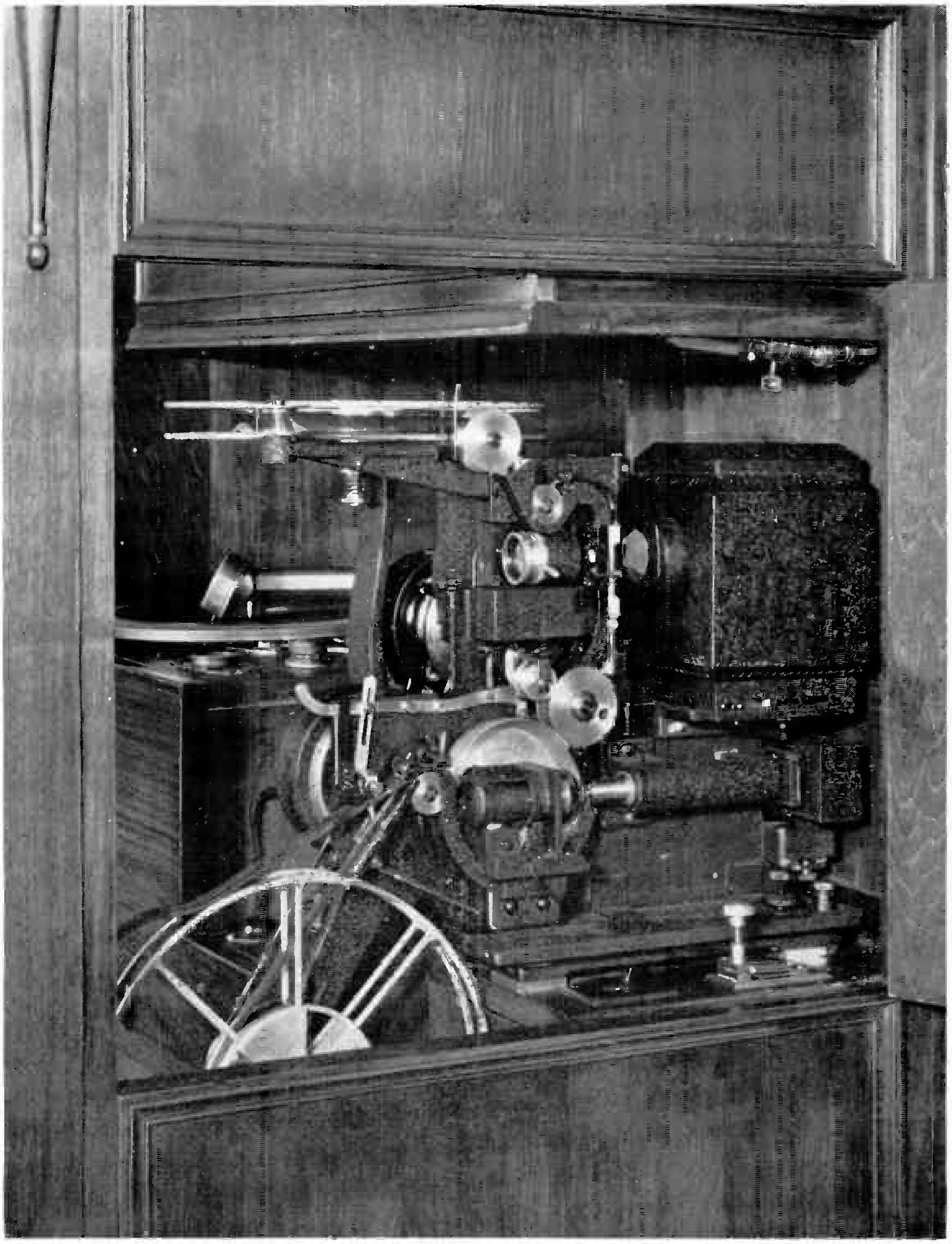
A private theatre for the showing of sound motion pictures.

Sound Motion Picture Apparatus

Vol. 58, No. 9 Dewey Classification R 580



With this type of home picture projector either sound-on-film or sound-on-disc recordings may be shown.

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Sound Motion Picture Apparatus

Commercial Apparatus

In a previous lesson you studied the principles of motion picture projection in general and the mechanism of the Powers Projector in particular. You will now study the equipment made by the following companies, the International Projector Company which is called the "Simplex" projector, the projector made by the Enterprise Optical Co. which is known as the Motiograph, the Baird projector, and the portable sound picture projectors of the R. C. A. Photophone and Western Electric Company.

An illustration of the latest type Simplex machine, known as the Super-Simplex, was shown in a foregoing lesson under the topic "The Projector." This model embodies features that are distinct improvements over earlier Simplex models and in the following text several different views of the picture head will be shown with explanations of the functions of the various parts.

Figure 1 shows the head from the "operating" side which in all machines is the right side of the machine looking toward the portholes or theatre screen. "A" is the guard shield that prevents accidental interruption of the light beam. "B" is the shutter guard inside of which the revolving shutter is located, and it will be seen that in this head the shutter is at the rear instead of in front, as in the Powers projector which you have studied. "C" is the mounting for the upper reel while "D" is the objective lens. Turning handle "E" opens the picture gate for threading the film into place. The knob "F" is used to frame the picture which as we learned, means to place one picture exactly in the aperture, and "G", is the shutter timing adjustment which regulates the revolving shutter so that it cuts off the light while the film is in motion thus preventing "travel-ghost." Turning the knob "H" moves the lens back and forth to permit focusing the image sharply on the screen. All of these adjustments, except that of the film gate mechanism, may be made while the machine is running.

In Figure 2, the same view is shown with the door removed so that the operating mechanism may be studied. The path of the film through the head is as follows: It goes from the upper magazine (not shown) down around the upper feed sprocket "A", being held in contact with the sprocket by the roller "B". Then it forms a loop upward and passes down between the flanges of the guide roller "C", continuing down through the gate "D" (shown closed) at the lower end of which the film goes around the intermittent sprocket "E", being held in engagement with its teeth by the lower and curved end of the gate "D".

From this point it forms another loop and then goes around the lower holdback sprocket "F" being held in place there by the two rollers "G". The film then passes down through the bottom of the head to the lower or take-up reel where it is rewound. The lever "H" works a sound track mask that has apertures of two sizes cut in it, one for film without sound track, such as silent film or sound-on-disc features, and the other for film with sound track on it. It is, of course, necessary

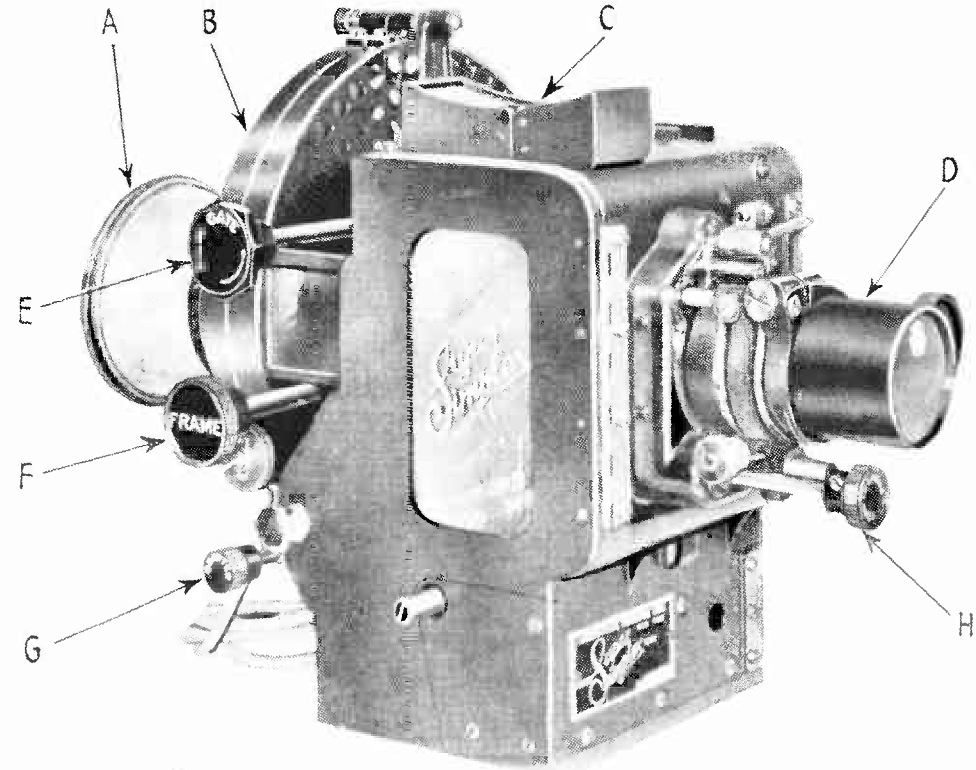

FIGURE 1—*Exterior view of Super-Simplex head from operating side.*

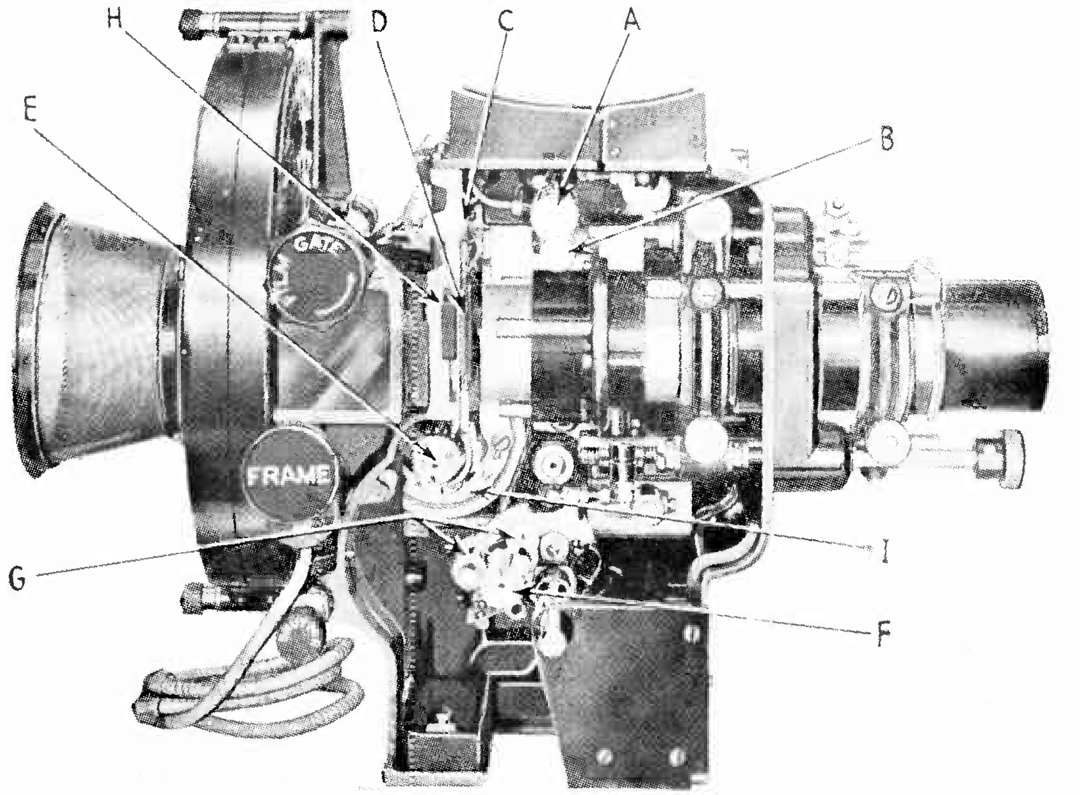

FIGURE 2—*Interior view of Super-Simplex head.*

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that provision be made for this, because the film is the same width in both cases and if the aperture were allowed to remain wide then the sound track would show up on the screen at the side of the picture.

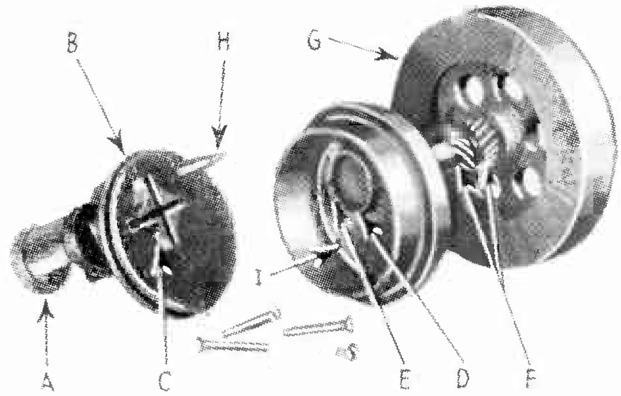

FIGURE 3—*Geneva cross intermittent mechanism.*

The Intermittent Mechanism

The intermittent housing that contains the "Geneva Cross" intermittent mechanism is shown at "I" and the intermittent movement itself is seen in Figure 3 where "A" is the intermittent sprocket wheel whose shaft goes through the plate "B" which carries on its end the "Geneva Cross" or "star" C. In the other part of the assembly "D" is a broken circle of steel with a pin "E" set in the break, and through a chain of gears this assembly is driven on the same shaft as the flywheel "G". When assembled the two parts of the intermittent are put together face to face as they stand with the tapered pin "H" fitting in the hole "I" so that the cross "C" has the proper position with regard to circle "D". When the assembly is completed it provides a single mechanism with the sprocket on one end and the flywheel on the other, as seen in Figure 4.

In actual operation the circle or cam "D" (Figure 3) driven by the projector engages its pin "E" in a slot of the cross "C", the point of the cross containing the slot moving into the center of the

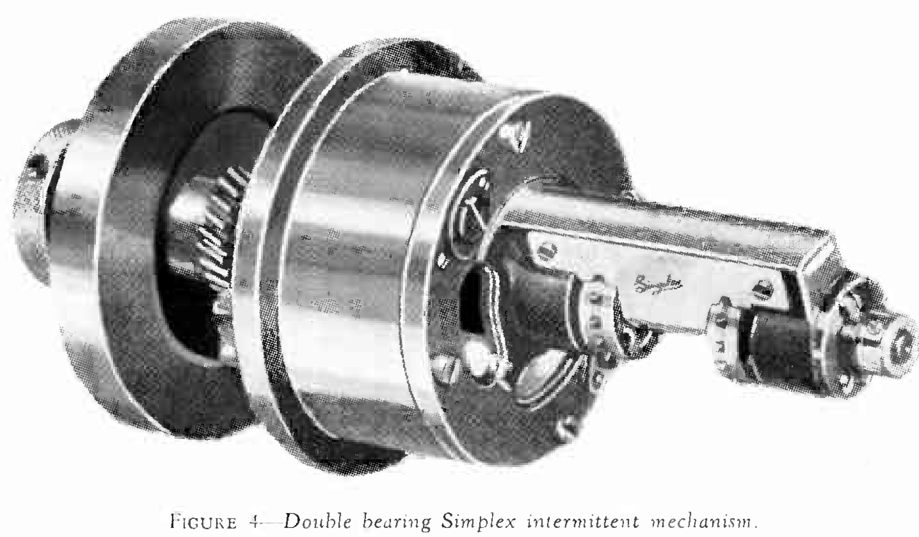

FIGURE 4—*Double bearing Simplex intermittent mechanism.*

circle through its "broken" part and the outside of the circle moving against the curved part of the cross. The cross is thus moved one quarter turn during a complete revolution of the cam "D" although the actual movement of the cross takes place only during a fraction of the revolution, the cross being locked in place during the rest of the revolution by the action of the outside curve of the cam running against the curve of the cross between two of its points.

The quick movement of the cross turns the sprocket on the other end of the same shaft one quarter turn, which pulls a frame of film down in the aperture where it is held during projection by the locking action of the cam and cross. During the next revolution of the cam the cross and sprocket are turned another quarter turn and locked in place and so on through the entire showing of the picture. The result of this action as far as its effect on the film is concerned is the same as that of the Powers Roller pin intermittent movement; both methods achieve the same result quite efficiently.

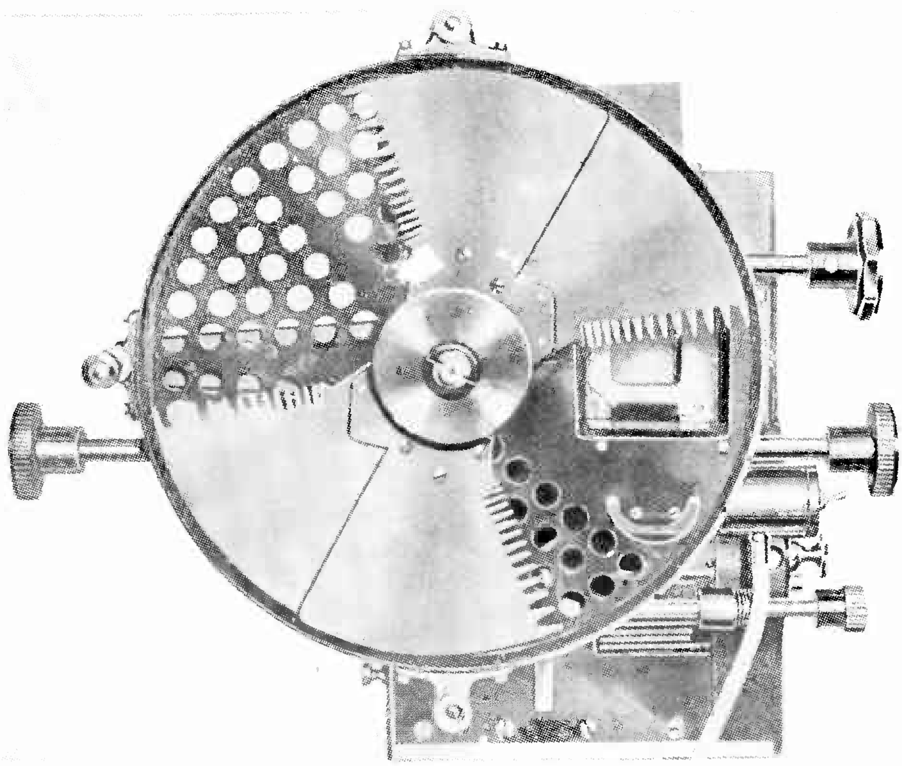

FIGURE 5—*Super-Simplex from rear showing new type shutter.*

The Shutter

The revolving shutter of a Super-Simplex is a radical departure from former models that were attached to the front of the machine and which cut off the light after it had passed through the film and lens on its way to the screen. The new type shutter is located at the rear of the head, between the lamphouse and the picture aperture, and in its operation cuts off the light before it reaches the film and lens. A view of this new shutter as seen from the rear of the head is shown in Figure 5, and while it is similar to many other shutters in that it has two blades they are seen to be of special design. One of the blades is the "master" or "working" blade and serves to cut the light from the screen while the film is being moved into place by the intermittent, and the other blade is the "flicker" blade and cuts the light from the screen for a fraction of a second while the film is stationary in the aperture. This last action as we already know is to reduce flicker and smooth out the illumination on the screen. The advantage gained from having the shutter at the rear of the head is that the light is cut off the film for half the time which reduces the heat to which the film is subjected.

Heat causes a film to deteriorate rapidly due to drying out which makes it brittle and subject to cracking and tearing as it goes through continued showings in theatres. Therefore, any method which retards this drying out process due to heat will prolong the life of the film and incidentally reduce fire hazard. Another result of heat on the film is to cause it to "buckle", that is, to wrinkle and twist as it passes through the machine, which also tends to cause breakage of the film. The heat that would otherwise fall on the film is intercepted by the blades of the shutter and in addition, the construction of the blades is such that they act as a fan to draw the heated air away from the film and aperture and dissipate it into the surrounding air.

The saw-tooth edges of the blades are called *vignetted* edges and give a dissolving effect to the light as it is cut by the blade instead of cutting it off sharply as a straight edge would do. The result is to reduce flicker to an even greater degree. In Figure 5, the shutter appears as seen from the lamphouse and directly behind the shutter can be seen part of the aperture with the fire shutter down, covering it. Before the new model Super-Simplex came on the market, the Standard Simplex was installed in large numbers and inasmuch as a motion picture machine has a good many years of useful life there are by far a greater number of the Simplex Standard heads in use than Super-Simplex heads. A complete Standard Simplex machine appears as shown in Figure 6. This equipment makes use of a new type stand that is sturdier than the pedestals formerly used so that the additional weight of newer and more powerful lamps and added sound equipment may be rigidly supported. The identifying notations are as follows: " " is the table switch for connecting current to the arc, "B" the arc controls, "C" the foot switch for starting and stopping the driving motor "D", "E" the standard head and "F" the revolving shutter which is located between the lens and screen in this model. The various other handles and wheels shown are for adjustments such as tilting, locking, and so on.

Figure 7 shows the same equipment with a Western Electric sound head added just below the picture head and the whole assembly tilted at a greater angle which would be necessary if the projection booth were high up in the gallery of a theatre. When the sound head is added the film travels from the top magazine "A" through the picture head "B", then through the sound head "C" and into the lower magazine "D".

Figure 8 shows the "spot" properly focused on the cooling plate of a Standard Simplex head and it will be observed that all corners of the aperture are well covered by the spot of light.

The operating side of the Standard head is shown in Figure 9, the threading of the film through the head being essentially the same as in the case of the Super-Simplex, that is, from the upper reel down around the upper feed sprocket "A", down through the gate "B", around the intermittent sprocket "C", to lower holdback sprocket "D", then down and out of the head into the lower magazine.

Figure 10 is a view of the driving side of the head showing the driving gears and the centrifugal governor weights "A". When the machine is at rest the two halves of the governor lie close together as shown but when the head is in operation the two halves fly out during rotation and by means of a lever "B" lift the fire shutter out of the aperture thus allowing the light to pass to the film. If the speed of the projector slackens too much the weights drop thus allowing the fire shutter to drop over the aperture and cut the light and heat from the film. The shutter may be opened or closed manually by means of the handle "C" which works in a slot in the head casing. The spindle shaft "D" carries the revolving shutter which can be procured in the two- or three-bladed type as shown in Figure 11. The three wing shutter will bring about a condition of less flicker than the two-bladed one but the loss of light is greater in the three-wing type due to the fact that more of the light is intercepted by the opaque blades.

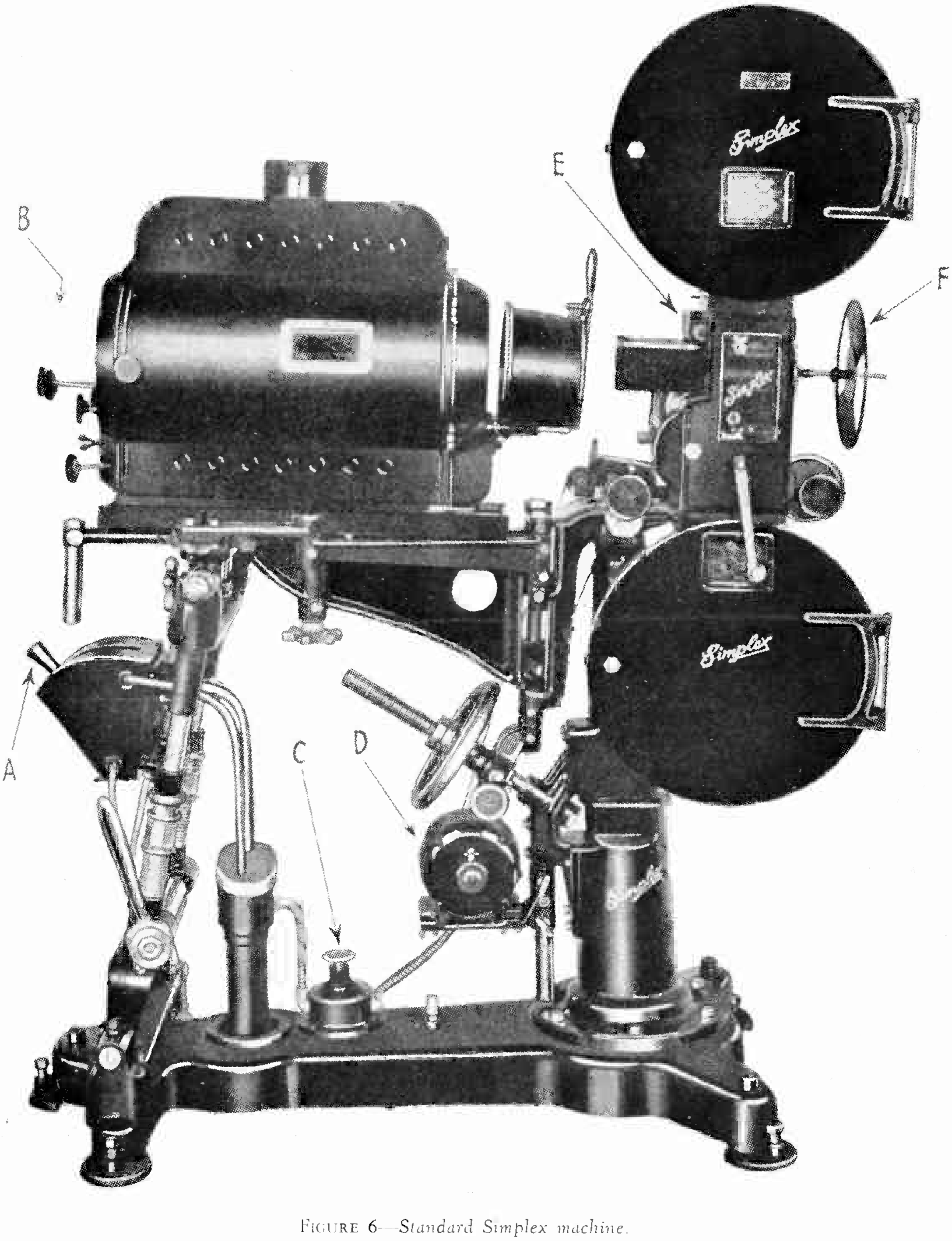

FIGURE 6—*Standard Simplex machine.*

The Standard Simplex on an older type pedestal is shown in Figure 12-A and Figure 12-B with an R. C. A. Photophone soundhead and disc turntable equipment added to the picture apparatus. "A" shows the complete assembly as viewed from the operating side, and it will be seen that the soundhead is located just under the picture head where it receives the film after it passes through the

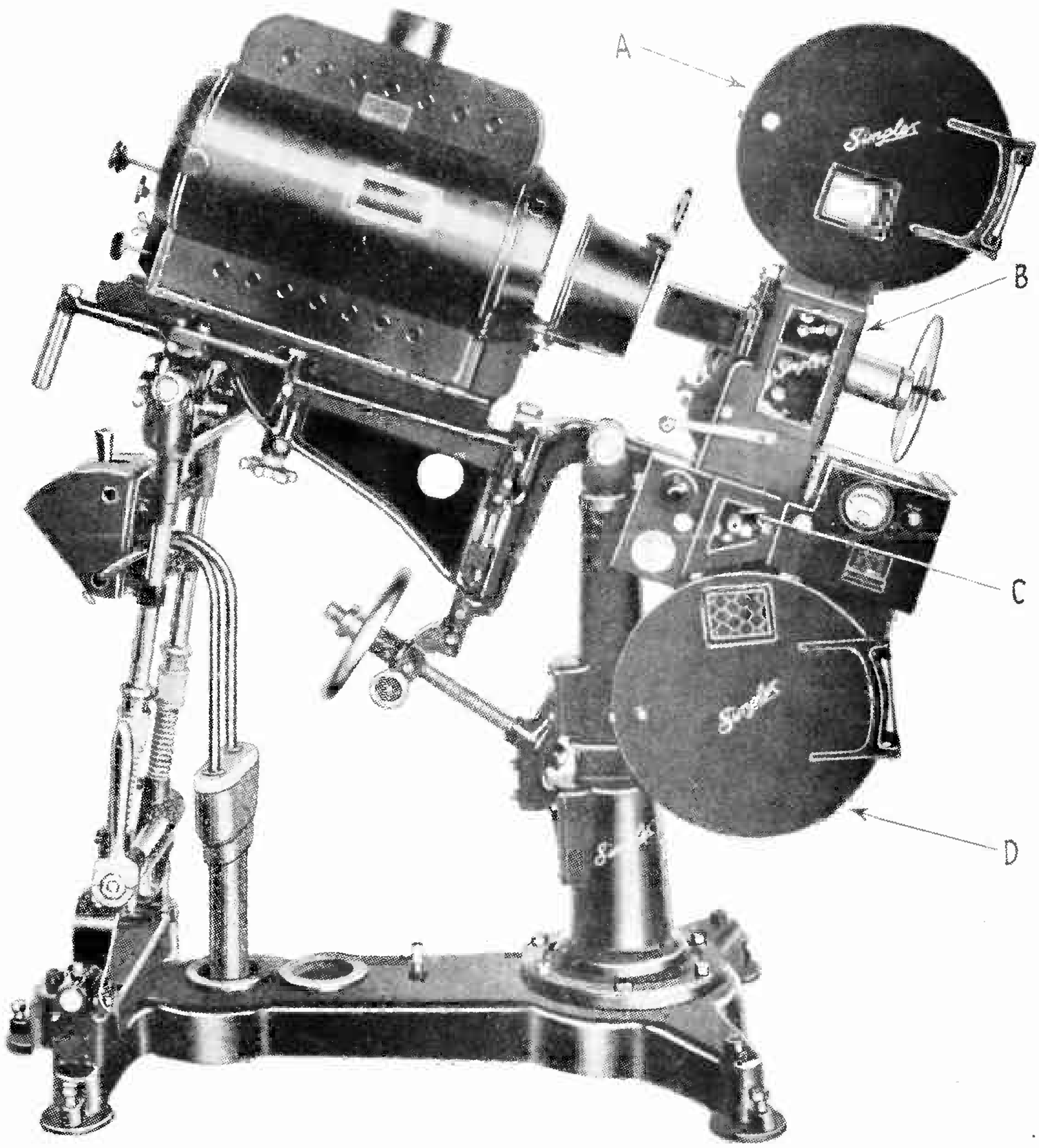

FIGURE 7—*Standard Simplex in tilted position with sound head added.*

picture head. "B" is a view of the same equipment as seen from the opposite side and shows the details of the disc sound attachment. The turntable of this attachment is directly connected to the projector drive so that the film runs through the machine at a speed that maintains its relation to that of the disc speed. In other words, if the film is threaded through the picture head with a certain "starting frame" of the film in the aperture, and the disc with the sound record on it is set so that the needle is on the record at a "starting mark", then when the machine is started, the picture thrown on the screen by the picture head and the sound being "taken off" the record, will remain in synchronism, or in step, through the [illegible] picture, due to the mechanically direct connection between

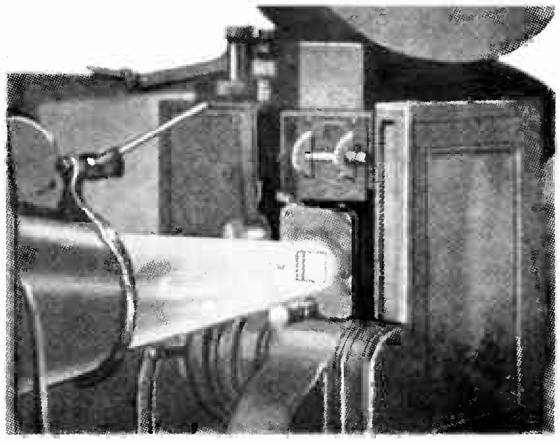

FIGURE 8—*The "Spot" is properly focused on the cooling plate.*

the turntable and the picture head drive. In Figure 12-B can be seen the arc control motor "M", attached to the Peerless lamphouse, while the drive motor for the picture head, sound head and turntable is seen at "D". The reproducer or pickup which holds the needle that runs in the record groove is shown at "P".

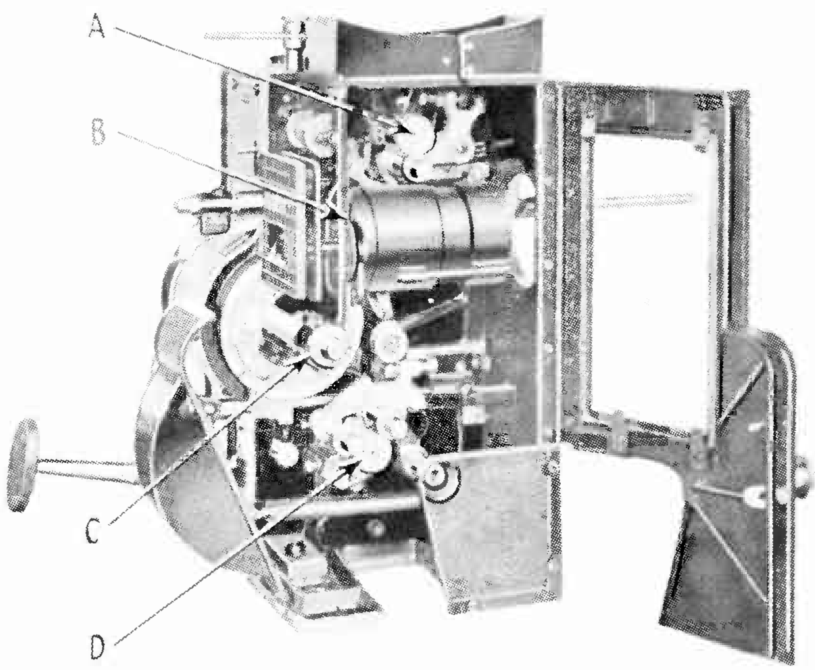

FIGURE 9—*The mechanism in a Standard Simplex head viewed from the operating side.*

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Simplex Incandescent Equipment

In motion picture theatres where the seating capacity on the main floor is 1,000 or less and ordinary conditions as to screen and house lighting prevail, satisfactory screen results are obtained on a "throw" up to 75 ft. with a picture width not exceeding 9 feet. In cases like this there are advantages gained by using incandescent lamps instead of arcs as follows:

Economy: The electric power consumed is usually less than that consumed by the arc.

Steadiness: The incandescent lamp produces a steady light that is not subject to flickering.

Adjustment: Once focused the incandescent lamp requires no further adjustment.

Softness of light: The light from an incandescent is softer than that from an arc and gives a good color quality for colored picture projection. Fire hazard is decreased due to the fact that there is no open flame.

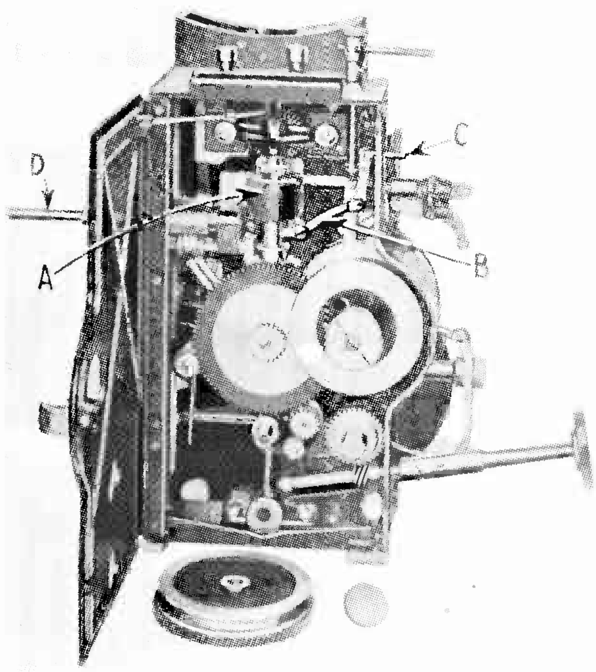

FIGURE 10—*The driving side of a Standard Simplex head.*

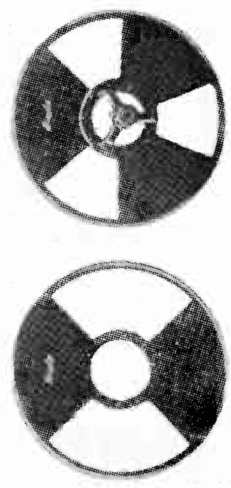

FIGURE 11—*Two- and three-wing shutters.*

Figure 13 shows the lamphouse carriage of the Simplex incandescent equipment. By means of knobs "E" and "F" the lamp filament "T" may be accurately centered in front of the mirror "L" and by use of knobs "A", "B", "C", and "D", the "spot" may be accurately focused to the proper size on the picture head aperture. Figure 14 is a cut of the complete lamphouse showing the double condenser lens assembly swung out for cleaning, while Figure 15 is a layout of the optical train of the equipment. Most portable sound motion picture outfits, including those made by R.C.A. Photophone and Western Electric Co., use incandescent lamps for the light source, and these portable outfits will be taken up in the latter part of this lesson.

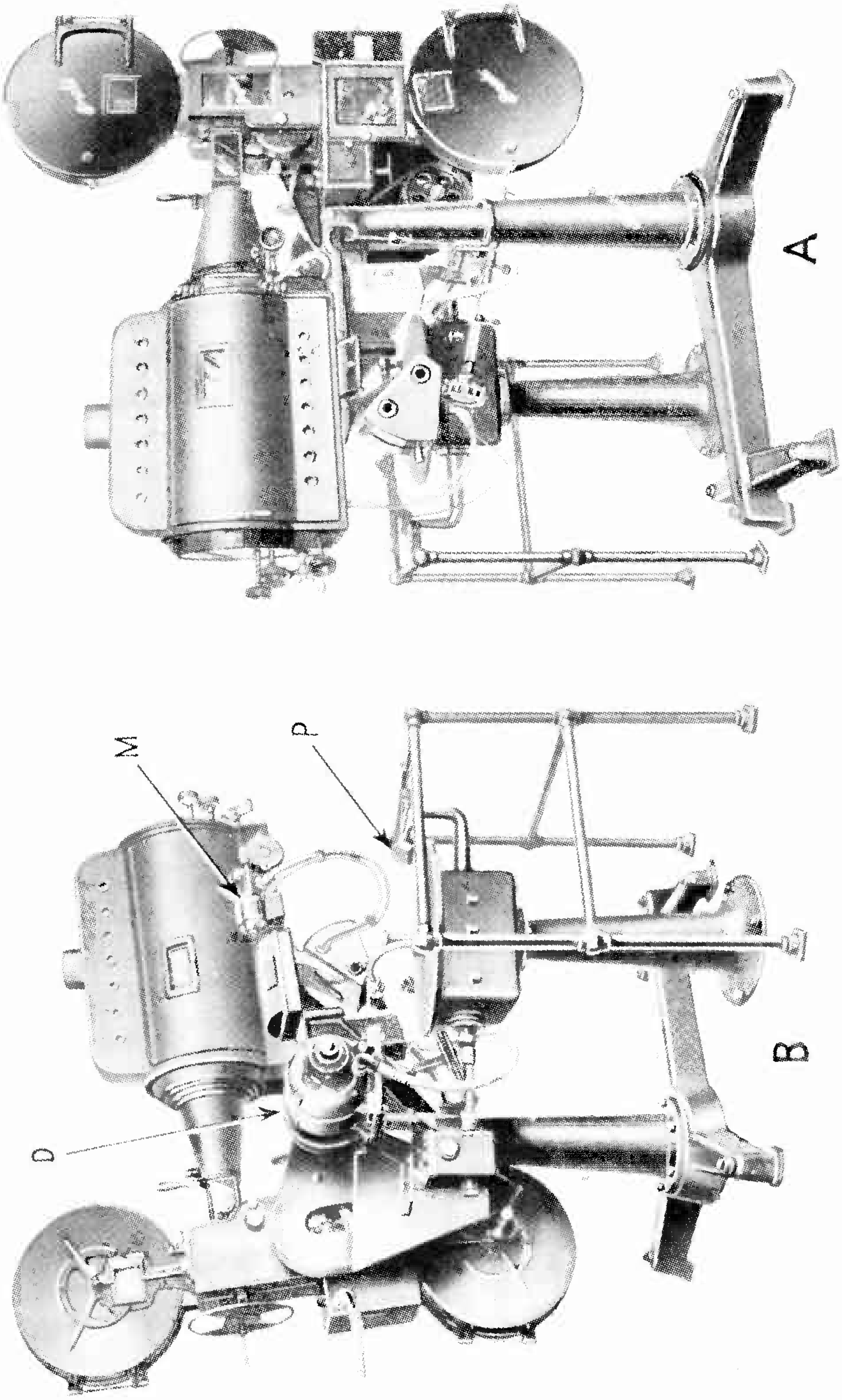

FIGURE 12—A Standard Simplex with R. C. A. Photophone soundhead and disc turntable equipment added to the picture apparatus.

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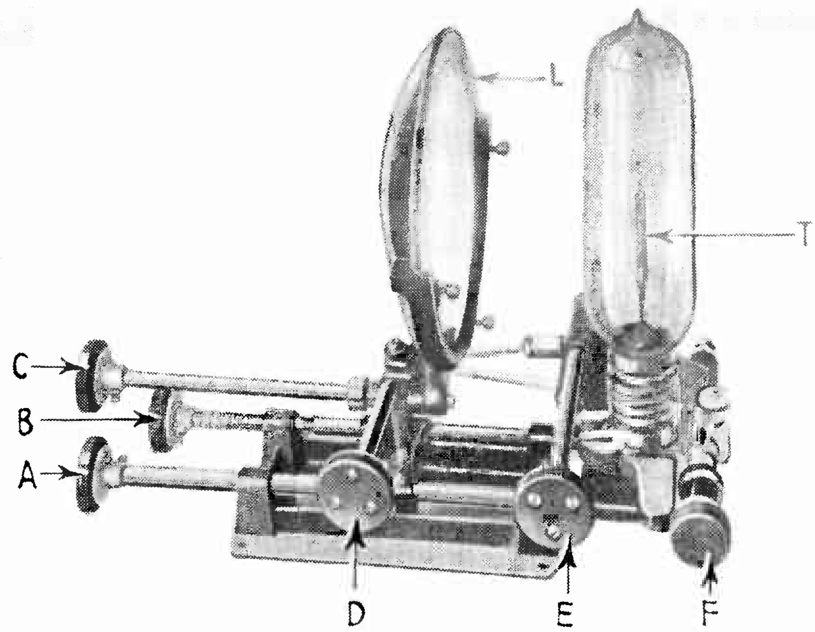

FIGURE 13—*Simplex incandescent lamphouse carriage.*

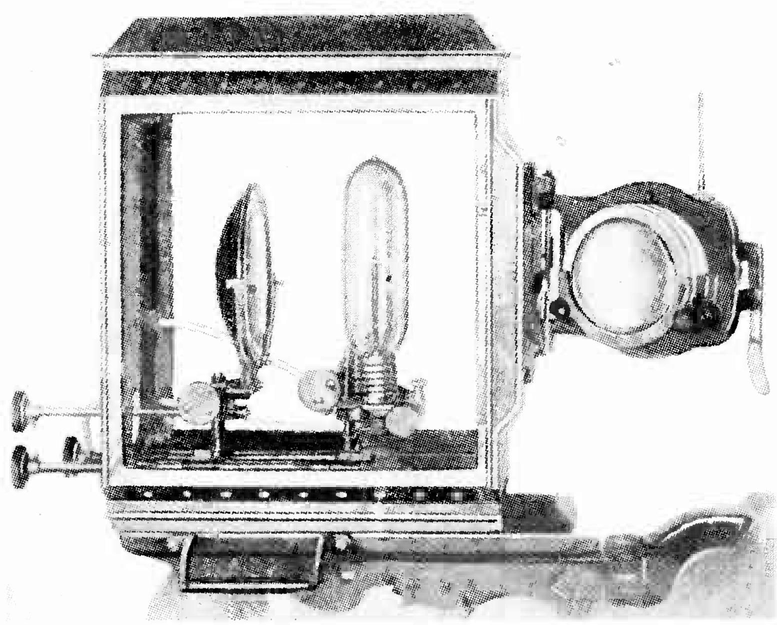

FIGURE 14—*Simplex lamphouse with double condenser lens swung open.*

Motiograph Projectors

Another type of projector in common use is the Motiograph, one model of which is shown in Figure 16. While this projector has a rear-type shutter, the main purpose of which is to reduce heat at the film, it can be seen that the shutter is radically different in design from that of the Simplex. Referring to Figure 16, the Motiograph projector head "M" is seen mounted on a Western Electric universal base as used in sound picture installations. The shutter "S", is a cylinder-like arrangement with wide slits or openings cut on opposite sides. The shutter has a fan-like action which draws the heated air away from the aperture and film.

In Figure 17 the operating side of the Motiograph head is shown. It will be seen that the Motiograph has three main sprockets similar to those used in the Powers and Simplex heads, namely, the upper feed sprocket "A", the intermittent sprocket "B", and the lower holdback sprocket "C".

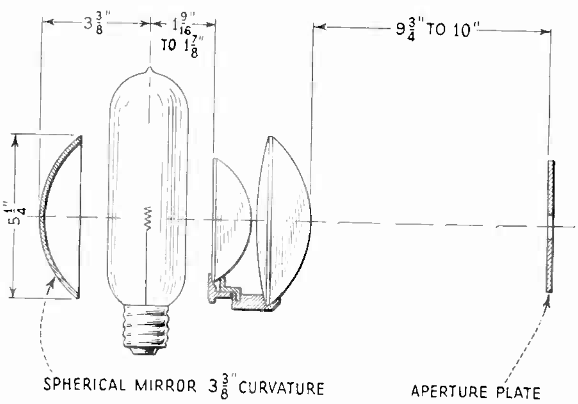

FIGURE 15—*Optical train of incandescent equipment.*

In order to thread the Motiograph, the whole rear panel of the head is moved backward by swinging on a hinge at the top of "D". This is accomplished by lifting the locking latch "E", pulling the gate backward and allowing it to rest in the open position on support "F". After the film is threaded the gate is allowed to swing back into place where it is locked securely by the latch "E". The "framing handle" is at "G", Figures 16 and 17, and is in the form of a small handwheel that moves the film carriage containing the intermittent up and down as the wheel is turned. The lens tube is shown at "H" and the lens focusing device at "I".

The driving side of the head shown in Figure 18 contains the gears for driving the various sprockets and the centrifugally operated device that controls the fire shutter which operates on the same principle as the fire shutter controls in both the Powers and Simplex heads. The fire shutter control is shown at "A", while "B" is a flywheel that smooths the action of the head.

A simple sketch of the shutter as seen from the rear of the head is shown in Figure 19, "A" being the aperture of the picture head showing through the slots cut in each side of the metal cylinder. As the cylinder revolves the solid metal part of it comes before the beam of light and cuts it off from the aperture at the same time that the intermittent is in motion moving the film past the aperture. This is a very efficient type of shutter due to the fact that the beam is cut from the top and from the bottom at the same time, as the top solid section of the cylinder moves downward and the bottom section moves upward. Referring again to Figure 17 the path of the film is down from the upper magazine through the fire-trap rollers, around the upper feed sprocket and after forming a loop, enters the picture gate and passes around the intermittent sprocket. The lower loop at this point feeds the holdback sprocket which passes the film to a set of firetrap rollers. Instead of going into the lower magazine, as it would in a silent installation, the film passes into the sound head, next

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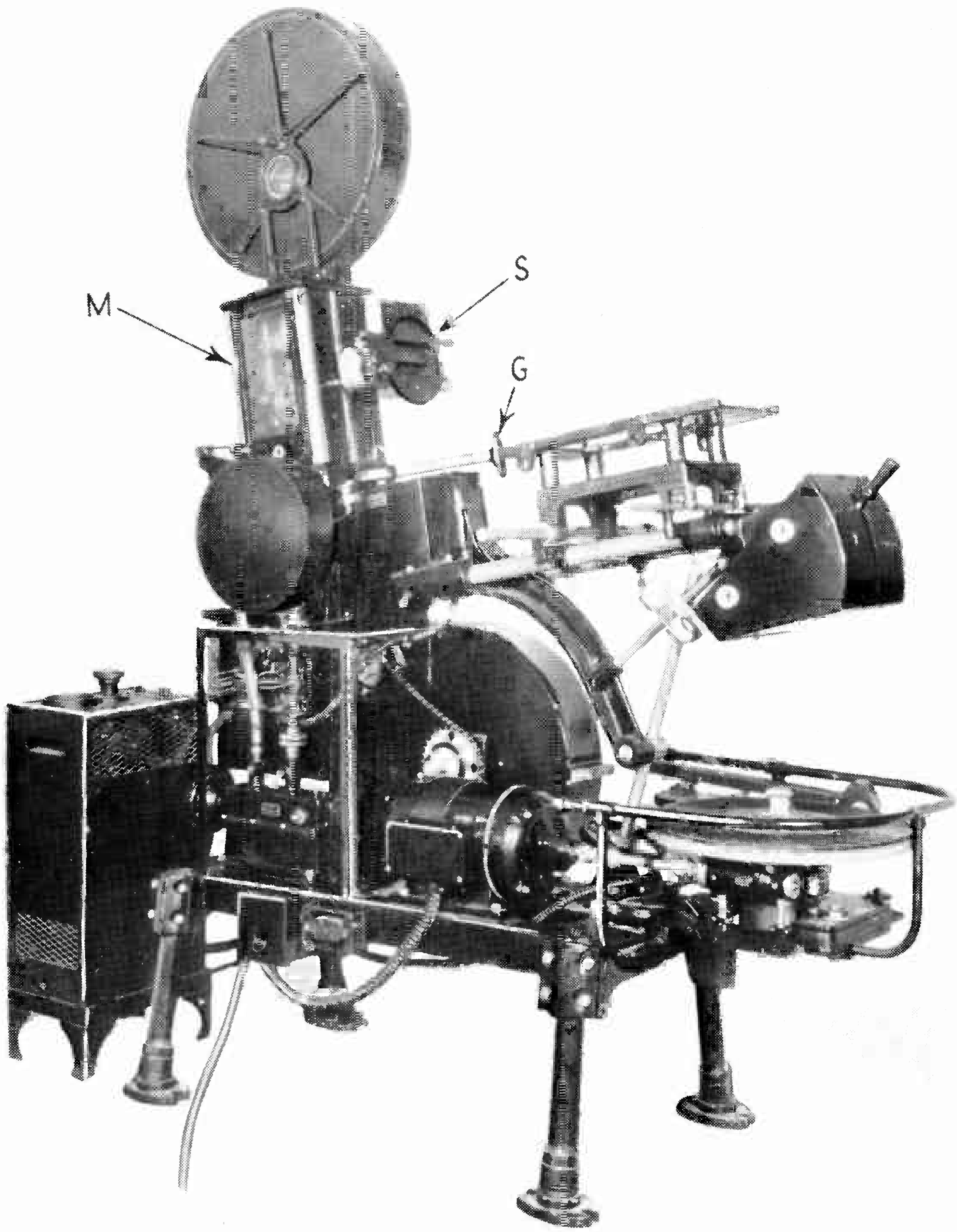

FIGURE 16—*Motiograph projection head on a Western Electric sound reproducer. (Courtesy Elec. Res. Prod., Inc.)*

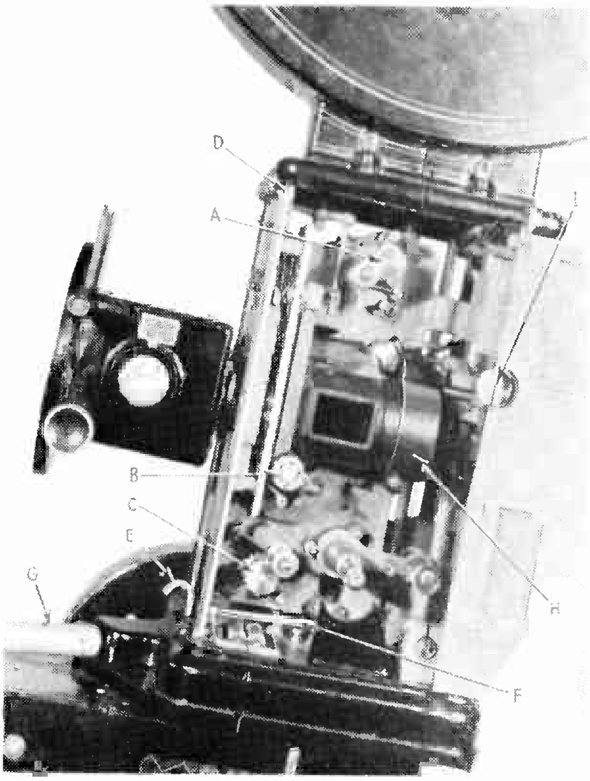

FIGURE 17—*Left side of a Motiograph machine.*

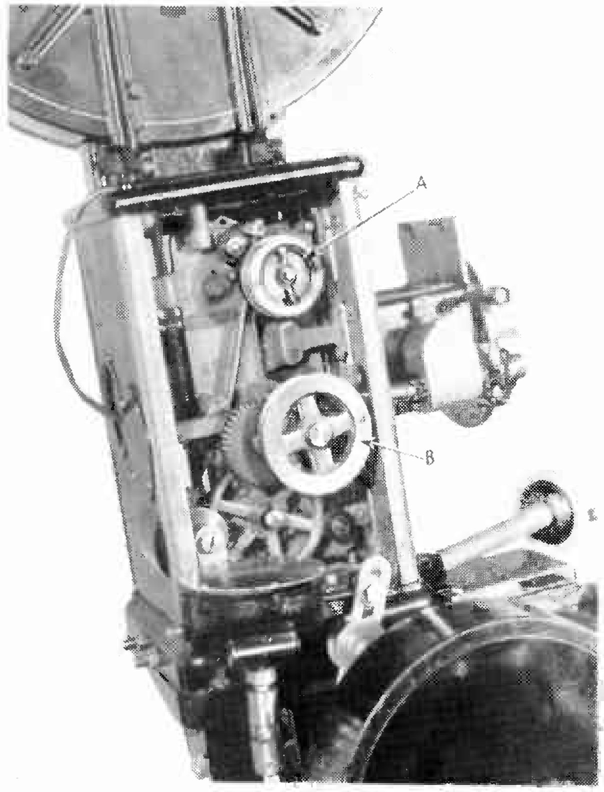

FIGURE 18—*Motiograph machine.*

over a guide roller, and finally over the curved surface of the sound gate where the beam of light from the optical system is focused on the sound-track. A constant speed sprocket then takes the film and it goes through the lower magazine firetrap rollers and rewinds on the take-up reel in the lower magazine.

It will be seen that the upper feed sprocket and the lower holdback sprocket have "stripper plates" adjacent to them. This is merely a strip of metal with slots cut in it to allow the sprocket

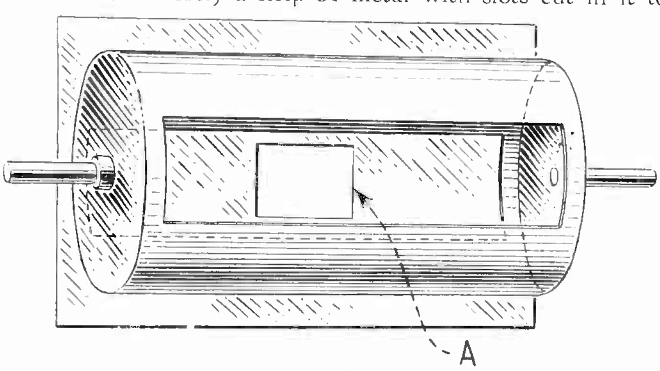

FIGURE 19—*Front view of horizontal-cylindrical revolving shutter in one of the Motiograph models.*

teeth to pass by, but should the film for any reason stick to the sprocket wheel and start to wind up on it, the "stripper" will lift it, or "strip" it off immediately. If ever in doubt as to which way a sprocket wheel turns you can be sure that it turns "against" the end of the "stripper", or in the opposite direction to that in which it is pointing.

The Baird Projector

The Baird Projector, while not in such widespread use as other makes so far mentioned yet it may be encountered in your duties as a Sound Service or Installation man and it will be well to look over several illustrations of this picture head so that you may become familiar with the location of the various parts.

Figure 20 is a view of the operating side of the Baird projector and shows that it is but slightly different in general operating characteristics from any of the other projectors studied. No picture

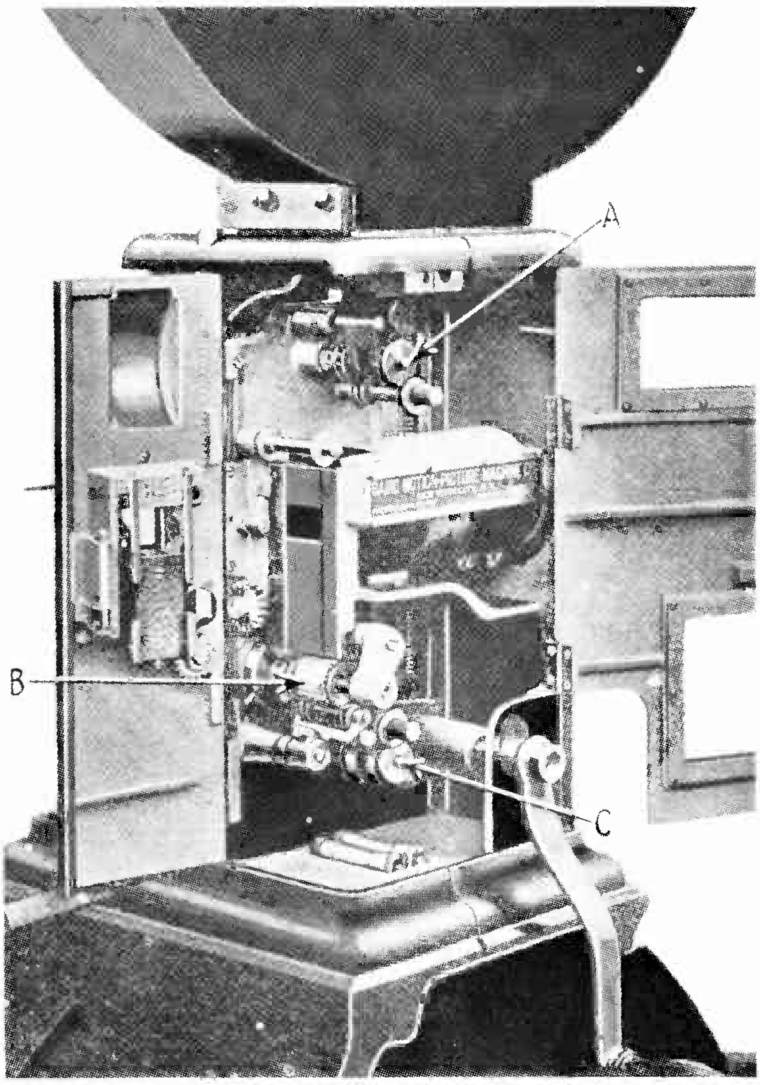

FIGURE 20—*Baird projection head looking from the operating side.*

head in fact should be much of a mystery to anyone who understands thoroughly the operating principles of a motion picture projector because there are but three main functions performed by any picture projector head which are as follows: 1st, pulling the film off the upper reel and feeding it to the picture gate, which is done by the upper feed sprocket; 2nd, pulling the film through the gate intermittently, and this function is performed by the intermittent sprocket; and 3rd, feeding the film steadily to the lower reel, which is done by the holdback sprocket.

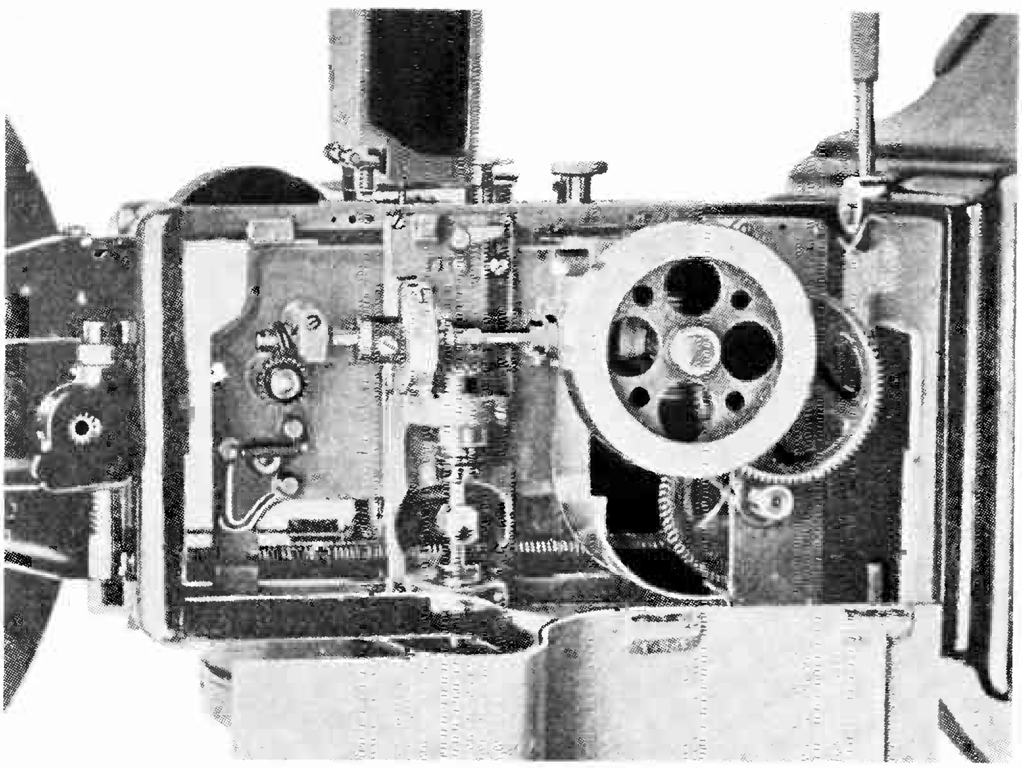

FIGURE 21.—*The driving side of a Baird projection head.*

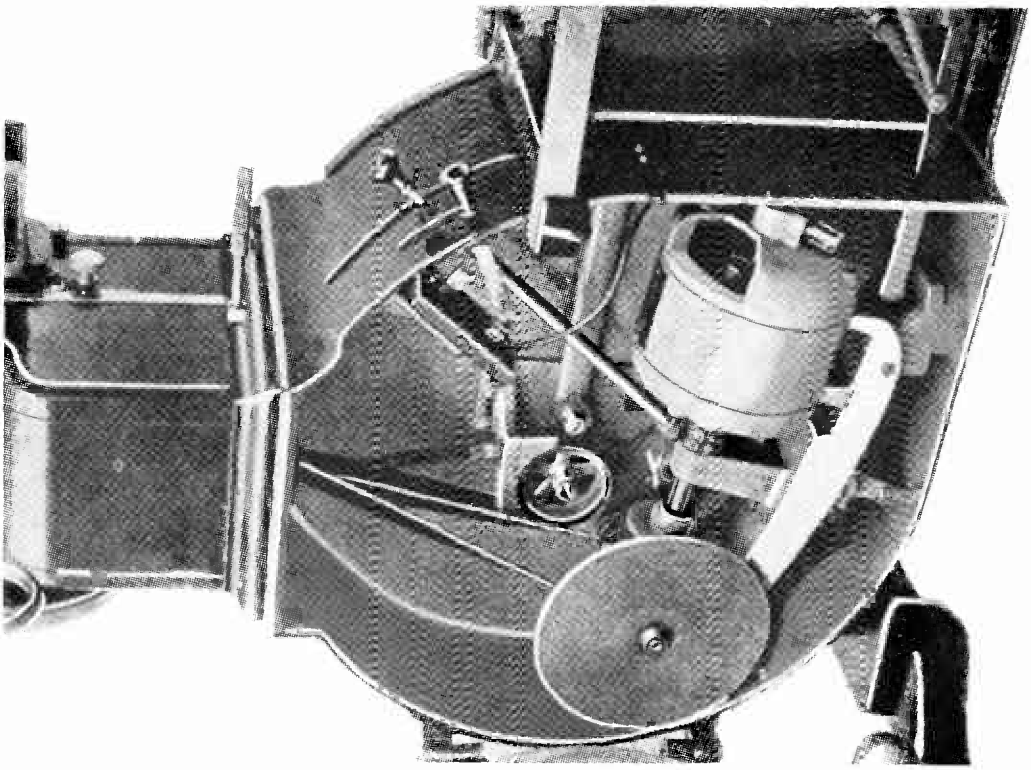

FIGURE 22.—*Baird drive motor and take-up mechanism.*

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In the Baird head shown in Figure 20, the sprockets are seen to be in the usual position, "A" being the upper feed sprocket, "B" the intermittent sprocket and "C" the holdback sprocket. The framing of the picture is done in different makes of projectors by slightly different methods all of which consist essentially of furnishings some means for moving the film into a new relation to the aperture, while the machine is running. Figure 21 shows the driving side of the Baird head with gears, flywheel and framing handle in full view. The drive motor and take-up mechanism of the Baird are contained in an enclosed, dustproof compartment located just below the picture head, as seen in Figure 22, the take-up reel running on the opposite side of the compartment.

R.C.A. Portable

The portable picture and sound projector put on the market by R.C.A. Photophone is designated as the PG-5 and since the main consideration is one of portability, without loss of quality of reproduction, the appearance and construction of the various parts is therefore quite unlike the theatre equipments. The projector may be set up and operated anywhere providing a 110 volt, 50 or 60 cycle a-c supply is available, but if only d-c is available, as it is in certain localities, then "converting" equipment is necessary to change the direct current to alternating current of the proper frequency. The electrical part of these projectors will be touched upon only lightly in this lesson but will be studied in detail later after you have covered the electrical subjects of this course. The entire R.C.A. Photophone Portable is quickly set up or repacked after using. The entire set including two projectors, an amplifier, loudspeaker, screen, and the accessories such as film patching and rewinding equipment and spare tubes, are contained in six trunks having a total weight of about 920 pounds. This number of trunks and their weight may not agree with the accepted ideas regarding portability, but compared with a regular theatre installation it is quite in the portable class.

Figure 23 is a layout showing the various pieces of apparatus making up the complete installation and the various cable connections between different units. Two projectors are always necessary to run a "continuous" show because most motion picture productions consist of several reels of film which must be run one after the other with no "break" between reels. This is made possible by running the first reel in one projector, meanwhile threading the next reel of film into the other projector. As the first reel nears the end of its run the second projector is started up. When a "cue mark" appears on the screen the picture from the first projector is cut off the screen by the use of the "douser" and the picture running in the second projector is thrown on the screen.

There is a certain amount of film at the end of each reel that has the same pictures and sound on it as the first part of the following reel and when the "cutover" is made it is not noticeable to the audience, hence, the showing is continuous. In old-time "movies" there was often only one projector used and the picture would stop during the change to the following reel and a slide would be thrown on the screen reading "One moment please while we change reels". Of course, that practice would not be tolerated today, so we find that practically every motion picture installation now has at least two complete projectors.

Figure 24 shows the operating side of the PG-5 with the film threaded into place and it will be seen that the picture projecting part of the unit has the three sprockets with which we have become so well acquainted in other projectors, namely, the upper feed sprocket (just under the upper magazine), the intermittent sprocket, (just below the gate) and the holdback sprocket (called in this projector the intermediate feed sprocket) which is immediately under the intermittent.

The various parts of the mechanism are named in the illustration, the film travel being as follows: It runs from the upper magazine around the upper feed sprocket down through the gate, around the intermittent sprocket and around the intermediate feed sprocket which completes its journey through the picture projection mechanism. The film enters the sound projection part of the unit by passing down through the sound gate, where the beam of light from the exciter lamp is focused on the sound-track, then around the "constant speed sprocket" which assures its passage through

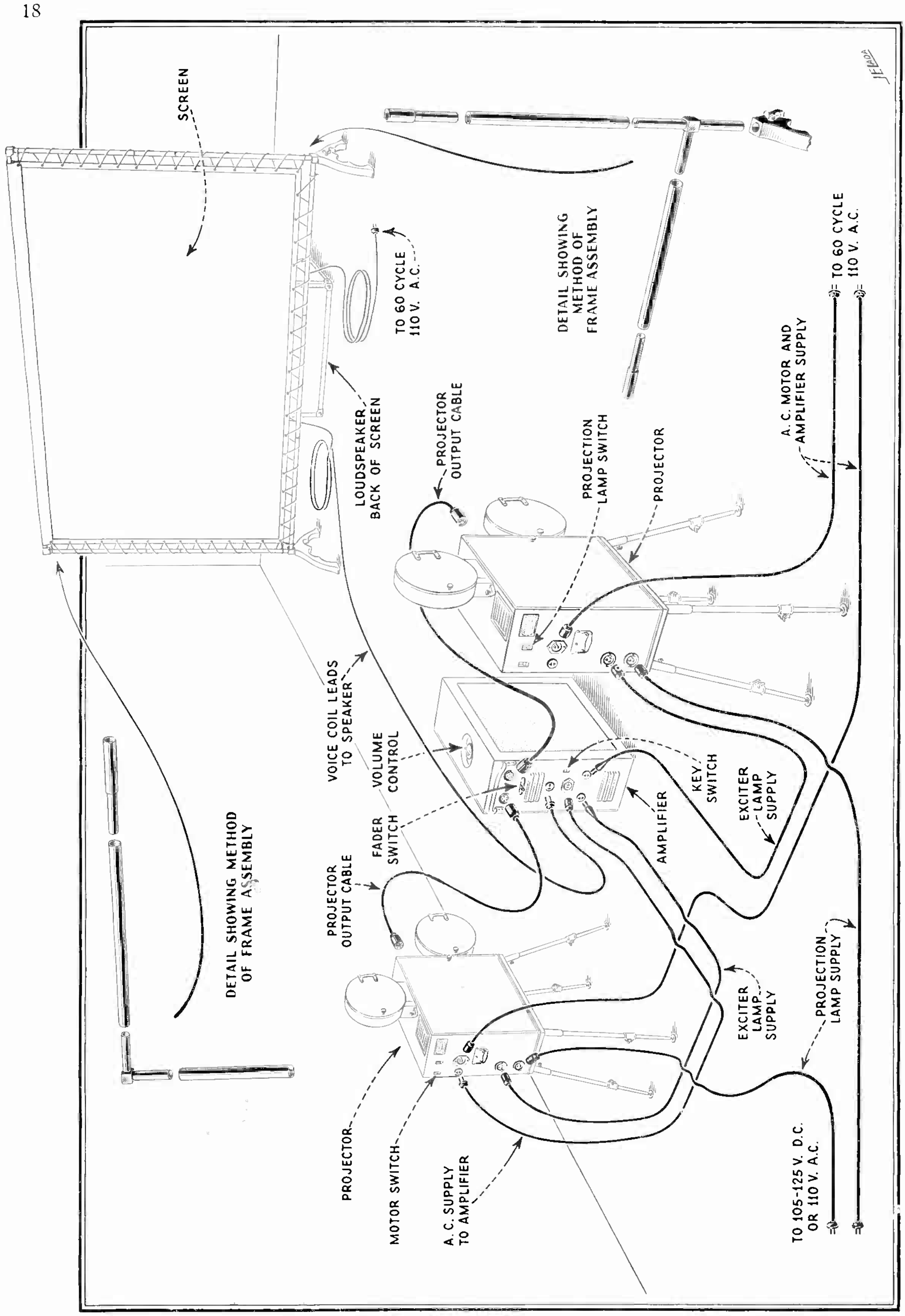

FIGURE 23—*The general layout of a complete portable installation showing the cable connections between the units.*

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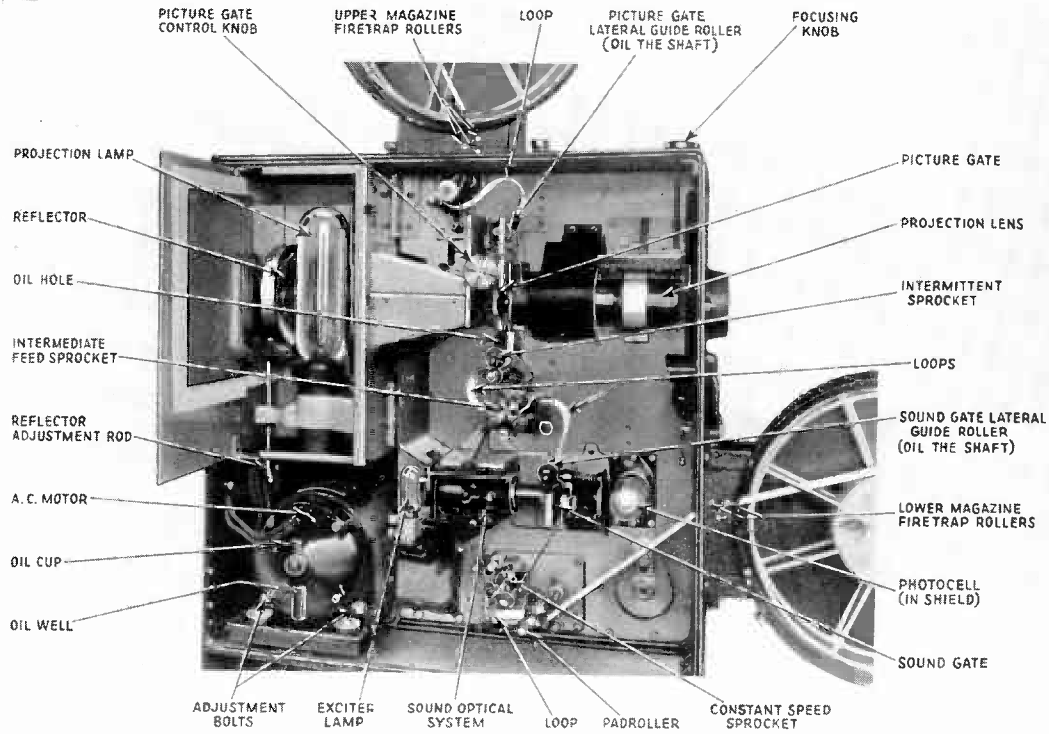

FIGURE 24—*Operating side of a PG-5 portable type projector with film threaded into place.*

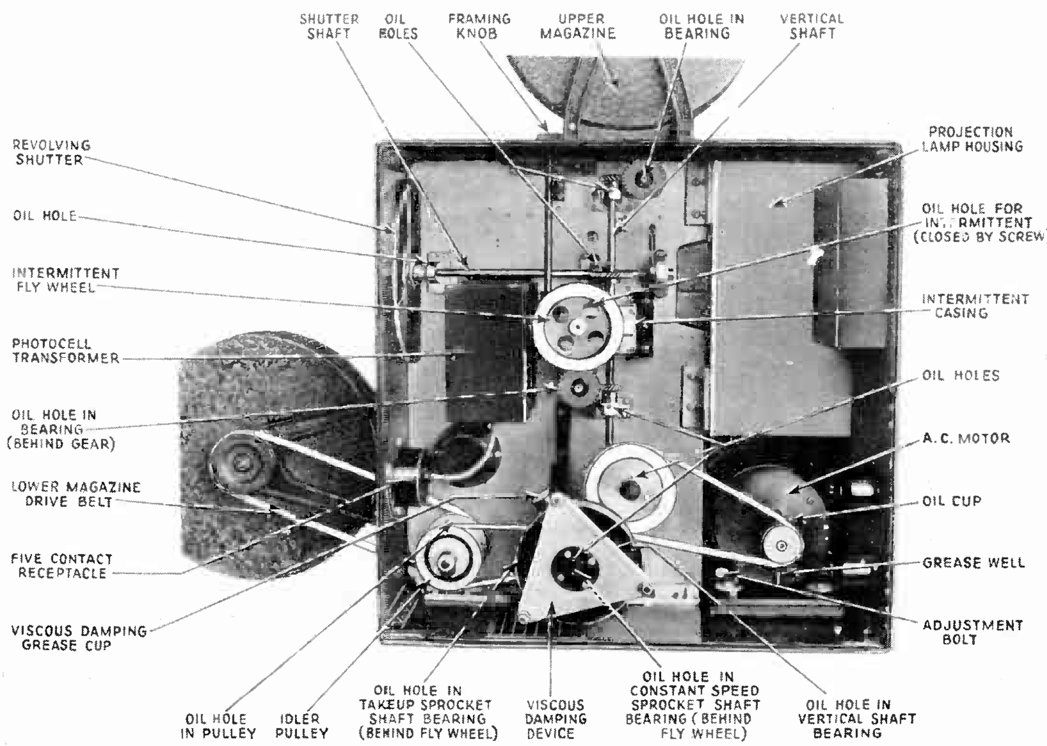

FIGURE 25—*Interior of the drive side of a PG-5 portable type projector.*

the sound gate at a constant rate of speed, and from there it passes around the holdback sprocket that feeds it to the lower take-up reel at the side.

The incandescent light source used for projecting the picture is enclosed in a separate compartment with its reflector that focuses the light to a "spot" on the aperture with the aid of a condenser lens. The lamp is rated at 1000 watts, 110 volts, and is mounted in a prefocused socket which insures its proper position in relation to the reflector and condenser lens. A standard "quarter size" projection lens projects a picture about 9 feet wide, at a distance of 40 feet from the screen.

The projector is driven by a one-eighth horsepower a-c motor operating on 110 volts at 50 to 60 cycles, and is equipped with two pulleys one of which is used with 50 cycle supply and the other with 60 cycle supply. This keeps the speed of film travel the same even though the motor runs slower on the 50 cycle current than it does on the 60 cycle supply.

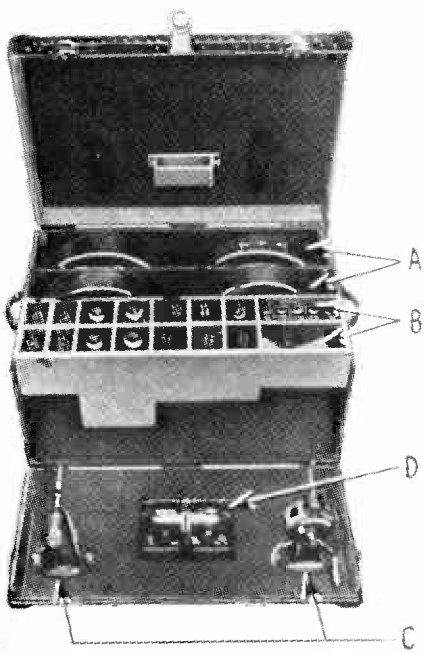

FIGURE 26—*One of the trunks used in packing portable type accessories.*

The drive side of the PG-5 is shown in Figure 25, the various parts corresponding pretty well with those on a standard theatre projector. The "viscous damping device" designated in this illustration is the apparatus that controls the speed of the "constant speed sprocket" about which we shall learn more under the subject of Sound Heads.

The "accessories trunk" in Figure 26, demonstrates how compactly the equipment is packed away for shipment. It contains: "A" the four film magazines, "B" a double set of incandescent lamps and amplifier tubes, "C" film rewinding equipment, and "D" a film splicer that is used to repair torn film.

E. R. P. I. Portable

The Portable sound picture equipment put out by Electrical Research Products, Inc., who control Western Electric sound picture equipments, is different from the R.C.A. Photophone Portable in many respects, most of which are constructional details, the main operating characteristics being the same. The feed reel and the take-up reel are on the same shaft, side by side, the take-up reel, of course, being driven by a slip-clutch arrangement and the feed reel being free to revolve with the pull of the film as it is unwound.

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Figure 27 shows the operating side of this projector and since the illustration is so liberally supplied with descriptive notations there is little further explanation needed. The direction of film travel is indicated by the short, heavy arrows beside the film. In Figure 28, the film path is shown as viewed from the front, coming off the feed reel at the left and re-winding on the take-up reel at the right after passing through the picture and sound projector mechanisms.

A photograph of the operating side of the W. E. Co. Portable is seen in Figure 29, showing the incandescent light source, reflector and condenser lens in addition to the parts shown in the sketch in Figure 27.

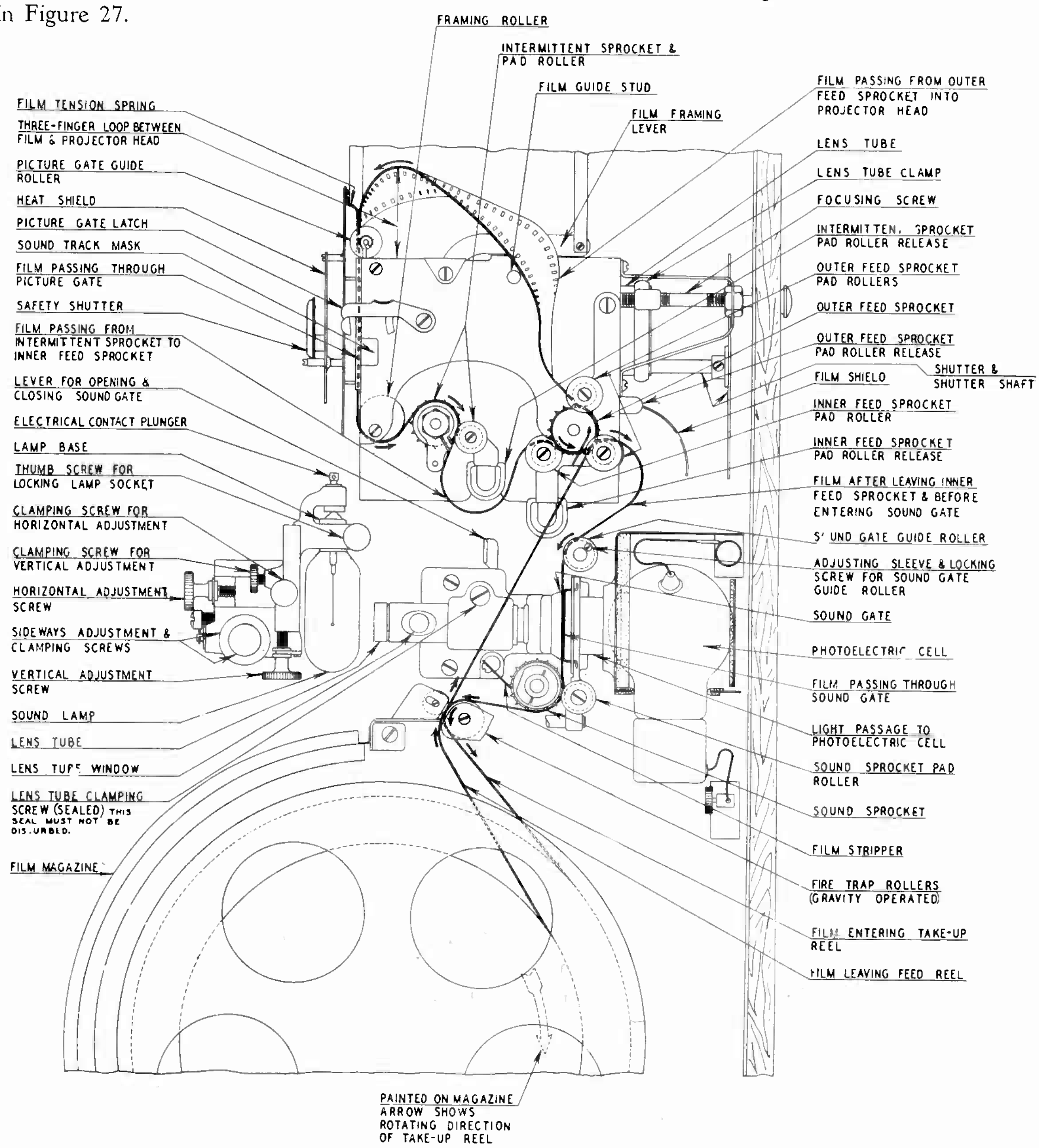

FIGURE 27—*The film path through a W. E. portable sound picture machine, as seen from the operating side. (Courtesy Elec. Res. Prod., Inc.)*

We will conclude this lesson with a brief description of the running of a feature picture. By far the greater number of theatres have at least two operators in the projection booth so we will assume that this is the case in the following description. In the first place, the lamphouses are kept scrupulously clean and the projector mechanism is oiled and cleaned every day. In the oiling of the various bearings in the projector head care must be taken not to use too much oil as it has a tendency to get on the film as it runs through the head, causing poor sound and picture reproduction. One drop on each bearing is sufficient, except in the case of the intermittent mechanism which runs in a well of oil which usually has a glass window with a mark on it denoting the proper oil level to be maintained.

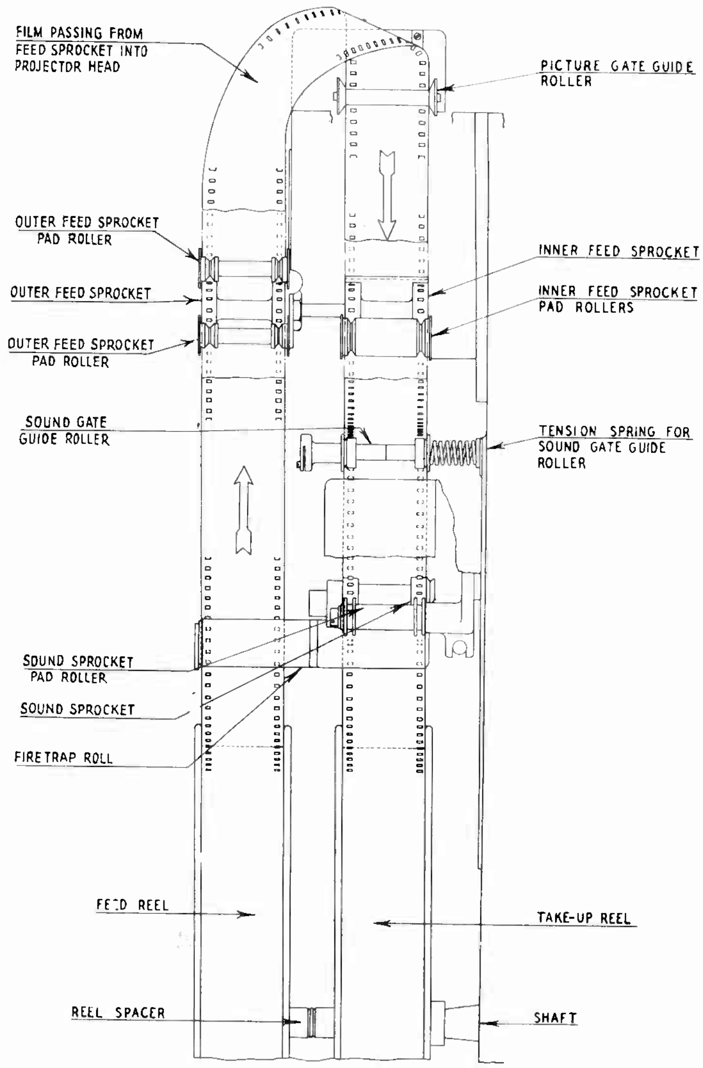

FIGURE 28—*The film is shown coming off the feed reel at the left and rewinding on the take-up reel at the right. (Courtesy Elec. Res. Prod., Inc.)*

When the equipment has been properly cleaned and oiled the first reel is threaded into one of the machines with the "start" picture exactly "in frame". It is quite necessary that this "start" frame be in the aperture when sound-on-disc features are run because the needle of the disc reproducer is started at an exact place on the record and the film and disc must run in proper relation to each other to maintain synchronism. It is not so necessary in the case of sound on film recordings, because the sound track and the picture are on the same film and cannot get out of synchronism.

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After the film is threaded a few feet are run through to see that it is "meshing" properly with all the sprocket wheels. This first reel may now be run to open the show and as it runs for about thirteen minutes there is ample time to thread the second reel of the same feature into the other projector.

Reel Changing

With each film feature the film exchange sends out a "cue sheet" which tells when to switch from one reel to the next and usually consists of a description of a particular part of the picture, and its corresponding sound, at which the "change-over" is to be made. For instance, if the "change-over" is to be made during the scene of a holdup, the picture cue might read "bandit draws gun" while the sound cue would be "hands up". When the projectionist saw the bandit draw his gun in

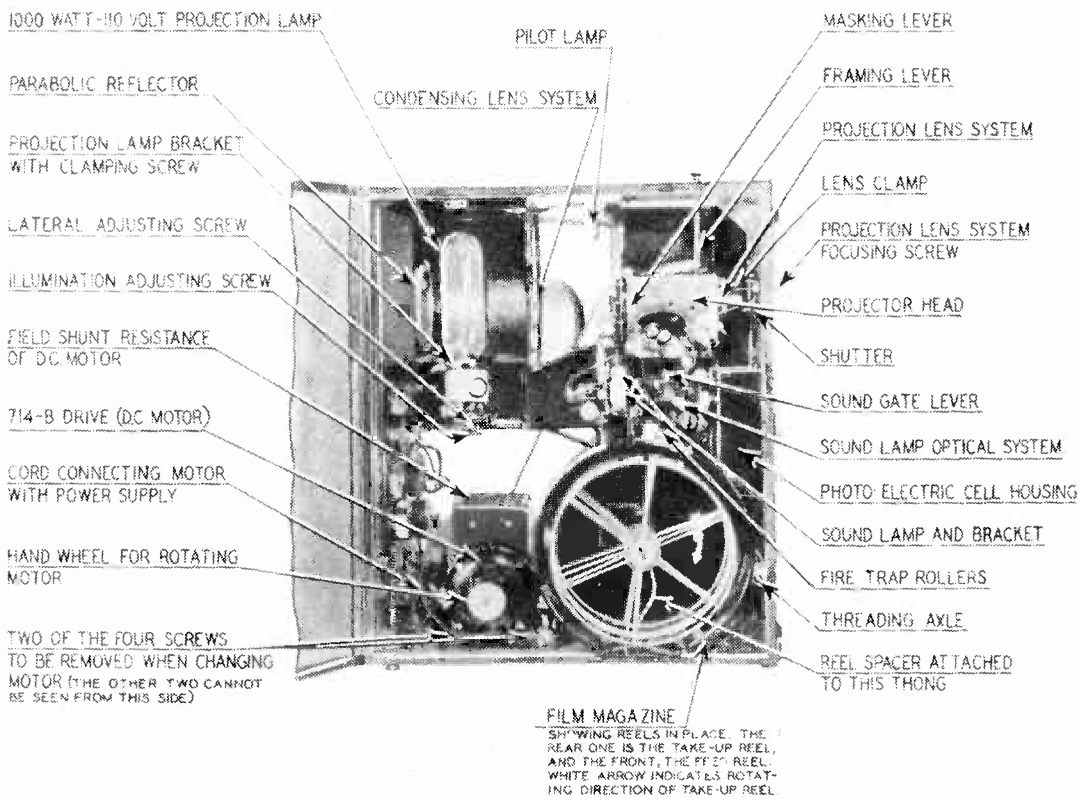

FIGURE 29.—*A Western Electric portable projector with the incandescent light source, reflector, condenser lens and other parts, as viewed from the operating side. (Courtesy Elec. Res. Prod., Inc.)*

the picture on the screen or heard the bandit's voice coming from the "monitor horn" in the booth saying "hands up" he would immediately switch off the picture and sound from one projector and turn the other on. There are two cue places for each change-over, however, one to let the projectionist know when to start the second projector up and the next cue to let him know when to switch the light and sound over to the "incoming" machine, for an incoming projector must be "up to speed" before it is "cut in". When the change-over from the first to the second reel has been made the first reel is allowed to "run out" until it is all wound on the take-up reel. This reel is then removed to the rewind room, rewound back on another reel and put in its proper place for the next running.

The third reel of the feature is threaded into the first machine, however, before the rewinding is done in order that it may be ready for the change-over from the second to the third reel. In this manner all the reels comprising the picture are sent through alternate machines without a "break" in the show, the change-overs being unnoticed by the audience. The arc of each projector is turned on only a minute or so before the projector is started and is turned off again when the reel is finished so that the only time both arcs are in operation is for a short time during change-over preparations. When the entire feature has been run the first reel is threaded back into the free projector and the same routine is gone through for another show.

EXAMINATION QUESTIONS

1. What three sprockets are common to all types of motion picture projectors?
2. What are the advantages of a "rear type" revolving shutter over a "front type"?
3. What other forms of light source than the arc are used in projectors and what advantages do they offer? What disadvantage?
4. Name the parts of a picture head encountered by the film in its journey from the feed reel to the take-up reel.
5. What are "strippers" and what is their purpose?
6. What function is performed by "pad rollers" in a picture head?
7. Which type of revolving shutter produces less flicker, the two blade, or the three blade type"? Why?
8. Draw a free hand sketch of the path of film through a Motiograph head, showing sprockets, guide rollers, pad rollers, and strippers.
9. Is it necessary that the "start" frame of a sound-on-disc production be threaded "in frame"? Why?
10. When is the "change-over" made from one reel to the next?

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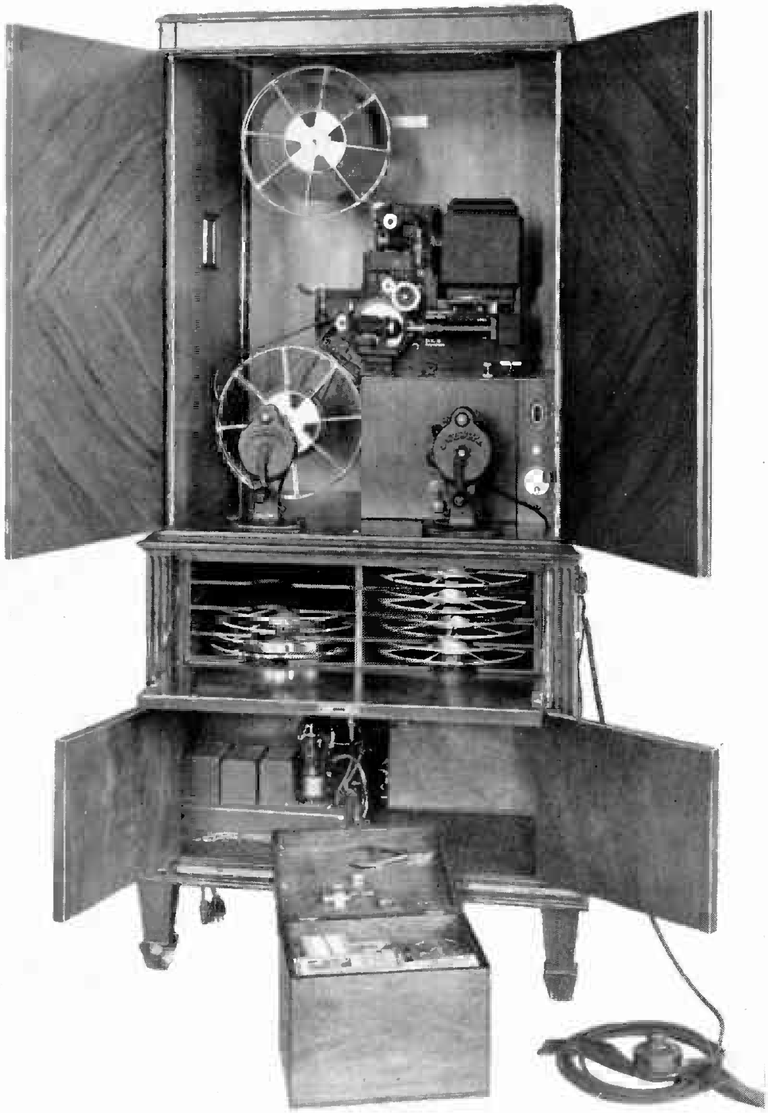
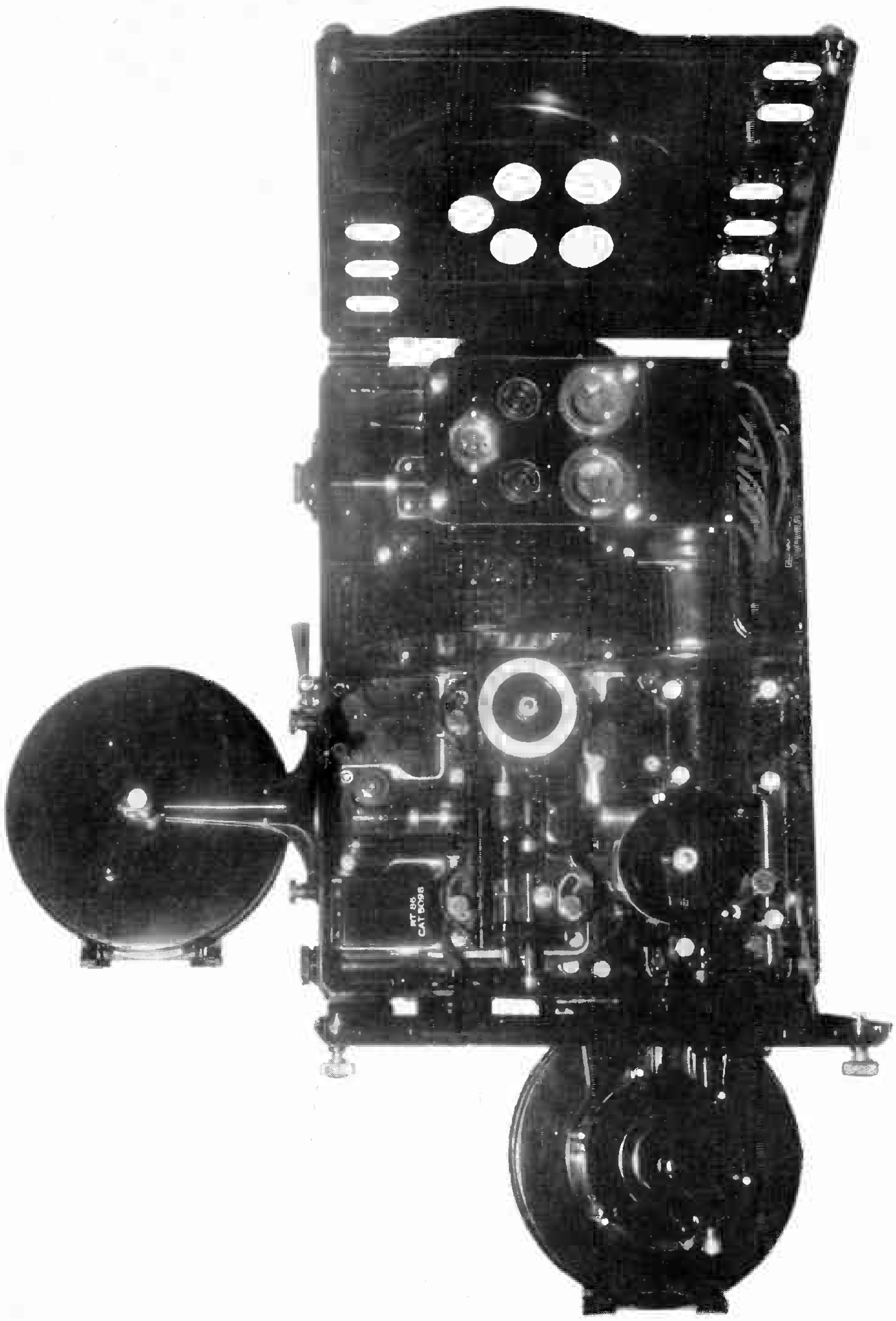


Sound-on-film motion picture projector for home entertainment.



Portable motion picture projector used by U. S. Navy. (Courtesy Inter. Proj. Corp.)

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America's Oldest Radio School

RCA INSTITUTES INC

A Radio Corporation of America Subsidiary

HOME OFFICE
75 Varick Street, New York
NEW YORK N.Y. CHICAGO, ILL. PHILADELPHIA, PA. BOSTON, MASS.

WHEN MAKING A VOICE RECORD THE HOME RECORDING MICROPHONE SHOULD BE HELD FROM ONE TO TWENTY INCHES IN FRONT OF THE MOUTH, THE DISTANCE DEPENDING ON THE INTENSITY OF THE NATURAL VOICE AND SENSITIVITY OF THE MICROPHONE.

Personal and Radio Recording-on-Disc For Home Entertainment

VOL. 58, No 19

THE MICROPHONE, PICK-UP UNIT AND OTHER PARTS, PERMIT THIS EQUIPMENT TO BE USED FOR PERSONAL AND RADIO RECORDING AND PLAYING PHONOGRAPH RECORDS IN CONJUNCTION WITH THE AUDIO CIRCUITS OF A RECEIVER

America's Oldest Radio School

RCA INSTITUTES INC. — A Radio Corporation of America Subsidiary

HOME OFFICE 75 Varick Street, New York

PERSONAL AND RADIO RECORDING ON DISC FOR HOME ENTERTAINMENT

Since the days of the first phonograph the subject of personal recording has been an interesting one. Early types of machines used blank cylindrical records which could be played back on the same machine only by a mechanical arrangement for removing the cutting or recording tool and substituting for it a reproducing tool of some kind coupled to a diaphragm acting as the "air-pump." Sometimes a change was required in the carriage carrying the mechanism for accomplishing the above. After the advent of the disc record the same disadvantage held for a while, in that the cutter had to be guided over the record by some threaded screw device for constant spacing of the average position of one groove from the next.

Considerable impetus was given to the interest in home recording when combination radio-phonograph reproducing equipment became standard equipment for the average home. The electrical amplifier supplied the power necessary for cutting the record without recourse to

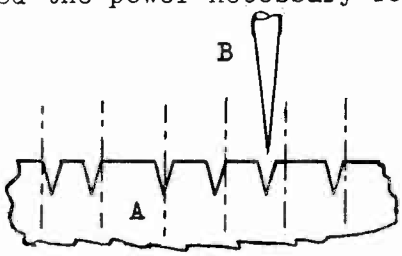


Fig. 1 - CROSS-SECTION OF STANDARD COMMERCIAL PHONOGRAPH RECORD

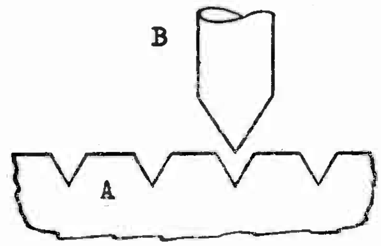


Fig. 2 - CROSS-SECTION OF A PREGROOVED RECORD

"brute force" methods previously used. An additional interest was recording in permanent form some favorite radio programs for repeated enjoyment at future times. Mechanical complications in directing the cutting tool with a continuous spiral motion interfered with the convenient use of the same mechanism for reproducing.

This can best be understood by referring to Figure 1 in which "A" is a cross-section of a commercial phonograph record. The recording is first made on a very smooth soft wax disc about an inch thick. As this blank is rotated by some suitable driving motor the cutting tool "B" is caused to rest in the wax a short distance, cutting a groove therein which takes on the form of a continuous spiral due to an additional mechanism which continually changes the distance of the cutter from the center of the disc by regular amounts. If no program is being recorded during this movement the groove will be a perfect spiral, with equal spacing between grooves, as shown by the dashed lines of the figure. When the electric currents caused by some program operate the cutter, its point is caused to move back and forth across the line of the spiral; the groove therefore departs more or less from the true curve in accordance with the vibration imparted to the recording cutter. This results in a spacing of grooves along the cross-section which depends on the direction and amplitude of the cutter vibration as it crossed the radial line at which the cross-section was made. The wax blank was necessitated by the fact that the minute cutting could not be done in the hard material of which the final record is made. Between these two record forms there is a complicated and critical process of electroplating in various stages which is obviously impossible for the home.

PREGROOVED RECORDS

The solution of these many troubles was reached in the development by the RCA Victor Company of a record blank in which had been pressed a perfect spiral groove of uniform spacing. This condition is shown by the radial cross-section illustrated in sketch A, Figure 2. The special needle B shown here has an angle of point which is somewhat greater than the angle made by the walls of the groove, so the needle rides along on the edges of the premolded grooves. The lateral vibrations during recording push back the top edges of the groove to an extent determined by the amplitude of vibration. It is seen that the home recording operation does not involve "cutting", but is instead a process that might be called "squeezing." The material employed in the making of these special records is such that its form may be slightly altered by pressure. Considerable study was necessary to obtain a material whose slot edges could be readily deformed for recording, but which would be sufficiently stable to hold such deformations during a reasonable number of reproducings. This was aided by using a weight placed on the pick-up while it was being used as a recorder, and removing it for playing back.

NEEDLES

The blunt point of the home recording needle causes it to ride along on the upper edges of the pregrooved slot, where lateral squeezing has previously deformed the edges in accordance with the program sound variations. The pressure of the pick-up on the groove makes the needle move sideways toward any part of a groove edge which has been squeezed back. This needle movement causes the generation of electric currents in the pick-up which are the electrical counterpart of the recorded program. The needles used for the playing of standard commercial records of the lateral-cut type are quite different. The general shape of the average needle used is shown in sketch B, Figure 1. It has less of an angle formed at the point than is formed by the side walls of the groove, as determined by the angle at the point of the cutter during recording operation. The needle will therefore ride in the bottom of the groove. As the groove is moved past the needle by the rotation of the disc, the needle point will follow any departures of the groove to one side or the other of the average position of the needle at that part of the spiral.

MOTORS

On account of the extra weight used in recording, a phonograph motor of the induction disc type will assume a slower speed during recording than during reproducing, unless some circuit arrangement is incorporated for compensating this effect. The driving disc is actuated by parallel field windings whose currents are maintained in split-phase relationship by unequal electrical design. The more nearly the phase relation between the two field currents comes to 90 degrees, the more torque the motor will have. Thus for recording purposes where the additional power is required a condenser is inserted in series with one set of field windings as in Figure 3. This brings that field current more nearly in phase with the applied voltage and nearer to 90 degrees phase difference with the current in the other field winding, whose inductance is high. In reproducing, the condenser is shorted by a switch and the extra torque is removed.

Such an expedient is not necessary with a synchronous motor having sufficient power, since a motor of this type will run at practically constant speed under various loads up to the overload point which makes the motor stop altogether.

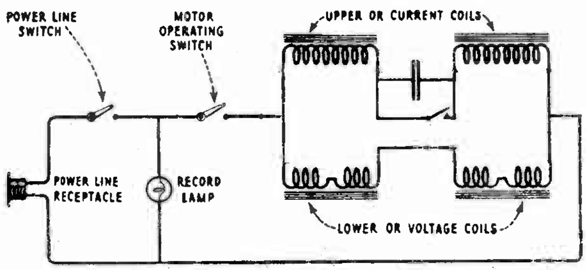


Fig. 3 - CONNECTIONS OF INDUCTION DISC MOTOR

CIRCUITS AND SWITCHING

In home recording the circuits in general are those employed in regular radio-phonograph combination machines. In utilizing the audio amplifier for recording as well as reproducing some complications arise from the switching mechanism which is necessary. The four functions which are desired are as follows:

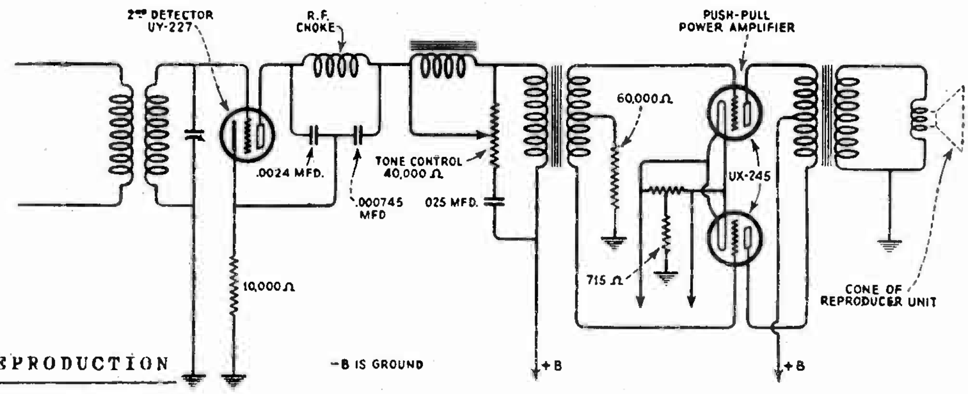
1. Radio Reproduction
2. Radio Recording
3. Home Recording - Personal Recording
4. Phonograph Reproduction

Fundamentally the switching arrangement must be so designed as to permit the phonograph pick-up unit to be used in the output of the amplifier for recording, and on the input of the amplifier in reproduction. Simultaneously a change in the circuit must be made to permit the use of the loudspeaker as a weak monitor during recording, and in the normal efficient manner in reproducing. In like fashion a shift must be made at will from local microphone to radio detector output, in accordance with the type of recording to be done. In the case of an induction disc motor it is desirable to have the same switch perform the shorting of the added condenser in the field circuit during phonograph reproduction.

Just what switches are used, and how they are wired, are matters of design in any particular combination. It is important to know the fundamental circuit conditions for the various functions listed above. To that end we show on pages 4 and 5 the four circuit conditions for the Radiola 86, with a description of the several functions and on pages 6 and 7 we show the circuit conditions for the RCA Institutes' A-C Pentode Kit Receiver combined with the Phonograph and Home Recording Kit with explanations.

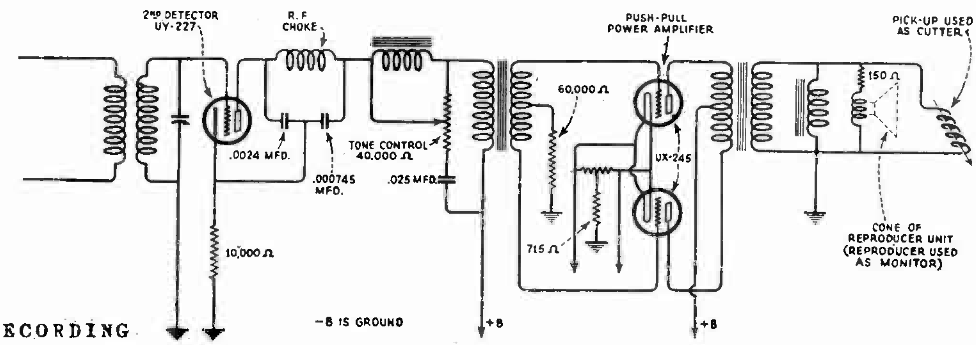
AUDIO CIRCUITS FOR RADIOLA 86

Fig. 4 —



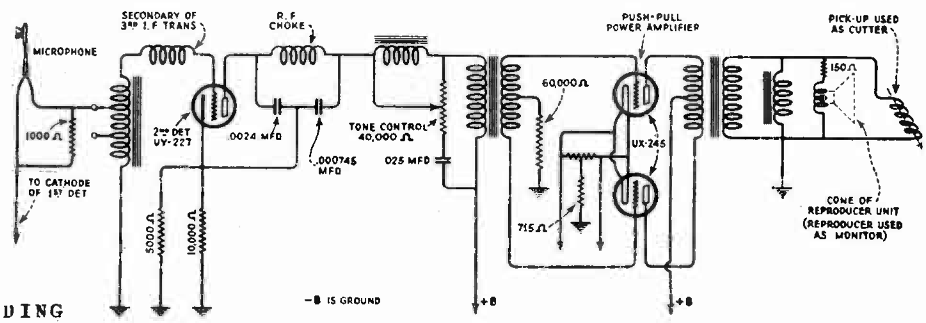
RADIO REPRODUCTION

Fig. 5 —



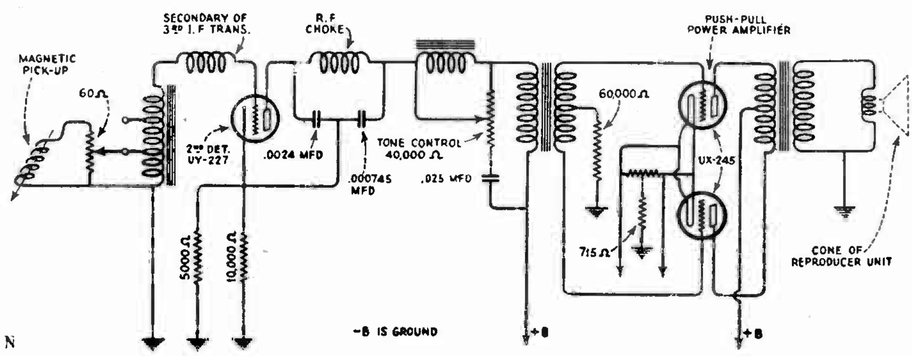
RADIO RECORDING

Fig. 6 —



HOME RECORDING

Fig. 7 —



PHONOGRAPH REPRODUCTION

AUDIO CIRCUITS FOR RADIOLA 86

RADIO REPRODUCTION (Fig. 4). This is the same as if the circuit did not have the change-over switch which permits other uses of the instrument.

RADIO RECORDING (Fig. 5). Any radio program may be recorded on the proper kind of blank with this instrument. The additional material required is a record blank and a special home recording needle. Extra care must be taken to tune the station exactly "on center." The volume control must be set for the maximum undistorted output as determined by first using the "Radio Reproduction" connections of the instrument. The electrical functions of recording a radio program are the same as that of receiving such a program with the exception that the pick-up is substituted for the cone coil of the reproducer unit. The cone coil is then connected across the output with a 150-ohm resistor in series so that the reproducer can be used as a monitor. The sound from the speaker will then be weak and somewhat distorted, but this is no indication of the true signal quality going through directly to the pick-up used as a recorder. The tone control is set for maximum high-frequency response. When acting as a recorder greater pressure by the needle is required on the record than when reproduction is in progress. Therefore a small weight is provided for placing on the pick-up head while recording. A reactor is placed across the output transformer to partially by-pass the currents of low frequency which otherwise would make the recording needle point swing wide enough to break down the sidewall of a groove and skip from the proper groove into an adjacent one.

PERSONAL RECORDING - HOME RECORDING (Fig. 6). In this position the radio portion of the receiver is made inoperative and the second detector is used as an audio stage to precede the power amplifier. A small hand microphone of the single-button type is provided for recording the voice or other program originating in the home. This microphone is connected in series with two sections of an input autotransformer and the bias resistor of the first detector of the receiver. Part of the current through that resistor is thereby diverted so that about 10 milliamperes flows through the microphone. The output of the autotransformer is applied to the grid of the second detector, whose action has been changed from detecting to amplifying. This is accomplished merely by shunting the normal grid bias resistor of the second detector with an additional resistor, lowering the voltage drop across it to a value which makes the tube function as an amplifier. The tone control is set for maximum high frequency response except when recording a voice which makes "hisses" of all the "s" sounds in words. The special home recording needle must be used and the weight placed on the pick-up as in radio recording.

PHONOGRAPH REPRODUCTION (Fig. 7). For this purpose the magnetic pick-up is lifted from the output circuit and returned to its more familiar position across a volume control potentiometer whose output side is connected to the first section of the autotransformer. The amplifier action is then the same as for microphone use, until the output circuit is reached, where the loudspeaker voice coil has been returned to its normal connection directly across the secondary of the output transformer, and the shunt reactor disconnected. The amplifier may now be used for the reproduction of programs previously recorded by either radio reception or microphone. The same type needle as used for recording is also used for reproduction, but the recording weight must be lifted off. This circuit connection is the

AUDIO CIRCUITS FOR RCA INSTITUTES' KIT COMBINATION

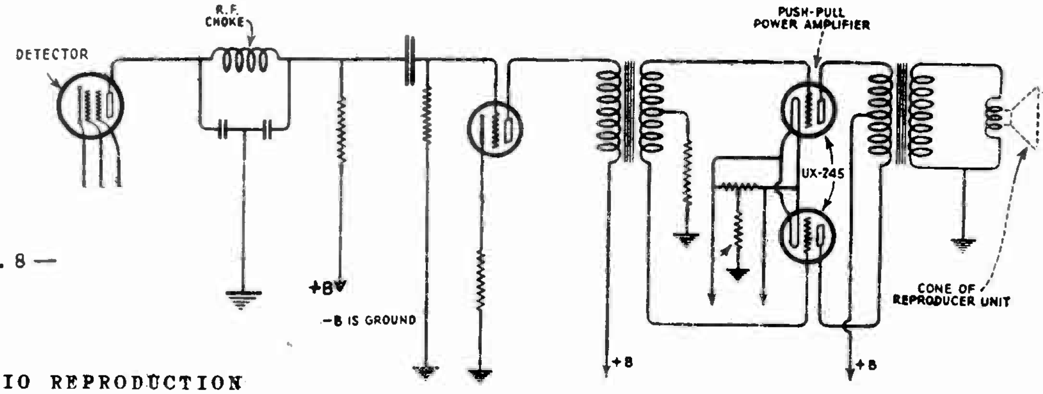


Fig. 8 —

RADIO REPRODUCTION

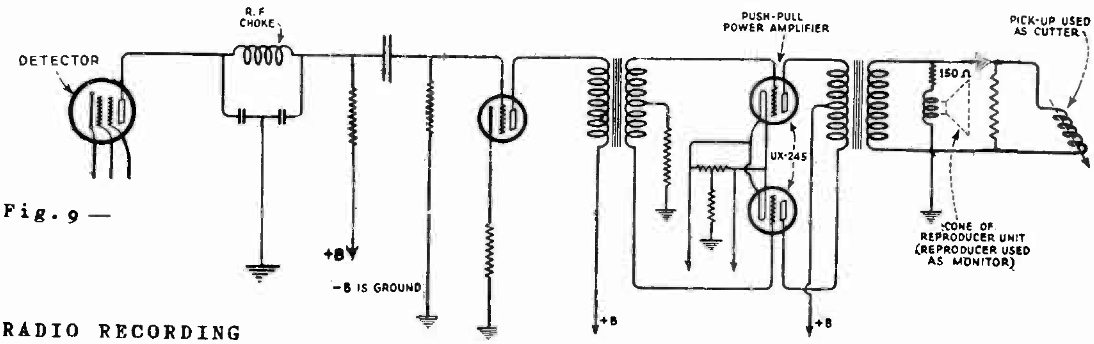


Fig. 9 —

RADIO RECORDING

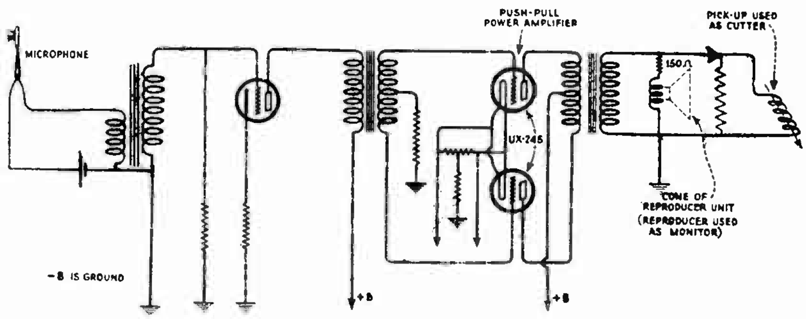


Fig. 10 —

HOME RECORDING

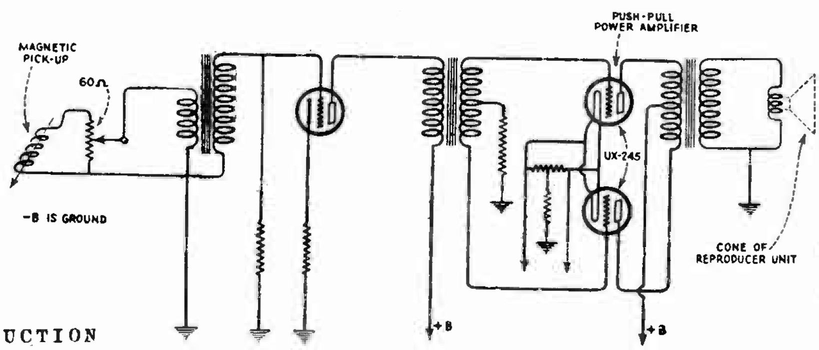


Fig. 11 —

PHONOGRAPH REPRODUCTION

normal one for reproducing from regular phonograph records, in which case the special home recording blunt needle is removed and use is made of one of the many types of ordinary phonograph needles as desired by the person operating the set. These ordinary needles are not to be used for home recording, and if attempts are made to use them for such reproductions the record will be ruined.

AUDIO CIRCUITS FOR THE RCA INSTITUTES' KIT COMBINATION

RADIO REPRODUCTION (Refer to Fig. 8)

This circuit arrangement in Fig. 8 differs from the preceding set in Fig. 4 as indicated by the schematics, but we are chiefly interested in the fact that the set in Fig. 8 employs a UY-227 tube in an audio-amplifier stage between the detector and the power amplifier. The coupling between detector and first audio stage is of the resistance type. The set is shown as adapted for the use of UX-245's. The original pentode circuits may be used for RCA-247 tubes.

RADIO RECORDING (Refer to Fig. 9)

For monitoring purposes the loudspeaker cone coil is connected across the output transformer secondary through a series resistor. The pick-up, weighted for use as a recorder, is connected across the end terminals of the potentiometer which normally serves as a phonograph volume control. One end terminal and the sliding contact go directly to the secondary of the output transformer. Leaving the potentiometer in such a relation to the pick-up is a matter of convenience and simplicity in switching. During recording the control is set at maximum as we have indicated by the heavy arrowhead, hence, as far as recording performance goes, it does not matter whether the variable contact is toward the transformer or the pick-up. There is no by-pass reactor used for low voice-frequencies and instead the Voice Autograph Records supplied by RCA Institutes have been made with a wider spacing between grooves to prevent groove-jumping.

HOME RECORDING - PERSONAL RECORDING (Refer to Fig. 10)

The output circuit and recorder remain the same as for "Radio Recording." The first stage amplifier has been changed; the grid of the tube and its grid leak have been shifted from the detector output coupling condenser to the high side of the secondary of a special audio input transformer. The primary of this is connected to the single-button microphone through a primary cell of 1.5 to 4.5 volts. Since the amplifier is not supplied with a tone control, there is no protection from the "hissing" type of voice. A convenient corrective device that may be used is a fixed condenser of from .0001 to .0005 mfd. shunted across the secondary of the microphone input transformer during recording only.

PHONOGRAPH REPRODUCTION (Refer to Fig. 11)

Here the loudspeaker has been restored to its full normal function since the pick-up and its volume control have been transferred to the primary side of the special input transformer. The system is ready for reproduction of recorded programs. The recording weight must be left off and the choice of needles depends, as before, on whether a home record or a commercial record is to be played.

IMPORTANT POINTS IN REGARD TO HOME RECORDING EQUIPMENT

RADIO CUT-OFF

During phonograph reproduction or home recording it is quite necessary to render the radio receiver inoperative as far as the audio amplifier is concerned; provision for a radio cut-off will prevent simultaneous recording or reproduction of two programs. There are many ways in which this can be done. For illustration we give some actual methods which are applied to certain receivers as follows:

1. In the Radiola 86 the lead between negative voltage supply and cathode of 2nd i-f tube is opened, which makes that tube inoperative.
2. The radio cut-off in the Victor RE-57 is accomplished by opening the voltage lead to the screen grids of the r-f amplifier tubes.
3. In the RCA Victor RAE-59 the necessary change is brought about by opening the lead between positive plate supply and the plates of the r-f and i-f tubes.
4. The RCA Institutes' Kit Receiver circuit is altered by disconnecting the grid of the first audio tube from the detector output.

DETECTOR-AMPLIFIER CONVERSION

If there is no audio-amplifier stage between the detector and the power stage, it becomes necessary, during microphone recording and phonograph reproduction, to convert the detector into an amplifier. The method depends on the manner in which the detector grid bias is secured. If self-biased, as in the Radiola 86, this reduces itself to changing the net resistance used for bias to such a value that the tube will operate on the linear portion of its characteristics. If the bias is obtained from a voltage divider, a tap may be used for the proper grid voltage during use as an amplifier.

MICROPHONE CURRENT SUPPLY

In the Institutes' Home-Recording Kit the microphone current is supplied by a small primary battery of from 1.5 to 4.5 volts. In commercial receivers the current is usually supplied from that portion of the filtered current system which is most free from hum and noise. In the Radiola 86 the microphone-transformer circuit is connected across the first detector biasing resistor where the voltage is created mainly by the direct-current component of the oscillator plate supply. In the Victor RE-57, it is connected directly to the screen-grid supply tap.

SHUNT CHOKE IN RECORDING OUTPUT

When such a choke is used, it is usually designed so that its impedance is less than the pick-up coil on frequencies below 1000 cycles. A material shunting of the currents having frequencies below 200 cycles results from this arrangement. However, the shunting effect at frequencies above 1000 is negligible. This frequency discrimination enables the choke to subdue the bass notes producing a wide needle-swing without materially affecting the higher register.

LOW IMPEDANCE PICK-UP

Home recording outfits use a low impedance pick-up because it becomes interchangeable with the voice coil of the electrodynamic speaker, by being connected to the same output transformer during recording. Since an input transformer must be used for the microphone anyway, it is a simple matter to have that transformer tapped at the proper place to provide the proper impedance to match the pick-up used during reproducing from phonograph records.

MICROPHONES

In home recording, a microphone is required which is sufficiently sensitive to be used without any amplification other than is provided with the component parts of the usual home combination instrument. This dictated the choice of the carbon type of microphone, which has certain disadvantages but provides the required sensitivity.

A single-button microphone used in home recording is shown in Fig. 12. It is of rugged construction to withstand handling by an inexperienced person.

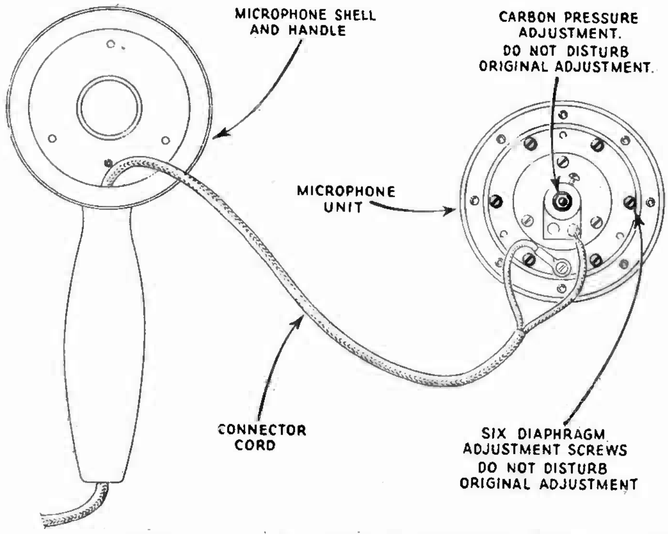


Fig. 12 - DETAILS OF SINGLE BUTTON MICROPHONE

A double-button type having a better fidelity characteristic is used in later receivers. It is more sensitive than the single-button type but appreciably more costly.

Precautions must be used in the handling of any of the carbon types of microphones. A serious jolt may disarrange the carbon particles and impair both its sensitivity and fidelity. If the jolt occurs with the current flowing through the microphone, the carbon may "pack" or "freeze", requiring return to the factory for repair by skilled workmen.

INPUT TRANSFORMERS

The double-button microphone requires a center-tapped primary on the input transformer, with the voltage supply connected between the

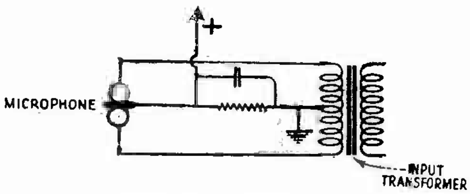


Fig. 13 - DOUBLE-BUTTON MICROPHONE USED WITH CENTER-TAPPED TRANSFORMER PRIMARY

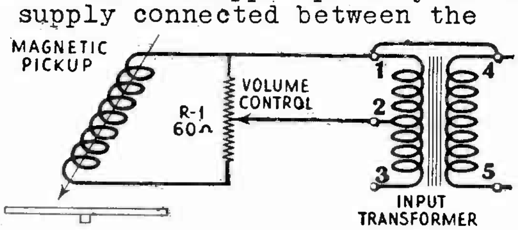


Fig. 14 - PICK-UP USED WITH CENTER-TAPPED INPUT TRANSFORMER

center-tap and the center of the microphone, as shown in Fig. 13. By correlation of the design of microphone and pick-up, it is possible to secure good operation of the pick-up for phonograph when connected across one-half of the primary winding, and this is usually done as shown in Fig. 14.

PRACTICAL ASSEMBLY OF THE RCA INSTITUTES PHONOGRAPH AND HOME RECORDING KIT

The following pages of this lesson are devoted to a practical discussion dealing with the construction and wiring of the RCA INSTITUTES' PHONOGRAPH AND HOME RECORDING KIT combined with the A-C PENTODE KIT RECEIVER. However, the description is sufficiently general, when combined with the preceding text, to permit the student to wire the home recording kit to any type of receiver. Whether or not a student has these parts to perform the actual construction work he should go over the following pages carefully because many practical points are to be learned from this subject.

MOTOR ACCESSORIES ASSEMBLY

The motor comes attached to the board so it is only necessary to add the gears and speed change lever to completely assemble it. First

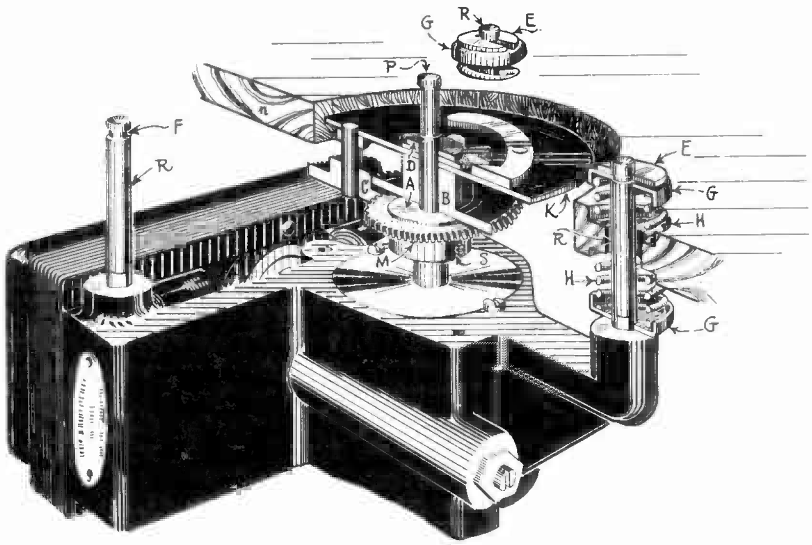


Fig. 15 - CUT-AWAY VIEW SHOWING CONSTRUCTION OF SPEED-CHANGE MECHANISM ASSEMBLED WITH THE MOTOR

put the set screw S (part #55651) in the gear M, shown in Figure 15, and assemble on the motor shaft as indicated. A hole has been drilled in the shaft and the set screw in gear M should be recessed in this hole until the gear is tight. It will be necessary to use a long thin screw-driver to perform this operation.

Next mount the speed change mechanism on the board as shown in Figure 16. One flat-head and two round-head wood screws are needed for this purpose. The speed escutcheon plate is next screwed to the board just beyond the lever arm. The center punchings marked I and J in Figure 16 were made in the board for mounting this mechanism.

As shown in Figure 15 next put the brass (or copper) washer A on the turntable drive shaft just over gear M. Now place the gear reduction mechanism on the shaft. It will be necessary to set the gear shift lever as shown in Figure 16 to allow the gears to mesh. Place the leather washer D on top of the reduction gear as in Figure 15.

When the gear shift lever is in position #1 (see escutcheon plate) it should clear the gear reduction mechanism. When it is in position #2 the pin on the bottom of the outer end of the lever arm should drop in the notch on the disc K (Figure 15) of the reduction gear and the hook on the end of the lever arm should catch on the end of the pawl B (Figure 16) pulling the pawl so that it does not mesh with the gear A.

PRELIMINARY TESTS

Make the following two tests:

(1) Set the speed shift arm in position #1, connect motor across 110 volts a-c and turn on the current. The turntable should turn at 78 r.p.m. If it operates satisfactorily shut off motor.

(2) Next set the speed shift arm to position #2, and turn on the current. This time the turntable should rotate at slow speed, that

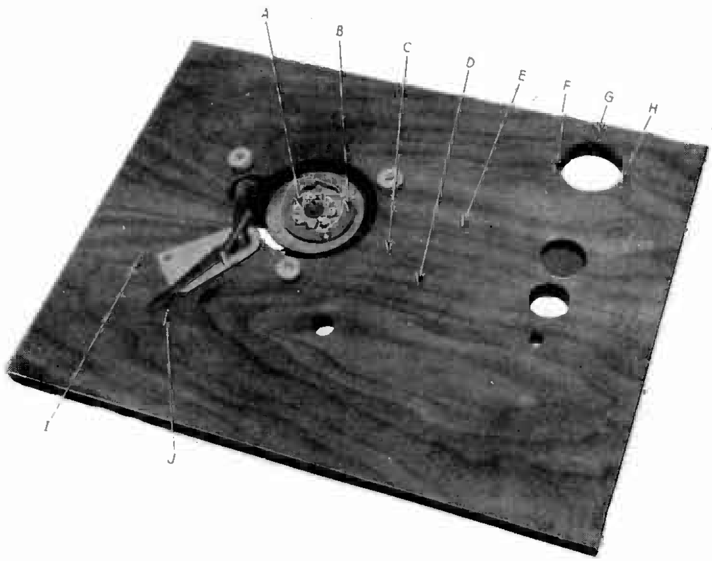


Fig. 16 - SPEED-CHANGE MECHANISM MOUNTED ON PHONOGRAPH BOARD

After the foregoing tests are completed then fasten the automatic stop switch, shown in Figure 17, on the board using the punchmarks C, D and E in Figure 16. The washers #60563, if needed, are to be inserted under the switch, one for each mounting screw, to raise it off the board so that the brake will make proper contact with the inner surface of the turntable. Bring one lead from the motor up through the small hole in the board and connect to one terminal on the automatic switch (Figure 17). The opposite terminal of the switch then goes to one side of the a-c line. The other lead of the motor goes to the other side of the a-c line. It will be necessary to remove the insulating cover of the switch when making these connections.

ASSEMBLY OF THE PICK-UP ON THE 2-SPEED MOTOR BOARD

The following instructions apply specifically to the assembly of the pick-up kit to the two-speed motor board assembly. These pick-ups can be used with other motor board assemblies providing there is a hole 2-1/8" diameter through the mounting board with 9-3/4" between the center of this hole and the center of the turntable drive shaft.

For assembly on the motor board refer to Figure 16. Insert pick-up head on pick-up arm. First it will be necessary to remove the machine screw in the head end of the suspension arm, replacing it again after the head is in place and tightening it to hold the head fast. Insert the connection plug into the pick-up head. As the pick-up arm is nearly balanced with the heavy counterweight it is essential that the arm be pivoted freely at the fulcrum A as in Figure 18 in order to obtain the correct needle pressure on the record. A drop of oil should be applied at this fulcrum and if this does not help sufficiently, loosen by prying with a screw-driver between the side of the arm and the fulcrum until the arm swings up and down freely. If the pick-up arm does not swing freely from side to side, put a drop of oil on the bearing B, Figure 18 . Also oil the bearing surface between the pick-up arm base and the top of the pivot.

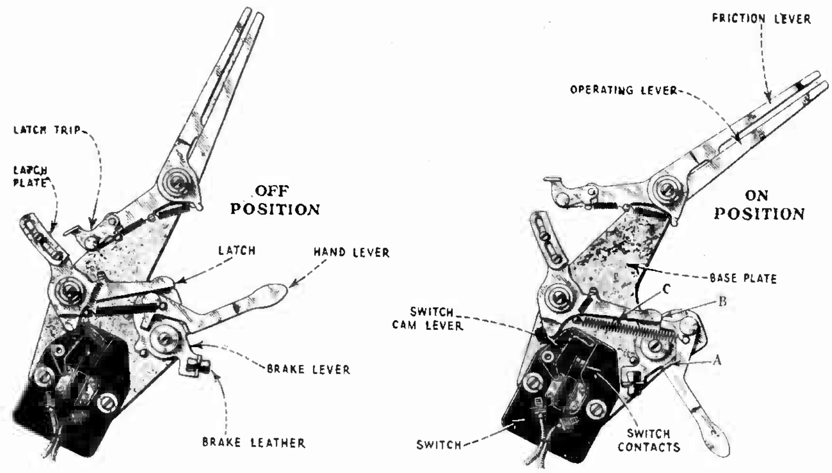


Fig. 17 - AUTOMATIC STOP SWITCH

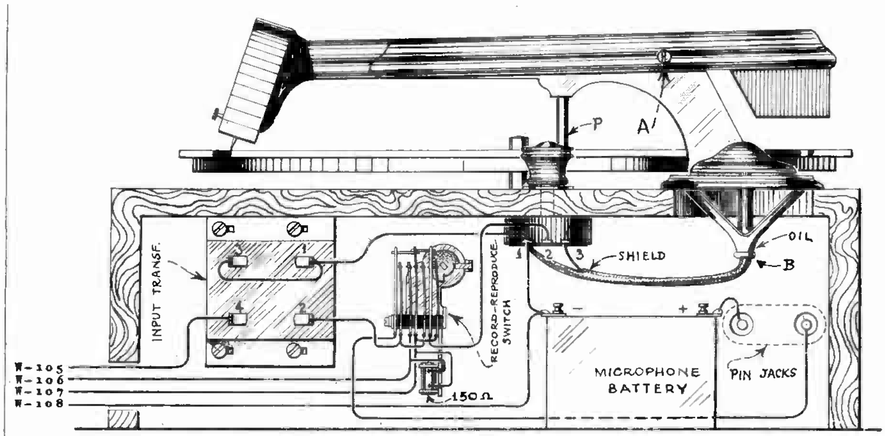
The three long round-head wood screws are used to mount the pivot for the pick-up arm on the board over the large hole in the upper right-hand end (Figure 16). Use the center punched markings, F, G, and H to locate the correct point for the mounting screws. Next mount the pivot and arm making sure that pin P, Figure 18, projecting from the arm is in the slot between the friction lever and the operating lever (Figure 17) on the automatic stop.

HOW TO CHECK FOR CORRECT OPERATION

To check the operation of this mechanism set the suspension arm toward the outside of the board. Now pull the hand lever on the automatic mechanism toward you (Figure 17). This releases the brake and closes the contacts on the electrical switch. Now swing the tone arm toward the center until the latch trip meshes with the ratchet. Next give the tone arm an outward swing. This should open the switch and set the brake. Put the turntable in place and repeat the above operation when the power to the motor is turned on. When the arm is pulled outward the switch will open the motor circuit and the brake should bring the turntable to a quick stop. This same operation is automatically obtained with records which have an eccentric groove at the center. When a record of this type has been played the needle continues to track in the eccentric groove which first swings the arm toward the center of the record and then away from it. This outward motion trips the latch, disconnects the motor from the line and sets the brake on the turntable.

FINISHING THE ASSEMBLY

Holes are provided on the motor board for mounting the volume control potentiometer and needle cups. No holes are provided for mounting the pin jacks or switch as it is not usually desirable to mount them on the board. However, the switch may be mounted on the top board by drilling a hole 1/2" in diameter. To mount the pin jacks drill two 1/2" holes 7/8" apart. The board is made oversize so it may be cut down to suit the user. The minimum size to which the board can be cut and still be used with the RCA pick-up suspension arm is 13" x 17½"; the size of the board as you receive it is 2½" greater each way of these dimensions.



WIRES TO

W-105 INPUT OF FIRST AUDIO AMPLIFIER STAGE THROUGH PHONO-RADIO SWITCH
W-106 HIGH END OF LOUDSPEAKER VOICE COIL
W-107 HIGH END OF SECONDARY OF OUTPUT TRANSFORMER IN RECEIVER
W-108 GROUND (FRAME) OF RECEIVER

Fig.18 - COMPLETED MOTOR-BOARD ASSEMBLY WITH PICK-UP IN PLACE ON A RECORD

If no cabinet is available for this kit a suitable mounting may be made from 3/4" soft wood making a bottomless box 15½" x 20" x 4" deep on which the board may be screwed. When this is done the pin jacks and switch may be mounted on the side of the box.

Other apparatus, such as the input transformer and battery, may be mounted on the under side of the board or on the side walls of the cabinet or box, as desired. Figure 18 shows a view of the completed motorboard assembly with pick-up in place.

When in operation the board should rest in a level position so that the needle will track in the record groove without danger of jumping from one groove to the next. This is especially important when playing a home recorded record because the needle used in this operation is rather blunt and will jump grooves with much greater ease than the usual sharp-pointed needle used with a standard record.

WIRING THE MICROPHONE, PICK-UP AND COMPONENT PARTS TO THE RECEIVER

Figure 18 is a picture drawing of a phonograph home recording kit with the four wires marked for making proper connection to the RCA Institutes' pentode kit receiver. Figure 19 is a schematic diagram showing how connections are made to the same kit receiver. The loudspeaker shown in this diagram is of the low impedance type (moving coil). The diagram does not show how the field current for the speaker is obtained as this will be determined by the apparatus on hand. The output transformer is the regular transformer marked T3 used in the kit. In this case, however, the two black leads (W-54 and W-53) from the secondary are now used. One of these is connected to a ground on the receiver. (This ground is preferably the ground marked G-2 which is shown on the complete wiring diagram in the instructions which go with the kit receiver.) The other lead is connected to W-107 shown in Figure 18 of this lesson. Next ground one lead of the voice coil to G-2, referred to immediately above, and connect the other voice coil lead to W-106 in Figure 18 of this lesson. W-108 connects to the ground of the receiver. This connection can be made through the right-hand "Phono" pin jack on the receiver. W-105 connects to the left-hand "Phono" pin jack which, in turn, connects to the grid of the first audio-amplifier tube through the phono-radio switch. The two leads to the "Phono" pin jacks should be closely twisted together throughout their length to prevent inductive effects.

In case a low impedance speaker is not available W-106 should be taped up and not used. This corresponds to opening wire marked "To L.S. VOICE COIL" in Figure 19. Now a regular magnetic speaker may be connected to the speaker pin jacks of the receiver. The principal objection to this method of operation is the annoyance that will result from the unusually loud sound output of the speaker and in addition the acoustic feed-back into the microphone is increased if it is used in the same room with the speaker. Unless an independent volume control (which does not affect the voltage of the output transformer secondary) is used with the speaker, the speaker should be disconnected from the set during recording.

A 150-ohm resistor in series with the voice coil of an electro-dynamic type speaker will cut the sound output of the speaker to such an extent that it is not uncomfortable to listen to even though recording the maximum undistorted output of a receiver. The loudspeaker in this event would be used merely as a monitor.

The switch, as shown in Figure 19, has two positions, namely, (1) for recording, and (2) for reproducing. A single-button microphone may be inserted in the pin jacks at the motor board and voice recordings made.

THE PHONO-RADIO AND RECORD-REPRODUCE SWITCHES PROVIDE FOUR POSSIBLE USES

By means of the phono-radio switch in the receiver and the record-reproduce switch on the phonograph four possibilities are provided, as explained under the following topics numbered 1 to 4. These uses were previously referred to in connection with the diagrams in Figures 8, 9, 10 and 11.

(1) RADIO REPRODUCTION. (See Figure 8) Place receiver switch in position for RADIO, and the motor-board switch in REPRODUCE position. The volume is to be controlled by the receiver volume control knob.

(2) RADIO RECORDING. (See Figure 9) Place the receiver switch in RADIO position, and the motor-board switch in RECORD position; the pick-up volume control being set at maximum. The radio signal intensity for recording must first have been adjusted with the switches in the positions mentioned in paragraph (1) above, for maximum undistorted output. When the switches are thrown to the radio recording position the sound from the loudspeaker will be weaker and distorted, which is normal for this position. The important thing is the correct value of undistorted signal voltage for operating the recording needle. For recording you should insert an RCA Victor blunt point home re-

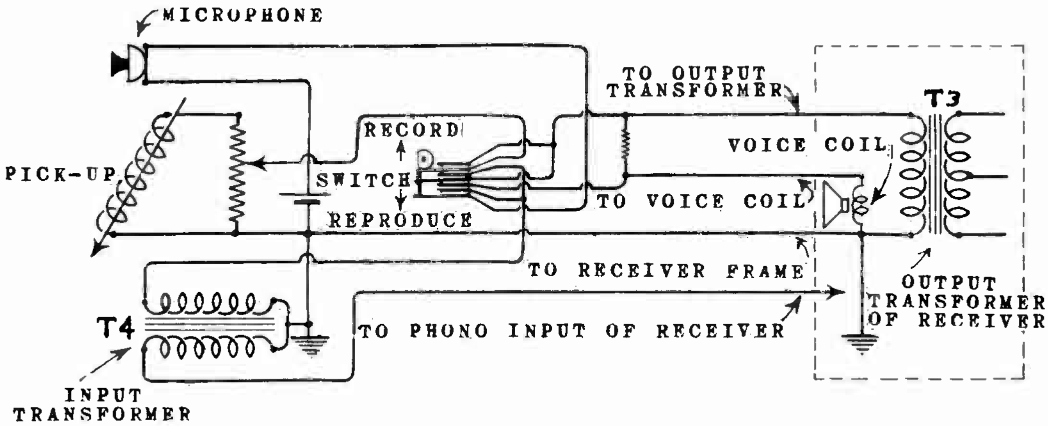


Fig. 19 - SCHEMATIC DIAGRAM OF CONNECTIONS TO AUDIO SECTION OF THE KIT RECEIVER

cording needle (red shank) in the pick-up unit. Next place on the turntable a pregrooved record of either the RCA Victor type or the RCA Institutes' Voice Autograph type. Put the weight supplied for that purpose on the pick-up head and start the motor at the desired speed. When the wanted signal is being received set the pick-up gently in the outer groove of the special record. Allow the motor to run as long as the desired program continues or until the record is filled. The recording process changes the appearance of the record slightly so that it is quite easy to tell at a glance where one recording stopped, and to determine whether there is room for another. The motor will automatically stop at the end of the record if this assembly consists of Kits #6 and #7 used with the Institutes' Voice Autograph Records.

(3) HOME RECORDING. (See Figure 10) Place the receiver switch in PHONO position and the motor-board switch in RECORD position. The pick-up volume control may be used to control volume, but it is advisable to make all recordings with that control at "maximum." This gives a high ratio of desired signal impression on the record as compared to needle scratch, etc. When reproducing you should remember to use the volume control for obtaining the wanted volume level. When a radio program is to be recorded you should use the same needle and follow the same instructions as for a microphone program recording.

(4) PHONOGRAPH REPRODUCTION. (See Figure 11) Place the receiver switch in PHONO position and motor-board switch in REPRODUCE position. The volume is controlled by the pick-up volume control on the motor-board. The speed lever must be placed in the proper position according to the record being played. This applies to the home recordings also, since these could have been made at either speed. The recording weight must be off the pick-up head. The choice of needle to be used depends on the record. For long-playing records the RCA Victor chromium needle (orange shank) must be used. For ordinary program records the choice is wide, with a long and satisfactory service being provided by a chromium needle with either a green or orange shank. The green shank needle will play 75 to 100 records as compared to 25 with the orange shank needle.

In reproducing long-playing records (at 33-1/3 r.p.m.), after the hand lever has been thrown for starting, the speed lever may have to be held at the extreme left-hand position while a light pressure of the hand is applied to the turntable to hold it until it is positivelv driven by the motor.

THE MICROPHONE AND ITS CIRCUIT

The microphone supplied with the kit is of the single-button carbon type having a resistance of about 200 ohms. A battery or other direct-current source must be provided to set up a flow of current through the microphone circuit. The higher the voltage applied within limits, the more current will flow and the greater will be the amplification of signal obtained. A 1.5-volt cell may be sufficient to give the necessary speech amplification, but 4.5 volts will be required in some cases. The voltage should not be so great as to cause the carbon granules to pack during normal handling of the microphone. In most cases the maximum voltage used will be determined by the tendency toward acoustic feed-back between the loudspeaker and the microphone. Usually where these two units are in the same room sound waves from the loudspeaker will be impressed on the microphone and re-amplified causing a strong howl. In circumstances of this kind a 1.5 volt cell is the highest that can be used.

PROPER USE OF THE EQUIPMENT

The following directions and suggestions should be observed:

1. When talking or singing into the microphone enunciate clearly and use a normal voice.

2. Hold the microphone from 1 to 4 inches from the mouth.

3. Do not touch the microphone with the lips.

4. It is sometimes desirable to turn the microphone slightly to one side so that the voice is not directed straight into its opening.

5. Hold the microphone in a vertical position and do not move it excessively.

6. Keep the microphone as far away from the loudspeaker as possible. Any trouble from feed-back can be remedied to some extent by deadening the room with draperies, holding the microphone away from reflecting surfaces and, particularly by keeping it away from the front of the loudspeaker.

7. If an acoustic howl occurs even when the microphone and speaker are separated as much as possible, it may be necessary to reduce the current flowing in the microphone circuit either by reducing the voltage of the battery or by inserting resistance in series with the battery and the microphone. An alternative method would be to increase the resistance which is in series with the loud-speaker voice coil during recording. This decreases the feed-back by decreasing the power to the loudspeaker.

CARE OF THE ELECTRIC MOTOR

The motor is of the synchronous type and does not require a speed regulator because it will always drive the turntable at the correct speeds when operated from a power line of the voltage and frequency for which it is rated. The motor used with the kit is rated at 110 volt a-c, 60 cycles.

The motor should be cleaned and lubricated with light oil once every six months. Two oil holes are accessible on top of the motor when the turntable and speed reducing mechanism are removed. The exposed gears under the turntable should be cleaned and lubricated once a year with light grease.

EXAMINATION QUESTIONS

1. Describe briefly the essential difference between the action of the recording point when making a commercial record and when making a home record.

2. Why is a regular phonograph needle not suitable for reproducing from a home record?

3. How can the turning power or torque of an induction disc motor be increased by an external means?

4. Give two reasons for inserting a resistance in series with the speaker voice coil during recording.

5. What is the effect of a choke in shunt to the recording output?

6. (a) In converting a self-biased power detector for use as an amplifier what is added to the tube circuit? (b) Where? (c) How would you determine its value?

7. What may happen to a microphone if it is roughly handled?

8. What steps would you take to determine the correct setting of the radio volume control of a receiver for recording a program?

9. Why must the radio set be rendered inoperative with respect to the audio amplifier during home recording?

10. Name two places in a receiver where a voltage supply could be obtained for a microphone circuit.

PICK-UP, HOME RECORDING WEIGHT, VOLUME CONTROL, AUTOMATIC STOP AND BRAKE FOR TURNTABLE, HAND MICROPHONE, MICROPHONE PICK-UP, TRANSFORMER, CHANGEOVER SWITCH AND BIAS RESISTORS—WITH THESE PARTS THE AUDIO CIRCUITS OF A RECEIVER CAN BE ADAPTED FOR USE WITH A PHONOGRAPH OR MICROPHONE AND FOR HOME RECORDING.

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RCA INSTITUTES INC.

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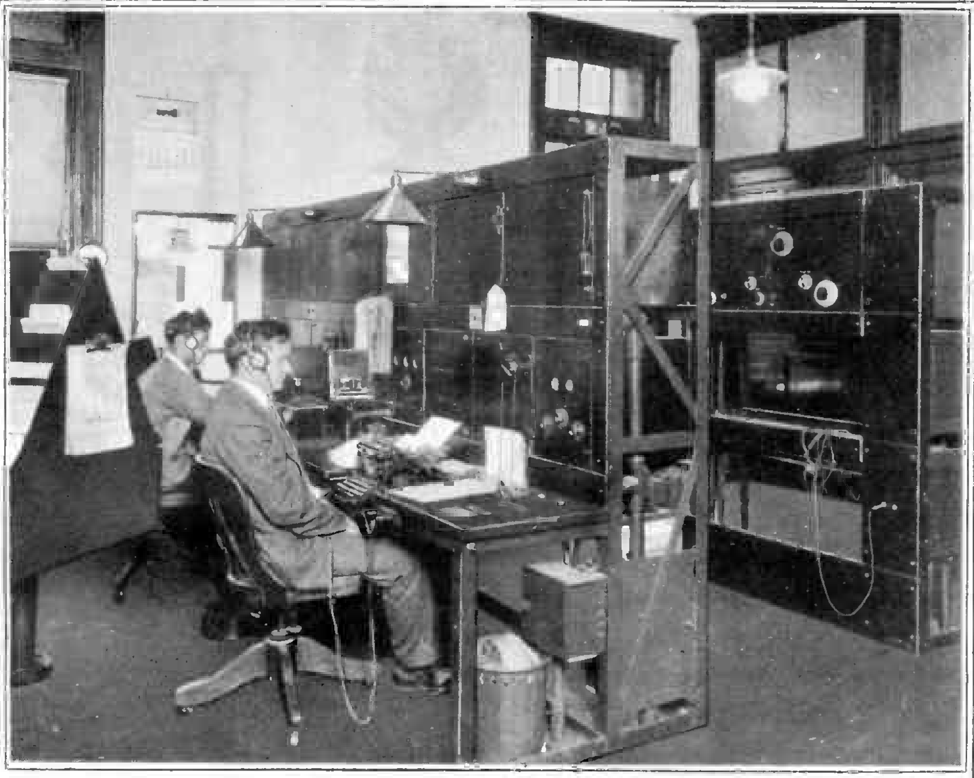
HOME OFFICE
75 Varick Street, New York



RADIO STATION WCC AT CHATHAM, MASS., THROUGH WHOSE CODE CHANNELS HAVE PASSED COUNTLESS MESSAGES BEARING WORD-PICTURES DESCRIBING HAPPENINGS OF PERSONAL OR PUBLIC IMPORTANCE.

Man's Early Efforts to Communicate by Word-Pictures

VOL. 59, No. 1

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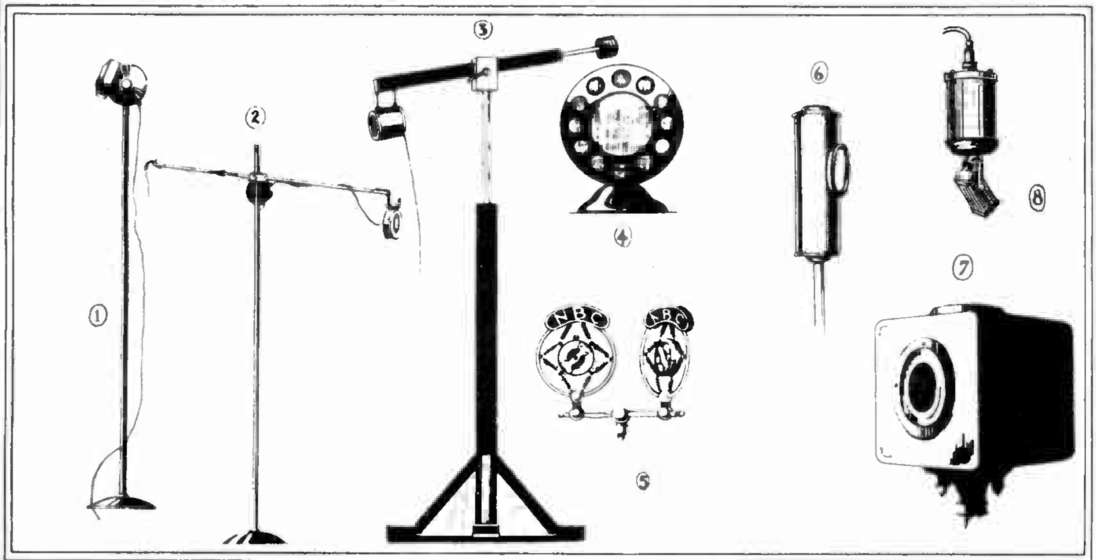

1 - The first microphone, ordinary telephone transmitter.

2 - Its successor was virtually the same mechanically.

3 - The "tomato can" was the first really successfull "mike".

4 - The "bird cage" which is now a symbol for radio.

5 - Its successor, is a refinement.

6 - The first condenser "mike" was a great improvement.

7 - The camera microphone, a refinement of the condenser "mike".

8 - The "ribbon mike", using electro-dynamic principles, is the last word in microphones.

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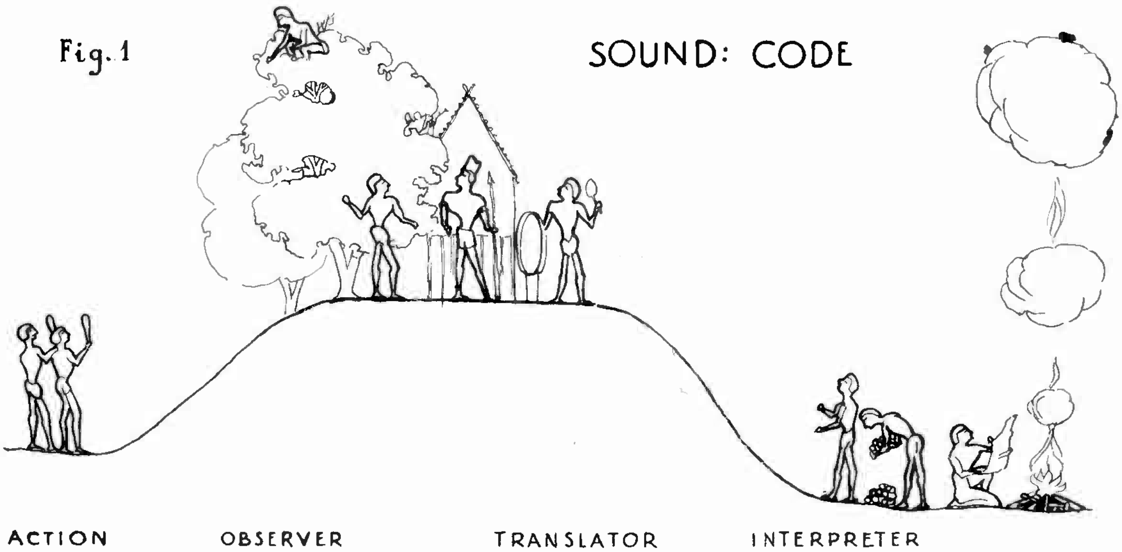
VISUALIZING AT A DISTANCE BY WORD-PICTURES.

Preliminary: In this lesson an outline will be given of some steps in man's progress toward the goal of bringing the whole world within the range of his senses of hearing and seeing.

Early Sound-Wave Systems. Let us consider the primitive scene depicted in Figure 1. The group of men, for protection of their lives and property, have stationed one of their number in the top of a tree, within calling distance. This elevated observer sees approaching from the left an enemy, and gives orally to those below a word-picture of the object and action. While these men are well within

Fig. 1



the voice range of the observer, they are too far away to summon vocally the remote workers in the fields below the village. Since voice amplifiers have not yet been invented, they have recourse to a source of sound power greater than that of their voices. A large drum of stretched skin, or a hollowed log, is mightily beat upon with the strength of their arms, and radiates sound-waves conveying a warning and a summons to those at the lower right of the picture. This signal may even carry an explicit word-picture describing the danger, by combining the drum-beats in certain groups. This is probably the earliest form of telegraph code. Even in these modern times it continues in the form of the tapping of a policeman's night-stick on the pavement to summon help.

Early Light-Wave Systems.

Another primitive method of conveying word-pictures a great distance is the use of one or more fires by night, or puffs of smoke by day (See Figure 1.) This system was elaborated into a code form for conveying a greater amount of information (a more detailed word-picture). This was by means of either a plurality of fires at unequal distances, or the successive revealing and concealing of the fire by the lowering and raising of a blanket between the fire and the distant watcher. This is actually a form of ether-wave transmiss on of intelligence, since light is one form of wave-motion in the same ether that serves to carry radiotelegraph messages and broadcast programs.

The above methods of increasing the "seeing power" of man are fairly quick, but the distance covered is limited by the sound-power or the light-intensity for signalling purposes. The next step to increase our distance of communication is to arrange a portable record of the word-picture we wish to transmit.

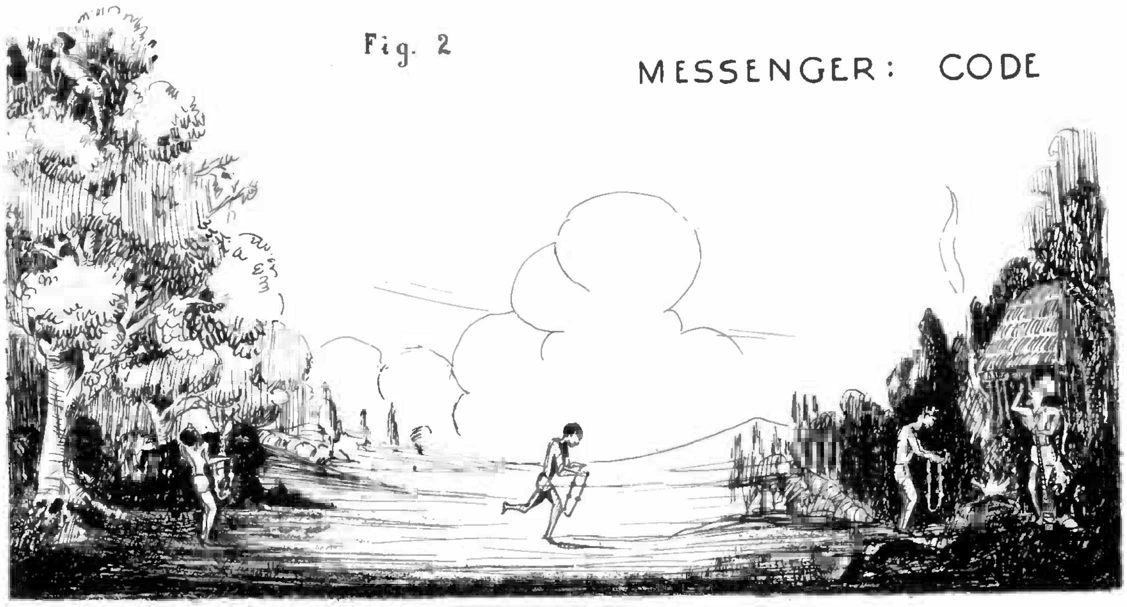


Fig. 2

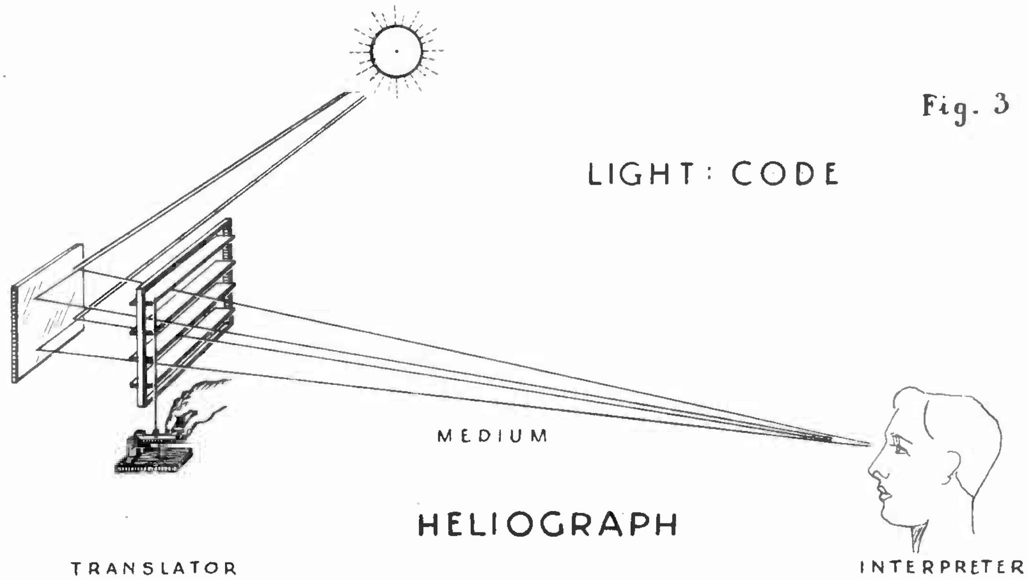
Early Messenger Systems.

In the voice form, these word-pictures are learned verbatim by a messenger (memory record). He travels or is transported to the immediate vicinity of the intended recipient of the information. There the word-picture is released by vocal "delivery". In the code form, a string of beads is made of unequal spacings, for example, in accordance with a pre-arranged system of word-substitution. These would be carried by the messenger to the recipient, as in Figure 2.

Now our communication system is getting more complicated. We achieve an improvement at the cost of an increase in personnel, some of whom may be specialized to some extent. For instance, an ACTION occurs at some point, an OBSERVER especially qualified by good eyesight informs a TRANSLATOR who has a particular skill in quickly, accurately, and economically setting up the string-and-beads equivalent of the word-pictures. Then a messenger of tried speed, endurance, and trail-knowledge becomes the MEDIUM of conveyance to the locality where the information is to be used. Since even a tribal chief may be too dumb, busy, or proud to be qualified in bead-reading, we may find here an INTERPRETER. The latter speedily and clearly changes the bead-and-string arrangement into vocal word-pictures which the RECIPIENT can understand. He does this by a process of visualization, which is forming visual images or mental representations of objects not present to the senses.

Modern Light-Wave Systems.

We have by no means finished with the possibilities of light-waves as a means of communication. While limited as to distance and path,

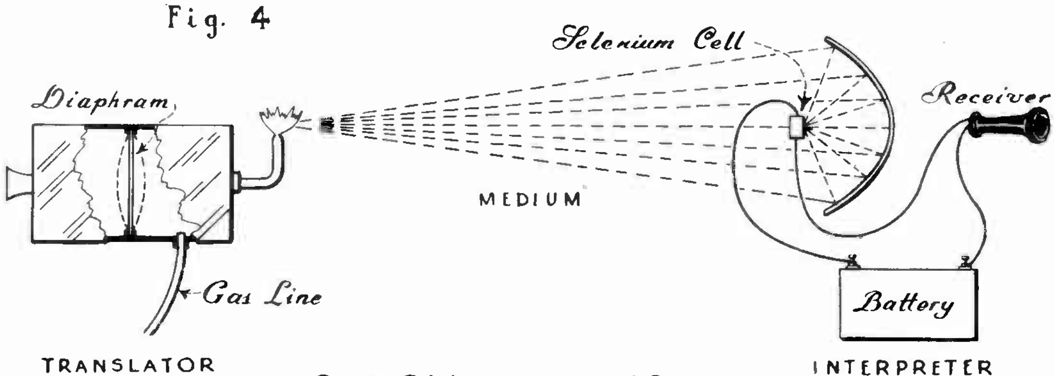


there is the advantage of using as a medium the all-pervading ether, of which light is one form of wave-motion. No physical medium need be constructed between sender and receiver as in the wire systems which we will discuss later.

The heliograph is a return to the code form of word-pictures, as shown in Figure 3. It uses the sunlight reflected by a mirror, with a shutter controlled by a key lever to break the light beam into code impulses, much like the blanket and fire system. This progressed to the use of an electric searchlight with a similar key-and-shutter control. By such a method, signalling was permitted by night and during the day when the sun was not available as a source of light-energy due to intervening clouds. Another form of this consists of a key controlling the switching on and off of the electric current which causes a lamp filament to become incandescent.

We find that at one time experiments were conducted with the transmission of voice over a beam of reflected light. Very little public attention was given to this because of its limited usefulness. The light from the sun or other source was caused to fall on a mirror which reflected the light continuously toward a receiving point, like the heliograph minus the shutter. The mirror was held loosely in a frame, at the rear of which was a mouthpiece. The sound waves of the speaker's voice vibrated the mirror, causing a variation in the completeness of reflection toward the distant point. Here a curved reflector contained a selenium cell at the focal point where the received light was concentrated. A selenium cell is a device whose effectiveness as an electrical conductor depends on the amount of light received on its surface. When this cell was interposed between a current source (battery) and a telephone receiver, the voice-ripples on the light-beam caused voice-ripples in the otherwise steady stream of current between battery and receiver. Now a telephone receiver is a form of air-pump operated by ripples in an electric current stream. Therefore the over-all result was that the receiver created air pulsations (sound waves) which were an approximate imitation of the voiced words of the distant speaker.

Fig. 4



OPTICAL TELEPHONE

Another system, somewhat similar, was called the optical telephone (see Figure 4). The transmitter consisted of a small box divided into two compartments by an india-rubber diaphragm. One compartment was connected to the open air by a mouth-piece. By means of a pipe, illuminating gas was supplied to the second compartment and passed out through another pipe to a burner. The brilliancy of the flame depended on the flow of gas, and this in turn depended on the pressure of the gas at the compartment end of the burner pipe. In operation, the voice of the speaker at the mouth-piece caused the rubber diaphragm to move back and forth in accordance with the impressed sound waves. This movement of the diaphragm increased and decreased the pressure of gas in the second compartment. The gas flame rapidly rose and fell, giving a light-stream that was moulded or modulated by the speaker's voice. The receiver arrangement was the same as for the preceding system.

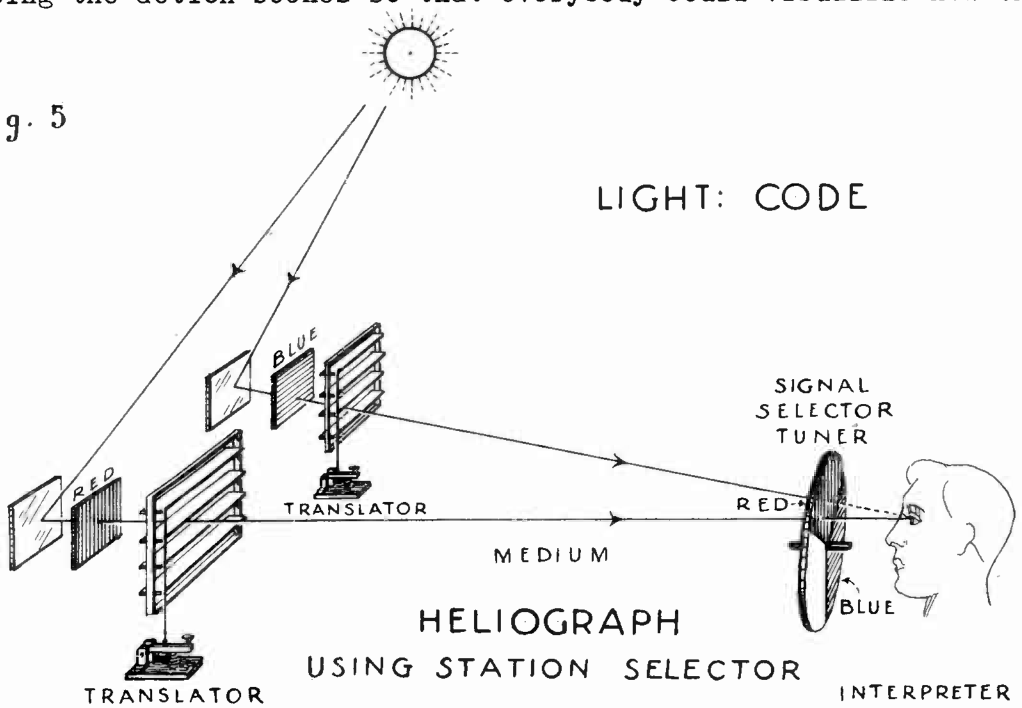
We even find that any of these systems could be developed to give station selection. If sunlight passes through a prism it is broken up into the colors of the rainbow. The primary colors are red, yellow and blue, and these are actually trains of light-waves of different wave-lengths. Applying a red glass filter to a heliograph transmitter, only the red component of the sunlight will be transmitted when the shutter is opened. A second heliograph could be equipped with a blue glass filter, and only the blue wave-length will be transmitted. Each of these heliographs transmits a different message. It is clear then that the receiving eye can be "tuned" to either the first or second transmitter station by holding up a red or blue filter respectively before the eye. (See Figure 5).

Modern Wire Systems.

Telegraph: The earliest wire system is the electric telegraph. Historically it would be grouped with the early photographs of the messenger systems, and the optical telephone method of the lightwave system.

The telegraph (and cable) was a great step forward in aiding high-speed communication. Events all over the world were transmitted to our local newspapers, which in turn printed the word-pictures describing the action scenes so that everybody could visualize how the

Fig. 5



events took place. The telegraph has long been the standard means of long-distance communication. The system has a limitation in that a path (wires) for conducting the electric currents must be constructed between the two points. The word-pictures are transmitted by a code system of impulses in the flow of electric current. This can be roughly compared with the heliograph system of code impulses in light.

The working principle is quite different. An electric current will flow along a path only when it can return to its source, in general terms. It may "go" on one wire and "return" on a second wire; or the return path may be the conducting properties of the earth itself. A source of electric energy is inserted at some point of the circuit, and devices worked by the current may be inserted at any point in the path. The simplest telegraph (see Figure 6) consists of a current source (battery), a conducting path (wires), a path-interrupter (key), and a work-unit (sounder). The latter is merely an electromagnet and an armature. When the current flows through the magnet coil which is part of the current path, the armature is drawn to the magnet and makes a clicking sound. A somewhat different sound is made when the armature returns to its normal position of rest. The time between the down-click and the up-click is a measure of the length of current flow constituting a dot or dash of the code system. This flow is controlled by the key at the transmitting point.

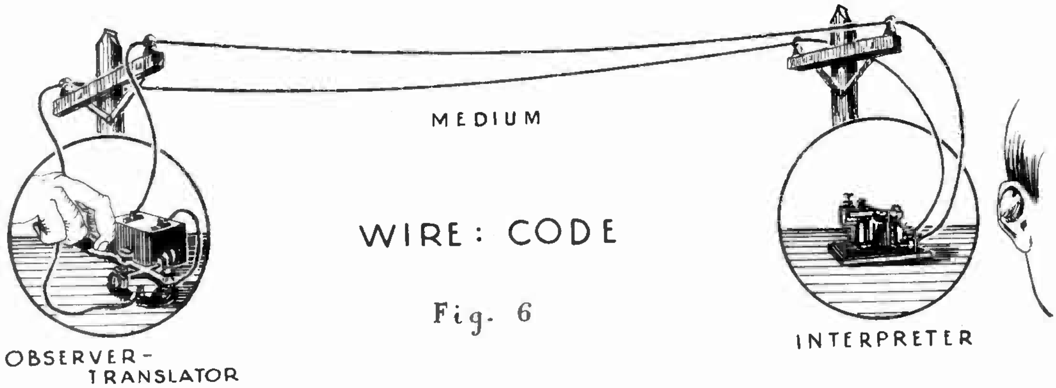


Fig. 6

The foregoing description is of the very simplest telegraph. By placing a key and sounder at each end of the circuit, two-way communication is achieved without the addition of a second pair of wires.

WIRE: VOICE

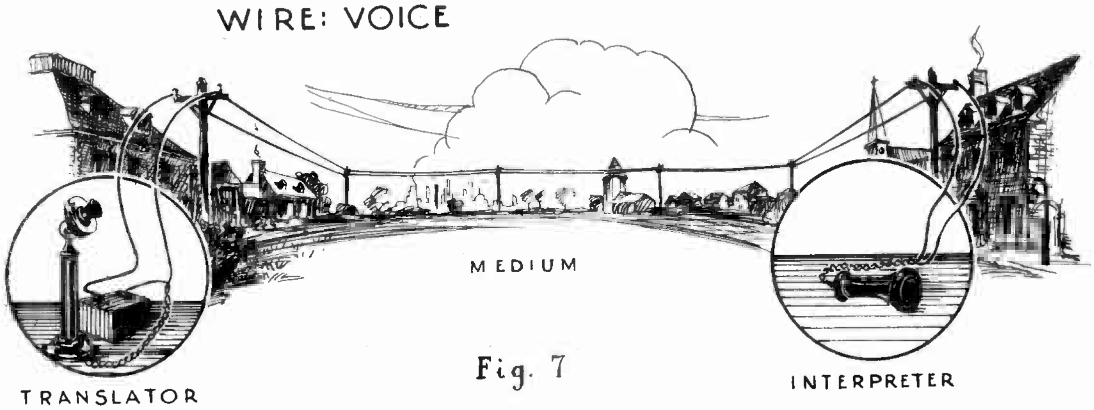


Fig. 7

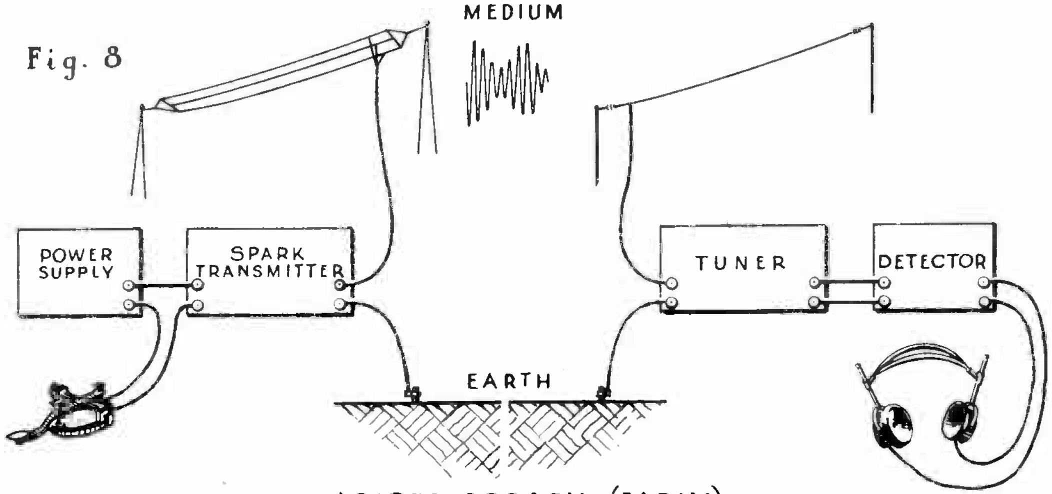
Telephone: Continuing our advance with mankind, the telegraph was not universal enough to meet his needs in quick accurate descriptions that he could send and receive himself. Some means had to be developed whereby he merely had to talk to an instrument which would convey his words directly to a distant person. The earliest development of this kind was the telephone. We can get a good understanding of this by going back to the telegraph. Let us replace the TRANSLATOR of the telegraph (operator and key) with a microphone; the telegraph INTERPRETER (operator and sounder) then is replaced by a telephone receiver (Figure 7). With the same wires, we now have a one-way telephone circuit.

In the telegraph, the key was either closed or open; the current was either flowing steadily or was not flowing at all; the sounder arm was either down or up. In the newer telephone system, a small steady current flows whenever the parties are connected, and the air is quiet at the microphone. When sound waves caused by a voice impinge on the microphone, the current flowing through it is rapidly varied or modulated. The effect may be described as putting voice-ripples in the steady stream of current through the wires and the remote receiver. These ripples cause the receiver diaphragm to move back and forth across its normal position of rest, with an air-pump action that creates sound waves. The total effect of these on the ear is a good imitation of the voiced words of the person at the transmitter. The central switchboard has been omitted because it is just a means of connecting one pair of wires to another, regardless of the complexity of the method. As with the telegraph, two-way communication was achieved by using a microphone and receiver at each end of the pair of wires.

Radio Systems.

Early Radiotelegraph: Nearly seventy years ago a scientist had asserted, from purely mathematical considerations, that a form of electromagnetic ether-wave energy existed of a different order from

Fig. 8



RADIOTELEGRAPH (EARLY)

light. He laid down a concept of the other wave form which was forty years later proven to be correct. These waves were known then as Hertzian waves, after the man who first made a practical demonstration of transmission of the waves and an indicating method for their presence at a short distance. For two decades more considerable scientific thought was given to a study of the nature of the phenomena. Various inventions were made improving the wave-generating and wave-indicating systems. This work was chiefly of the across-the-room type. Most communication systems remain within four walls for some time, as did this one. However, a rude shock was given to the laboratory minds of the day when one young man sought an every-day and everyman utility for the new science. To Marconi is given the credit of bringing the new radio art into being. Actually his chief contribution at the beginning was the use of the earth as one electrode, and an elevated aerial wire as the other electrode.

It is probable that as much credit is due the British Government for their open vision when Marconi first proposed to them his system, and for their persistent faith and financial backing of the costly experiments in the first few years of his work. We can readily see why that government would be one institution above all others which would have a vital interest in such work. The Empire has the British Isles as a relatively small "headquarters". The main area of the Empire is scattered over the face of the earth. The chief means of rapid communication between its integral parts was the telegraph and cable, mostly the latter. These were subject to complete interruption through being cut in the water. Also, some lines had sections actually crossing and owned by other countries. Therefore any means of communication which would pass by or over other countries without possible interruption of service meant increased security for the lives and property of the Empire, as well as economy in construction.

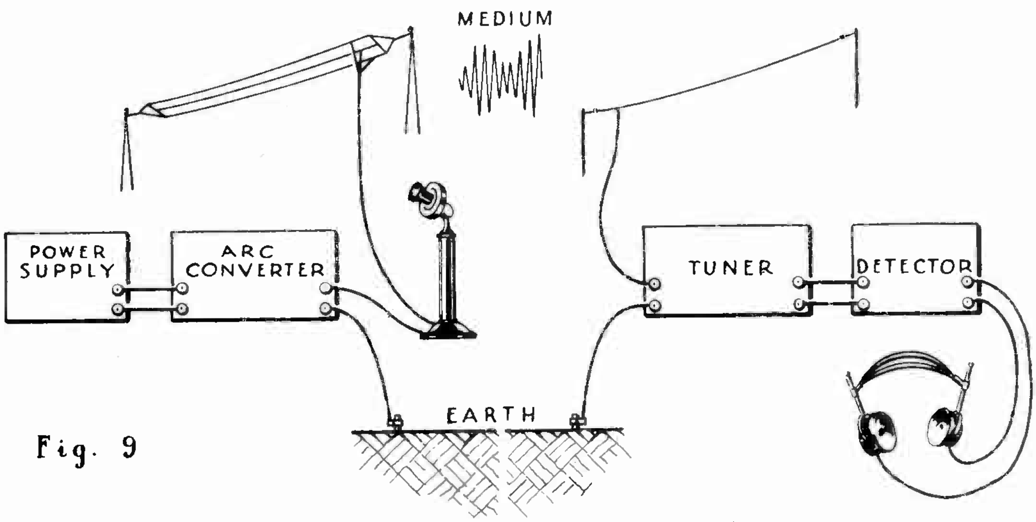


Fig. 9

RADIOTELEPHONE (1905)

His early work was followed, confirmed, and added to by men of other countries, largely encouraged by their own governments. Many uniquely varying circuits and equipment were devised to generate and detect the Hertzian waves, as they were known. These waves were transmitted from an aerial and ground system on which were impressed very high-frequency currents of an oscillatory nature. As sources of these oscillations there were used several types of arcs and sparks associated with Leyden jars (condensers) and wire coils (inductances). In order to make code impulses of the transmitted energy a telegraph key was used, (see Figure 8). This interrupted the power circuit supplying the oscillation generator in spark systems. The keying for arc systems had several variations and usually occurred in the circuit of the oscillation generator rather than in the power supply to it. The two wave types required different methods of detection at the received point. Just as the selenium cell was required for the change from light-wave energy to electrical energy, so another form of detector was required to transfer the radio-frequency currents into electric currents capable of operating a telephone receiver. These detectors were of the coherer, electrolytic, magnetic, and crystal types.

Early Radiotelephone. Even during this era of the code systems, much attention was being given to the telephone use of the new medium. Some oscillation generators, of the arc type, provided the constant amplitude of energy stream which is the beginning of voice methods, comparing with the steady value of battery current in the wire telephone before voice modulation is put on. But the value of the oscillatory current to be controlled in the radio transmitter was considerably higher than the battery current, and no microphones had been built which would stand up in this heavy service. However, a considerable amount of experimental voice transmission was done, including some of a broadcast nature to the general field of amateurs (see Figure 9). The crystal detector and headphones made audible the voice-modulations on the radio carrier wave stream. Usually a heavy background of noise, originating in the transmitter, rendered the system unfit for programs of an entertainment nature.

In the matter of station selection by the receiver, we are not faced with quite the problem we had with light waves, where most of the light-energy sources produced a number of wave-lengths. In a radiotelephone transmitter adjusted for good efficiency, the very principle of oscillation generating determines that in general the

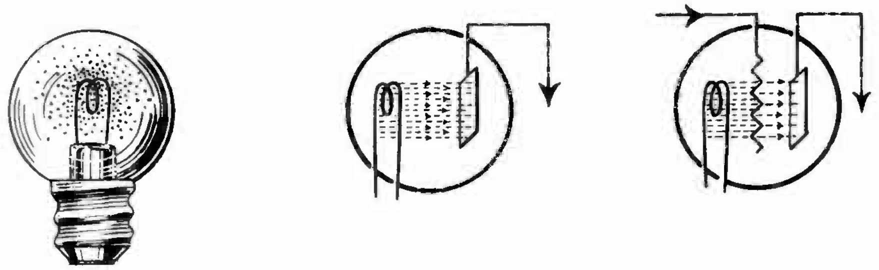


Fig. 10

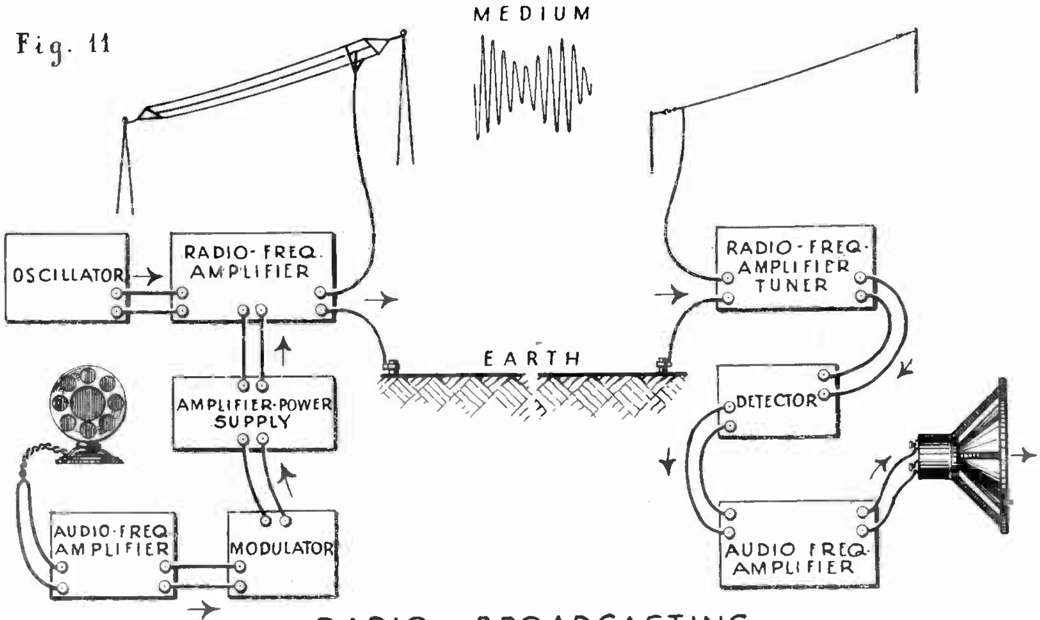
radiation will be at only one wave-length. We have in the receiving equipment an analogy to the color-selecting filter placed before the eye for the colored heliograph signals. The circuit connecting the receiving aerial and the detector contains an electric filter called a "tuner". It passes the current of the desired signal on to the detector and phones; it wastes the signal current of undesired stations on other wave-lengths, just as the red glass filter wasted the light coming to it from the blue heliograph transmitter.

The Vacuum Tube. While Edison was still in the early stages of developing his incandescent lamp, he observed some effects of what we now know to be the emission of electrons from the hot filament. Later a metal plate was included in the lamp bulb and connected to the filament by an external conductive path which included a battery. It was noted that a current flowed through this circuit when the positive battery terminal was toward the plate, but not when the positive terminal was toward the filament. This one-way conductivity gave the tube the name of "valve", and it was first used as a detector of modulated radio-frequency currents in a receiver.

It had the property of changing a modulated wave-stream into a pulsating direct current which would operate the headphones.

A most important step was the addition of a third electrode, or grid, to control the electron flow, (see Figure 10). The new tube was first used as a detector and proved much more sensitive than the crystal type. Subsequent study and many experiments brought out its use as an amplifying device and as an oscillation generator, when connected to circuits of proper design. As a radio-frequency amplifier, several tubes were associated with several tuned circuits. In a receiver this provided a greater sensitivity (for distance) and better selectivity between stations. As a generator it gave a relatively pure output of greater stability of oscillation-frequency than previous methods had done.

Fig. 11



RADIO BROADCASTING

The microphone came into its own. It was now able to mould the wave-stream of the most powerful transmitters, through the use of other vacuum tubes as amplifiers of the weak voice-frequency currents at the microphone. (See Figure 11). The effective distance range of the wire telephone was increased tremendously by similar amplification to compensate for the losses in hundreds of miles of wire. Multiplex telegraphy and telephony brought a new speed of transmission of word-pictures. The improvement in telephone methods meant that a radio station might be erected in a locality which provided best transmission through the ether medium to the destined point. The microphone was brought, in effect, into the transmitter room by the long-distance telephone.

Radiotelephone Broadcasting. During the World War the development of the art was speeded up considerably by the unusual demands of a military emergency. This applied not only to the commercial equipment for point-to-point communication. It affected appreciably the interest and technical qualifications of the thousands of amateurs who had gone into radio service in the war and returned home with an increased fascination for "the radio game". In addition, thousands of young men of no radio experience before the war had received months of schooling and actual operating experience. Their restlessness found expression in the far-flung world of amateur radio. We see then that there was a fertile field for the experimental broadcasting of music and voice programs by the Westinghouse engineers in 1920. The popular interest shown in these occasional programs brought into being the famous pioneer station which was given the call letters KDKA after broadcasting the election returns of November, 1920. This started the ball rolling in what has become not only a major industry but a major public service as well.

A great portion of the program hours is of the nature of directed entertainment, and hours are devoted to matters of a real educational value. As a news service, it brings not only the immediate words of important men, but is the medium of conveying word-pictures of events almost simultaneously with their action. That the public is interested in visualizing at a distance is proved by the interest shown in descriptions of the scene as well as the action, in broadcasts of athletic and political events.

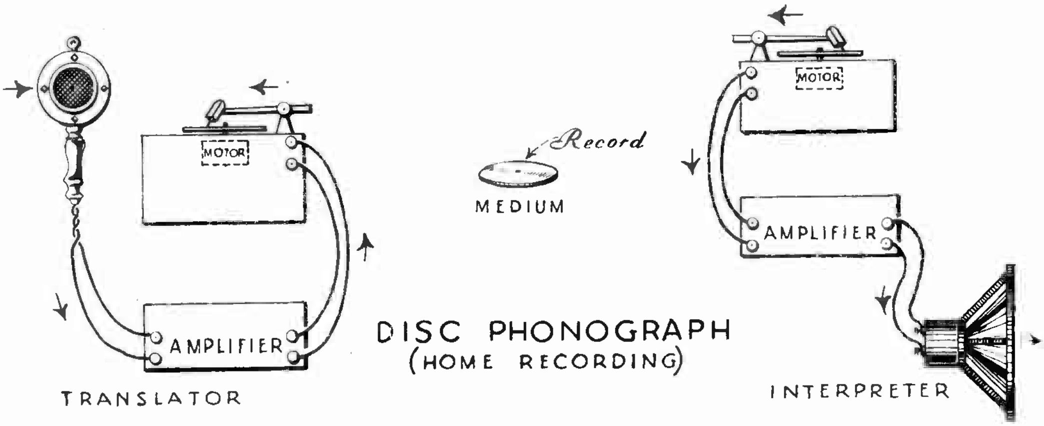


Fig. 12

The TRANSLATION function is performed by the series of apparatus commencing with the microphone and ending with the antenna and ground connection of the transmitter. This equipment is actually much more complex than shown in the functional diagram of Figure 11. It includes telephone lines, their associated repeaters, volume indicators, switchboards, loudspeakers for monitoring of quality, etc. The INTERPRETING function commences at the receiving antenna and ground, and ends at the diaphragm and baffle of the loudspeaker. It is obvious that this system can transmit only word-pictures, and that therefore a great deal is still left to the visualizing powers of the individual.

Modern Messenger or Common Carrier Systems.

Disc Phonograph: The phonograph is chiefly known as a means of conveying vocal and instrumental music to a number of recipients remotely scattered. We have a good example of its use as a means of transmitting word-pictures. This is the home-recording electrola (Figure 12). It has served particularly to make a permanent and portable record of words describing the actions and events in one home to interested recipients in another home. We note that the OBSERVER speaks the descriptive words into a microphone connected to an amplifier and recorder, which operates in the spiral groove of a disc rotated by a motor. This system becomes the TRANSLATOR of our general case. The result is a complex series of waves in the otherwise clear spiral groove of the record disc. The MEDIUM of conveyance is of the messenger type, as represented by the postal or other carrier system. The INTERPRETER consists of a system comprising a motor, pick-up, amplifier, and loudspeaker.

Film Phonograph: Another form of phonograph, chiefly used in sound movies, is that in which the sound record is made on a strip of photographic film. (See Figure 13). In recording, the amplified output of the microphone controls the intensity or width of a beam

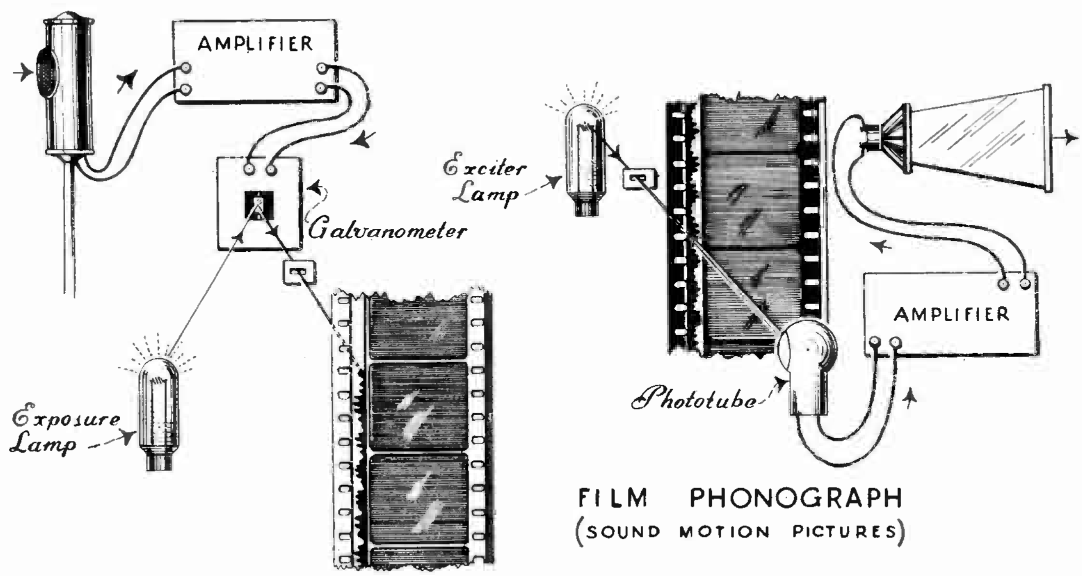


Fig. 13

of light. This shines on a narrow section of a moving negative film strip. Along the entire length of this strip is a sound track which either has a constant density and variable width, or a constant width and variable density. In the projector a light beam is passed through the sound track and directed to a phototube. The illumination of this tube (and therefore its electric current) is modulated by the sound track as the film moves rapidly and at uniform speed past a point in the optical path between the light source and the phototube. The electrical modulation here is a reproduction then of the current modulation originating at the microphone. Suitable amplifiers and loudspeakers provide the desired sound projection.

In the film phonograph, the record usually represents the miscellaneous sounds and conversation accompanying the action photographed for a motion picture. The latter itself is capable of providing sufficient visualization of the action, and seldom requires word-pictures of a descriptive nature.

EXAMINATION QUESTIONS

1. Name three kinds of waves used for communication.

2. Which two of the three kinds above occur in the same connecting medium?

3. What is the fundamental principle of the sun-ray telegraph?

4. Compare it (the heliograph) with the radio telegraph.

5. How does a radio receiving tuner compare with a bunch of colored light filters?

6. Why, in your opinion, is the optical telephone impractical?

7. What is the principle of the telephone transmitter, better known as a microphone?

8. How is its action different from a telegraph key?

9. What particular device was most responsible for the final success of radiotelephone broadcasting?

10. Name two types of phonograph records which differ in the material used and the method of recording.

THE SMALLEST AND LARGEST VACUUM TUBES REQUIRED TO OPERATE RADIO STATION WEAF AS A 50-K.W. TRANSMITTER.

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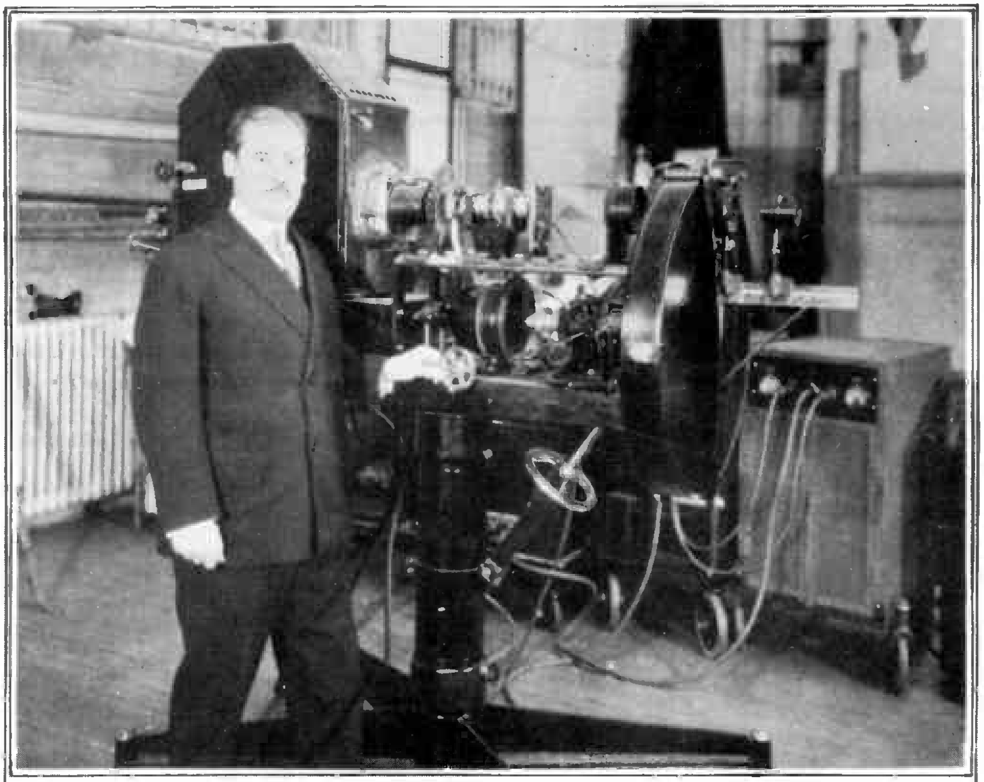

DR. E. F. W. ALEXANDERSON, OF THE GENERAL ELECTRIC COMPANY, AND HIS PROJECTOR AS USED IN THE THEATRE-SIZE TELEVISION DEMONSTRATION IN MAY, 1930, AT RKO PROCTOR'S THEATRE SCHENECTADY, N. Y.

Seeing and Hearing at a Distance with Sound Pictures and Television

VOL. 59, No. 2 *Dewey Classification R 500.09*

VISUALIZING AT A DISTANCE

MEDIUM	BY WORD-PICTURES: VOICE	BY WORD-PICTURES: CODE	BY SIGHT-PICTURES: DRAWINGS PHOTOS, PRINTS	BY SIGHT-PICTURES: VISION CONTINUOUS ACTION
Air	Observer Talking	Drums, Horns	————	————
Light Waves	Optical Telephone	Smoke, Fire, Heliograph	————	Telescope Beam Television
Messenger	Disc Phonograph Film Phonograph	Stringed Beads	Carrying the original	Motion Pictures
Wire	Telephone	Telegraph	Wire Facsimile	Wire Television
Radio	Radiotelephone Radio Broadcasting	Radiotelegraph	Radio Facsimile	Radio Television

Notes: Sound Motion Pictures are a synchronized combination of Motion Pictures with either a Disc Phonograph or a Film Phonograph.
Sound Television is a simultaneous transmission of Television (wire or radio) and Radiotelephone or Wire Telephone.

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VISUALIZING AT A DISTANCE BY SIGHT-PICTURES.

In this lesson we will discuss various direct methods of creating the impression of sight or vision at a distance. Before going into a review of the improvements that modern science has given us, let us study somewhat of the nature of light.

The Sun is the Primary Source of Light.

The primary source of light is the sun. This body is at so high a temperature that it has the quality of incandescence, or radiating some of its energy as waves in the ether which is supposed to fill celestial space. The human eye is an organ which is sensitive to these waves, both as to color and intensity. We have man-made sources of light-waves in the primitive torch, a camp-fire, and the incandescent electric lamp. None of these would be of much use to us except for a certain optical principle called reflection. We speak of "seeing" a cold object which gives no light of its own, whereas we actually see whatever light-waves are reflected from its surface, whether the original source is the sun or some man-made device. The light-waves falling on an object are reflected in many directions, and at different intensities. Whatever waves, and of whatever intensities, enter the window of the eye by a direct line (including mirrors and prisms) from the object, cause the mental response that we call vision.

The clearness of this vision depends on the intensity of the light reflected into the eye, the opening of which is only about one-eighth of an inch. As the observer moves farther from the object, less and less of the light reflected from the object reaches the eye, and the vision becomes less clear.

The Telescope.

Man went on through the early ages craving to be able to see beyond the scope of his eyes alone. The invention of the magnifying glass brought on the study of the science of optics. By means of lenses and prisms, man learned to turn the light waves from their normal straight line. It is common knowledge how a magnifying glass may receive light waves over one entire surface from the sun, and turn these until they meet in a much smaller area. The optical principle of this "burning glass" enabled man to combine several glasses into a device called a telescope, which is an instrument for scoping or viewing at a distance. The telescope in its earlier form is monocular, i. e. for use with one eye. A later form, the binocular, is for use with both eyes. The latter retains somewhat the perception of depth and relative distance which is lacking in a "one-eye" observation.

Even this invention did not satisfy his need. Among other limitations, the eye could still see only those objects from which the diffused light could travel in a straight line. We will continue then with other systems not so limited as to path or distance.

Picture-Messenger Systems.

Drawings. So far we have noted that in voice and code systems a great deal is left to the powers of visualization of the recipient. It is time that we give him a better service by leaving less to his imagination. This actually started when early man developed the art of engraving or painting crude pictures of the objects before him. These drawings, on wood or stone or plant-leaf, conveyed enough to permit the recipient to visualize the action. This was aided materially when the artist had learned to draw the moving parts of the observed action in such postures and positions as would normally occur only in the midst of some motion.

Photographs. Photography is a combination chiefly of two sciences, optics and chemistry. A good deal was known of optical principles before the world of chemistry made available a working knowledge of the effect of light-waves on some chemical compounds. This resulted in the present art, which has become a popular recreation and at the same time an effective aid to business. It broadened man's vision considerably by enabling him to study objects and scenes that were not common to his locality. As time went on a more realistic picture was wanted. One attempt was to give the photograph depth. This was done by taking two simultaneous photographs by a pair of adjacent cameras. These photographs were later viewed through the two eye-pieces of a stereoscope so that they were superimposed in the brain in the same manner that the vision of some nearby object by both eyes results in a concept of depth or distance.

Just as in the case of primitive drawings, motion and action in a scene can only be suggested, in a single photograph, by the posture or position of the moving object when the exposure is made.

Motion Pictures. It can readily be seen that we can get a more definite idea of the action of the scene if we have a series of photographs during the action, and subsequently view them in the same order in which they were taken. The time element here introduced allows us to create a system which will give, at the remote point of viewing the pictures, a sensation of continuous sight of the action. This is the basis of the motion pictures. Suppose a man is walking down the street, followed by a cameraman who takes a series of photographs in rapid succession. Each successive picture will show the man in a more advanced position. These pictures are then printed at even spacing on a positive print film. The film is put through a projection machine consisting of a source of light, an optical system, and a mechanical system. The latter is designed to hold each picture in succession in a steady position while light is permitted to shine through it onto a screen; and when each picture is replacing the one before it in this beam of light, the mechanism cuts off the light to prevent the film movement from being seen on the viewing screen.

If more than twelve pictures are projected per second, the eye responds as if it were a truly continuous action. If fewer pictures are projected in a second of time, the eye responds to each separate picture. This effect is known as "flicker", and causes eye-strain.

We note that the OBSERVER function is performed by the optical system of the movie camera. The TRANSLATOR function starts with the light-sensitive chemical compound which coats the negative film; after passing through many processes and many hands, it winds up with the final positive film print. The latter is usually the portable record. The MEDIUM of conveyance has likewise become more complicated, including the related activities of distributors, express companies, railroads, and so on. The INTERPRETER function consists of the projection machine and screen.

Just as in the case of still photographs, an effort was made to eliminate the flatness of the usual motion picture. An illusion of depth and distance is achieved by the stereoscopic camera and projector.

We know the movies chiefly as a source of entertainment of a fiction nature. However, through the newsreels we receive distant vision of action-scenes in the real life of a world community. Home movie cameras also provide a portable record of more personal scenes of action. This is still far from man's goal of instantaneous vision at a distance, or television. The motion pictures have one particular advantage over television in that the recipient may view the action at a later time and place convenient to him.

Sound Motion Pictures. The sound picture problem (Fig. 1) is largely a technical one concerned with the proper synchronization of the sight and sound records when projected. Each of these records consists of physical materials in motion. Reality can be simulated only when the projection of picture action and accompanying sound are timed accurately and automatically. A mass of other problems were presented in securing a good fidelity of reproduction in both picture and sound.

The personnel involved has become tremendously increased. Optical experts, chemists, mechanical engineers, and sound engineers are only a few of the types of experts required to bring into being even the first models of such equipment. Its manufacture, installation, and maintenance require many other men of varied training.

PICTURE and FACSIMILE TRANSMISSION SYSTEMS.

In General. In the commerce and the news of the world a photograph or drawing is very useful in improving the amount of detail which it is possible to convey quickly by word-pictures, whether telephoned or telegraphed. The art of transmitting still pictures or drawings from one place to another is sometimes called telephotography.

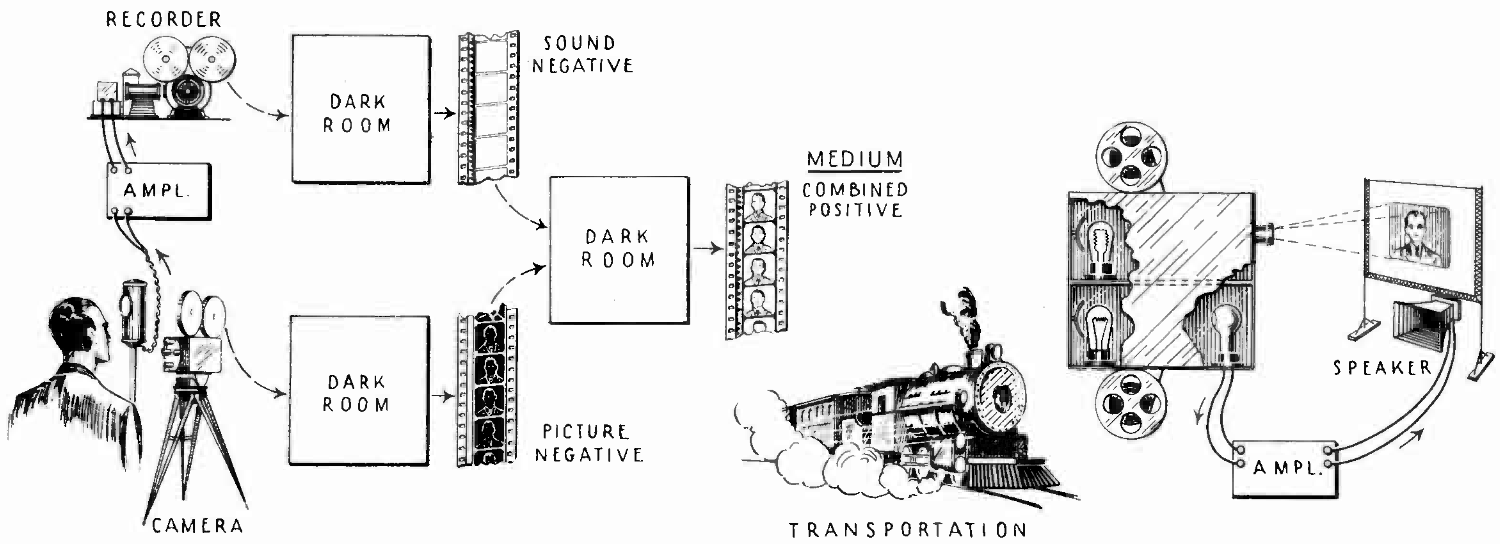


Fig. 1 — SOUND MOTION PICTURES PROVIDE A DELAYED DELIVERY OF EXCELLENT ENTERTAINMENT COMBINING REPRODUCTION OF SOUND AND ACTION.

Whether the medium connecting the two points is a wire circuit or a radio channel does not appreciably affect our present explanation.

In order to tackle the understanding of this problem, let us consider a fanciful situation where the graphic record we desire to transmit is a mosaic pattern of a tile floor. It is desired to construct a facsimile of this design or picture at a remote point. At the original mosaic an observer is stationed, having a telephone connecting him with the remote point. Here the receiver is held by a tiler who is prepared with a stock of tiles of the same shade as those composing the original. We will limit these for simplicity to white, gray, and black.

It is evident that the simplest and quickest way would be for the two men to have a definite understanding as to what order will be used in viewing and calling the tiles. For instance, the OBSERVER starts at the top of the pattern and scans the first row of tiles from left to right, TRANSLATING the different shades of tile into different telephone currents, by calling out "white, white, gray, black, etc." as the case may be. When he comes to the end of the first row, he starts at the left end of the second row, calling the tiles as he scans to the right. All this time the distant tiler has been INTERPRETING the telephoned instructions and laying down tiles of the designated shades and in the same order. Continuing this process until the whole mosaic has been scanned, there will result at the remote point a pattern identical in picture-effect with the original. Another point is of interest. So long as the individual tiles at the receiving end are of the same shape as the original tiles, they may be of any different size and still give an identical picture-effect. The sizes of the patterns will be proportional to the sizes of the tiles.

Continuing this fanciful description, it is probable that much time and labor could be saved by replacing the observer and the tiler by two machines connected by the same two wires that previously connected the telephones of the two men. Let the transmitting machine be equipped with an electric eye (a colloquial name for a photo-electric device translating changes of light intensity into changes in electric current). The receiving machine which lays the tile must be designed to automatically lay the proper shade of tile as dictated by the current changes in the connecting circuit. As the transmitter rolls across the original mosaic, tile by tile, and row by row, the receiving machine would (by separate synchronized control of motion) roll across the remote floor, laying tiles in succession in the same order as those scanned by the transmitter. The final complete picture would be a facsimile of the original.

Actual facsimile or picture methods vary from the case described. The original may be a photographic print or film, a half-tone print or film, a line drawing, or engraved or printed page. It is usually placed on a drum, which is caused to rotate in front of a scanning device. (See Figure 2). The scanning system consists of one or more lamps, a photo-electric cell, and lenses, prisms, and reflectors as required to make an efficient optical path between the light source, the picture, and the cell, usually a phototube. This whole system moves as a unit in a direction along the drum axis. A common system uses a restricted flood lighting from the lamps around the scanning point, which is actually only the focus of a lens system (like a reversed telescope). This spreads into the phototube the light reflected from the picture at the focal point. The opposite type of optical system is where the direct light from the lamps is concentrated through a lens system into a focal point at the surface of the picture, like the "burning glass"; the variable light reflected diffusely from the picture is then gathered by a close-fitting reflector and directed into the phototube. It is with the photographic prints and other opaque originals that the reflected light is used; with a photographic film or a drawing on tracing-cloth, etc. the scanning light passes through the original, and the drum must be transparent. Compare this method with the photo-electric pick-up from the sound track on film, in sound motion pictures.

The combination of the rotation of the picture drum and the lateral movement of the scanner unit is exactly like the movement of a phonograph cylinder and reproducing needle in a dictating machine. The point scanned therefore follows a similar continuous spiral line about the cylindered picture. The variations in the light reflected from the picture along this line cause corresponding variations in the otherwise steady current through the phototube. This is applied as a modulation to an audio-frequency current which is the tone signal transmitted by either a wire or a radio channel. The effect on the transmission of the use of this tone is the same as though the picture itself were being broken up into small regular areas corresponding to the tiles of the mosaic pattern. The tone may be introduced in another way. An opaque disc having holes pierced in it at regular intervals around a circle may be placed in either section of the light path of the scanner. This light chopper, as it is called, puts a regular succession of impulses in the illumination of the phototube, and passes a musical tone through the amplifier. The picture causes a variation in intensity of the successive light impulses, and therefore a variation in amplitude of the successive cycles of the audio-frequency current which constitutes the tone signal.

When a photographic picture is transmitted, the gradations of shade between white and black will be infinite; the receiving system must be capable of reproducing all these shades at their true relative values. Usually a drum recorder is used, on which is mounted a sheet of ordinary bromide paper as used for photographic prints. The drum is caused to rotate at the same speed as the transmitter drum. The recorder conveniently consists of a lamp whose light is concentrated, through a lens system, into a fine area at the surface of the paper. This lamp is a special kind of glow lamp, and its brilliancy responds very rapidly to changes in the amplitude of the electric impulse coming to it from the transmitter through various amplifiers, etc. This method naturally requires time for the developing of the print.

The transmission of line drawings or printed matter is simpler, since only the white and black values of shade are represented in the original. The recording process can be less intricate. On an early type a jet of hot air is moved across a chemically treated sheet which is normally white. It turns quite dark wherever the hot air jet has been released by the impulses in the signal current. A second type of simple recorder makes use of a roll of white paper which slowly unwinds under a sheet of carbon paper. When the transmitter scanning point crosses a black element of the original picture, a signal current is caused which operates the recorder in such fashion that a lever presses the carbon paper against the white paper. This makes a black picture-element at that point of the received picture corresponding to the point then being scanned at the transmitter. The complete record is "turned out" as soon as the scanning of the original is complete.

Mention has been made of a synchronized control of motion as applied to scanning and recording. We have also previously mentioned, under "Sound Motion Pictures" the synchronism of the sound record and picture in order to make the projected program a unified effect. In facsimile, synchronism means controlling the motion of the original and the facsimile record so that each picture-element of the two will be identically located in their respective areas. One method of doing this is to control the speed of the transmitting drum and the recording drum by a tuning fork at each end which have accuracies in vibration frequency of closer than one part in several hundred thousand. A second method is for the transmitting station to generate a separate alternating current which operates the drum by a synchronous motor. At the same time this alternating current is impressed, as a constant unmodulated tone signal, on the wire or radio channel used also for the picture signal. At the receiving end the synchronizing tone signal is filtered out from the picture signal and applied to the driving motor of the recording drum, which effectively locks in step the motions of the two drums.

Uses. This service has been expanded to include the transmission of whole newspaper pages across the continent by means of radio, the general scheme being to transmit several columns at a time and patch these columns together by hand at the receiving point. Successful sending of weather maps to ships at sea, and even to airships, has been achieved. Letters reproduced in the original handwriting have added a new integrity to long-distance communication. By far its greatest usefulness to date has been in the transmission of news pictures, whether by wire or radio. The distribution to the masses of people is therefore by printing these pictures in newspapers. It is seen that the cheapness of newspapers and the speed of the modern news presses has practically made it not at all worth while for individuals, in their homes, to possess receiving equipment capable of reproducing these still pictures. It is probable that there will be no general home service of this kind, except where the still picture is held up before the pick-up of a television transmitter. This will cause a considerable loss in the value of the picture, for the reason that a still picture could be transmitted slowly as a facsimile and a great degree of detail maintained. The same amount of detail transmitted by a television transmitter would require an almost prohibitive breadth of communication channels, and would be quite wasteful. It would appear that an unwarranted amount of space has been given thus far to still pictures when we are particularly interested in other subjects. This is done because in dealing with still pictures we contact with very tangible things, such as photographic prints, etc., and these have a touch and feel to them which the student can realize. On the other hand, although technically there is a great deal of similarity between the images seen on printed pictures and the transmission of televised images, yet images of the latter kind seem to be such very unreal things to anyone studying this subject for the first time. So having devoted a reasonable amount of time to a study of still pictures before going into a full account of television will no doubt make this work easier for you to understand.

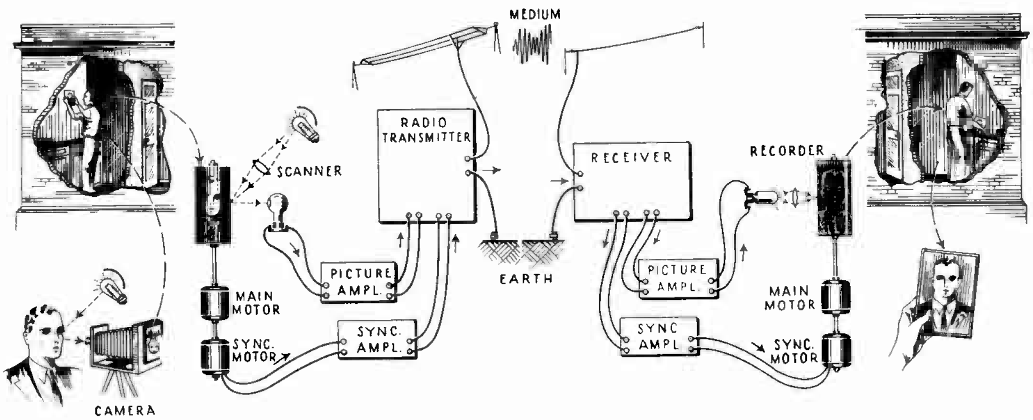


Fig. 2 — STILL PICTURES BY FACSIMILE TRANSMISSION ARE ESPECIALLY USEFUL IN ILLUSTRATING NEWSPAPERS; WORDS ARE ADDED IN TYPE.

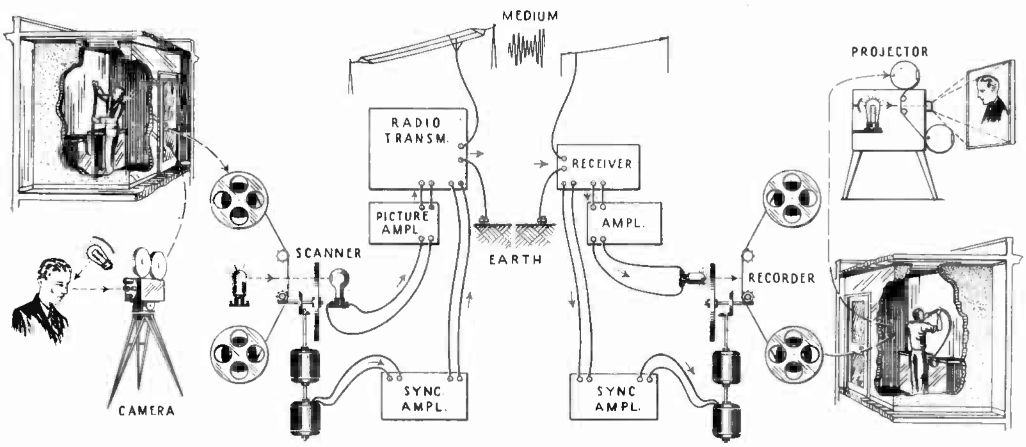


Fig.3 — MOTION PICTURES BY FACSIMILE TRANSMISSION SAVE PART OF THE TRANSPORTATION TIME, BUT AT A SACRIFICE OF PICTURE QUALITY.

RELATION BETWEEN FACSIMILE, MOTION PICTURES, and TELEVISION.

It can readily be seen that no difficulty would be encountered in handling a motion picture film over a facsimile system as in Figure 3. At the transmitter, the positive film strip would be fed into a mechanism bearing a facsimile scanner. The signal channel would be the same as before. At the receiver an unexposed film strip would be passed continuously through a photographic recorder. After developing, the resultant would be the same orderly arrangement of separate photographs as seen on the distant original. If the facsimile strip were of the identical size and had sprocket holes properly placed, it could be put into a motion picture projector and shown on a screen. The time of transmission and subsequent developing would be so great that only in rare cases would any benefit be derived over the ordinary messenger or common carrier system of delivery.

But let us see what an opportunity we have here. The motion picture film represents an original camera action somewhere at a film speed of 90 feet per minute, or 24 frames (pictures) per second. In the facsimile transmitter this film would be made to pass the scanner at the rate of perhaps 4 inches per minute, resulting in a delivery to the facsimile recorder at the rate of 1 picture in about 10 seconds. After the tedious recording at this rate, the finished film would be projected at its intended rate of 24 frames per second on to a viewing screen. If the facsimile picture rate can be increased from 1 frame in 10 seconds to 24 frames in 1 second, we will have accomplished delivery at the rate intended for projection of the picture on the screen. Then all we have to do is eliminate the usual recording and developing process, and make the facsimile signal control some method of directly illuminating the viewing screen. This immediate "delivery" of the pictured action was secured by mechanically or electrically breaking up the continuous facsimile picture signal in such fashion that each picture-effect or frame was laid down in succession in the same place as the one before it, on a viewing screen. (See Figure 4). Here again that quality of the eye called "persistence of vision" enters in to cause the effect of continual vision.

The chief interest of course lies in the immediate television of the remote action-scene. Dispensing with the motion picture camera which first OBSERVED the action and TRANSLATED it into a film which could be scanned at will, we advance in technique to where the scene is observed (scanned) directly by a photo-electric system which instantly translates into electric signal impulses the progressive examination of the scene, as shown in Figure 5. This is true <u>television.</u> The receiving equipment is identical in principle with that for the transmitted motion pictures.

In either of the above types of transmission of continual action we have a synchronizing problem such as we had in facsimile. It is clear that some system must be used at the receiver to assure each frame (scanning repetition) being laid down exactly over its predecessor, point for point. The crude early method was to have a hand-operated speed control for the motor which turned the distributing disc. Later this motor had part of its work done by another and smaller motor driven synchronously by some alternating current component of the scanning signal.

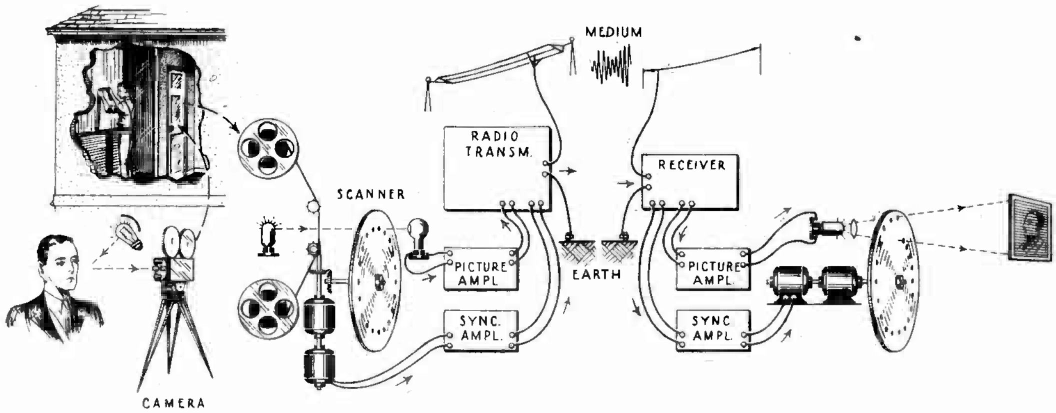


Fig. 4 — TELEVISION TRANSMISSION OF MOTION PICTURES GIVES SIMULTANEOUS PROJECTION AT THE RECEIVER, BUT THE PHOTOGRAPHIC PROCESSING DELAYS THE TRANSMISSION CONSIDERABLY AFTER THE ACTION.

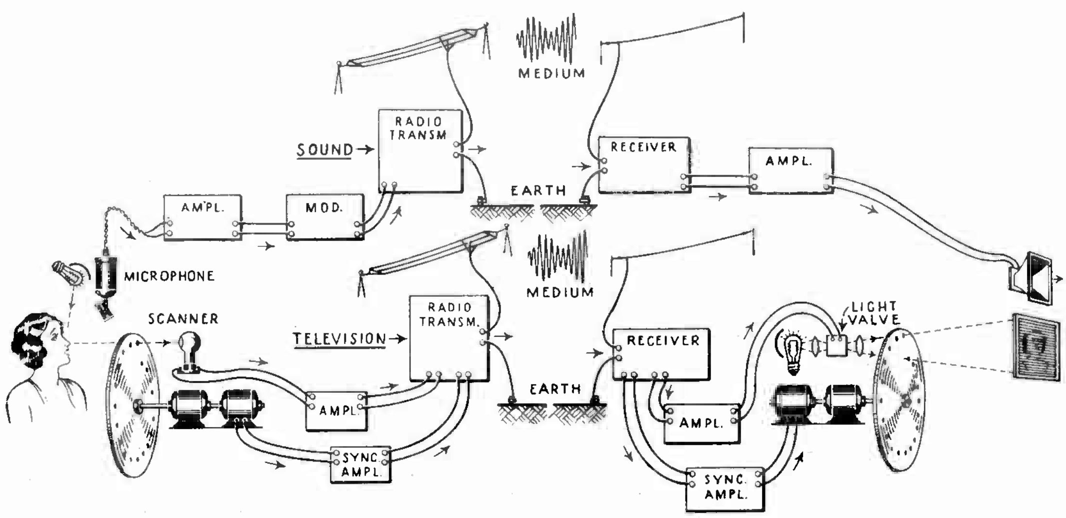


Fig. 5 — TRUE TELEVISION (WITH SOUND) PROVIDES INSTANTANEOUS REPRODUCTION OF BOTH ACTION AND SOUND AT A REMOTE POINT.

Sound Pictures. It is perhaps obvious that there is little entertainment value in the transmission of silent motion pictures. In transmitting sound motion pictures, the sound record, whether on a disc or on the film, is picked off in the same fashion as for theatre projection. The amplifier output, instead of going to nearby loudspeakers, is transferred to a wire or radio channel as a medium of delivering the sound program to the same point as the picture program. Here an ordinary telephone amplifier, or the equivalent complete radio receiver, feeds a loudspeaker adjacent to the screen.

TELEVISION.

Television, in brief, consists of a transfer from light to electricity at the transmitter, an electrical path, and a transfer from electricity to light at the receiving point.

We have seen how radio began with the theoretical calculations of scientists published years before a demonstration was made of intelligible transmission. In like manner, the fundamentals of the science of television were known and published decades ago. The electrical equipment available then was simply not sufficiently developed to permit the clear use of the knowledge.

The real advance of television began with the development of electronic tubes, and particularly the phototube, in which the electron emission is produced by the illumination of an electrode. The rapid response of this tube to changes in intensity of light overcame the difficulty encountered with the early photo-conductive cells using selenium, in which the electrical response lagged appreciably in time behind the light stimulus. The present quality of performance of the phototube is due largely to the momentum given its development by the exacting demands of its use in sound motion pictures.

In television reception methods, advance came first through the development of better glow lamps, which give a response in light intensity that depends on the value of electrical stimulus The new problems in signal amplification had a firm basis of solution in the experience gained in designing voice-frequency and radio-frequency amplifiers for radio broadcasting and sound motion pictures.

A television scanning system consists of a source of illumination, a phototube, and a means for shifting the optical path connecting these so that the point of reflection progresses over the scene in regular fashion, repeating this entire scanning operation periodically at not less than twelve times per second, to prevent flicker in the image. The process may be by progressive illumination or by progressive observation. The first uses a concentrated light beam which shows as a small spot of light on the object or scene. The phototubes are spread out to receive the reflected light from that spot as it travels rapidly over the scene. The second method uses flood lighting of the scene, and the observation of the reflected light by the phototube is confined by lenses to a small area or spot of the scene at a time. The observing path progresses rapidly over the scene until the entire area has been covered. The second method is useful outdoors or in a lighted studio. The first method has some advantages for indoor studio work.

We find a good deal of similarity between the scanning system at the transmitter and the early forms of projecting system at the receiver (Figure 5). In scanning, there is a regular shifting of the optical path between a source of constant illumination and the phototube that receives the reflected light of varying intensity. In the receiving projector, there is a regular shifting of the optical path between the eye and the light source whose intensity varies with the electric signal which had its beginning in the phototube at the transmitter. In the early systems, use was made of a disc invented by Nipkow in 1884 and having a single turn of holes placed in a spiral form. Scanning discs of identical layout but perhaps different size, were used to shift the optical paths at both transmitter and receiver.

Then the receiving system was improved to eliminate the disc or other mechanical distributors for the light. These were replaced by a weightless cathode ray which was electrically shifted. Illumination of varying intensity occurred at a fluorescent screen which was bombarded by the cathode ray at varying electron density, controlled by the television signal. A modified form of cathode ray tube has also been used as an electrically shifted means for scanning the object at the transmitter.

Sound Television. The accompanying sound program for a transmitted motion picture merely required a simultaneous pick-up from the sound track of the film. When an action-scene is scanned directly for television, a microphone adjacent to the action is used for the sound pick-up. In either case the sound program is put on a separate wire or radio channel. Reception likewise is independent of the television reception. To produce an illusion that the television and sound are one and the same program, the loudspeaker is placed as near the televisor as possible. It will be remembered that in sound motion pictures, the sound projectors are placed right behind the projection screen to similarly perfect the illusion.

It is interesting to note that sound television is not troubled with synchronization of sight and sound, as was found in sound pictures, where they are recorded in physical form. In the former. we find that the velocity of light and radio waves, and of the electron flow in wires, is so great that the time of travel for different paths is negligible. Simultaneous projection is therefore assured.

LIGHT-BEAM TRANSMISSION OF TELEVISION. Laboratory experiments have demonstrated that a beam of light can be used as the transmitting medium in place of the usual radio transmitter. With this system a scene could be televised and the television signals put onto a wire circuit running to a transmitter consisting of a powerful lamp and a means of modulating the intensity of its light with the television signals. The rays of the lamp would be directed toward a point perhaps several miles away, where a straight-line view could be had of it by an "electric eye". This photoelectric cell would transform the light-beam impulses into varying currents and with suitable associated equipment it would provide ordinary television projection.

Conclusion. In the foregoing review covering the development of sound and picture transmission we have not attempted to give a thorough discussion of the historical or technical features relating to radio, television and sound pictures. The lessons which you will study go into the details. This review with its pictorial illustrations serves to give you a good idea of the general scheme of things in these fast growing industries.

EXAMINATION QUESTIONS

1. What is the purpose of the telescope?

2. Consider your five senses: smelling, seeing, tasting, hearing and feeling. List them in the order of their importance in your life.

3. Through which of these senses could you get the most information about things around you, in the shortest time?

4. What is the technical basis of motion pictures?

5. What processes in motion pictures are concerned with each of its following functions: A. Observation, B. Translation, C. Transportation, and D. Interpretation.

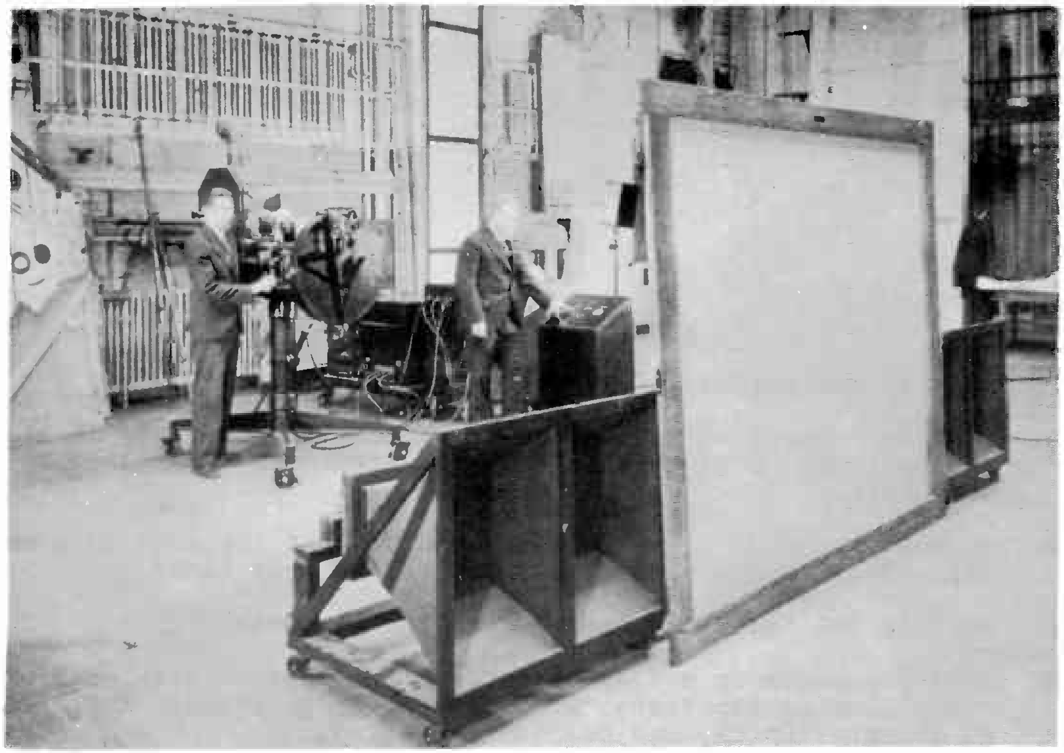
6. A Sound Motion Picture system is really a combination of what two forms of communication?

7. In a few words what is the difference in purpose of a microphone and a photoelectric cell?

8. Why is the facsimile transmission of line drawings and typed print matter simpler than the transmission of photographs?

9. In what way does the television method of delivering motion pictures at a remote point differ from the facsimile method of delivering the same?

10. A Sound Television system is really a combination of what two distinct forms of communication?

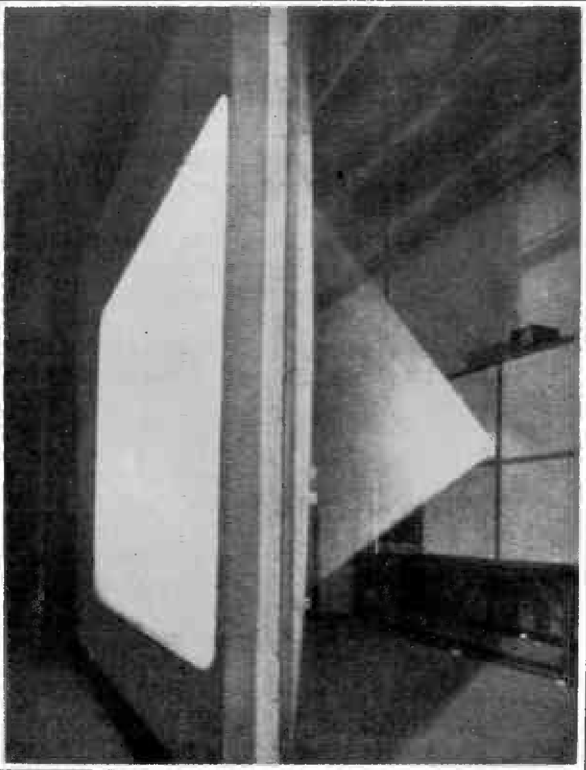


ABOVE:

A BACK-STAGE VIEW OF THE TELEVISION PROJECTOR AND SCREEN AS USED IN THEATRE TELEVISION DEMONSTRATION ILLUSTRATED ON THE FRONT COVER.

RIGHT:

A BACK-STAGE VIEW OF MOTION PICTURE PROJECTION BOOTH AND SCREEN, AS USED AT THE ASSEMBLY THEATRE, NEW YORK CITY. (PHOTO COURTESY TRANS-LUX DAYLIGHT PICTURE SCREEN CORP.)



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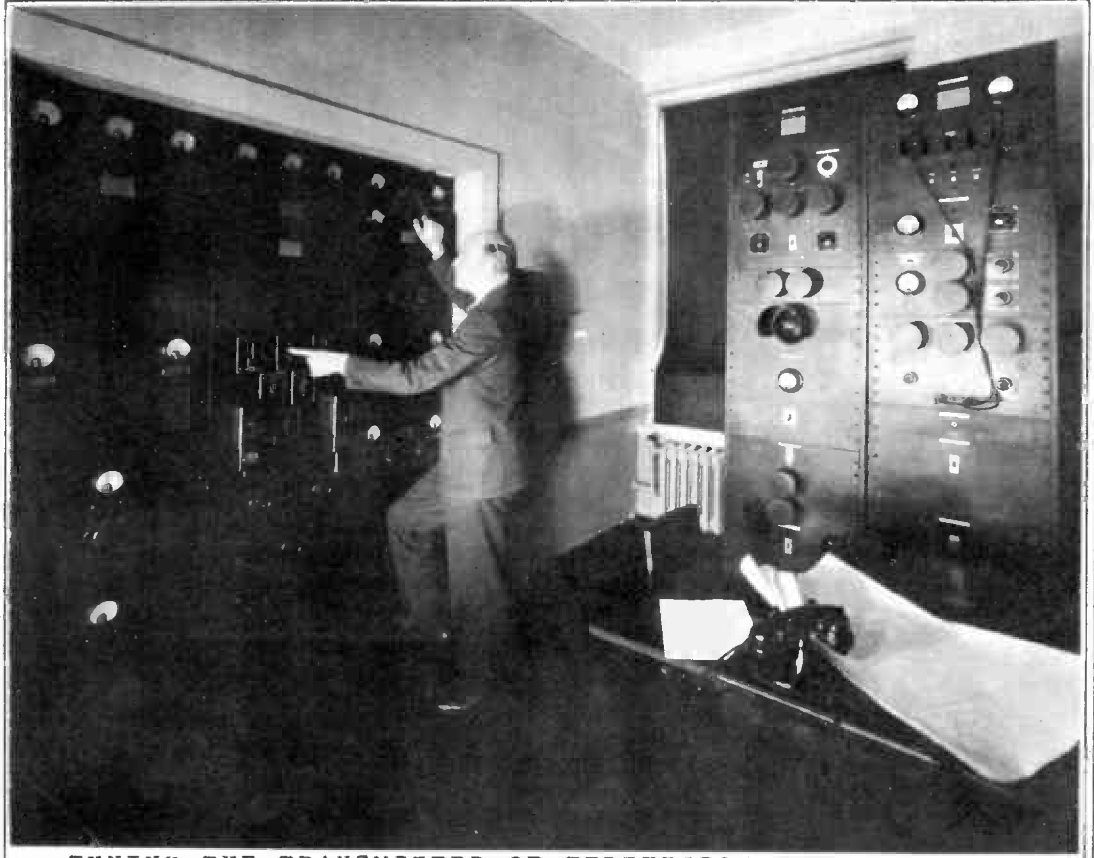
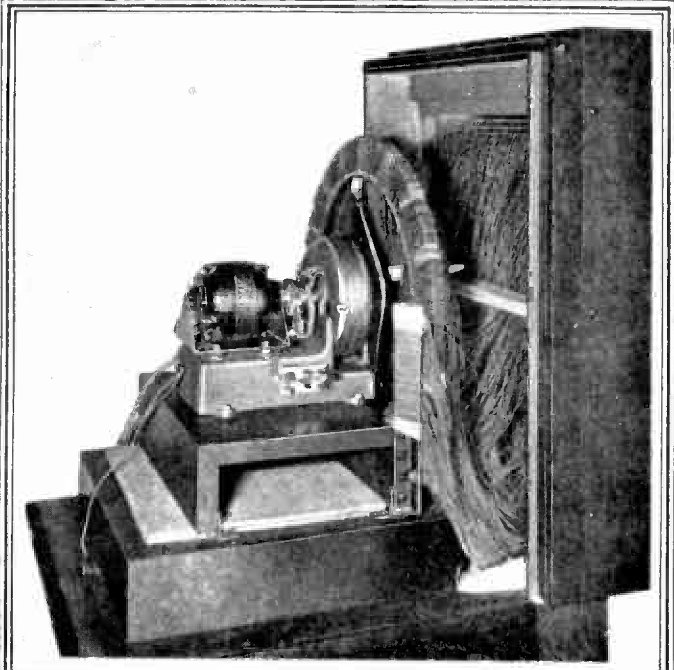


TUNING THE TRANSMITTER OF TELEVISION STATION W2XAB. (COURTESY COLUMBIA BROADCASTING SYSTEM.)

— TELEVISION —

IMITATING THE HUMAN EYE

VOL. 59, No. 3



AN ELECTRICAL DISTRIBUTOR WITH 2500 CONTACT POINTS CONNECTED TO AN EQUAL NUMBER OF LAMP ELECTRODES, PROVIDING 2500 POINTS OF LIGHT ON A LARGE GRID. USED IN A DEMONSTRATION OF WIRE AND RADIO TELEVISION BY THE BELL LABORATORIES IN 1927. (COURTESY BELL TELEPHONE LABORATORIES.)

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TELEVISION ATTEMPTS BASED ON IMITATING THE HUMAN EYE

For years the world has produced men endowed with keen penetrating minds whose ambition it was to originate devices that would be of assistance to faculties already possessed by man. To successfully work along these lines and conduct intelligent research they have in many instances drawn upon the patterns laid out by nature.

The action of the telephone invented by Alexander Graham Bell, for instance, imitates the action of the human ear drum and because of the development of this invention the human ear is, figuratively speaking, capable of hearing sounds which originate at the ends of the world.

Before aviation progressed to its present state of development, hours upon hours were spent by engineers in observing the flight of birds, obviously a study of nature.

Greater and greater extension of sight beyond that possessed by the human eye has always been a goal of scientists. This was given an impetus by Galileo who developed a telescope with which he discovered the satellites of Jupiter, and from whose time modern physics may be said to have begun.

It does not require any great stretch of the imagination, therefore, to realize that scientists for years have directed their studies along a line of thought whereby existing models, both artificial and natural, have been drawn upon to furnish information leading to certain desired results.

So, in the study of television, we find that its progress has been slow. We also learn that contributions have come from many sources, which at their time were perhaps remote from the goal but, nevertheless, progressing toward a central point out of which the necessary information was obtained to construct apparatus that would allow the eye to see an image beyond the barriers of light waves. At the very start, therefore, we will begin our study by first becoming acquainted with nature's system of television provided by the human eye.

THE HUMAN EYE

Here, without question, is a part of nature's handiwork which everyone recognizes as a marvelous organism. We are able to account for certain functions of the human eye, but true to Nature's method of doing things she allows the puny mind of man to go just so far; there the curtain is drawn and we are left to conjectures.

The cornea is a bulging transparent tissue which forms a round window at the front of the eye ball admitting light to the lens. The amount of light thus admitted is controlled by the iris, in the center of which is an opening called the pupil. The iris is composed of muscle fibers capable of expanding and contracting thus changing the size of the pupil. If the eye is directed toward a source of strong light these muscles act in a reflex manner to cause the iris to contract and in this way close the pupil aperture. When in a dim light the pupil is opened by these muscles so as to admit all the light possible. Immediately back of the pupil is the lens, the shape of which is changed by the action of a set of muscles in order that it may bring to a focus upon the retina the light rays proceeding from an object to which the eye may be directed, and thus form an image upon the retina or screen, as it may be called. The retina, a delicate membrane, is composed of an enormous number of minute cells each connected to the brain by nerve filaments over which the brain receives the impulse. Just how this impulse of the inverted image thrown upon the cells of the retina is generated is not known but from some scientific sources the action is conceded to be caused by the presence of a light sensitive fluid in the cells of the retina. This fluid, present in the millions of minute cells, is affected by the light rays impinged upon it and an extremely fine mosaic image of the object is built up in varying degrees of light and delicate shadings.

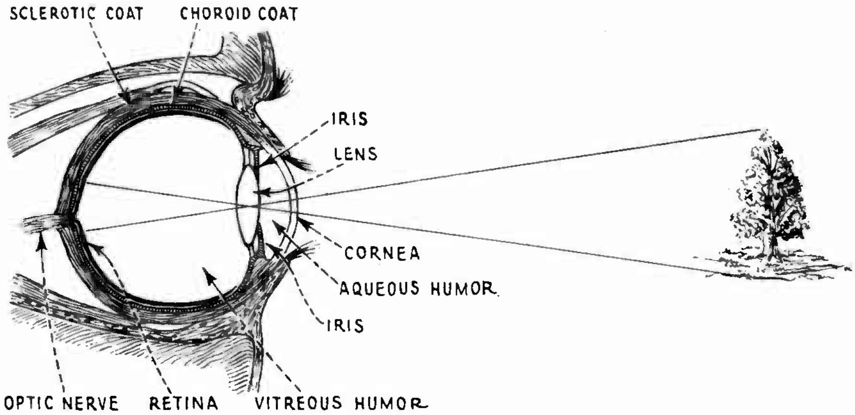


Fig.1 - THE HUMAN EYE — THE FIRST LENS SYSTEM.

The aqueous humor is a watery fluid while the vitreous humor is a fluid of jelly-like consistency. The two humors act to keep the eyeball distended and also act with the lens to form a real inverted image upon the retina. The choroid coat immediately back of the retina is intensely black and absorbs all the light rays reflected internally. The sclerotic coat (an opaque lining) covers the choroid coat in back of the eye ball and forms the cornea in front of the eye ball. When the eye lid is opened and objects before us are sufficiently illuminated, or the object is a self-luminous body, vision is the result.

All the senses with which man is endowed are important but the two which stand out in our studies are the sense of "hearing" and the sense of "sight." If we were allowed to retain only one of the two we would no doubt choose sight because, with sight, material objects take on a concrete form. Impressions conveyed to the mind by the eyes make lasting records, and perhaps to a greater degree on our conscious mind than writing or the sounds of a language. Furthermore, our eyes permit us to take in scenes and actions at a mere glance which could not be described in the spoken or written word in nearly as short a time nor with the same degree of satisfaction that comes from actually seeing the events.

For ages man has toiled and studied in an effort to improve the means given him by nature to better see objects, and most especially objects beyond normal range of vision (the unseen). It is unnecessary to say that any attempt to change the human eye to produce greater vision is a dangerous undertaking and would be sure to fail, therefore, the only thing that seemed possible was to copy nature and produce an artificial device that would extend the range of vision. The study of how this was accomplished is interesting for it brings to us first hand the contributions of science which have been applied to television, and also the various divisions of scientific thought called upon to solve the problem, such as light, optics, chemistry, mechanics and electricity. Close attention will be required in this study to enable the student to recognize the closing of the links in the chain of discoveries, some of which were, perhaps, remote from the subject of television at the time, but eventually doing their share in the development.

It seems fairly well established that magnifying glasses were unknown to the ancients. Pliny, a Roman, in his historical writings tells us of the use of crystal globes filled with water which were employed as cauterizing agents by bringing the rays of the sun to a focus on the wound to be cauterized. Also, from Roman history we learn that letters seen through a glass filled with water appear enlarged but indistinct. No attempt, however, was made to explain this phenomenon at the time.

Perhaps the earliest known record relating to the invention of lenses used as spectacles is that appearing in a manuscript from Florence, dated 1299. The year 1285 is considered by some writers to be the date when spectacle lenses were first known and it was later discovered that a Florentine, Salvino Armati, was the inventor. Something of the science of optics, therefore, must have been known at this early date. Our first knowledge of lenses came from these people and since the use of lenses and light are both important in television we, too, must know something of the behavior of light rays when passed through mediums of optical density.

OPTICS — A STUDY OF LIGHT

What is the meaning of the word "light?" According to our present theory it is a form of radiation, that is, a vibrational movement in space which affects the human eye. The eye is sensitive to the relative amplitudes of the vibrational movement. From this we can say that light is the external oause of the sensation of sight. This would lead us to believe that light is necessary to enable us to see. This is a correct belief as we shall soon learn.

There are luminous and non-luminous bodies. Under the first heading we have the sun, electric lamps, arc lamps, candles, the heated filaments of your vacuum tubes, and so on. Under non-luminous bodies we have the moon, wood and iron as common examples. A luminous body, then, is one which throws out light, while a non-luminous body becomes visible only after it has received light from a luminous body and reflects this light to the eye.

When you go into a room at night and snap on the electric switch controlling the current supply to an electric lamp the objects in the room receive light, part of which is absorbed and part reflected. From this we obtain our definition of the term "illumination" because the filament of the electric lamp, normally a non-luminous body, has been transformed to a condition of incandescence by an electric current and changed into a luminous body which emits light, and in turn illuminates the objects about the room. The light thus created follows certain laws; for example, a substance such as air or clear glass will allow light to pass through it, and we say that such substances are transparent. Ground glass, thin sheets of paper and oiled paper are substances which do not provide a perfect passage for light waves; they are termed translucent substances. Under the opaque classification we find many substances such as iron, wood, sheets of cardboard, and so on, which will not allow light to pass. This brings us to the study of how light travels — an important phase of the work because it has a great significance in television.

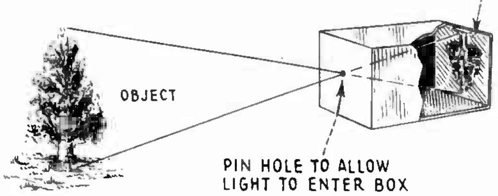


Fig. 2 - A PIN-HOLE CAMERA PROVIDES AN IMAGE WITHOUT THE USE OF A LENS.

Light travels in straight lines through any medium that is transparent and of uniform density. This fact is evident because of common phenomena which is familiar to everyone. Sunlight streaming through a crack or knot hole in a barn, or any building that is otherwise dark, illuminates the particles of dust floating in the air and forms straight lines of light.

Another illustration is the "pin-hole camera" shown in Figure 2. This consists of a light-proof box having a minute opening in one of its sides. Any light reaching the hole from an illuminated object will pass through the hole and continue in a straight line. The result is the formation of an image of the object on the side of the box opposite to the opening. When a sheet of sensitized photographic paper is placed against the inner surface of that side, and exposed sufficiently long, an excellent picture will result after proper development.

REFLECTORS

It was previously stated that an object to be seen must first be illuminated· also that light travels in straight lines. Therefore, when viewing an object through a mirror there must be no obstruction between the eye and the mirror. Although we can see around corners or view events taking place behind us by means of mirrors, this does not alter the law that light travels in straight lines for remember that between the object and the mirror, there must be no obstruction for the light ray, and neither can there be a barrier between the mirror and the eye. When you look into a mirror it appears that objects you see are located at some distance behind the mirror when actually they are not, and it seems as though you see these objects through some sort of an opening in the wall. The eye sees only an image of the objects because the light from the objects is reflected light rays striking the eye from the direction of the mirror, and since the eye sends an impulse to the brain only of the direction from which light enters it, the object appears to be in that direction. If the frame of a mirror could not be seen and the reflecting surfaces were not detected the eye would not be able to distinguish the difference between the real object and its image in the mirror.

A mirror of spherical shape is sometimes employed in television work. A mirror of this type, shown in Figure 3, is called a con-

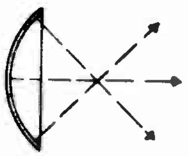


Fig.3 - A SPHERICAL MIRROR.

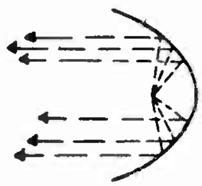


Fig.4 - A PARABOLICAL MIRROR.

cave mirror. The parabolic mirror shown in Figure 4 is a familiar type, and is used often when a broad beam of light is required from a small or point source.

When light rays strike a polished surface, the regular reflection permits seeing a good image of the object providing the light. When the rays impinge on a rough or unpolished surface such as paper, ground glass, etc., the reflection is diffused, and no image results from the direct light falling on the surface. An image may be formed on the rough surface by means of a lens, but this is a separate effect.

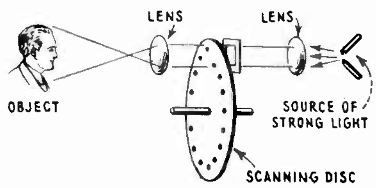


Fig.5 - GENERAL FEATURES OF A MECHANICAL SCANNER.

Figure 5 shows, fundamentally, some parts of a system utilized for scanning a subject. The object illuminated reflects the light by irregular or diffuse reflection. If light sensitive cells are placed in the path of this reflected light they will function in such a manner as to cause a current to flow through a circuit. Before going into further detail, however, we must pause long enough to become acquainted with what is known as the optical system of this group, namely the lenses, and to find out what effect they have upon the passage of light rays. This phenomenon will be readily understood after reviewing the meaning of certain terms given in the paragraphs immediately following.

REFRACTORS.

"Refraction" is a term used to describe the bending, that is, the change in direction taken by a light ray in passing through mediums of different optical density.

In the study of optics we note that air, water, glass, liquid or solid bodies that are sufficiently transparent to allow light to pass, may be termed optical mediums.

Fig. 6 - A DOUBLE-CONVEX LENS.

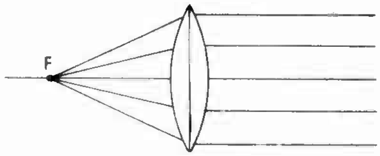


Fig. 7 - FOCUSING ACTION OF A LENS.

By density is meant the compactness of the substance which makes up the medium; thus, air is less dense than water and water is less dense than glass. "Lens" is the name given to a solid of glass

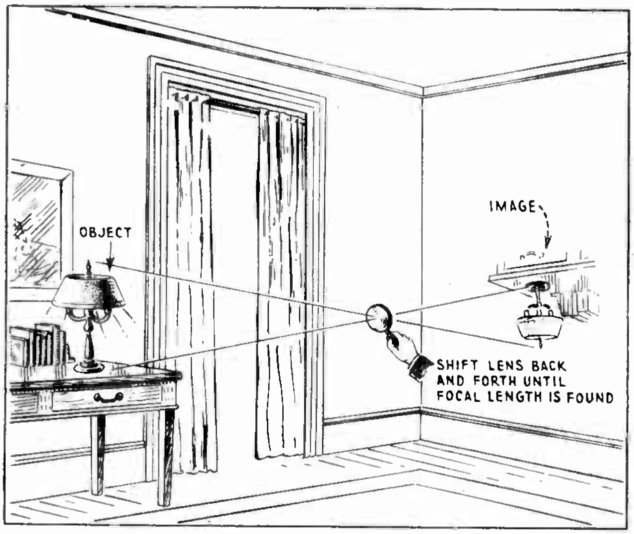


Fig. 8 - AN IMAGE MAY BE FORMED ON A WALL OR OTHER FLAT SURFACE.

which is a transparent medium capable of diverging or converging rays of light that pass through it due to the curvature of its surfaces.

Another type of lens we are interested in because of its use in television is called the "double convex lens" shown in perspective in Figure 6. As a child, how many times have you used this type of glass to burn holes in leaves, paper, and so on, by focusing the sun's rays, that is, bending them toward a single point as shown at F in Figure 7?

The pin hole camera previously mentioned will reproduce the image of an object regardless of its distance from the aperture and with great clearness of outline, but if we attempt to increase the opening the image becomes indistinct. Now, this opening may be enlarged to obtain a greater increase in brightness, that is, allow more light to strike the screen, if we place in the aperture a double convex lens, such as we have been discussing. Distinctness of outline will not be sacrificed if the screen and the object are at the conjugate focuses of the lens. That is why, when you take pictures with certain cameras you move the lens back and forth until the light rays striking the lens from the object are focused clearly upon the screen. In the camera the screen is the sensitized film or plate, as the case may be.

You may perform a simple experiment in your own room by placing an ordinary magnifying glass between some illuminated object and a screen. The screen may be the opposite wall of the room. When the proper focal length is found an exact image will appear on the screen. Figure 8 illustrates how this experiment may be carried out

We see, therefore, that lenses are not only useful for refracting light but are also capable of producing images.

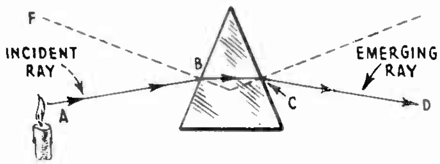


Fig. 9 - A PRISM REFRACTS A LIGHT RAY.

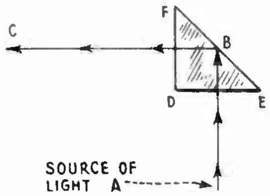


Fig. 10 - A PRISM MAY BECOME A REFLECTOR.

A second form of refractor is the prism, which is shown in Figure 9. This is used in television where the direction of a light ray or beam is to be changed slightly, but no focusing is desired. On passing from the medium of air to the denser medium of glass, the ray is bent in direction, and again on emerging from the glass into the air a further change of direction is caused.

When a prism is used as in Figure 10, it becomes a total reflector, instead of a refractor.

Let us sum up the work we have been over. First we found that nature produced the first televisor, the eye, which generates an impulse resulting in vision. Next we discovered light to be absolutely necessary before vision was possible. History tells us that for years scientists have been constantly working to improve apparatus that would assist vision. First came the pin hole camera. Then later it was found that glass worked into the proper shape would cause light rays to converge forming an image of objects appearing before it, and from this knowledge was born the microscope and telescope.

The electrical era arrived and work was begun on apparatus that would enable one to talk with friends miles away by wire telephony. Next came the wireless telephone, and in its footsteps followed radio broadcasting of voice and music, resulting in the reception of sounds from London as distinct as listening to your own voice. Then finally we come to the ambition to couple all of this with an electric eye (Television) which would enable one to see with whom he was speaking.

Before attempting to grasp all ow the ideas of a television system suppose we draw analogies to make comparisons along lines with which most of us are more or less familiar.

Speech, music and other audible sounds produce sound waves which, in striking your ear drum, cause it to vibrate. The inner ear receives these vibrations and generates an impulse which is carried to the brain and the brain interprets this impulse.

Because speech and music can be heard for only a comparatively short distance we place a telephone transmitter, or you may call it an electrical ear in a location where it can pick up these sounds. You speak into this device, and immediately a rise and fall of electric currents take place corresponding to the sound waves that were created when you spoke or when music was played. At the other end of the wire connected to the transmitter is the telephone receiver, or electrical mouthpiece which converts the varying electrical currents back into sound waves forming the spoken words or music picked up by the transmitter.

In television our purpose is to transmit an image instead of sound, therefore, we shall have to change our terminal apparatus from an electrical "ear" and "mouth" to an electrical eye, and provide some device which will duplicate in light what the electrical eye observes.

To obtain an electric eye was one of the difficulties encountered by scientists in their effort to place television on a successful experimental basis. Chemistry, however, came to the assistance of the early investigators along this line of endeavor in the development of a non-metallic element called "Selenium." This element was discovered in 1817 in the deposits of sulphuric acid chambers. In its native state selenium has an extremely high resistance (many times that of copper), but on being prepared by a heating process and then allowed to gradually cool, it forms into a crystalline state changing in color from a blue to a dull slate.

The prepared selenium, it was found, possessed the property of varying in electrical resistance directly in proportion to the intensity of light waves to which it was exposed, the resistance decreasing as the light increased and increasing as the light decreased. In this element, therefore, the scientists placed high hopes, since the essentials were there for a device which would operate in such a manner that varying intensities of light could be made to cause a corresponding flow of electric current.

Selenium cells were made by placing a film of the prepared selenium over two german silver or platinum wires of No. 20 to No. 30 gauge wound on a small 2 by 1 inch mica form. The windings were spaced about one thirty-second of an inch apart as shown in Figure 11 and then placed in a box provided with a window to admit light, somewhat as suggested in Figure 12.

The selenium cell found many uses, perhaps the most important, commercially, was in marine buoys and isolated lighthouses along the coast where it was employed to control switching mechanism to turn on the light when darkness set in and to turn it off at daylight, the light of the sun furnishing the requisite energy.

For television work, however, science was again disappointed because of the property of inertia inherent in the element. The change in its conductance lagged so far behind the instantaneous values of light to which it was exposed that a considerable time exposure was required before a proportional current would flow for a given intensity of light. Selenium, therefore, had to be abandoned as an electric eye for television.

A new development eventually appeared, the photoelectronic cell, or phototube, which found immediate acceptance because this was the first device produced that would follow with true fidelity the rapid varia-

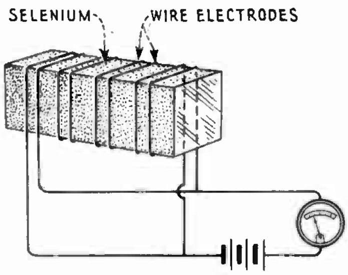


Fig. 11 - TYPICAL CONSTRUCTION OF A SELENIUM CELL.

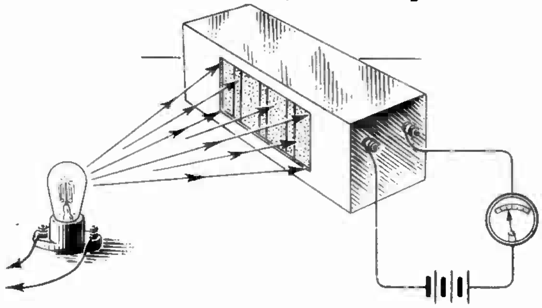


Fig. 12 - LIGHT FALLING ON A SELENIUM CELL RELEASES A FLOW OF CURRENT.

tions of light and shade necessary to form an image and produce an instantaneous current in proportion to the various delicate shading that forms a picture. The photoelectronic cell is a vacuum tube depending for its action upon an electron-emitting cathode and an electron-attracting anode.

Figure 13 shows one general design of the cell. Figure 14 shows the cell connected in a simple circuit and when light is allowed to enter the window a deflection of the galvanometer will be noticed, thus indicating that a current is passing through the cell.

The instant light is cut off, that is, prevented from reaching the light sensitive element, the current through the cell ceases. On the other hand, by increasing the intensity of light the electron emission is increased and a greater current flow will be indicated by the current-indicating instrument connected in the circuit. By repeated experiments it was found that the current passing through the photoelectric cell was directly proportional to the amount of light striking the cell. If the light varies in intensity the current instantly conforms to the change in light, so when the light increases the current rises in proportion and, conversely, when the light is decreased the flow of current decreases in proportion to the decrease in light.

What takes place is explained as follows: Light waves, passing through the circular opening or window of the glass envelope, strike the potassium hydride coating on the inside of the bulb. The potassium, having the property of emitting electrons when exposed to light waves and especially those predominating in blue violet light, emits clouds of electrons which are attracted at once to the positive electrode. This electrode is a loop or rectangle of wire made of some photoelectrically inactive material such as nickel or platinum. The electrons are considered to constitute an electric current which flows through the cell and the circuit connected to the cell in which the source of electromotive force maintains the anode at positive potential.

It has been mentioned that the potassium type of cell is particularly sensitive to blue-violet light. On the other hand a cell using a thallium-sulphur compound in the cathode surface shows a great sensitivity at the red end of the color spectrum. This color-sensitivity quality brings several unique features into the field of television.

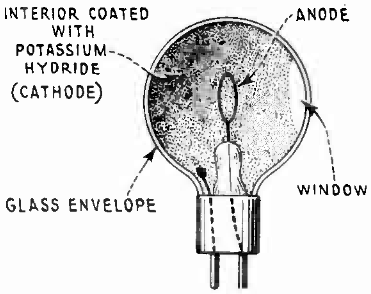


Fig. 13 - CONSTRUCTION OF A TYPICAL PHOTOELECTRONIC CELL.

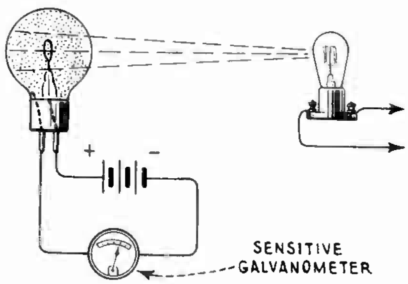


Fig. 14 - EFFECT OF LIGHT ON THE PHOTOTUBE.

When using the potassium cell it is possible to televise with an intense blue light without the discomfort to the players that comes from using a white light which includes all the heat-producing rays at the red end of the spectrum. When using the thallium-sulphur cell, invisible infra-red light can be used to televise an object or scene, providing distant visibility of things that are in darkness to the human eyes present at the scene.

Let us return to the time when the epochal invention of the selenium cell was made. Having a device of this kind the science of television moved another step toward success.

PHOTOELECTRIC SCRUTINY OF COMPLETE IMAGE

The early work in the field of television was conducted upon the principle of constructing an imitation of the human eye. This manufactured eye employed a great many selenium cells and attempted to build up a mosaic pattern of the object or scene to be televised. The effort failed; first, because of the inherent time lag in selenium and, second, because of the prohibitive cost of the great number of selenium cells and wire circuits required.

This can be better understood by comparison with Figures 1 and 2. A light-tight box was built similar to a camera but much larger. Instead of a photographic plate, the back surface of the box was covered with scores of selenium cells placed in regular rows like a tile wall. This corresponds to the retina of the human eye, and the image of the scene was focused on this photoelectric wall, whose function was to "analyze" the image, or break it up into its component parts. Corresponding to the optic nerves which connect the retina and the brain, there were a multitude of wires leading from the selenium-tiled wall, each cell using a pair of wires. These wires were made part of battery circuits connected with the distant point.

Here an upright frame was used to support a sort of honeycombed box, in which were installed a bank of lamps equal in number to the selenium cells at the transmitter. The function of this lamp bank was to "synthesize" (meaning "put together") a light pattern resembling the original image. In front of each lamp was a shutter, magnetically operated by the current coming to it through the pair of wires connected to the selenium cell placed at the same relative point in the transmitter frame. Whenever a selenium cell was acted upon by a light-element of the image, the corresponding lamp-and-shutter combination provided a light-element at that point of the receiver frame.

When an object moved in front of the transmitter box, its image moved correspondingly across the photoelectric wall inside the box. The values of light falling on the various cells at any instant determined the open or closed condition of the corresponding light shutters at the receiver. The pattern formed by these many light sources in the honeycomb structure gave an approximate image of the object televised.

It is to be noted that this form of television equipment, while cumbersome and costly, transmitted the entire picture-effect at once. The analyzer and synthesizer were continuously connected, each wire channel having to carry only one element of the image. Others continued to experiment along similar lines but finally the development turned toward working out the problem by employing only one wire channel between the two places. With this limitation of equipment, it is not possible to analyze the image in one operation, nor is it possible to synthesize the light pattern completely at once.

There will be required the progressive examination of the light values of small sections of the image, and to this process we apply the term "scanning."

Retaining the effect of a selenium-tiled wall of many cells, but now using only one circuit, there must be some way to shift this lone circuit from one selenium cell to the other in rapid succession. Likewise, there must be some way to shift the opposite end of the circuit from one lamp to another in succession. At the instant when any particular cell is connected to the transmitter end of the wires, the other end must be connected to the particular lamp which is placed in the corresponding location on the receiver screen.

This mechanism required two rotary switches, each having as many contact points as there were cells or lamps. The switches sometimes took the form of commutators as used in motors, etc. These switches were required to rotate in synchronism. This means that not only did isochronism (same revolutions per second) have to be maintained, but also the proper relation (phase) between the switch-positions at each end. This was necessary in order that each selenium cell in turn might get the "right party" among the distant lamps.

In order to comprehend the necessity for speedy rotation of these switches we must have a clear understanding of a certain faculty of the human eye, which is explained on the next page under the topic "Persistence of Vision."

PERSISTENCE OF VISION

When light strikes the retina of the eye, the impression caused by the light will remain, that is, it will persist, for an appreciable time after the source of light has been cut off. Because of this peculiarity we continue to see brightly illuminated objects for a short time after the object ceases to transmit or reflect light to the eye. The following two experiments may be performed to illustrate this phenomenon.

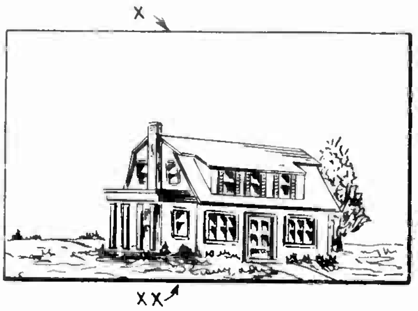


Fig. 15 - DRAWING OF A HOUSE. (SEE FIG. 17.)

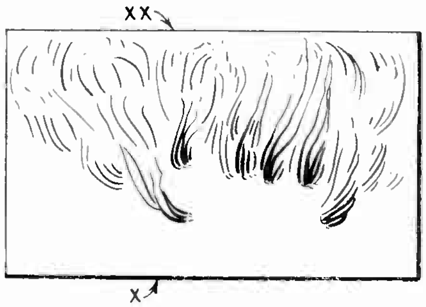


Fig. 16 - ILLUSTRATING FLAMES. (SEE FIG. 18

First, swiftly swing a flashlight in a circle. The image recorded by the retina in any one position of the swinging light will persist until it is again renewed on the retina by the light arriving in the original position. The result is that we see a continuous circle of light.

Second, use the pictures shown in Figures 15 and 16 to construct the model described in the following paragraph. This demonstration explains why the path-changer of a television transmitter is rotated at a certain speed so that the last part of the object is examined before the light representing the first part fades from the retina.

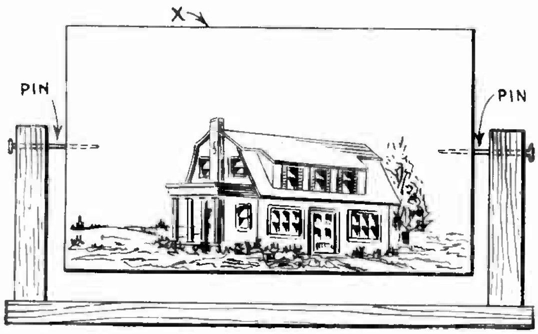


Fig. 17 - VIEW OF HOUSE MOUNTED ON ONE SIDE OF CARD.

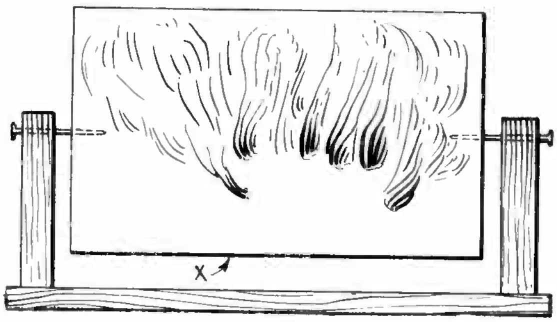


Fig. 18 - DRAWING OF FLAMES MOUNTED ON OPPOSITE SIDE OF CARD.

Redraw Figures 15 and 16 on two separate pieces of white paper of the same size, or cut them out of the text, as desired. Mount the finished drawing of Figure 15 on a piece of stiff cardboard of the same dimensions. Now, without allowing edge "X" to leave the table, raise edge "XX" and turn the card over by giving it a rotary motion away from you; edge "XX" will now be at the top and "X" at the bottom. Completing this, mount Figure 16 on the cardboard so that side "XX" is at the top of the card. Next construct a support using some suitable material which is handy, so that when a pin is stuck in each end of the finished card and mounted on the supports as shown in Figure 17, or held by both hands, the card can be rotated freely. With this completed and the "house side" of the card facing you, slowly turn it until edge "XX" is facing you, in which position neither view is visible. Continue to turn the card in the same direction and the view in Figure 18 is now seen. The purpose in rotating the card very slowly at first is to show that at this speed each view you have of the house and the flames is distinctly separate and independent.

Now, with the card in the position as shown in Figure 17, cause it to rotate rapidly and you will see the house enveloped in flames. The house appears to be burning because as soon as the image of the house fades from the retina of your eye the flames are superimposed upon it.

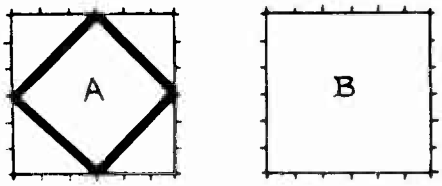
CONCLUSION

You have advanced now to where you should have a good understanding of the growth of television up to and including the systems which employ:

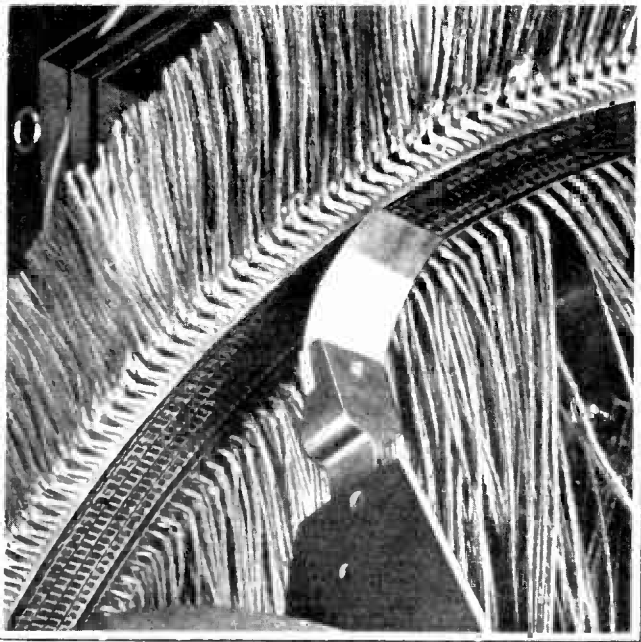
(a) Analysis by multi-cell arrangement.
(b) Synthesis by multi-lamp arrangement.
(c) A single channel for television signals.
(d) A path-changer on the electric side of the photoelectric cells.
(e) A path-changer on the electric side of the television lamps.

EXAMINATION QUESTIONS

1. What fundamental principle of optics is used in the pin-hole camera?
2. Why was a lens added to the pin-hole camera?
3. Is selenium suitable for television? Why?
4. Compare the telephone and television.
5. Explain the construction and operation of the electronic type of photoelectric cell.
6. Why is television scanning sometimes done with a blue light?
7. What is the difference in principle between photoelectric scrutiny and modern scanning?
8. In an electrical scanning and distributing system, what would be the picture-effect at the receiver if its commutator switch were travelling at the same speed as the transmitter switch, but exactly one-third of a revolution behind the transmitter? Using sketch A as the transmitted design, fill in the blank square in sketch B with your answer and copy the latter on your answer sheet.



9. What is the function of the bank of lamps used at the receiver?
10. (a) In the scanning system described last, the scanning path-changer is located on which side of the photoelectric pickup cell?
    (b) The distributing path-changer at the receiver is on which side of the photoelectric reproducer (lamps)?



DETAILS OF THE DISTRIBUTOR. THE SLIDING BRUSH BEARING THE TELEVISION SIGNAL VOLTAGE IS A STRIP OF THIN SHEET METAL.

(Courtesy, BELL TELEPHONE LABORATORIES.)

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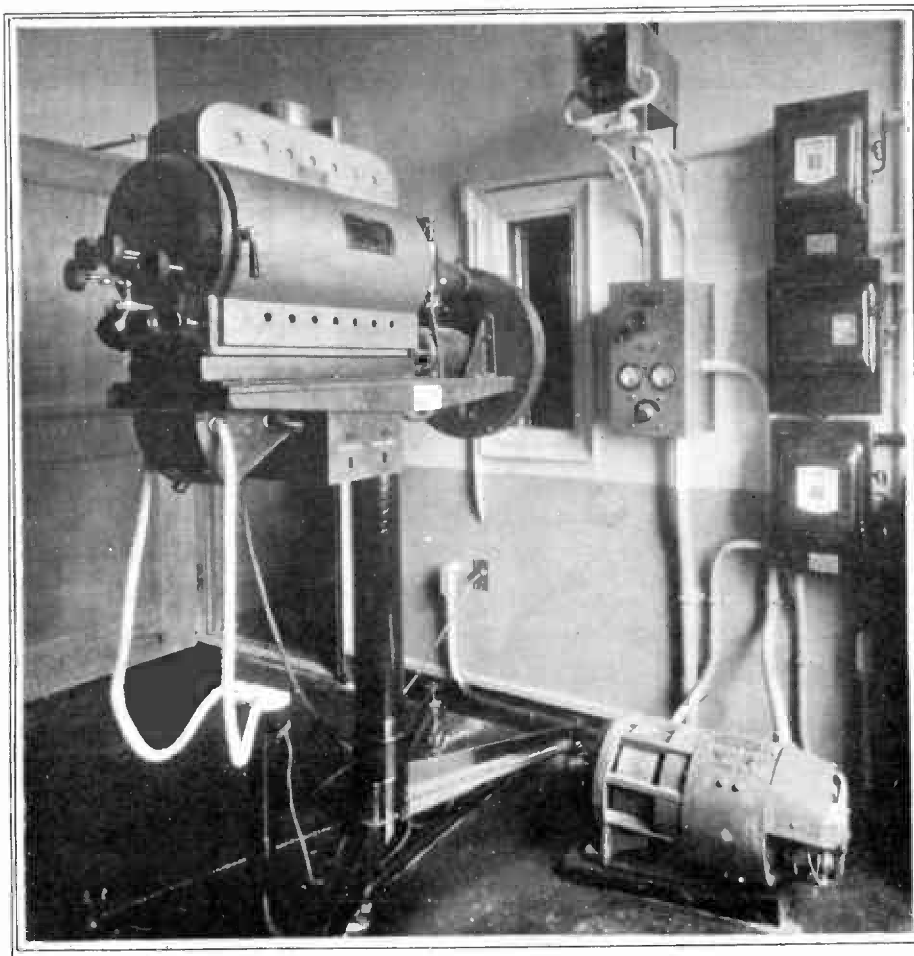

SCANNING BY THE FLYING-SPOT METHOD USES A HIGH-INTENSITY ARC LAMP.
(COURTESY COLUMBIA BROADCASTING SYSTEM)

Scanning Methods in Modern Television

VOL. 59, No.4

Dewey Classification R500.09

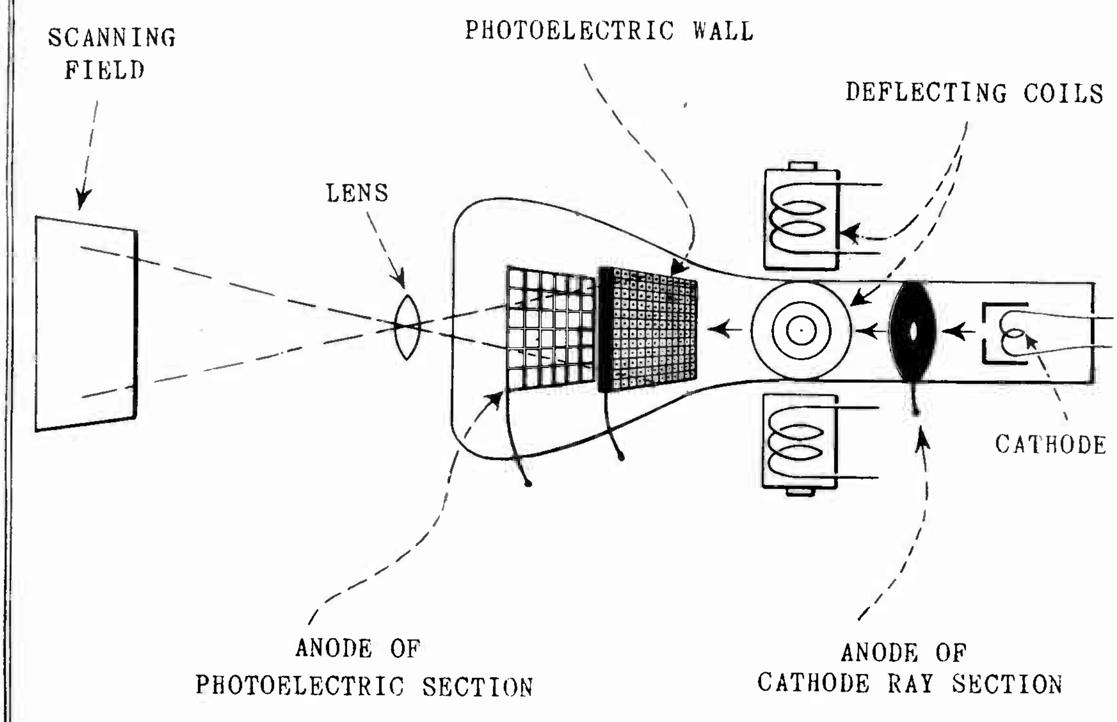

Fig. 1 - POSSIBLE CONSTRUCTION OF A CATHODE-RAY SCANNER

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SCANNING METHODS IN MODERN TELEVISION

The principle upon which any system of television must operate, in order that an image of an object or scene can be viewed at a properly designed receiver, is that the object must be exposed to light rays. The diffused reflection from each point of the object thus exposed is then picked up by one or more photoelectric cells, translated into an electric current which varies according to the change in brightness of the object thus exposed, and then passes over whatever channel is available for the communication of this current. How well this system operates will depend upon the fineness of detail required, the sensitiveness of the photoelectric cell, and the efficiency of that part of the system employed to amplify the minute currents generated by the light-sensitive cell.

CATHODE-RAY SCANNING

One method of electrical scanning of an image makes use of a device which is a combination of a multi-electrode photoelectric cell and a cathode-ray tube. These two sections have certain electric parts in common, but are separated by a gas-tight wall, in order that each section may hold gases at certain pressures which will enable them to perform their respective functions with greatest efficiency. Figure 1 illustrates this arrangement.

The photoelectric section comprises a metal gauze screen which serves as the anode, and a honeycombed wall containing a great number of metal bars, insulated from each other. On the side toward the gauze screen, these parts are tipped with a photoelectronic substance as in the ordinary phototube. A lens outside the glass wall focuses an image of the object on the photoelectric wall. The light-sensitive coating on each bar will emit a quantity of electrons proportional to the light intensity of the image-element which is focused on it. These separate bars and their common anode, the gauze, are in effect a multi-cell photoelectric pickup.

Up to this point, no selector system has been shown permitting us to switch from one photoelectric element to another to accomplish scanning. This commutating function is performed by the second section of the tube, embodying principles used in the cathode-ray oscillograph. At the right end of the figure is shown an oxide-coated filament, the cathode of this section. Around the cathode is a cylinder closed at one end except for a small opening through which electrons pass, as they are attracted by the positively-charged disc which serves as the anode of this section. Some of the electrons reach this anode surface and constitute a current flow through the battery circuit of the anode. The action so far is quite similar to that of an ordinary two-electrode vacuum tube.

However, this anode has an opening through which a quantity of electrons pass at such a high velocity that they are not turned aside toward the anode. These electrons are narrowed into a fine ray, partly because of a certain influence of a surrounding gas. Now this electronic stream constitutes an electric current just as much as if it were following a metallic conductor. Although the electron stream in a gas obeys certain fundamental electric laws of such currents, it can be made to move more easily than when confined in a metallic conductor. The electron ray can be deviated (changed in direction) by either an electrostatic or an electromagnetic field. In the illustration are shown coils for creating two magnetic fields at right angles to each other, and both at right angles to the electron ray. When alternating currents of the proper wave-shape and relative frequencies are fed to the deflecting coils, the electron ray is made to sweep in succession over the uncoated ends of the metal bars constituting the photoelectric wall. This action is similar to the movement of a stream of water from a firehose, as it is played across the face of a burning building. In this fashion we get one narrow electronic stream which is put in series, successively, with the electron streams of the first section, which depend on the image elements. The wire screen receives, therefore, electrons varying continuously with the picture elements thus scanned. This electron flow constitutes the television signal current.

MECHANICAL SCANNING

We have so far covered only the scanning process using a photoelectric unit for each element of the image, with a selector or commutator which shifts the electric path between them and the common transmission channel. We will now consider further developments which use:

1. Analysis by a single photoelectric cell, or several in parallel acting as one.
2. Synthesis by a single television lamp.
3. A single channel for the television signal.
4. A path-changer on the light side of the photoelectric cell.
5. A path-changer on the light side of the television lamp.

Since television is still a growing art, no attempt will be made to record hard and fast rules, or describe fixed combinations of apparatus. Our study will be confined to fundamental principles, the subject here being devoted to "one-eyed" scanning systems.

SCANNING PRINCIPLES

The early attempts in this field were made by flood-lighting the object by a powerful source of light, ranging into thousands of candlepower. Because of the comparatively short distance between this intense illumination and the object, human beings could not be televised successfully without extreme discomfort due to the enormous heat generated by a light so powerful, hence inanimate subjects were used. Figure 2 shows in detail the principle just mentioned. The object at the right is placed under the powerful light. Lens 1 is placed between the object and the rotating scanning disc in such a position that part of the reflected light rays from the object pass through the lens and produce an image of the object on the rotating disc.

Before continuing further it will be necessary to go into detail concerning the scanning disc so that the tracing out of parallel lines of an image will be clearly understood. Appendix "A" at the back of the lesson has been included for the purpose of illustrating this principle.

Let us return to Figure 2. About the disc in the form of a spiral are drilled a number of small holes, usually either round or square. As the disc rotates the small openings trace parallel lines of sight

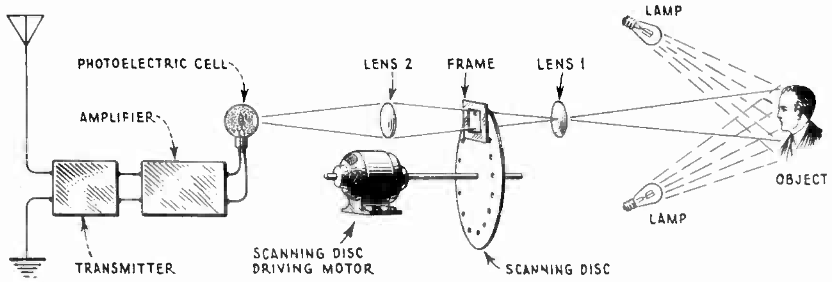


Fig. 2 - PROGRESSIVE OBSERVATION AS A SCANNING METHOD

across the image, one after the other in rapid succession. On the opposite side of the disc is a frame, the opening of which is the same size as the formed image. This frame prevents more than a single opening being in the image at any one time. The bottom edge of the frame will usually be shorter than the top edge, because the innermost hole of the spiral which traces the bottom scanning line has a somewhat shorter useful path than the outer or top hole. As each opening moves into the image, light passes through it and is converged by means of lens 2 into the photoelectric cell, where it causes a current to pass through the cell. The amount of current that passes will be directly proportional to the brightness of that small portion of the image area which at that instant is viewed by the cell.

This method of scanning is described as "progressive observation", because it is the path of observation between photoelectric cell and object which is made to move progressively.

Because of the extreme inconvenience due to continuous excessive heat and light, television carried out by the formation of an image on the disc was temporarily discarded. This called for some other method of scanning; therefore, instead of exploring an image of the object, the object itself was explored by a rapidly moving pencil of light.

"Progressive illumination" is the term applied to this method, for it is the illuminating path which moves progressively across the object.

This does not change anything we have previously covered except the optical system which has been completely reversed, as you will see by referring to Figure 3. The "pencil" is actually a concentrated beam from a source of intense light such as an arc lamp. This light is passed through a lens which confines the rays to a small area. A rapidly revolving scanning disc, driven by a small motor, is placed in the path of the light beam. A small frame placed between the disc and the lamp prevents light from passing through more than one of the disc openings at a time. A demonstration of this principle can be made with the model shown in Appendix "B" at the back of the lesson.

As the small intense pencil of light passes through the openings in the disc the features of various objects are rapidly explored. Referring to the figure above, we find that some of the light, upon striking the object, is absorbed, and part is reflected. The amount of light reflected into the photoelectric cells will depend upon the subject being scanned. For example, suppose a man is seated before the scanning disc. As the spot of light passes across his hair, which we will assume is dark, considerable of the light will be absorbed and little reflected. As the light spot passes across the face more light will be reflected and the total output current of the photoelectric cells will be increased. This current will therefore follow accurately the brightness of the individual areas of the man's features as he is explored or scanned by the spot of light.

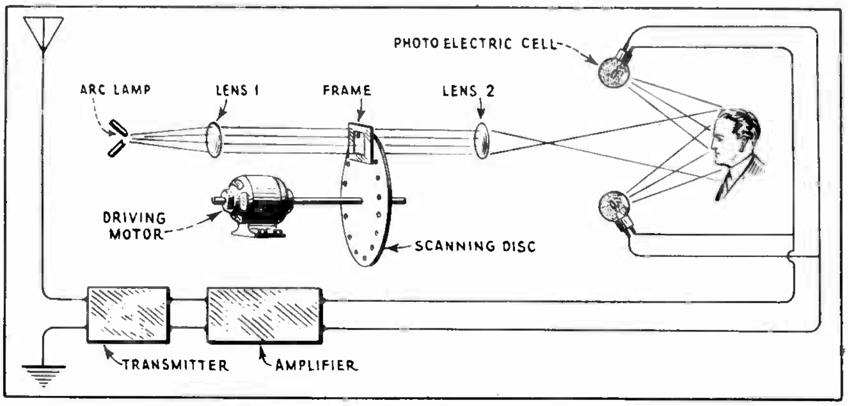


Fig. 3 - PROGRESSIVE ILLUMINATION AS A SCANNING METHOD

The current output of the photoelectric cell, or cells as the case may be, is very small. When it is passed through a resistance a voltage is developed across the terminals of the resistance; this is a signal voltage which is then fed into several stages of amplification. The increased signal voltage is used to modulate the carrier wave of a transmitter from whence it is broadcast in the usual manner. We now have a modulated signal impulse which is following the brightness of the elemental areas of the subject being televised, and it remains for us to intercept this signal and reconvert it to light.

Before entering upon a study of the problems and methods of transmitting the television signal, and interpreting it at a distant point, it is well that we cover thoroughly the physical forms and optical methods of scanning systems.

In review, it is seen that the mechanical scanning system is marked by the following features:

1. It uses a source of illumination and a photoelectric cell.

2. It requires an optical path connecting light source and cell.

3. The object or scene to be transmitted acts as an irregular reflector interposed in that optical path.

4. The two sections of this path are, in order, the illuminating path and the observing path.

5. If the illuminating path is wide (flood lighting), the observing path must be constricted and narrow.

6. If the illuminating path is constricted and narrow (spot lighting), then the observing path must be wide (phototubes spread in an open bank).

7. A path-changer (such as a scanning disc) must be in the constricted path when using either of the methods in paragraphs 5 or 6.

8. Progressive observation uses flood lighting and camera image observation by the cell, with the scanner between the object and the cell.

9. Progressive illumination uses a spread-out bank of cells and spot lighting, with the scanner between the light and the object.

As long as these principles are kept in mind, it is possible for us to investigate other path-changing systems than the disc with plain holes. The difference will be in (a) the mechanical form of the moving parts and (b) the optical principles involved.

SCANNING MOTION HAS TWO COMPONENTS

A televised scene or image appears to the electric eye as a flat picture and may be measured by a vertical height and a horizontal width, but not depth or distance. Since this is so, any analyzing system applied to that area must have a motion with two components. One component is a horizontal motion, and the other a vertical motion.

In the Nipkow scanning disc (holes placed spirally) as used in America, the horizontal component is provided by the nearly straight lines made by the scanning holes as they are rotated from one side of the image to the other. The vertical component is provided by the spiral formation of the group of holes. This is explained by saying that each hole in the spiral group is at a different distance from the center of the disc. Since the field of view is above the center of the disc, it means that each hole in succession crosses the image at a different vertical height from its bottom edge.

The same scanning disc is used differently in the chief television system of Great Britain, and also in other European countries. Instead of scanning through the top of the disc, the optical path passes through the holes when they are at one side, as shown in Fig. 4, where the holes are moving in a vertical direction.

An inspection of Figure 4 will make this clear. The scanning holes move up or down the image, providing the vertical component. Then the spiral order of the successive holes brings each one in turn closer to the center of the disc, but this displacement is now a vertical component. The model described in Appendix "B" may be used to illustrate this point.

We have accomplished the breaking up of the picture in two opposite methods, as used in American and European systems, but have used the identical disc for both. It is important to bear in mind such flexibility of mechanical design.

Whenever a system of analyzing has been decided upon for the transmitter, the same system must be used for picture-synthesis at the

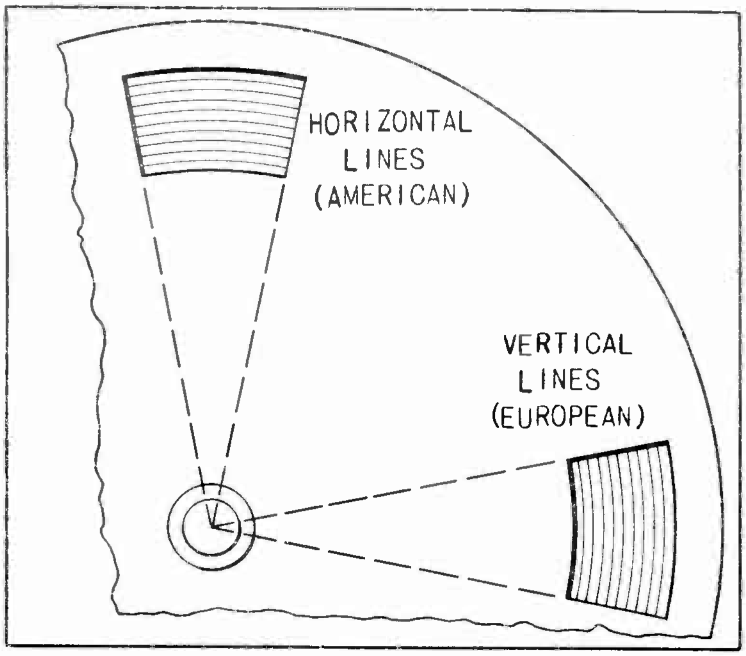


Fig.4 - A SCANNING DISC MAY BE USED FOR EITHER HORIZONTAL OR VERTICAL SCANNING

receiver, so far as the relation of horizontal and vertical components is concerned. If the horizontal scanning line is used, there would be no use in having the receiver disc placed as for vertical scanning lines, because then the picture received would be laid down on its side, as it were. It could be viewed satisfactorily only by a person lying down.

Another point may well be brought out. The scanning holes of the transmitter disc do not have to be in a single perfect spiral. For instance, instead of scanning in order with the holes representing lines 1, 2, 3, 4, 5, etc., a scanning disc may be designed so that the placement of the scanning line holes around the disc may be in some other order. This holds good as long as the holes have an equal angular displacement around the periphery. One possible arrangement would be four short spirals composed of holes which uncover the scanning lines in this order: 1-5-9-13, 2-6-10-14, 3-7-11-15 and 4-8-12-16, as applied to Figure 14. Remember that 16 is the number of holes used in our model, shown in Appendix A, only for the sake of simplicity, and actual scanning systems are not satisfactory with less than 60 lines. Whatever successive order of the lines is used at the transmitter, the same order must be used in distributing the lines of light which constitute the picture at the receiving end.

DIFFERENT FORMS OF MECHANICAL SCANNERS

With this principle clearly understood, that it is only necessary to break down the image or scene area into a group of strips, let us proceed to study other methods used to accomplish the same purpose. Holding for the present to the idea of plain holes in the scanner, we find two other devices, a cylindrical drum and a belt. The latter has not been used much because of the mechanical difficulties in making the belt run so true that any given hole in it will continue to cover exactly the same strip of the image with every repetition of its scanning function.

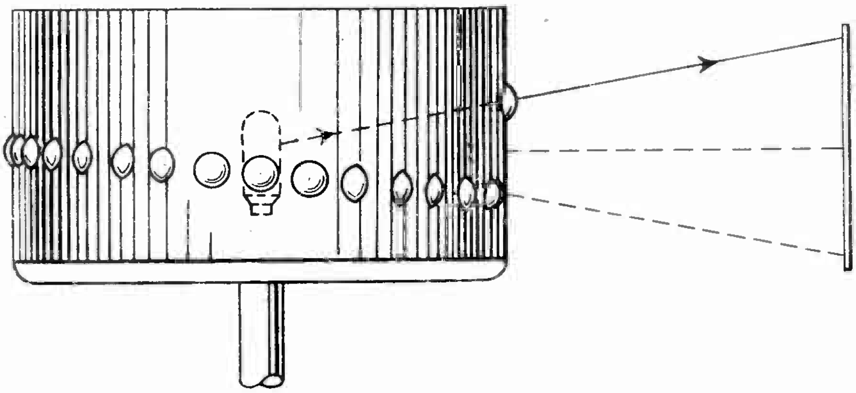


Fig. 5 - THE ADDITION OF LENSES IMPROVES THE DRUM SCANNER

On the other hand, the cylindrical drum lends itself more readily to the construction and operation of rotary mechanism which can do the accurate optical work of scanning. Figure 5 shows a perspective view of such a drum. It is seen that the horizontal scanning lines are formed by the rotation of holes in the surface of the drum, which is mounted on a vertical axis. The vertical component of the scanning motion is provided by the placement of the holes in a helical spiral, so that each hole is displaced vertically a slight distance from the adjacent ones. The drum is shown equipped with lenses.

LENSES AND PRISMS BRING IMPROVEMENT. Plain holes in scanning rotors have the same limited effectiveness which marked the pin-hole type of camera. Just as the early form of camera was improved by the use of a large opening with a lens in it, so we find that a considerable advance was made when lenses were applied to scanning discs. The plain holes of a small fraction of an inch in diameter were enlarged to an inch or more. Lenses were placed over the holes and optically centered on the spiral line. As with the camera, this allowed the passage of much more light to or from the object being scanned, and thus the optical efficiency was increased.

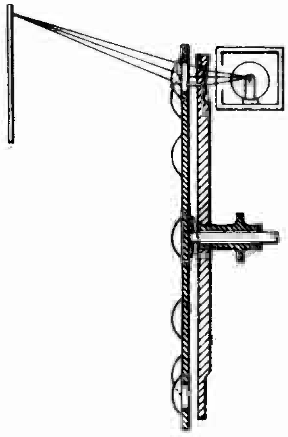


Fig. 6 - LENS AND PRISM DISCS SEPARATELY PROVIDE TWO COMPONENTS OF SCANNING MOTION

A modification of the lens disc is that shown in Figure 6. The spiral is dispensed with and the lenses are placed in a circle, which satisfied our requirement for a horizontal component of scanning motion. However, it does not take care of the vertical component. For this a separate disc is used whose border consists of a peculiar glass section comprising a prism of continuously varying cross section. With every revolution of this prism disc the light-beam makes one complete vertical crossing of the image, because of the gradually changing angle of the refraction of the beam.

The same effect is secured with a single disc in another way as shown in Figure 7. This disc has a circular line of holes each equipped with a lens having the usual convex side. Each lens bears on the opposite side a small prism section which refracts the scanning beam somewhat in a vertical direction. Since each prism-section, from the nominal first one on, has an increasingly greater angle of refraction, it is seen that in one revolution of the scanning disc the

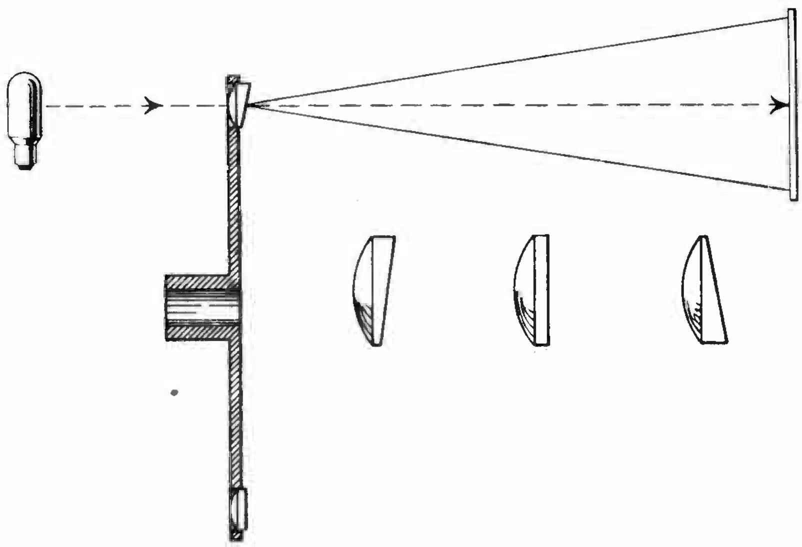


Fig. 7 - A SINGLE DISC BEARING COMBINATIONS OF A LENS AND PRISM

scanning path makes one complete vertical crossing of the image. This crossing or traverse consists of a group of horizontal lines equal in number to the transparent openings in the disc.

The drum type of scanner with lenses mounted over its enlarged openings has been used more in European practice than in American.

MIRROR WHEELS. To comprehend the use of mirrors in scanning, you are reminded of the universal trick of a child in twisting a small hand-mirror to make a spot of reflected sun-light sweep across a window, or the face of some playmate or grown-up within range.

In television, one form of mirror scanner makes use of a wheel, around the rim of which are a number of flat (or curved) mirrors. These are equally spaced, tangent to the rim, and with edges touching. All are parallel to the axis of the wheel. This identical placing makes each mirror have an identical effect on a beam of light directed toward the mirror rim.

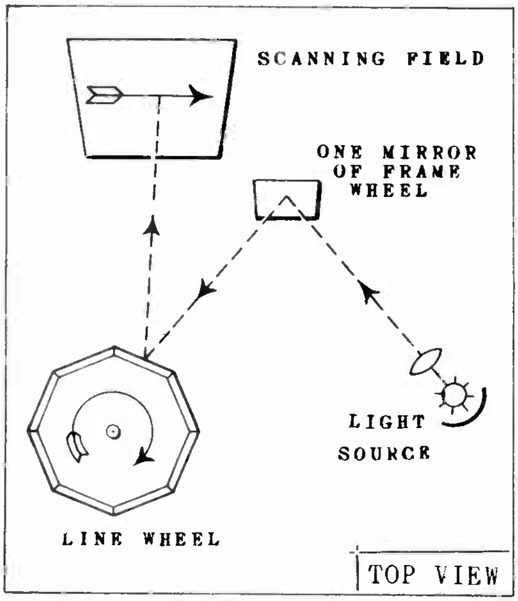


Fig. 8 - SCANNING ACTION OF THE LINE WHEEL OF A MIRROR SYSTEM

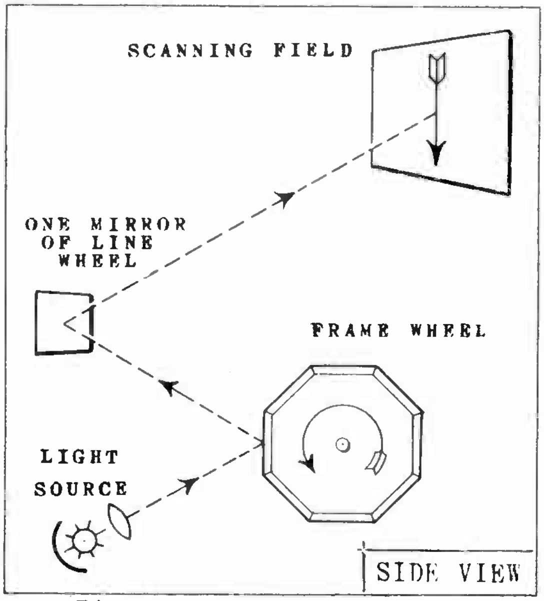


Fig. 9 - SCANNING ACTION OF THE FRAME WHEEL OF A MIRROR SYSTEM

There are two such mirror wheels used in the first system to be described. We will study, one at a time, the action of each mirror wheel on the scanning path and to do this the other mirror wheel is assumed to be stationary. Figure 8 which illustrates this principle shows that a light beam impinges on a mirror (one face of the wheel which is held stationary) and is reflected to the second mirror wheel, from which it is again reflected toward the object. The object is shown here as just the lines bounding the field of vision, marked "scanning field." As the second wheel rotates in the direction shown by the arrow, the beam is given a horizontal motion that sweeps a light spot across the picture from left to right. As it continues to rotate the spot moves off the right edge of the viewing field, the light from the stationary mirror now falls on the next moving mirror face, and a light spot comes onto the left edge of the field of view. It sweeps across as did the previous light spot. It is seen then that we get one horizontal scanning line every time one of these mirrors passes in front of the incident light beam. We will call this second wheel the "line wheel."

Now let the line wheel be held stationary, as in Fig. 9, while we examine the action of the first wheel in the light path. This rotates about a horizontal axis and hence any mirror on its rim will tend to move the light spot in a vertical line. With this wheel rotating in the direction shown, the spot will make a complete traverse or crossing from the top to the bottom of the viewing or scanning field. As it moves off, another spot will appear at the top and follow the same path. This is due to the next mirror face which moved into the light beam as the first mirror left it. This wheel may be called the "frame wheel."

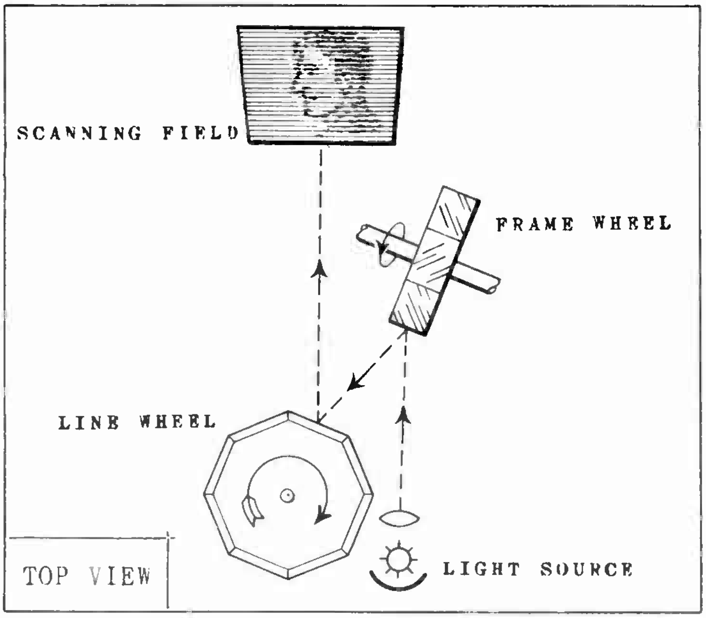


Fig. 10 - COMPLETE SCANNING ACTION OF LINE WHEEL AND FRAME WHEEL

Here we have the essentials of a true scanning motion consisting of horizontal and vertical components. When both wheels are rotated at related speeds, the scene is scanned by the light spot progressing in parallel horizontal lines down the field of view, as shown in Figure 10. The scanning rate for this method is based on: (a) one scanning line per mirror of line wheel, and (b) one frame per mirror of the frame wheel.

The same effect can be brought about by the use of one wheel, closely resembling those described above, but having the mirrors tilted slightly instead of parallel to the axis. The difference in angle between mirrors is uniform, and therefore the scanning lines will be equally displaced in a vertical direction from one another. The construction is shown in Figure 11. The scanning rate for this method is based on: (a) one scanning line per mirror, and (b) one frame per revolution of wheel. A minor variation of the mirror principle is found in the use of mirrors on a rotating wheel whose rim is cone-shaped rather than cylindrical. A mirror construction which has received more attention in Europe than in America is the "mirror screw." It uses a large number of long narrow mirror faces which are disposed along an axle and set at right angles thereto. The centers of the mirror strips are tangent to the circumference of the axle, but equally displaced from one another around the circumference. This construction makes it look like a double spiral staircase of colonial style.

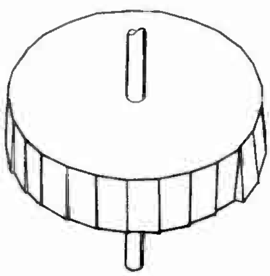


Fig. 11 - COMPLETE SCANNING PROVIDED BY ONE WHEEL HAVING TILTED MIRRORS

APPENDIX "A"

DEMONSTRATING PRINCIPLE OF SCANNING BY PROGRESSIVE OBSERVATION

Figure 12 has been drawn for explanation purposes only and not as a model to illustrate how a scanning disc is actually constructed. This point is stressed for the reason that the size of the disc, the number of openings, and the radial offset of the apertures assume different values in discs which have a practical utility in television.

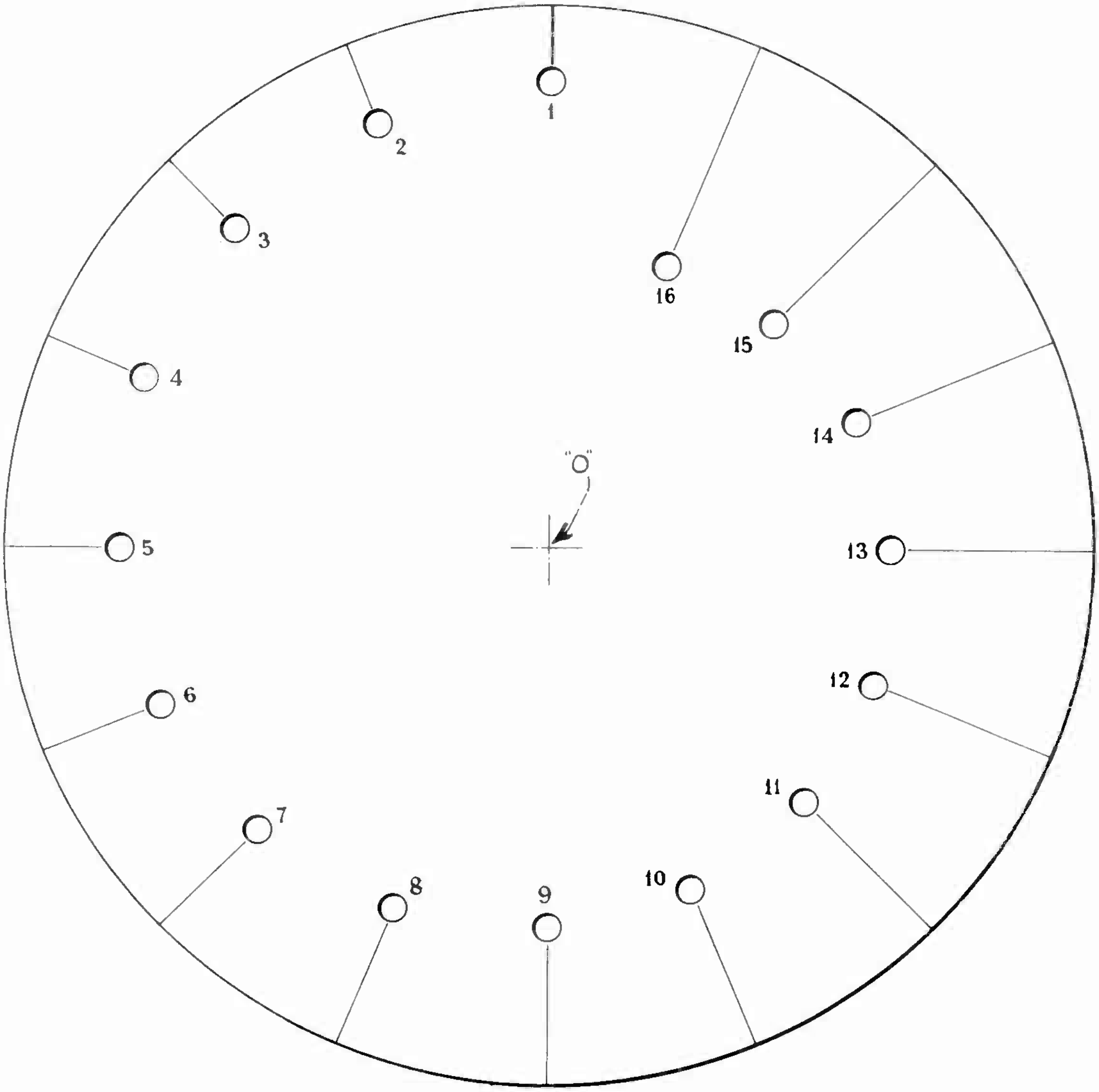
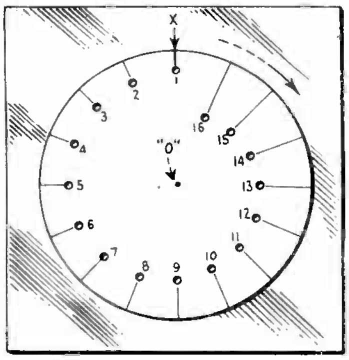


Fig. 12 - EXPERIMENTAL SCANNING DISC

With this clearly in mind use Figure 12 as a guide and redraw or trace out the figure on a sheet of paper, pasting this on a piece of cardboard of sufficient weight to insure against curling or warping. Trim the material off to the edge of the circle, and cut out each opening accurately, taking care to follow all lines.

Next lay the finished disc on a white sheet of paper about 8 inches long by 7 inches wide, and place a pin through the center "O." Draw a short line "X" on the paper to coincide with line #1 on the disc. This is shown in Figure 13. With a sharp pointed pencil inscribe a small numeral "1" on the white paper at the center of opening #1. Slowly rotate the disc clockwise as shown by the arrow until opening #2 coincides with "X", and within the boundary of this opening inscribe a small numeral "2" on the paper. Repeat this for all the openings. 16 in all.

If this is carefully completed you will have drawn a row of numerals on the paper as shown in Figure 14. Enclose this row by four lines to get an area 7/8 inch wide by 1 inch long. We may let this represent the image. Further, we can let this series of numerals represent a series of slightly curved parallel lines. Again rotate the disc clockwise, at the same time peering through the openings as they come opposite point "X." When the numeral "1" is seen, hole #1 will be crossing the image area in what we will call scanning line #1. When hole #2 is crossing the area, scanning line #2 will be exposed, as marked by the small numeral "2." During one complete



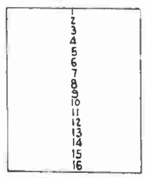


Fig. 14

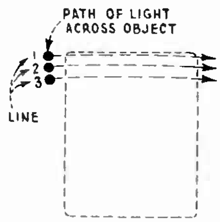


Fig. 15

Fig. 13 - EXPERIMENTAL DISC TO DEMONSTRATE PRINCIPLE OF SCANNING

revolution of the disc the image area will have been completely explored from top to bottom by a series of parallel lines, as shown in Figure 15. One complete exploration of a scene or its image is called a "frame."

APPENDIX "B"

DEMONSTRATING PRINCIPLE OF SCANNING BY PROGRESSIVE ILLUMINATION

We may again use the disc model to illustrate the second method of scanning, by the application shown in Figure 16. Procure a small block of wood and on it erect two wooden standards, V1 and V2, the upper ends of which are rounded out as shown by the small sketch A at the right. The shorter standard V1 supports a small wooden shaft "S" at point "H", the bearing for the rear end of this shaft being provided by a nail or pin through V2. A flashlight is inserted in a close-fitting tube T, or wrapped in stiff paper to simulate a tube. The standard V2 must be long enough to hold the flashlight tube at the proper elevation to cover all the scanning holes. The disc D, when mounted on the shaft "S", must revolve true, and the tube "T" must be as close to the disc as possible without touching it, thereby allowing a minimum of light to escape.

When this arrangement is complete snap the flashlight on and turn the disc so that hole #1 is in line with the light beam. A spot of light will appear on the screen, and as the disc is slowly rotated a slender pencil of light will move across the screen from left to right. As hole #2 comes around the light shining through will trace a path slightly lower on the screen. The line made by hole #3 will be lower still, and so on until #16 is reached which will be the lowest path traversed by the spot of light. These two extreme positions of the light, #1 and #16, represent the height of the scanning field. You should draw some kind of a figure on the screen between these limits and continue the experiment.

Now spin the disc by twirling the shaft between the forefinger and thumb. While doing this watch the screen and imagine your own eyes are taking the place of the several electric eyes placed in the vicinity of an object being scanned. As the various holes move by in succession, and allow the screen to be illuminated, your eyes respond to the varying intensity of the light reflected from different parts of the figure you have drawn. You will also have a sense of direction telling you from what part of the image the light is coming. On the other hand, the electric eye does not have a sense of direction. It would see those scanning lines just as though they were laid end to end on a continuous tape until the whole picture image had been passed; likewise, it sees the successive repetitions of the complete image just as though they were also laid end to end on the tape. This explains why there is a continuous signal being transmitted by a television station. Of course it must be clear that there is no signal while the scanning path is crossing an area which does not have a variation in reflection, any more than there would be a signal in between the words transmitted by a radio broadcasting station. The signal modulation actually represents work being done in the communication of intelligence, whether the effect is "sound" or "sight."

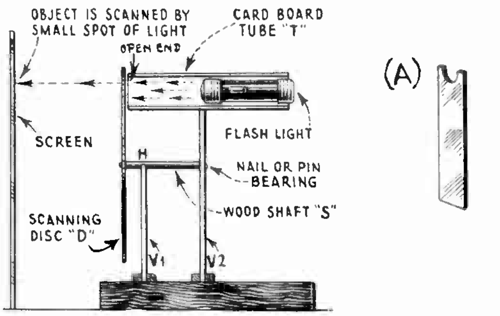


Fig. 16 - ILLUSTRATING PRINCIPLE OF SCANNING BY PROGRESSIVE ILLUMINATION

EXAMINATION QUESTIONS

1. In the cathode-ray scanner described, what are the two electric uses of the photoelectric wall?
2. Give the fundamental features of an optical-mechanical scanning system.
3. What is the chief difference between progressive observation and progressive illumination?
4. What is the advantage of lenses in the rotating part of a mechanical system?
5. Describe the scanning action of the single mirror wheel.
6. Give three ways in which the action and construction of the receiving distributor disc must resemble the transmitting scanner disc.
7. What important difference between sound broadcasting and television transmission requires the use of a scanning method?
8. What two things must be connected to the photoelectric cell to produce a television signal voltage?
9. When a scanning disc is used having the openings in a circle, what optical device can be used to provide the other component of scanning motion?
10. In the cathode-ray scanner, what two methods may be used to deflect the ray?

THE PHOTOELECTRIC CELLS ARE SPREAD IN A WIDE BANK
WHEN THE FLYING-SPOT IS USED FOR SCANNING.

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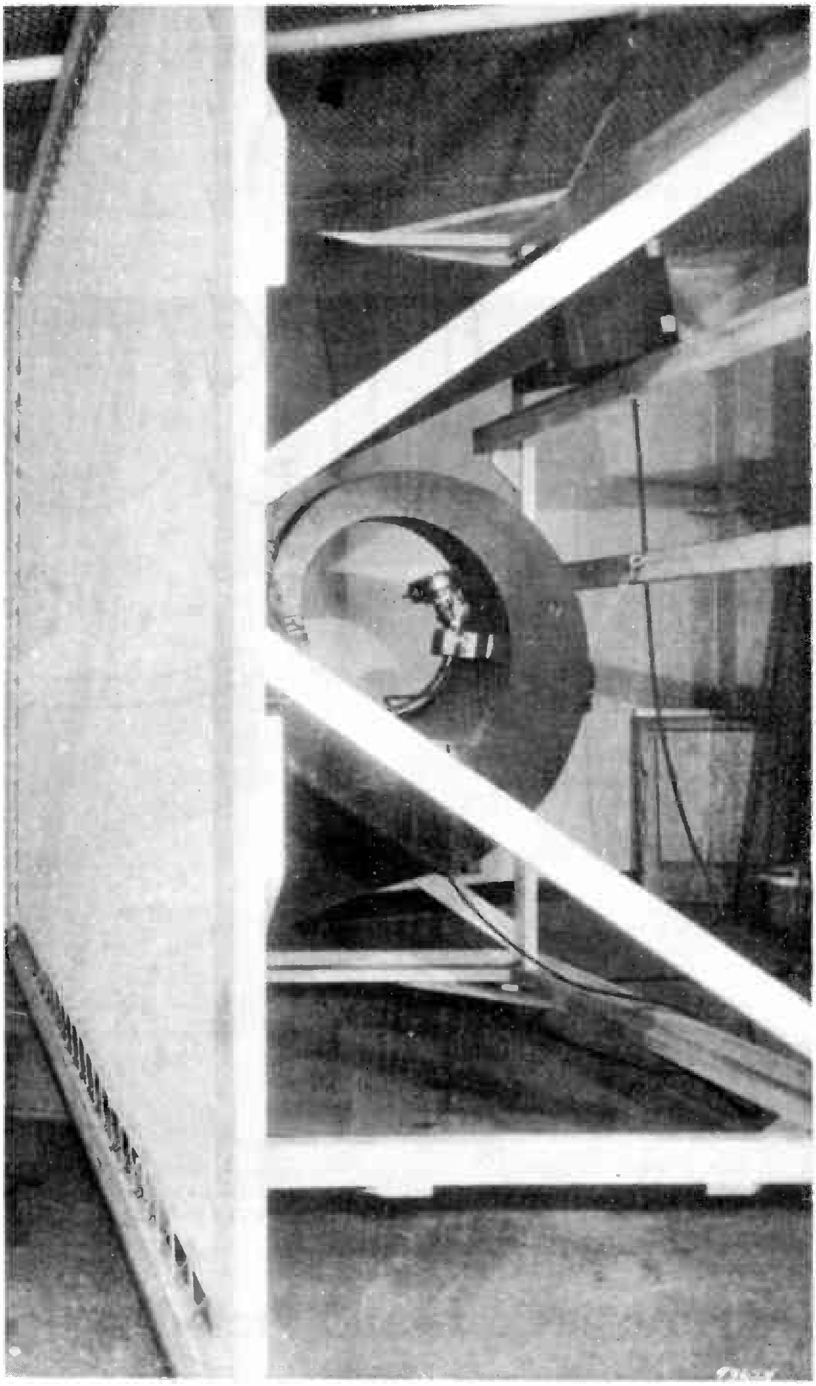

STAGE HORNS MOUNTED BEHIND SCREEN

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LOUDSPEAKERS AND PICK-UPS
— MAGNETIC AND DYNAMIC TYPES —

Students who have followed the devious path of an impulse, originally a sound wave, through the microphone, amplifier, recorder, reproducer pick-up amplifier and loudspeaker have no doubt wondered whether sound could at last be obtained, for it seemed that the impulse would be lost after passing through so many pieces of apparatus.

You must remember that the sound originally produced was a vibration of the air. This was permitted to affect a microphone, which produced alternating currents of the same frequency as the air vibrations. These currents were then amplified, until powerful enough to actuate the recorder's cutting tool, which engraved a wavy line or record of these alternating currents on a wax disc. We thus changed a vibration of the air during an interval of time into a wavy groove occupying space on a record disc.

If now we move this wavy groove on the disc past a needle, or stylus (as it is called), the disc will act as a sort of cam, and cause the needle to vibrate to and fro. If the disc moves past the needle at the same speed as it did past the recording tool, the needle will vibrate to and fro as many times per second as did the recording tool, and consequently as the air molecules originally producing the sound. If we were to attach a diaphragm to the needle, it would set the air molecules in its vicinity into vibration and thus reproduce the original sounds. This is the principle of the mechanical phonograph. However, it was not found desirable to reproduce the sounds directly from the record. One reason was that the sound was confined to the vicinity of the record, another was that the volume of sound in many cases was not adequate and a third reason was that it was difficult to design a mechanical structure rugged enough to reproduce the sounds with sufficient volume, to respond to the highest as well as lowest frequencies, and yet not to cause excessive wear on the record.

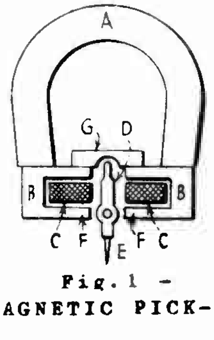


Fig. 1 - MAGNETIC PICK-UP

For all these reasons it was found advisable to convert the mechanical vibrations of the needle into electrical currents once more, as in the case of recording. This is done by means of the disc pick-up, and is usually of the electromagnetic type.

Figure 1 illustrates this type of pick-up in its most usual form. It consists of a permanent magnet A, in contact with soft iron pole pieces, BB. These are shaped as shown, so as to contain the coil CC, and the armature D. The latter is hollow, for a part of its distance, so that a needle E can be inserted into it, and clamped to it by means of a set screw (not shown).

The armature D pivots at the lower ends of the pole pieces, where it is suspended in a rubber strip. The latter thus encases its lower end and acts as a bearing in the pieces in which the armature may rotate. The reason for using rubber for a bearing is that it can be packed in tightly and thus avoid buzzing and rattling of the armature at this point. Moreover, rubber can be sheared more readily than it can be compressed, so that if the needle E is pushed by the record groove to the right or left, the particles of which the rubber is composed will slide with respect to one another instead of being compressed into one another by the force on the needle, so that the top end of the armature will swing in the opposite direction, or, in other words, the armature will rotate around F as an axis instead of moving laterally at F.

It has been found that at certain frequencies the armature resonates, i.e., vibrates excessively due to the reaction of its mass upon its elasticity. In particular, it has been found that the top vane of the armature flexes about the main mass directly beneath it at some high frequency. This "whipping" of the vane produces an exaggerated response at this frequency, and results in distortion of the reproduced sound. To prevent this effect, a rubber block, G, is fastened to the tops of the pole pieces, and the vane of the armature fits into a slit in this rubber block. As the armature vibrates, the vane compresses the rubber to either side, and this absorbs energy from the armature, and particularly so at resonant frequencies, where the amplitude of vibration is excessive. In this manner the rubber block G damps the armature vibration and decreases the otherwise excessive response at resonant frequency. Another important feature of this rubber block is that it prevents the armature from "freezing" against either upper pole piece. When the armature is deflected from its normal mid-way position, the pull of the pole piece which it has approached becomes greater than the other, and this unbalanced force tends to pull the armature all the way over to the pole piece. The rubber block, however, becomes more compressed under this condition, and forces the armature back to its neutral position.

There is one more point of interest to the student regarding the mechanical design. The set-screw is located at the point at which the armature pivots. In this way its moment of inertia, that is, its flywheel effect, is reduced to a minimum, and it is therefore easier to vibrate the armature at high frequencies without the needle and record groove encountering excessive opposition to driving the armature at these high frequencies.

We are now ready to examine the manner in which the pick-up generates alternating currents of the same frequency and wave shape as the motions of the cutting tool. It may strike the student as strange that this device is really an alternating current generator, since he is accustomed to seeing such a generator consist of a stationary and a rotating part. The reason is that the latter is a special adaptation of the fundamental principle of electromagnetic induction, and the pick-up is another special adaptation especially suited to the requirements at hand. In either case a voltage is induced in a conductor due to change in the amount of magnetic flux linking it. In the alternator this is brought about by conductors cutting through the magnetic flux; in the pick-up this is brought about by varying the amount and direction of the magnetic flux through a coil of wire (conductor).

Figure 2 shows how this is brought about. An enlarged view of the pole pieces, coil, and armature, in cross section, is shown.

Letters have the same significance here (where used) as in Figure 1. In "A" we see the armature D in the midway or neutral position. Each pole piece has two projecting parts as shown. The air gap between the top projecting parts is greater than between the bottom parts (where the armature pivots). This means that the reluctance to the passage of magnetic flux through the top parts is greater than the bottom ones, hence more of the magnetic flux passes through the latter than through the former. It will be seen from A that the magnetic flux passes through the armature at right angles, instead of along its length. Since this flux is constant in magnitude, and, moreover, does not thread the coil CC, no voltage is induced in the latter.

Now suppose that the needle E is deflected to the right by the record groove, as at B. The air gap between the top of the left pole piece and the armature has been decreased, and that between the top of the right pole piece and the armature increased. As a consequence, flux will flow from the north pole N down through the armature and thence up through the right pole piece, as shown. The important thing for the student to notice is that the flux flows down through the armature and hence through the coil surrounding it. This induces a voltage in the coil in one direction.

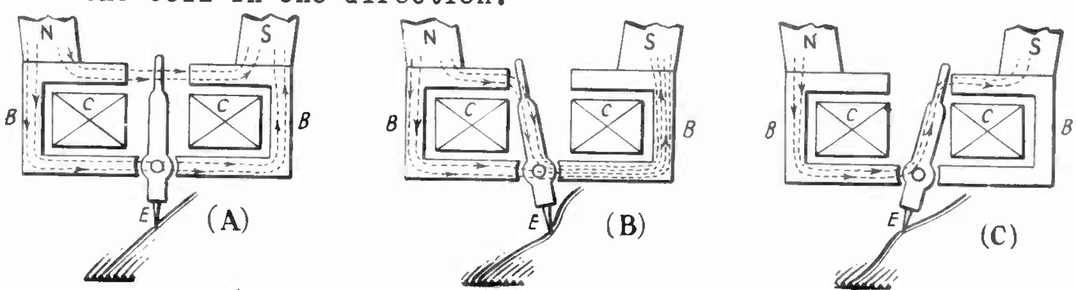


Fig. 2 - SHOWING PATH OF LINES OF FORCE

Now suppose that the needle E is deflected to the left by the record groove, as at C. Conditions are reversed as compared with those depicted in B, and in particular, the student will note that now the flux passes up through the armature. A voltage is induced in a direction opposite to that in position B.

We now perceive that as the armature vibrates to and fro, alternating voltages are induced in the coil, and these voltages are an electrical replica of the wave shape engraved on the record disc. If an impedance, such as an ordinary resistor, be connected to the pick-up coil, an alternating current will flow under the impress of the induced voltages in the coil, and this current will set up a voltage in the external resistor, which voltage may be impressed between the grid and cathode of the tube in the first stage of an amplifier, and thereby amplified to a value sufficient to actuate a loudspeaker and produce adequate volume in the auditorium in which the loudspeaker is located. Thus the pick-up may be located in the booth of a motion picture theatre, and the loudspeaker or speakers, back stage (behind the screen). Furthermore, the pick-up armature can be made exceedingly light, so that the wear on the record groove is negligible, yet the amplifier can be set to actuate vigorously the remote loudspeakers.

One of the problems attached to disc recording was the difficulty of recording the higher frequencies because the peaks and valleys in the grooves had to be so fine. Another was the difficulty of recording the very low frequencies because the amplitudes of the peaks and valleys in the groove were so great that they would encroach upon those of their neighboring grooves (lateral cut record). We shall now see more clearly why this is so.

The voltage induced in the pick-up coil depends upon the time rate of change of the magnetic flux passing through the armature within it. The time rate of change of the magnetic flux, in turn, depends upon the velocity with which the pick-up armature moves. If the latter moves with the same velocity at 100 vibrations or cycles per second, as it does at 1000 cycles per second, the same voltage will be generated in the pick-up coil at both frequencies. Suppose the amplitude of vibration of the armature at 100 cycles is .01 inches. The total distance covered by the armature in one second will be its travel in one cycle multiplied by the number of cycles per second, or .01 inches by 100 or 1 inch. Its velocity is therefore one inch per second. If it is vibrating 1000 times per second, its amplitude (for the same velocity) would have to be one inch divided by 1000 or .001 inches. The voltage generated, as stated above, would be the same in either case, although one voltage would alternate 100 times a second, and the other 1000 times a second.

This brings out the fact that for the same voltage to be generated in the pick-up coil, the amplitude of the wave in the record groove must vary inversely as the frequency, that is, the amplitude decreases in proportion as the frequency increases. This explains why a low frequency note of the same loudness as a high frequency note must occupy so much more space on the record disc, and also why a fairly large air gap must be had between the upper parts of the pole pieces of the pick-up.

Another feature of disc reproduction is that of needle scratch or surface noise. The material of which the record is made is not absolutely uniform in texture, and in addition, abrasive material is incorporated in the material to make it grind the needle point to a good fit of the record groove after a few revolutions of the disc, in order that the needle point pressure be not prohibitive. These small particles and uneveness in texture also deflect the needle, and produce voltages in the pick-up coil Since these particles are so minute and numerous, the vibrations and consequent voltages produced are of very high frequency, and are mainly in the region between about 3500 cycles and 10,000 cycles per second. Moreover, the resonant point of most pick-up armatures is between 3000 and 4000 cycles per second.

It has been found that satisfactory reproduction may be obtained with a frequency range not greatly in excess of 3500 cycles per second, hence the pick-up response above this range may be greatly attenuated without very noticeably marring the reproduction, and at the same time most of the surface noise will be eliminated. To do this, one of two methods, or a combination of the two, may be employed. One is the incorporation of a series resonant circuit across the pick-up coil.

This is shown in Figure 3. The resonant filter consists of a condenser, C, an inductance L, and a resistor R. The condenser and inductance are tuned to be resonant somewhere between 3500 and 4000 cycles. The resistor R broadens the tuning effect of the two, and renders the filter effective over a somewhat greater resonant range, and also decreases the attenuation at the resonant point, as it would otherwise be too great. As can be seen from Figure 3, this filter shunts out the higher frequencies, so that less of these are passed on to the amplifier, where they would be amplified and reproduced by the loudspeaker. Filters similar to the above are often employed in the amplifier itself to remove peaks in the response at certain frequencies, so that a flat frequency response may be obtained.

The second method consists merely in shunting the pick-up coil with the proper value of resistance. This resistance draws current from

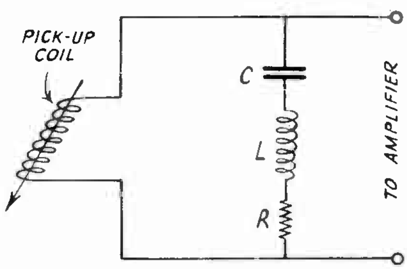


Fig. 3 - CIRCUIT TO PREVENT NEEDLE SCRATCH AND SURFACE NOISE

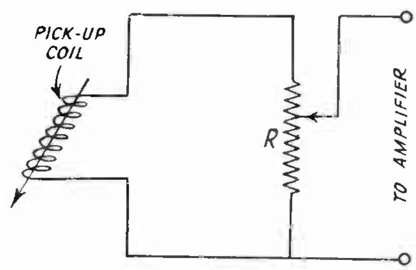


Fig. 4 - RESISTANCE ACTS AS VOLUME CONTROL

the coil when a voltage is induced in the latter. The circuit is shown in Figure 4. As can be seen from this figure, the resistor R is really a potentiometer and functions also as a volume control. In what follows we shall assume that the amplifier draws a negligible current from the pick-up compared to that drawn by R. Let the voltage generated in an ideal pick-up coil be Eg. Let the resistance be R ohms in value. Then, by Ohm's Law, the current I that flows through the circuit is equal to Eg $\div$ R. Since R is constant for all frequencies, the value of the current that flows will be independent of the frequency of Eg. The voltage across the resistor R will be IR and equal to Eg, or also independent of frequency. We therefore see that in an ideal pick-up, the voltage across the load resistor (which is the value impressed upon the input terminals of the amplifier) will be the same as the generated voltage, so that there will be no attenuation of the surface noise.

However, the actual pick-up has a coil which possesses both resistance and inductance. Usually the resistance is negligible, but the inductance — call it L — is not. When current flows in the pick-up coil, we have a potential drop in the coil itself, which drop must be subtracted from the generated voltage, Eg, to give the actual voltage impressed across the resistor R. This voltage drop is equal to $2\pi fLI$, as the student will no doubt recollect from his study of Alternating Currents.

Under these conditions, we have the current I flowing in the circuit,

$$I = \frac{Eg}{\sqrt{R^2 + (2\pi fL)^2}}$$

The voltage across the resistor is IR, or, if we substitute for I the right-hand expression above to which it is equal, we have

$$IR = \frac{REg}{\sqrt{R^2 + (2\pi fL)^2}} \text{ or } \frac{R}{\sqrt{R^2 + (2\pi fL)^2}} \times Eg$$

We immediately see that the voltage across R is not equal to Eg, but to the latter multiplied by the fraction

$$\frac{R}{\sqrt{R^2 + (2\pi fL)^2}}$$

In the denominator of this fraction we find the quantity f — the frequency — involved. This means that if f is large, the denominator is large, and the fraction small, so that the voltage across R is equal to a small fraction of Eg. If, on the other hand, f is low, the fraction is almost equal to unity (one), and the voltage across R is almost equal to Eg.

From this analysis we come to the conclusion that if the coil has inductance, the voltage across the load resistor decreases as the frequency increases. Due to the form of the fraction given above, the decrease at first is slow, but as the frequency increases, the decrease becomes more and more rapid until finally the voltage across the resistor - at very high frequencies - is very small and practically zero in value.

Let us now consider the effect of decreasing the value of the resistance R. This makes the effect of the inductance L more predominating, so that rapid attenuation of the voltage across the resistor begins to occur at a lower frequency. By using the proper value of R, this rapid attenuation can be made to occur at frequencies of 3500 and greater, and thus the resistance acts as a scratch filter. In engineering terminology we may say that the load impedance has been mis-matched to the pick-up in such manner as to cause attenuation of the higher frequencies.

Let us now examine another type of electromagnetic pick-up; the type 4-A manufactured by the Western Electric Company, and employed in their sound motion picture and non-synchronous reproducing equipment. Figure 5 shows a view of its mechanism. Here too we have the permanent magnet, A, and but one split pole piece B. The coil, C, is in two sections, one on each part of the pole piece. The magnetic circuit is completed through a circular steel membrane, D, separated from the split pole piece by an air gap. On this membrane or diaphragm is mounted a piece of soft iron E, and this has a hole to contain the needle, F, and also has a set-screw, G, to clamp the needle firmly to it. Another function of this piece of soft iron is to concentrate the magnetic flux directly over the split pole piece by virtue of its low reluctance.

When the needle point is deflected to either side by the record groove the diaphragm is flexed so that one end of the soft iron member is brought close to its pole tip, and the other farther away from the pole tip adjacent to it. The flux through the former pole tip is increased, that through the latter is decreased, and opposite voltages are induced in the two respective sections of the pick-up coil. These two sections are connected, however, in such polarity that the two voltages are additive in effect, and give a potential equal to their sum across the output terminals.

When the needle is deflected in the opposite direction, the voltage induced in either section is opposite, so that the total voltage across the output terminals is reversed with respect to its previous direction. Therefore, as the needle and associated members are vibrated to and fro, an alternating voltage is generated in the pick-up coil.

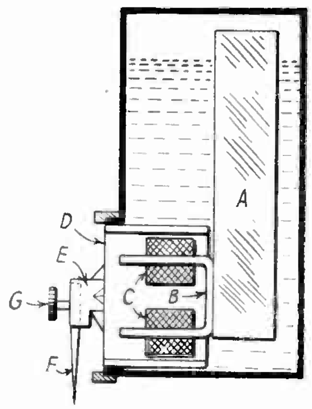


Fig. 5 - TYPICAL OIL-DAMPED PICK-UP

A different method of damping is employed in this type of pick-up. Its casing is filled with a viscous oil, and the oil presses against the diaphragm. As the latter is caused to vibrate by the needle, it is damped by this viscous oil, and thus the excess energy at any resonant peaks is absorbed by the viscous oil, and converted into a tiny amount of heat energy. Finally, it is interesting to note that the diaphragm is made sufficiently light and stiff to have its resonant frequency above 5000 cycles, so that in the normal audio range of frequency the response of the pick-up is very uniform, particularly when the action of the oil is taken into account.

From time to time other types of pick-ups have been built or suggested, such as the condenser type, the moving coil type, and the piezo-electric type employing a Rochelle Salt crystal . These are not in marked commercial use at the present time, however, and therefore will not be discussed in this lesson. Accordingly we shall proceed to a study of the loudspeaker.

The loudspeaker is a mechanism for transforming electrical energy into that special form of mechanical energy known as sound. Ordinarily we think of mechanical energy in the form of steady motion of belts or cars, or the continuous rotation of wheels. Sound energy, however, is vibratory or oscillatory in nature, and the elements producing or transmitting it therefore move to and fro in alternating directions. We may therefore say that sound energy bears the same relation to ordinary mechanical energy that alternating current bears to direct current energy.

With these facts in mind, we can begin to appreciate the structure of the loudspeaker. This is essentially an oscillating electric motor which drives a piston or diaphragm. The latter beats upon the air in the room and sets it into vibration, and this vibration causes the listener to hear the sounds reproduced.

The student may at this point raise a question regarding the motor element, as ordinary motors have a rotating part called an armature, whereas here the armature oscillates. We shall show, however, that the basic principle is the same in either case, and that the two types of motors differ only in the arrangement of their mechanical parts. This difference is exactly the same as that between the electromagnetic pick-up and the alternator used in power plants, and was pointed out earlier in this lesson.

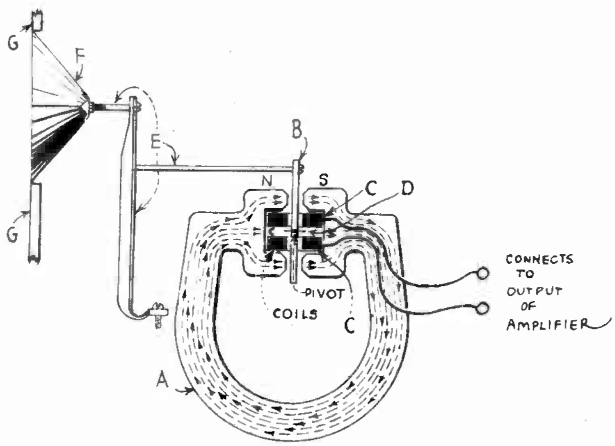


Fig. 6 - GENERAL CONSTRUCTION OF ONE TYPE OF LOUDSPEAKER

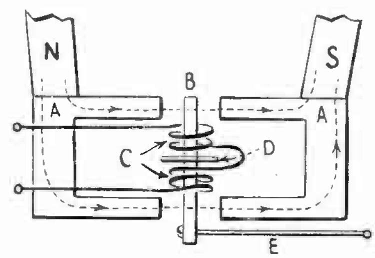


Fig. 7 - DETAIL OF ARMATURE AND POLE PIECES

Accordingly, let us examine the actual construction of one type of loudspeaker, Figure 6. This is known as the magnetic type, and is still in use, although it does not enjoy the same vogue as it did formerly. The student will note that the motor element is almost the same as an electromagnetic pick-up shown in Figure 1. This need occasion no surprise. since practically all generators can operate as motors, and vice versa.

The important difference between this motor element and the pick-up is that in the former, the armature is pivoted at its center, so that its both ends move, and in opposite directions. This permits a more efficient utilization of the materials used in the motor, and is possible because there is no such limitation as the fastening of a needle into one end of the armature, and presenting the point of the needle to the record groove, which limitation exists in the case of the pick-up.

Let us analyze Figure 6 more carefully. A is the permanent magnet; B is the armature; CC, the stationary armature coils; D, the torsional pivot; E, the connecting linkage between the armature and the piston or diaphragm F, and G, the baffle board.

In Figure 7, the armature and pole pieces are shown in greater detail. The two ends of the permanent magnet terminate in the split pole pieces, AA. The magnetic flux streams across the air gaps as shown by the two arrows. The two parts of the left pole pieces are thus north poles, while those of the right pole piece are south poles. Suppose a current flows into the armature coils CC in such direction as to make the top of the armature a north pole, and the bottom a south pole. The top of the armature will move to the right, and the bottom to the left, since these two ends are attracted to opposite poles. The armature therefore pivots about the torsion element D at its center. D is a strip of spring steel which is securely fastened to the armature. The two ends of D are then fastened to the pole piece assembly. The armature can thereupon vibrate about its center by twisting D in one direction or the other. This kind of a pivot also tends to keep the armature centered between the pole pieces, so that it will not freeze to either side when deflected from its central equilibrium point. The student will recollect that in the case of the pick-up, this function was performed by the top damper block. In the case of a loudspeaker, the use of the latter is inadvisable, as it would seriously damp the vibration of the armature and thus decrease the efficiency of the loudspeaker. In the case of the pick-up this is not so important as no further use of the energy is to be made except to generate an electric current, which is then to be amplified.

Suppose now that the current through the coils CC is reversed. The top of the armature becomes a south pole, and the bottom, a north pole, whereupon they move to the left and right, respectively, or the armature now rotates through a small angle in a counter-clockwise direction about its torsional pivot.

From the above we see that if alternating (audio) currents — such as the output from an amplifier — be sent through the coil, the armature will vibrate to and fro at the same frequency (or frequencies) as these currents, and hence as did the air molecules producing the original sound.

Let us now study the acoustic part of the loudspeaker, namely, the diaphragm, or piston. This element acts as a kind of fan, or — as we term it — piston, and sets the air into vibration. Air, however, is very light, or as we say scientifically, has very little mass, hence, in setting it into motion with a relatively heavy diaphragm, the major portion of the force generated by the motor will be consumed in setting the diaphragm (and associated armature and linkage) into motion, and only a very small portion of the force will be consumed in setting the air into vibration. This is one of the great difficulties in loudspeaker design, and accounts for the comparatively low efficiency of these units as compared to many other mechanical devices. The student will note that the whole crux of this problem centers in the requirement that the air be moved to and fro. If the problem were to move the air continuously in one direction, then the element causing this could come up to speed in that direction, and thereafter its mass, or rather inertia effect, would be eliminated and power would be consumed in continuously setting new quantities of air into motion. But where air must be moved back and forth, the element producing this motion must move likewise, and immediately its inertia comes into effect, and absorbs most of the force, so that little is available for setting the air into motion.

A similar problem is encountered in the design of reciprocating machines, such as a gas engine. Here the to and fro motion of the pistons sets up large forces in the crank shaft and connecting rods, but by the use of oppositely moving pistons, and a flywheel, as well as the ability to load up the engine sufficiently, these forces can be rendered relatively negligible compared to the load placed upon the engine. Moreover, a high speed gasoline engine may rotate at a speed, let us say, of 3600 r.p.m. This corresponds to 60 r.p.s. (revolutions per second). A loudspeaker diaphragm vibrating at this frequency would produce a very low (60 cycle) note. Yet this same diaphragm may have to vibrate 5000 times a second to produce a note in the upper range of sound. This would correspond to 300,000 r.p.m. which is a truly tremendous speed. The student is therefore now in a position to appreciate some of the problems that arise in designing a loudspeaker.

From the above it is evident that the diaphragm must be as light as possible, yet rigid, so that its shape will not be distorted by the pressure of the air it is setting into motion. Among the various materials that are light, we have ordinary paper. A flat disc of paper, however, would have very little rigidity. It is here that the study of geometry and strength of materials comes into use. From these sciences we know that the same amount of paper, when rolled up in the form of a cone, forms a much more rigid unit than when in the form of a flat disc. That is why the piston element is conical in shape, and gives rise to the term "cone loudspeaker". It is, as mentioned above, generally made of paper which is subsequently impregnated to render it waterproof. Sometimes cloth is used, in which case it is shaped in one piece, whereas the paper cone has a seam along its length.

It has been found, however, that when such a cone is vibrating at high frequencies, it does not move as a rigid plunger, but various parts of it move with respect to other parts of it. We say that the cone breaks up into "segmental vibrations". This is due to the fact that the cone is driven by the drive pin at its apex, and the force is therefore not applied evenly throughout its entire surface. These segmental vibrations may cause the cone to assume one of two forms, either A or B, Figure 8. In A, the rim, as shown, is no longer a circle, but is scalloped. In B, the elements of the cone are no longer straight lines (as shown by the dotted lines), but instead have a wave shape, due to the ripples that travel out from the apex to the rim, are reflected from there, and travel back to the apex. In doing so, the reflected ripples meet the fresh oncoming ripples, produce standing waves, and give the cone its shape as shown. In practice, the internal damping of the paper cone is in many cases great enough to absorb the ripples before they are reflected back, especially at the higher frequencies, so that only the portion of the cone near the apex vibrates, and that portion near the rim remains practically stationary. As a result, as the frequency increases, less and less of cone vibrates, but it so happens that at higher frequencies less of the cone need vibrate to radiate the sound energy into the room.

The segmental vibration shown at A, Figure 8, is the worse of the two. This is so because the cone is fastened to its surrounding support by flexible leather strips cemented to its rim and bolted to the support. This enables the cone to vibrate freely, yet the leather strips act as an air seal and thus prevent air from the front of the cone from passing directly to the rear of the cone. The student can readily appreciate that if the cone vibrates as shown at A, Figure 7, the leather strips will be distorted, and the cone itself stressed. The result is "paper rattle", a noise similar to that produced by a stiff page of a book when it is bent sharply while turning it over. To obviate this effect, the cone is corrugated as shown in Figure 9. These corrugations stiffen the cone to this sort of segmental vibration, and prevent it from assuming this escallopped shape. These corrugations, however, do not prevent segmental vibrations of the type shown in B, Figure 8, but these produce no harmonic distortion in the sound, and hence are far less objectionable. Indeed, by corrugating the cone properly, the frequency response can be altered to have any desired characteristic.

We have now built up our loudspeaker into a mechanism capable of producing sound, but our story is not as yet complete. We have an oscillating motor, and a piston driven by it, and in turn, driving the air. When the piston is driven forward, the air is compressed in

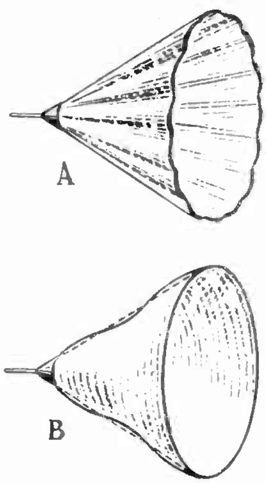


Fig. 8
SHAPES ASSUMED BY CONE WHEN VIBRATING

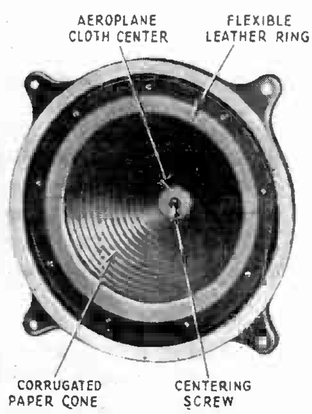


Fig. 9—CORRUGATED CONE

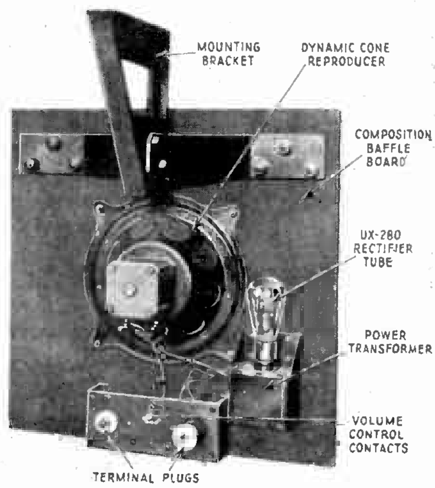


Fig. 10 — SHOWING POSITION OF BAFFLE

front of it and forced forward. Simultaneously, the air in back of the cone is left behind, or a vacuum is formed behind the cone. In sound terminology we say that a condensation is formed in front of the cone, and a rarefaction in back of it. It is obvious that the compressed air, instead of moving forward, will travel around to the back of the cone and there neutralize the vacuum, or, in short, the action on the air is short-circuited, and practically no sound is radiated.

This effect must be prevented, and it is here that the baffle comes into use. This is nothing more than a rigid surface surrounding the cone, and sealed to it by the leather strips, so that the air must take a circuitous route around it to get from one side of the cone to the other. Figure 10 shows the cone and baffle.

As mentioned above, the cone, in vibrating, sends out a series of condensations and rarefactions from each side. These travel with the velocity of sound away from the cone, i.e., approximately 1140 feet per second. The distance between successive condensations or rarefactions is known as the wavelength of the sound, and is equal to the velocity of sound divided by the frequency of vibration. Thus, a 100 cycle (per second) note would have a wavelength of $\frac{1140}{100} = 11.4$ ft

For a simple note of one single tone, the cone moves with a sinusoidal motion, that is, like the end of an ordinary pendulum. From this we see that a simple note consists of a series of disturbances in the air, known as condensations and rarefactions, and these blend from one to the other in the same way that the positive and negative alternations of a sine wave blend into one another. Thus, at any instant, we have a point of maximum air pressure, and to either side of this point the pressure tapers off until one quarter wavelength away the pressure is normal atmospheric. Farther on the pressure decreases below atmospheric to a minimum (maximum rarefaction) which occurs one half wavelength from our starting point and then farther on to normal atmospheric (three quarters of a wavelength away. A moment later these points moved forward a distance depending upon the time elapsed and the velocity of sound, and the above description applies to a new region of space. This distribution of pressures at any instant is shown in Figure 11.

Fig.11 - DISTRIBUTION OF PRESSURES

As this sound energy is radiated by the cone, it tends to spread throughout the medium and, as we saw above, a condensation from one side of the cone travels around to the other side of the cone and neutralizes the rarefaction on that side, and vice versa. If we can prevent this from occurring, at least for one wavelength or so, the energy will have spread out into the medium to such an extent that very little will be lost by neutralization of the two opposite pressures on the two sides of the cone. According to a theoretical analysis it would indicate the diameter of the baffle should be one-quarter wavelength of the tone in question to insure its being adequately radiated. This is so because the distance from one side of the cone to the other side will be one quarter wavelength, and by the time a maximum condensation from one side of the cone gets around to the other side, the cone will be about to radiate a condensation from the other side. Actually, the rarefaction and condensation from the two sides of the cone will meet at the edge of the baffle and produce neutralization at this point, or, as it is scientifically known, interference. However, these effects appear only in the plane of the baffle, and not where the listener is usually located, that is, on one side or other of the cone and baffle.

The rule is therefore that the diameter of the baffle shall be one quarter wavelength of the tone. For low tones (low frequencies), the wavelength is great, so that if we wish the baffle to be effective at low frequencies, it must be large in diameter. A simple example will serve to illustrate this point. Thus, suppose we wish to radiate sound down to 50 cycles. The wavelength is

$$\frac{1140 \dfrac{\text{feet}}{\text{second}}}{50 \dfrac{\text{cycles}}{\text{second}}} = 22.8 \text{ feet.}$$

One quarter wavelength is $22.8 \div 4 = 5.7$ feet, or the diameter of the baffle should be 5.7 feet.

There is one more point of interest in connection with this. If the diameter of the cone is small compared with the wavelength of the sound it is radiating, the cone acts as what is known as a point source of radiation, which means that the sound waves proceed from the cone in ever-widening hemispheres. The molecules of air therefore oscillate along the radii to these spheres. The net effect is that the sound wave is spherical (or more accurately hemispherical) in shape, and spreads rapidly to all parts of the medium.

If, on the other hand, the diameter of the cone is comparable to the wavelength of the sound, which, for a small cone, would be true at the higher frequencies, the sound wave travels in a narrow beam, the molecules of air oscillate parallel to one another along the direction of travel of the sound wave, the wave front of the sound is straight, and we call this beam of sound a plane wave. Such beams are directional in character, and can be pointed to whatever region we wish to cover with sound.

Now due to the high reflecting properties of most auditorium walls, it is of advantage to prevent the sound from striking these walls, and to focus the sound upon the audience. This could be done even at the lowest frequencies if we used a large enough cone. From what has been mentioned previously, the student will appreciate the fact that it is very difficult to vibrate a large cone by means of a motor driving it at its apex so that the cone will move as a rigid plunger, and that is why small cones are preferable as a general rule. These, however, radiate the lower frequencies as spherical waves, which allows them to spread. An additional disadvantage is that the radiation efficiency for spherical waves is less than for plane waves, since the cone is not getting as good a grip on the air if it allows it to spread into a spherical wave front.

The above considerations all point to the need of some means for radiating the sound in the form of a plane wave, even at low frequencies, in order that directional effects be obtained, and a higher efficiency of conversion from electrical to sound energy be realized. This is accomplished by the use of a horn or directional baffle. This confines the sound wave in the form of a beam even after it has left the bell or opening of the horn, and so the sound energy is restricted to an area occupied by the audience, or that part of the audience to be reached by this particular horn.

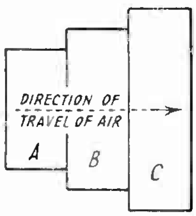


Fig. 12
EFFECT ON SOUND WAVE

The student will get a better idea of the action and value of the horn from the following considerations. In Figure 12, let air under pressure proceed from a region A to a region B, and thence to C. Suppose that these are three cylinders, of which A has the least, and C the greatest diameter. It is evident that the air will expand as it passes from A to B, or from B to C. This expansion will cause a corresponding reduction in pressure which is in proportion to the increase in area, and as a result the air from the smaller cylinder will rush into the larger cylinder, thus increasing the pressure somewhat in the larger cylinder, and decreasing it more markedly in the smaller cylinder. It is thus evident that a decrease in pressure, or rarefaction, travels opposite to the flow of air, or more accurately, to the flow of the pressure wave. The rarefaction corresponds to a reflection of the pressure wave or condensation as the latter passes from the smaller to the larger cylinder, that is, the condensation is partially reflected back as a wave of opposite phase, i.e., a rarefaction. This is because the velocity of sound propagation is greater in the larger cylinder than in the smaller one.

It will be well to point out to the student at this time that the study of sound is part of the larger study of wave motion in general, which embraces sound, radio waves, light, etc. Whenever a wave motion passes from a medium where it has one velocity to another where it has a different velocity, reflection of the wave occurs. If the wave has a higher velocity in the second medium, it is reflected just as readily as if it were slowed up by the second medium, with the difference that in the former case the wave is reflected in the opposite phase, i.e., with reversed amplitude, and in the latter case in the same phase. Thus, the pressure wave is reflected from the larger cylinder where it has a higher velocity of propagation as a rarefaction.

Returning once more to Figure 12, it might be expected that the reflection will be greater if the air expands directly from cylinder A to cylinder C, instead of through cylinder B. This is indeed the case, and it can be demonstrated that the reflection is least when the partial reflection from A to B is equal to that from B to C, that is, the reflection is least when it occurs in equal amounts between the three cylinders. Since the reflection is in direct proportion to the change in area, it is evident that if we wish a sound wave to expand from one area to another, it is best to do this in many small equal steps, or mathematically speaking, the percentage change in area should be constant. This at once defines the change in area to be logarithmic or exponential in character, and gives rise to the exponential horn. In this horn, the area varies exponentially with the length, so that a sound wave proceeding from the narrow end of the horn proceeds with a minimum amount of internal reflection to the larger end of the horn, which is known as its bell.

The value of the horn is therefore this: If the small diaphragm or cone acts directly on the air, as in the case of a flat baffle, the small column of air directly in front of the cone expands directly into the larger volume of the auditorium, with resultant reflection and loss of energy radiated. On the other hand, if the cone pumps air into the small end of an exponential horn, there is far less reflection and thus more energy is radiated into the auditorium. Moreover, the sound waves issuing from the bell of the horn are plane waves, and therefore act as a beam, instead of proceeding in all directions.

This property of minimizing reflections and also of radiating plane waves is possessed by horns of other shapes, but not to as great a degree. The student is no doubt familiar with the ordinary megaphone, which is conical, instead of exponential or trumpet shaped. Here, too, the speaker's voice is directed towards a desired region in the form of a beam of greater intensity than the sound of spherical wave shape that normally issues from the speaker's mouth, which is a point source for most of the frequencies emitted.

The exponential horn has several interesting properties. It will transmit sound of all frequencies down to a certain definite low frequency, having a certain long wavelength. Below this frequency sounds will not be transmitted by the horn, but are reflected internally and never reach the bell. This minimum frequency is known as the cut-off frequency, and depends upon the rate of flare of the horn, that is, upon the percentage increase in area per unit length.

This can be seen more clearly from the following formulas. Suppose the initial area of the horn (at its narrow end) is A_o. Then at any point l distant from the narrow end, the area is

$$A = A_o e^{Bl} \qquad (1)$$

where e is the base of the system of natural logarithms, and is equal to 2.73 +
and B is a number which determines how fast e^{Bl}, and hence A, increases for a given value of l, that is —B determines the rate of flare of the horn. If the student will examine equation (1) he will see that the larger B is, the faster A will increase as l increases, or the horn flares more rapidly.

It can be shown mathematically that the horn will cut off at a frequency given by the following equation:

$$f = \frac{Ba}{4\pi} \qquad (2)$$

In this equation f is the cut-off frequency; B, the rate of flare, a, the velocity of sound in air, and π the number 3.1416+. If all measurements are made in centimeters (the scientific unit) then $a = 34{,}400$ centimeters per second. Thus, if we wish a horn to transmit sound down to 50 cycles, we use this as the cut-off frequency in equation (2) and obtain

$$50 = \frac{B \times 34{,}400}{4\pi}, \text{ or}$$

$$B = \frac{4 \times 50 \times \pi}{34{,}400} = .0183$$

We can now substitute this value of B in equation (1), and obtain

$$A = A_o e^{.0183\,l}$$

A_o, the area at the narrow end of the horn, is determined by the size of the diaphragm working into the horn. Knowing this, we can now proceed to calculate the value of A for $l = 1$cm., $l = 2$cm., $l = 3$cm., etc., and thus obtain the size of the horn at various points along its length.

The question arises as to how long we shall make our horn. This is determined by the area necessary for the bell. If the latter area is too small, the low frequency sound waves, upon emerging from the horn, will suddenly expand to their normal size in free air. This - as we saw in an earlier part of this lesson - will cause a reflection to take place back into the horn, and this not only means that the lower frequencies will not be radiated as strongly, but also that the reflected waves will react upon the fresh oncoming waves to produce standing waves in the horn and consequent resonant effects. Indeed, this is the very mechanism by which an organ pipe produces the note for which it is tuned, i.e., to which it is resonant.

In a horn we do not wish to have such resonant effects. On the contrary, we desire that the horn radiate evenly all frequencies down to the cut-off value from its bell and then cease to radiate any sounds below this value. This means that the bell must be large enough to allow the sound wave of the cut-off frequency to emerge from it without expanding.

This will occur if the diameter of the bell (in centimeters) is

$$D = \frac{4}{B} \qquad (3) \qquad \text{or}$$

$$D = \frac{\lambda}{\pi} \qquad (4)$$

In the alternative equation (4), λ is the wavelength corresponding to the cut-off frequency, so that

$$\lambda = \frac{34,400}{f}$$

and is measured in centimeters. If the cross section of the bell is not circular, then it must have an area equal to that of a circle whose diameter is D. It is evident, then, that we must calculate the horn for values of l (in equation (1)) up to such a value that we obtain a value of A equal to that of a circle whose diameter is D, as given above in either equations (3) or (4). In the case of a 50 cycle note,

$$D = \frac{4}{.0183} = 219 \text{ cm. or } 86.2 \text{ inches (by equation (3)}$$

$$\text{or } D = \frac{\lambda}{\pi} = \frac{34,400}{50} \times \frac{1}{\pi} = 219 \text{ cm. or } 86.2 \text{ inches (by equation (4).}$$

This means that the horn must have a final diameter (at its bell) of 7 feet, 2 inches in order that it radiate a 50 cycle note from its bell. The horn may start with a very small initial diameter — possibly 0.7 inch (depending upon the type of unit connected to it). It must expand very slowly (B must be small) so that it will not internally reflect the 50 cycle note. It must end up with a bell 7 feet, 2 inches in diameter. It is obvious that the horn must therefore be very long, in this particular instance, it must be 17 feet, 3 inches long!

We now have an insight as to the design of exponential horns, why they must be made so long and so large, and a clue to their value. In Figure 13 we have a pair of curves showing the amount of energy radiated by an exponential and a conical horn which have equal initial and final (bell) areas. Note how superior the exponential horn is down to its cut-off value, which in this particular case is about 50 cycles per second. Below this frequency the conical horn is a better radiator of sound, but its radiating ability is not constant. On the other hand, if the exponential horn be designed with a cut-off frequency below those frequencies we desire to radiate, it will radiate the desired frequencies more equably and to a greater extent than a similar conical horn. Below the cut-off frequency the conical horn will be superior, but this will be below the range we are interested in radiating.

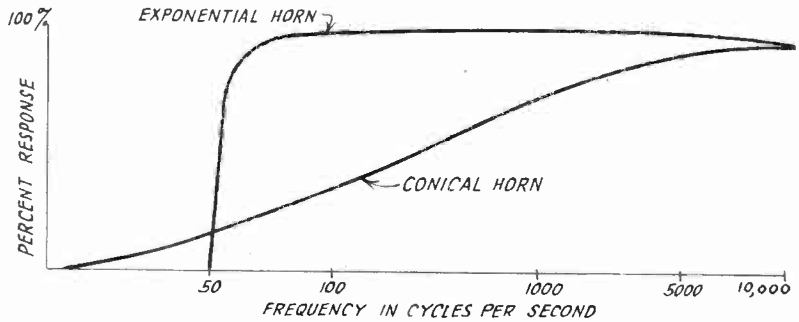


Fig.13 - HORN CHARACTERISTICS

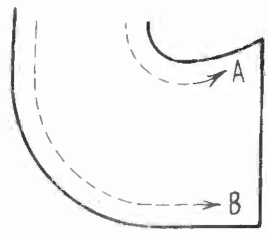


Fig.14 -A CURVED HORN

Due to the great amount of space occupied by a straight horn, it is found advisable to fold it or curve it so as to make it more compact. This folding must be done where its cross section is small, otherwise we shall experience trouble from interference effects at the higher frequencies. Thus, suppose we have a curved section of the horn as in Figure 14. The length of path A along the inner curve is much less than the length of path B along the outer curve. If the difference between these two lengths of path is equal to the wavelength of the transmitted sound, we shall have a rarefaction along one path in line with a condensation along the other path. The result will be cross currents and neutralization of the pressure, or attenuation of the sound. This is more apt to occur in a normal size horn at the higher frequencies where the wavelength is short. For this reason abrupt bends, particularly at the larger cross sections of the horn are to be avoided.

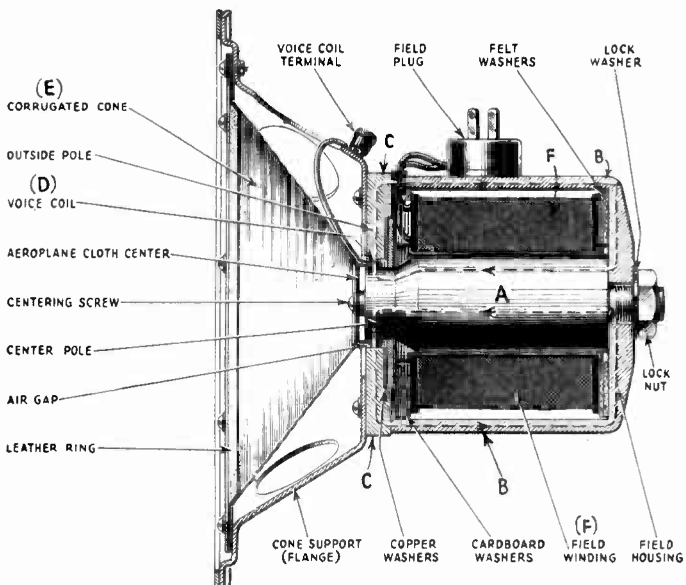


Fig.15 - CONSTRUCTION OF DYNAMIC CONE REPRODUCER

We have covered in this lesson so far the magnetic type of motor unit, the cone diaphragm, the flat baffle, and the exponential horn or baffle. Let us now consider another type of motor unit known as the moving coil or electrodynamic unit. This type of unit possesses many advantages over other types, and is therefore in widest use today.

Its action depends upon the fundamental principle that a current-carrying conductor situated at right angles to a magnetic field is deflected at right angles to itself and the direction of the field. The student will recognize this as the motor principle, and no doubt will recollect the left-hand three finger rule for determining the direction of motion of the conductor. In the case of the moving coil unit, the field and armature have been designed with the object of producing a reciprocating movement, which motion can then be imparted to the diaphragm. Figure 15 shows the field magnet and armature in cross section. A is the central iron core, BB is a cup-shaped iron part into which A is fastened, and CC is an iron plate or cover to BB. In the center of CC is a hole through which A protrudes, and large enough to allow an air gap around A. FF is a coil of wire wound around A, and through coil FF is passed a direct current, which magnetizes the above-described structure and makes it the field magnet of the unit. As shown, flux passes, let us say, up through core A, thence radially across the air gap to plate CC, then down through the walls of the cup or magnet pot, as it is called, and around the bottom back to core A once more. The main thing to notice is that the flux passes through the air gap in a radial direction. The armature is a coil of wire, shown in cross section at D. This is the moving coil. Since it is circular in shape, it is everywhere perpendicular to the magnetic flux passing through it in the air gap. This is due to the geometrical theorem that the circumference of a circle is perpendicular to any radius of the circle. If we now pass a current through the coil D, we shall have a current-carrying conductor which is perpendicular to the magnetic flux in which it is immersed, and according to the motor principle, it will move at right angles to itself and the flux, which in this case means either up or down. If the current is in one direction, it will move up; if in the opposite direction, it will move down. Therefore, if the current is alternating in character, the coil will move up and down as many times as the current alternates. If the latter is the audio current output of an amplifier, for instance, the coil will vibrate at audio frequencies. The coil is usually directly attached to the diaphragm, in this case the cone E. The latter will thus vibrate and produce sound.

The advantages of this motor unit are many-fold. In the first place, the coil moves along the air gap, hence it is in no danger of striking the iron parts of the field, as is the case when a vibrating armature is used (magnetic type unit). Thus large amplitudes of vibration necessary for low frequency sounds are possible without the above limitation or the danger of distortion of the field flux.

In the second place, the efficiency of this device is very high. As the coil moves, it cuts the magnetic lines of force and generates within itself a counter electro-motive force (c.e.m.f.) which opposes the impressed voltage that forces current into the coil. This is exactly similar to the C.E.M.F. of an ordinary motor. It can be shown that the efficiency of the unit is expressed by the ratio of the c.e.m.f. to the applied voltage. Now the c.e.m.f. depends upon the velocity of the coil, and the strength of the magnetic field in which it moves. In particular, the greater the field strength is, the greater the c.e.m.f. and hence the efficiency. In other types of units, such as the magnetic type, if we make the field strength too great, the iron armature will become saturated, and decreased output and increased distortion will result. In the case of the dynamic unit, the armature is made of copper or aluminum wire, is non-magnetic, and therefore not subject to saturation. Hence a very strong magnetic field can be used, and high efficiency obtained.

The third advantage is that of no distortion in a properly designed unit. The movement of the coil does not affect the magnetic flux, and the force exerted on the coil is in direct proportion to the product of the field flux and armature coil current. For a constant flux, therefore, the force, and consequent motion, will be in direct proportion to the current alone, and hence a faithful replica of it. This is not true for other types of units, and accounts for the distortion that may be heard from these, particularly at high volumes. There is only one precaution that must be observed in the design of this unit, and that is that the flux must extend over a sufficient distance so as to cover the voice coil even when it vibrates through large amplitudes at low frequencies and large power output.

A fourth advantage is that the voice coil is mechanically simple in structure and can be made very light, particularly if it is wound with aluminum wire. Also, it may be directly fastened to the cone itself, and this makes for a rigid yet very light assembly, which in turn increases the high frequency response of the speaker.

From the above the student will have gathered that a strong magnetic field is required. He will also have noted that the field structure is rather unconventional in appearance. For these two reasons it was found necessary to make the field an electro-magnet, rather than a permanent magnet. This, of course, is a disadvantage in that direct current must be supplied for the field winding, but the results justify this additional complication. There are available, however, at the present time dynamic speakers with ingenious permanent magnet field structures such as the one shown on the back cover page.

Where an electro-magnetic field is used, the current may be obtained from a storage battery, a rectox supply (shown in Figure 16), a vacuum tube rectifier, or from the rectified current obtained from the amplifier power pack. Since the magnet field has a high inductance, it may be used as one of the choke coils in the filter of the power pack. It is connected into the filter the same as any other kind of a choke coil, except that it is usually placed in the negative side of the line, which is nearly at ground potential. This prevents any high voltages being set up between the field coil and the magnet pot surrounding it.

The field coil may be wound with many turns of fine wire or fewer turns of heavy wire. In all cases it is desired to obtain a certain amount of magnetomotive force in order that the requisite flux be set up. The magnetomotive force depends upon the ampere turns, i.e., the current multiplied by the number of field turns through which it passes. If a large amount of current is available — such as one or two amperes — comparatively few turns of wire are required to furnish the needed ampere turns. The wire, however, must be large to carry this current. This makes for a low resistance field winding, so that the d-c voltage to be impressed across it can be low. If a small amount of current is available such as 20 to 100 milliamperes, many turns of fine wire are required. Such a field coil has a high resistance and requires a high voltage to force the current through it. Thus we have field coils wound for 6, 12, 100 and even 300 volt operation.

In a previous part of this lesson it was mentioned that a cone at high frequencies breaks up into segmental vibrations. In practice this means that only the central portion of the cone, that near its apex, vibrates at the higher frequencies, so that the active mass of the cone is reduced. The mass of the voice coil thereupon becomes an appreciable part of the total mass vibrating, and since the radiating surface has been reduced, the amount of air set in motion is less, or more of the force set up in the voice coil is required to overcome the inertia of the latter, and hence less of the force is available to set the air into vibration. It can therefore be appreciated by the student that anything which will decrease the mass of the voice coil will result in a greater amount of high frequencies being radiated. This is accomplished by using aluminum wire for the voice coil. While aluminum has a greater electrical resistance than copper wire, so that a larger size aluminum wire, or less turns, is required, nevertheless the reduction in weight is so great that a net gain results — as mentioned above — at the higher frequencies.

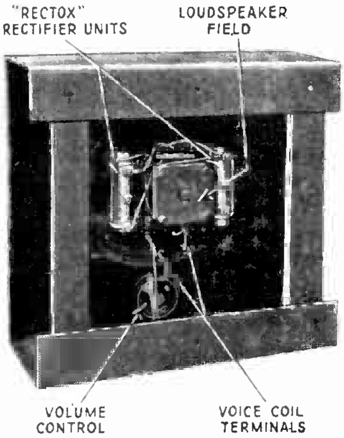


Fig.16 - LOUDSPEAKER USING RECTOX RECTIFIERS

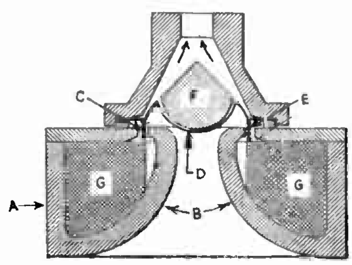
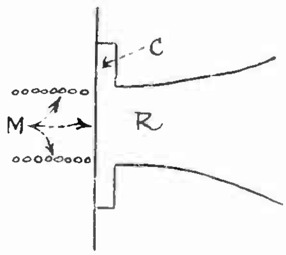


Fig.17 - MOVING COIL DRIVING UNIT
(Courtesy Bell Telephone Laboratories)

Let us now examine a loudspeaker unit used in horn type speakers such as that manufactured by the Western Electric Company, Inc. Here a dynamic motor unit is employed. In Figure 17 we see the component parts. A is the magnet pot, of which B is the field core and C the air gap. The diaphragm D is made of duralumin - a very light yet strong aluminum alloy - and it is domed or arched in shape, because an arch is, like a cone, a very rigid shape for a given amount or weight of material. The voice coil E is made of aluminum ribbon wound edgewise, and successive turns are insulated from each other by a light film of cementing enamel. This enables the air gap to be filled with a maximum of conducting material, aluminum ribbon, and a minimum of insulating material. Moreover, the heat generated in the voice coil, as it is called, can be radiated directly across the remainder of the air gap into the pole pieces and thence to the surrounding atmosphere. In this way the voice coil can stand large overloads without burning out. Field coil is marked GG.

F is a conical-shaped plug directly above the diaphragm. Its function will be explained further on. The entire unit, known as the 555W Receiver, is fastened to the small end of a horn, and in this way radiates the sound energy into the surrounding medium.

There are some interesting features of the design of the unit. Especially interesting is the electrical analogue to it, namely, a low pass filter. The student will remember that an inductance opposes any change of current through its winding - either increase or decrease of current. The inductance is thus similar to a mechanical mass, which requires the expenditure of a certain amount of force to set it into motion, and an equal but opposite force to bring it to rest once more. Thus inductance and mass are analogous. In a similar manner we can show that a condenser (capacitance) and a spring (elasticity) are analogous. Thus, when current flows into a condenset, and charges it up with coulombs of electricity, the dielectric of the condenser is strained and the potential between its oppositely charged plates increases directly in proportion to the increase in electrical charge in the condenser. When a spring is bent by the application of a force, it exerts an opposite force trying to restore itself to its original shape. The restoring force is in direct proportion to the amplitude of deflection of the spring, so that we perceive that the spring is analogous to the condenser, and furthermore, that force is analogous to voltage, amplitude of deflection to coulombs and velocity of the member (total amount of deflection per



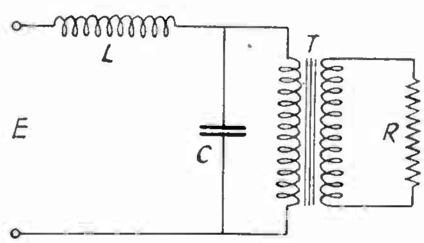


Fig.18 - ELECTRICAL ANALOGY FOR LOUDSPEAKER UNIT EMPLOYING BOTH MASSES AND ELASTICITY

second) to current in amperes, which is coulombs of electricity per second. The analogy between the electrical and mechanical systems is so complete that even the mathematical formulas for the behavior of either are analogous. Let us now study the electrical analogy for the above loudspeaker unit, which employs both masses and elasticity. Figure 18 shows a simplified diagram of this unit and the corresponding electrical analogy.

M is the combined mass of the diaphragm and voice coil. The edge of the diaphragm is made so flexible that for all possible amplitudes of vibration of the diaphragm and coil, the restraining force of the edge is negligible. This is possible in a moving coil motor because the coil floats in the air gap and has no tendency to freeze against either pole piece, as in the case of a magnetic unit. The diaphragm, being in practice suitably stiffened by its arch shape, moves substantially as a rigid piston at all audio frequencies. The force generated in the voice coil has, in part, to overcome its inertia in order to cause it to move, i.e., attain velocity. Hence M corresponds to inductance L in the electrical analogy, since e.m.f. E has to overcome the reactance of L in order to send the electrical current — corresponding to velocity — through the inductance.

The diaphragm, in moving, causes the air in the chamber C and horn R to move, or the velocity of the diaphragm is imparted to the air. However, since we are comparing velocity with current, it is immaterial in our comparison whether we are dealing with the velocity of the diaphragm or of the air. The air becomes compressed in chamber C and reacts on the diaphragm. It therefore corresponds to the capacity C in the electrical analogue. The pressure of the air in chamber C is relieved, however, by the escape of the air through the horn R. The velocity of the air in the horn can be shown to be in time phase with the applied force for frequencies above the cut-off value. If current through a load is found to be in phase with the voltage across the load, the latter is resistive in nature. Hence the horn is really a mechanical resistance, and its electrical analogue is resistance R.

The transformer T now requires explanation. It is shown as a step-down transformer. This means that the current through R is greater than that through L, and also that the voltage E in the primary circuit is greater than that across R. In this diagram to be analogous to the left-hand mechanical one, we shall have to show that the velocity of air in the horn R is greater than that of the diaphragm, and the total force acting on the diaphragm is greater than that on the air in R.

Examination of the left-hand diaphragm shows a chamber C of large area in front of the diaphragm, which chamber communicates with the smaller area of the horn orifice R. It is evident that as the diaphragm moves, the air in chamber C must be partially compressed and partially forced out through the small area R. It therefore is forced out through R at a much higher velocity than that of the diaphragm itself, or the first condition mentioned above is satisfied. The chamber C corresponds to the large cylinder of a hydraulic press, and the orifice R to a small cylinder. It is well known that a small force acting on the piston in the small cylinder of such a press can balance several times such a force acting on the piston of the large cylinder. Hence, in the case of the above speaker, the small force (generated in the horn orifice) opposing the motion of air in the orifice is multiplied many times (in proportion to the ratio of the area of C to that of R), and gives rise to a much larger force acting on the diaphragm. This means that only a small part of the force developed in the voice coil is used in overcoming the inertia of the diaphragm and coil (mass M), and that most of the force is utilized in shooting the air in and out of the horn orifice at a high velocity. The result is a higher efficiency than if the diaphragm acted directly upon the air in horn R instead of through the agency of this hydraulic press arrangement. The latter is thus analogous to transformer T in the right-hand electrical diagram.

Let us now examine this latter diagram. We are immediately struck by its resemblance to a low pass filter. The transformer T can be regarded merely as a means of matching a lower value of R to the filter section. Thus, if R were directly connected across C, it would have to have a value equal to

$$\sqrt{\frac{L}{C}}$$

to terminate the filter properly. If a transformer of step-down ratio A is interposed, R need only equal

$$\frac{1}{A^2}\sqrt{\frac{L}{C}}$$

in order to terminate the filter with the correct value.

Such a filter, when terminated properly as above, has the following interesting characteristics:

(1) It transmits all frequencies up to a certain high frequency equally well. Above this frequency very little energy is transmitted into the terminating resistor, so that this frequency is known as the cut-off frequency. Its value is determined by the inductance and capacity of the filter, and is given by the following formula:

$$f_{\text{cut-off}} = \frac{1}{\pi\sqrt{LC}}$$

Evidently $f_{\text{cut-off}}$ can be increased if both L and C are made small. Thus, if we wish to transmit all frequencies up to a very high frequency, L and C must be very small.

(2) The second characteristic is that the filter, for all frequencies below the cut-off value, acts as a resistor, that is, the current is in phase with the voltage. This shows that the condenser and inductance, when combined as shown with the proper value of resistance, is in resonance not for one frequency, but for a band of frequencies.

The mechanical system is a complete analogy to the above electrical filter. Thus, it transmits all frequencies to the horn up to a certain value, whereupon it cuts off and ceases to transmit any higher frequencies. The velocity of the diaphragm, and of the air in the horn, is in phase with the force developed in the voice coil. This means that the unit operates at a high power factor (theoretically 100%), so that the losses are low. By properly proportioning the area of the throat of the horn to that of chamber C, the proper step-down ratio in this hydraulic press action is obtained, and the resistance of the horn, which is a fixed amount per square centimeter, is matched to the mass of the diaphragm and the elasticity of the air chamber to produce the proper band pass effect.

We saw that in the electrical case, if the low-pass filter is to have a high frequency cut-off, L and C must be small. In the mechanical system, this means that the mass of the diaphragm, and the elasticity of the air chamber must be small. With available material today, the diaphragm size is limited to a radius of one inch or so for rigidity and yet lightness. To make the elasticity of the air chamber small, or in other words, the stiffness high, the depth of the air chamber must be small. When these are properly proportioned, the cut-off frequency can be raised to 5000 cycles or higher. However, if the depth of the air chamber is made small, the diaphragm will strike it if its excursions (amplitude of vibration) are too great. This will be the case particularly at low frequencies, where the diaphragm must move through large amplitudes in order to attain the same velocities as at high frequencies. If the air chamber depth is increased in order to allow the diaphragm a greater amplitude of vibration and hence sound output at the lower frequencies, the elasticity is increased (stiffness of the air chamber decreased) so that the cut-off frequency is decreased. In order to keep this as high as possible, the mass of the diaphragm must be decreased. With available materials this can be done only by decreasing its area. This in turn decreases the amount of air displaced, and thus the power output, so that we are back to where we started.

The student will now appreciate the difficulties encountered in designing a unit having a large frequency range and high power output. The latter is limited by the amount of power desired to be radiated at the lowest frequency. At all other frequencies up to the cut-off value of the unit, the power that can be radiated increases directly with the frequency.

Hence it has been proposed to use a comparatively large, heavy diaphragm, with a large depth of air chamber, in one unit for radiating the low frequencies. This unit will be supplemented by another having a smaller, lighter diaphragm and lesser depth of air chamber, so that its cut-off frequency is higher, for radiating the high frequencies. Such a unit, however, could radiate but little energy at low frequencies, because its amplitude of vibration is limited by

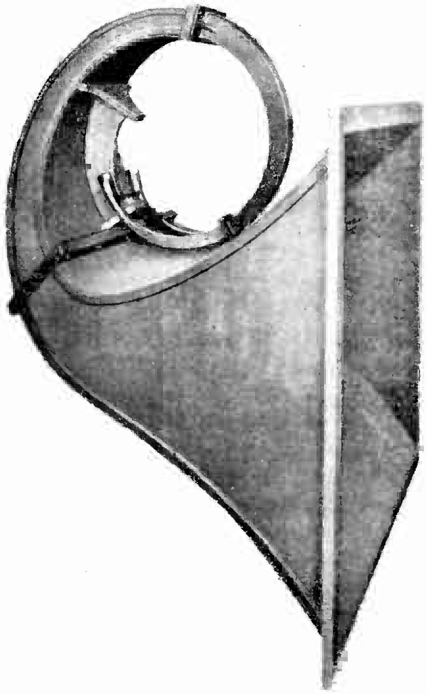


Fig. 19 - HORN WITH A MULTIPLE THROAT FOR USE WITH TWO UNITS
(Courtesy Western Electric Co.)

the shallowness of the air chamber. Hence a suitable electrical circuit would be employed in conjunction with these units to send the low audio frequency currents into the large unit, and the high audio frequencies into the small unit. In this way each unit would be operated at maximum efficiency, and a large frequency range would be obtained at high power output.

Another proposal is to use a number of small units having large frequency ranges, and to feed the output of all these units into one horn by the use of a multiple or split throat. Figure 19 shows a horn having such a multiple throat designed to operate in conjunction with two units. It is also possible to use several horns having each several units. Each horn, however, sends out a beam of sound, and this property is utilized to direct the sound to various parts of the auditorium, such as one to the orchestra floor, another to the first balcony, another to the second balcony, etc. Where, however, more sound is required in any one place, one horn with many units, directed to that place, is employed.

In practice, both methods are used together, i.e., multiple unit horns and high and low frequency units. Thus, in the Western Electric system, the 555 W unit has a flat frequency response up to about 5000 cycles, although it radiates frequencies higher than this. This is usually sufficient for most installations, but where the highest quality of reproduction is desired, a supplementary designed unit is used as well.(Fig.20). This radiates frequencies up to 12000 cycles per second, but overloads readily for frequencies below about 3000 cycles per second. Hence it is connected together with the 555-W unit to the output transformer by means of the circuit shown in Figure 21. The inductance L, by-passes the low frequencies and prevents them from going through the high frequency unit. Condenser C_1, however, permits the high frequencies to pass through it. Condenser C_2, however, prevents these high frequencies from passing through the 555 W unit, where they would be ineffective. In this way each band of frequencies is confined to the proper unit.

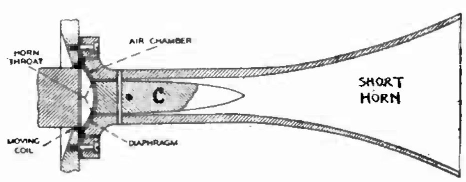


Fig.20 - A SPECIAL HORN FOR HIGH AUDIO-FREQUENCY REPRODUCTION ONLY (Courtesy of the Bell Telephone Laboratories)

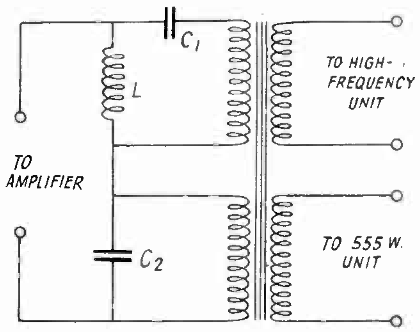


Fig.21 - SCHEMATIC OF CONNECTION FOR A HIGH AUDIO-FREQUENCY UNIT

Since the high frequency unit radiates only the higher frequencies, it need not have a large horn. In practice the horn has a rapid flare, its bell is slightly more than 2 inches in diameter, and its length a little over one foot. This has one particularly desirable advantage. When high frequencies are radiated from the bell of a large horn, they are very directional in effect, i.e., the beam is very narrow. When, however, they are radiated from the small horn described above, they can be made to spread through an angle as great as 90°, and hence cover an area as large as the lower frequencies. Another advantage is that the horn and unit are very small and compact, so that they can be suspended in the bell of the larger horn, and thus occupy no additional space.

To give the student an idea as to the design of the unit, it is to be noted that the depth of the air chamber is but .01 inch, and the diameter of the diaphragm but 1 inch. This gives a small mass and elasticity, and hence a cut-off frequency as high as 12000 cycles per second.

The plug noted in this unit and also in the 555-W unit deserves mention. The student will recollect that the wavelength of the sound decreases as the frequency increases, since their product equals a constant — that of the velocity of sound in air. At sufficiently high frequencies the wavelengths will be so short that interference will take place between the sound radiated from the center and circumference of the diaphragm. In Figure 22-(A) we see an ordinary unit construction. As the diaphragm moves forward with a rigid, plunger action, air is forced simultaneously from all parts of it into the horn. The student will note that paths A A are much longer than path B. When this difference in paths is equal to $\frac{1}{4}$ wavelength of the sound to be radiated, which occurs at some very high frequency and short wavelength (because the diaphragm is small), a condensation from the periphery of the diaphragm arrives at its center en route to the horn throat just as a rarefaction is about to be radiated from this point, and vice versa. The result is neutralization of these two pressures, so that little, if any sound is radiated into the horn. This same effect occurs to a lesser and lesser extent as the

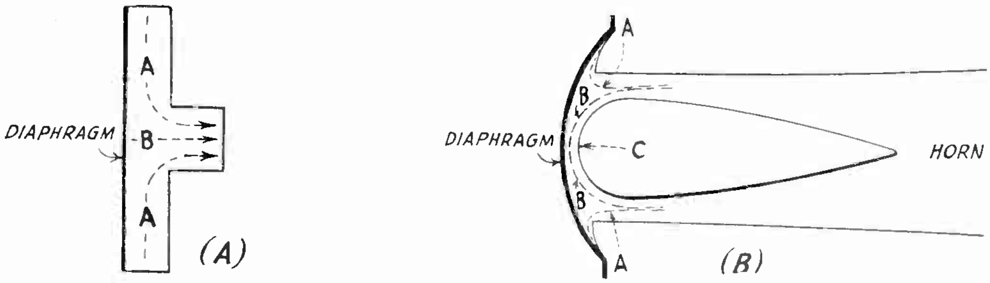


Fig. 22 - SHOWING RELATIVE AIR PATHS IN DIFFERENT SOUND CHAMBERS

frequency is lowered, so that the net effect is that the higher frequencies are attenuated. In (B), Figure 22, it will be noted that the plug renders the paths from all parts of the diaphragm to the horn throat more nearly equal, so that the wave is practically in phase from all parts even at the highest frequency. This arrangement is known as the "high frequency channels." Another beneficial effect is obtained at point C. The clearance at this point between the plug and the diaphragm is quite small, so that the friction encountered by the air in moving past this region is quite high. This increases the damping on the diaphragm, and compensates for any out-of-phase reactions (with respect to the velocity of the air) in the horn. Experiment and theory indicate that the horn is not a true mechanical resistance, and therefore not quite the proper terminating load for this mechanical low pass filter. The additional damping introduced by the plug remedies this condition and tends to give a flatter frequency response.

At this point it is well to bring up the matter of phasing. When more than one unit of any type is employed, precautions must be taken to see that the diaphragms of all units move in phase, i.e., vibrate back and forth in synchronism. This is particularly necessary when horns or directional baffles are employed. If one diaphragm moves opposite to another, we shall get interference effects exactly similar to those cited above. The net result will be regions of total neutralization, or no sound. In the case of horns, where all frequencies are approximately confined in one narrow beam, this neutralization will occur along a line where the two beams touch. By walking across the two beams, this can be readily detected. The remedy is comparatively simple. In an ordinary motor, if the direction of rotation is wrong, either the field or armature connections are reversed, but not both. In the case of a unit, either its field or voice coil connections must be reversed to bring it in phase with the other units. Usually the units are all made identical, so that if a common output is connected to similar terminals of all units (both field and voice coil) the diaphragms will be in phase. A check on the wiring will usually reveal the error made in connections. Another point to check comes up in the case of loudspeakers fed by separate amplifiers energized by a common input. If the amplifiers have the same number of stages and identical parts, their outputs should be in phase. It is possible, however, that one is of different manufacture from the other, or has been differently loaded from the other, so that the two outputs are slightly out of phase by a small angle, such as 20°. The velocities of the diaphragms of the connected loudspeakers will be out of phase by approximately this angle, and interference at certain frequencies will result with consequent impairment of tone quality.

We now come to the Photophone Model 4PL30 loudspeaker. The photograph in Figure 23 shows various parts of the loudspeaker. It employs a six inch cone and aluminum wire voice coil, which results in increased output at the higher frequencies. The aluminum throat A shown gives this unit a hydraulic press action similar to the smaller units described above. See also the diagram in Figure 18. This action occurs only at the lower frequencies in which range the cone

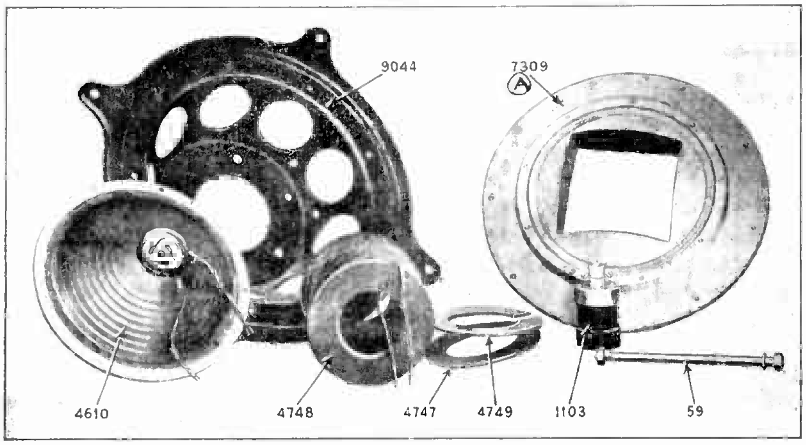


Fig. 23 - SHOWING VARIOUS PARTS IN ONE TYPE OF LOUDSPEAKER

moves as a rigid plunger. Thus adequate low frequency response with a comparatively small cone is assured, and the amplitude of vibration is kept down to a value such that the voice coil remains within the air gap at all times, so that it is always in a region of constant flux density. If it vibrated through such an amplitude that it passed out of the air gap, its motion would no longer be sinusoidal in character, and wave shape distortion would occur.

At higher frequencies — above approximately 2500 cycles per second — the cone no longer moves as a rigid plunger, but breaks up into segmental vibrations. The internal friction is so high that most of the wave energy proceeding from the center to the periphery of the cone is absorbed, so that in effect, at high frequencies only the center part of the cone vibrates. This renders the aluminum throat practically ineffective for these higher frequencies, but fortunately the efficiency of electrical to sound conversion is greater at high frequencies because the air "packs" harder in this range and thus loads up the diaphragm better. Thus the radiation efficiency is fairly constant throughout the audio range. and its frequency response is remarkably flat (for a loudspeaker).

Its design follows much the same laws as the 555W unit, but it differs from the latter unit in that the cone does not move as a rigid plunger at all frequencies, of which advantage is taken to use a large air chamber for high power radiation at low frequencies, while at high frequencies only that portion of the cone within the aluminum throat vibrates, so that no shunting effect occurs due to the large elasticity of the air chamber. The speaker box has been properly designed to match the acoustic impedance of the cone and directional baffle, and the felt back of the box absorbs the radiation from the rear of the cone.

This speaker has at least two important advantages.

1. Due to the comparatively large (6 inch) diaphragm used, the directional baffle throat is 4 x 4 inches in size instead of 3/4 inch diameter or so for the regular horn units. Thus, for a given rate of flare and bell area, the directional baffle can be much shorter than the ordinary horn. This eliminates the need for coiling it, and — as we have seen — prevents interference effects at high frequencies due to abrupt curves in the horn.

2. The large air chamber depth - about 1/8 inch - and large diaphragm area enables a large amount of low frequency energy to be radiated without the cone striking the aluminum throat. This enables this speaker to handle easily 10 watts of electrical power, or the output of two UX250 tubes in push-pull arrangement.

The above covers the design and construction of practically all loudspeakers in commercial use today. Other types have been built, such as the electrostatic and ordinary telephone receiver type, but these are not in any marked use at present because either their frequency range is limited or distorted, or their power output is small, or they do not stand up mechanically, or their efficiency is low. Indeed, no other speaker unit approaches the moving coil electrodynamic type in these respects, particularly efficiency, and that is why it is the most popular unit in use today.

A word or two at this point may not be amiss regarding the placing of loudspeakers and their orientation (pointing). The horn as designed, has a certain flare to the beam of sound it emits. Thus, the beam may flare at an angle of 60 degrees in the horizontal plane, and 30 degrees in the vertical plane. This depends upon the relation between the width and height of the horn, while the product of these two dimensions gives the area they must equal for exponential flaring of the horn itself. From the design calculations, the manufacturer can tell you the angle of beam, and also the angle the axis of the horn makes with the plane of the bell, although usually this angle is 90 degrees. Knowing all this, you can now point the horns, i.e., their axes, so that the beam of one does not materially overlap that of the other, but just fringes it, providing there are auditors in this overlapping region. If not, the beams may diverge considerably, as in the case of one horn trained on the people in the orchestra, and another on those in the balcony.

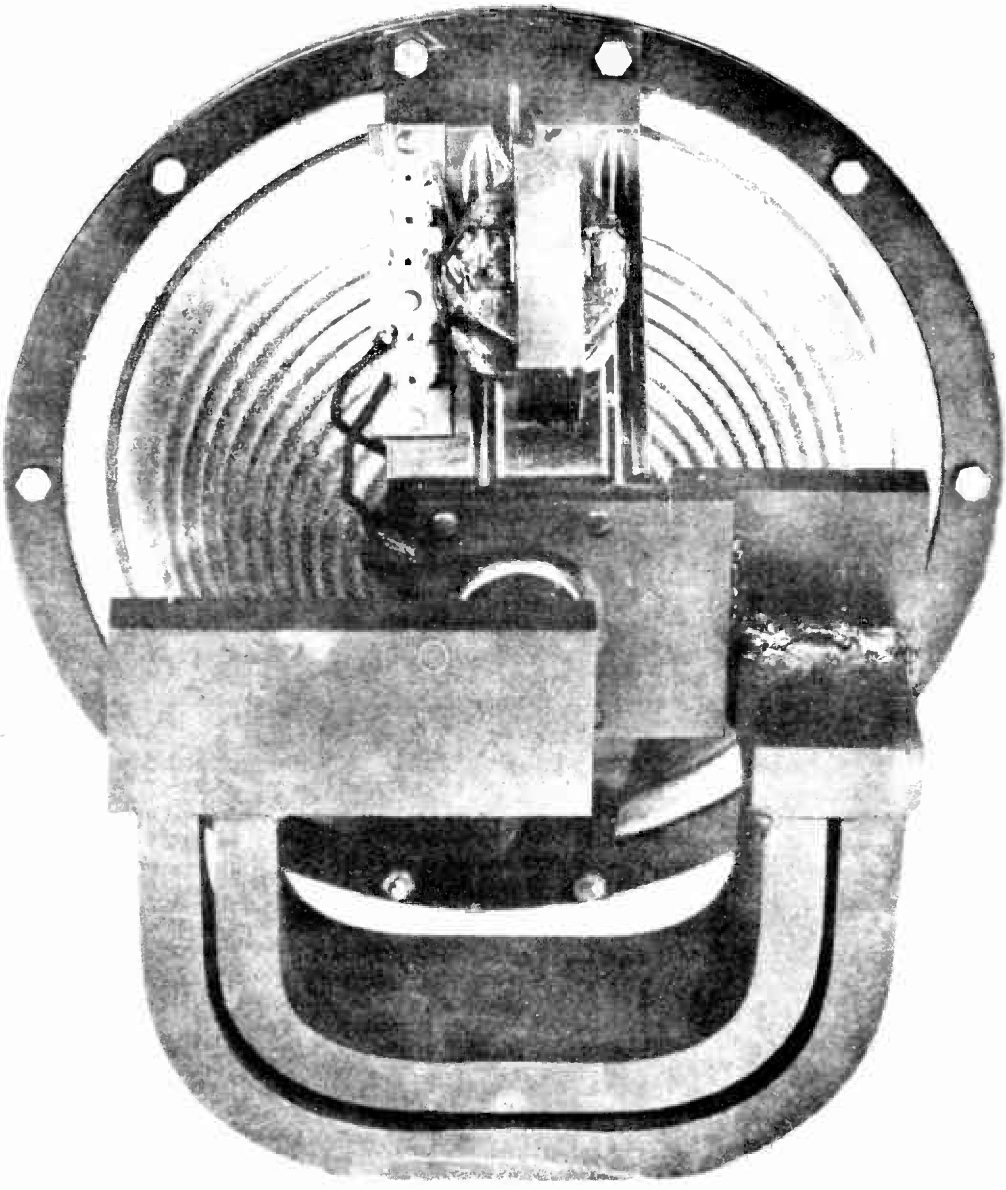
It is not advisable to cross the beams of sound. Thus, it is preferable to have the lower horns on the stage or platform pointed at the people in the orchestra, and the upper horns at the people in the balcony. Also, as mentioned above, the units must all be in phase to prevent interference effects where their beams touch.

In case the horns are used in conjunction with a microphone to reinforce the speaker's voice (Public Address System) the installer must be very careful in his placement of these two units in order to avoid acoustic coupling and feed-back between the horns and the microphone. The phenomenon is similar to the howling produced when the receiver of the ordinary telephone is brought close to the transmitter. To avoid this, the horns should be mounted above the speaker and microphone, so that they may be pointed at the audience without their sound beams striking the microphone. The amplifier cannot be operated at too high a gain, either, as the coupling and howling is directly influenced by this factor.

This concludes the lesson on pick-ups and loudspeakers. The student has been shown the various types of pick-ups, and their action, and also the two principal types of motor units used, the types of diaphragms and their action, the theory and design of flat baffles, horns and directional baffles and loudspeaker units by their electrical analogues, and finally, a brief account as to how to use loudspeakers.

EXAMINATION QUESTIONS

1. What is the purpose of the electromagnetic pick-up?
2. Give a brief description of its action.
3. What is a "scratch filter", and what is its purpose?
4. Describe briefly the magnetic type loudspeaker motor unit.
5. Describe briefly the electrodynamic moving coil loudspeaker motor unit.
6. What are four advantages of this type of motor over other types?
7. Why are diaphragms made either arch or cone-shaped?
8. (a) What is the purpose of a flat baffle?
   (b) What should be the diameter of a flat baffle for a low frequency cut-off of 100 cycles per second? Assume the velocity of sound to be 1100 feet per second.
9. (a) Give the equation for the exponential horn and explain the meaning of each symbol or quantity.
   (b) What two factors of a horn determine its low frequency cut-off, and how do these vary as the cut-off frequency is lowered.
10. (a) Explain very briefly the construction of a Western Electric 555W loudspeaker receiver.
    (b) Explain very briefly the construction of a Photophone Type loudspeaker unit.



PERMANENT MAGNET TYPE DYNAMIC LOUDSPEAKER

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VOL. 65, No. 1

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Sound Effect Machines Used In Broadcast Studios.

PHYSICS OF SOUND

VOL.65,NO.3 Dewey Classification 534

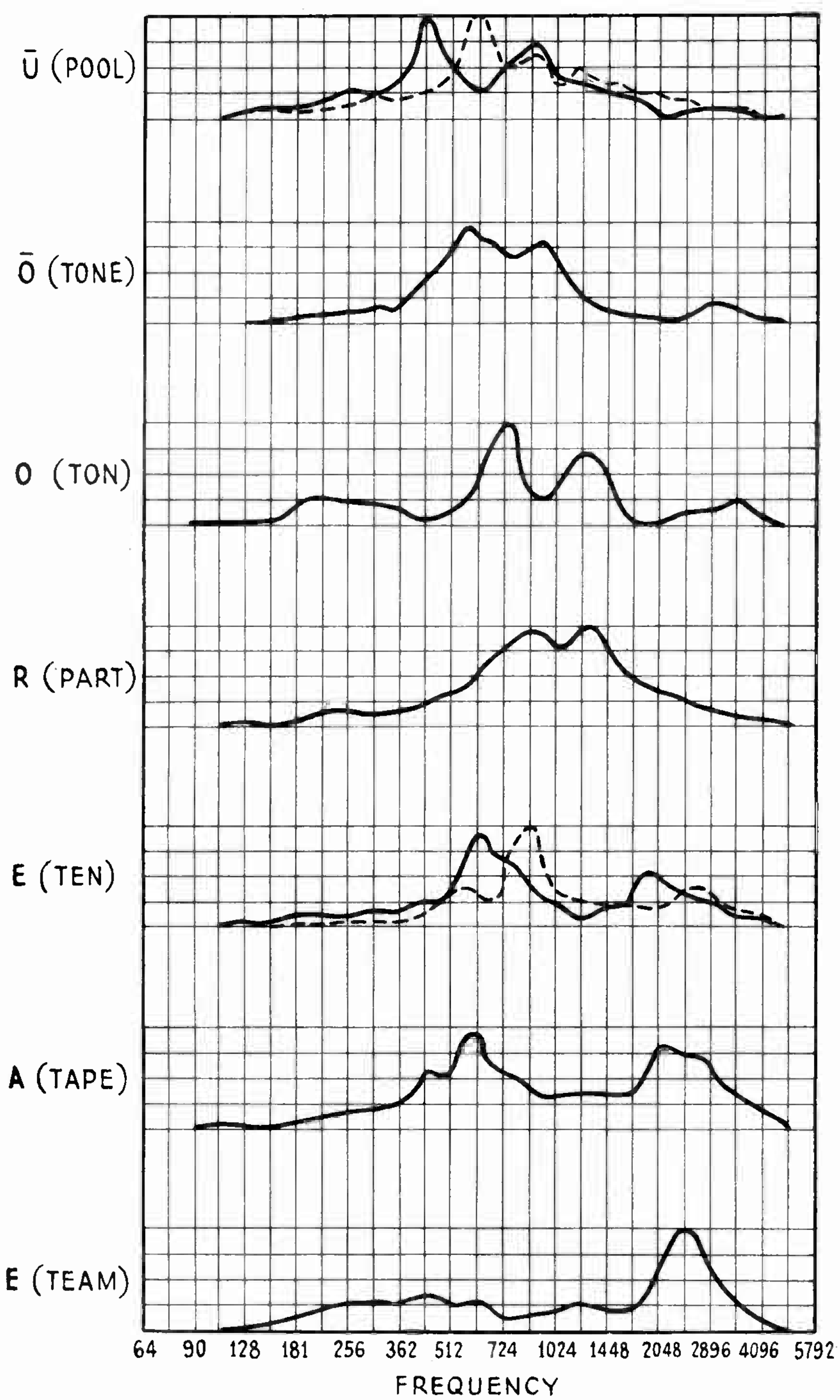

Chart showing frequency analysis of spoken vowel sounds

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PHYSICS OF SOUND

In our study of sound we are faced with the condition that has become prevalent in the allied industries of referring to it as "waves" instead of "pulsations". In this lesson, because it is accurate and more intelligible, we will use the latter term; then in later lessons, because of its popular use in the industry, we will return you to the use of the term "waves", hoping that such a use will not interfere with your continued understanding of the phenomena which you are studying.

In like fashion, we find that the term "sound" is used with two meanings. In the first place, it is properly used to denote the particular physical phenomena of producing air pulsations and propagating them through space. In the second place, if these pulsations produce the sensation of hearing on the part of some person or animal, the sensation is also referred to as sound. This is unfortunate, as we can readily see. In order to help you to clearly understand the text of this lesson, we will herein restrict the use of the word "sound" to denoting a succession of atmospheric pulsations which are capable of producing the sensation of "hearing". Furthermore, if these pulsations are too weak, too fast, or too slow to cause the brain response we call hearing, then we will not consider them as sounds. It will be left for other texts on the more advanced phases of atmospheric pulsations and phenomena, to consider these when they are beyond the ability of the ear to appreciate.

STRAIGHT-FORWARD THINKING OF AN OLD-TIMER

For simplicity and accuracy, we can do no better than go back to the plain words of a profound scientist who died over two centuries ago, Sir Isaac Newton. Writing in Latin, which was the scientific language of his day, he made a statement based on the common terms in use then, which might be translated: "Sound can be nothing else than pulses of air". Used in this way, the word "pulse" is meant to convey the impression of what we to-day would call "a pulsation". Perhaps your comprehension of this meaning will be helped by considering just what occurs when a succession of pulsations in the blood-stream of your forearm produces the collective effect we know as "the pulse".

A muscular contraction of the heart pushes a quantity of blood into arteries which are already filled with that fluid. Therefore the pressure increases at the heart end of the arteries, and this condition tends to right itself by an evening up of the pressure, which comes about either by an extension of the walls of the arteries to a greater diameter, or by the movement of fluid along the arteries. Actually both occur in this case. However, the expansion of the walls near the heart is not very easy. Therefore the pressure increase is chiefly taken care of by an actual forward movement of particles against those in front of them, increasing the pressure on these, while the pressure on the ones behind lets up a bit. This forms a pressure area which travels along the arteries.

Now at the forearm, close to the wrist, the artery is very close to the surface, and has rather thin walls. The pressure against the arterial walls is not very great at the beginning of a pulsation. The pressure increases then until it has reached a maximum value after which it declines again to the normal pressure value. The

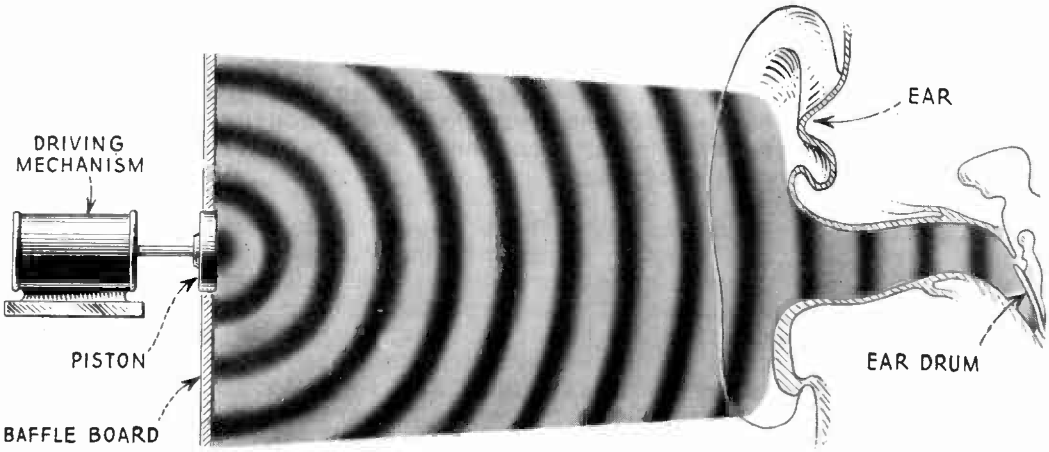

Fig.1 - Device for creating sound pulsations in the air.

rise in pressure value during the pulsation is very slight, but the walls are so thin and resilient that they tend to expand, causing a definite pulsating movement of the finger applied to the forearm as an indicator.

If it were possible for a person to "feel the pulse" of the air which is the common medium for sound propagation, all would be easy. Since this is not so, let us continue with a direct comparison of the two ideas.

SOUND PROPAGATION

In Figure 1 is shown a simple device for causing pulsations in the air. In operation, the piston moves back and forth through the hole in the center of the baffle board, and on its forward motion (to the right) pushes the particles of air before it. This compresses the air into what is called an "area of compression". The particles are crowded together near the face of the piston, and their natural tendency is to find elbow room. This they do by pressing toward the air particles in front of them which were up to that time evenly located in space (steady uniform pressure), crowding these in turn until they are in succession crowded closer together. This displacement of the air particles has somewhat relieved the tension (pressure) among the crowded air particles against the hard face of the piston. Meanwhile, the feeling that "I'm being pushed, so I'm going to push you" has been communicated to the whole mass of air in the vicinity of the piston, and for some distance outward. This does not take the form of a riot, as would be the case if the air particles were human beings, with the struggle going on in every direction, and each person against every other person.

Nature has a more orderly way of doing things. When the pressure is applied on one side of a particle, it naturally gives way in the direction in which it has the greatest freedom to move, which is usually directly opposite to the applied pressure. This results in the area of compression expanding outward in all clear directions from the body that started the movement, namely the piston. When the piston has moved as far as the driving force makes it, and has returned to its position of rest, it starts compressing the air to the left of it, but causes a rarefaction of the air at its face. The term "rarefaction" is derived from the words meaning to "make rare". And that is just what happens at the face of the piston when it moves to the left. Where the piston was at the end of the stroke to the right, there would now be a vacuum, but for the tendency of the air particles to follow into the space left otherwise empty by the retreating piston. The normal air pressure causes the particles closest to the piston to follow it, and those still further away tend to follow these, because each in turn has a pressure exerted against it by all its neighbors. If the neighbors on one side give way in following the piston, a particle normally at rest will also give way due to the pressure exerted on its opposite side by the neighboring particles crowded together there. This leaves in the vicinity of the piston an area of rarefaction (but not a vacuum).

As the piston is made to move in and out continuously, in effect it repeatedly pushes and pulls the air particles. This causes alternate areas of compression and rarefaction to travel forward and outward, as shown by the dark and light bands of Figure 1.

It is well to realize here a difference between the action of the air driver and the heart. The latter has a true pumping action, in that the fluid is continually being supplied to it from one side through a valve, and driven forward by the heart into the arteries with an intermittent action. The periodical increases in fluid pressure which cause the pulse action at the wrist are accompanied by a movement of the fluid along the artery in spurts, but always in the same direction. On the other hand, the function of the air-driver which causes sound is not to deliver a fresh quantity of air at a distant point. Its only function is to cause the pulsation in air. The action of the piston is therefore forward and backward across a certain normal position of rest, causing an alternate compression and rarefaction of air. The compression must be followed by a rarefaction, because no new air is supplied to the piston, whereas the heart is always securing blood from one blood-stream, and passing it on to another. Its action is such that the movement of blood particles is always forward from a position of rest.

In Figure 1 the areas of compression are shown as circles expanding out from the central point which is the piston. This view happens to be a cross-section; the areas of compression actually are shaped more like spherical surfaces constantly expanding and becoming larger. This may be likened to the blowing of soap bubbles at a hole in a wall corresponding to the piston. The first air pulse would produce a half of a bubble expanding out from the hole, with its edges resting on the wall corresponding to our sound baffle-board. After the first half-bubble had gotten a short distance, the next forward movement of air (the next pulsation) would produce another half-bubble, shaped like the first one, which would follow it outward at a uniform distance.

Each bubble would consists of only a certain amount of soap and water, so as the bubble gets larger and larger, it has more surface, but becomes much thinner. This can be compared to the area of compression, like half the surface of a sphere, which expands outward, having a greater area, but has pressure change as the area moves outward. This is because at the surface of the piston we did a certain

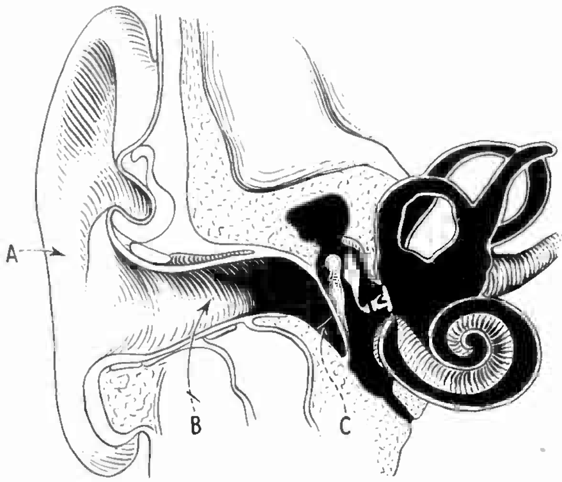

Fig. 2 - Construction of the human ear.

amount of work in increasing the pressure of air over the face of a piston having a certain area. As the compression area expands into an area greater and greater than the original compressed area at the piston face, it is evident that the particles of air at some distance away have much more room than those closely crowded together at the piston face, and therefore the pressure, or crowding of particles, at a distance is less than at the piston. As the areas of compression and rarefaction continue to expand, the compression or rarefaction becomes distributed over such a large spherical area that the actual change in pressure from the normal pressure at that point is negligible, and we say that the sound has "died out".

HEARING

In order to realize better the distinction we have made between air pulsations as sound and the sensation of hearing which is the effect caused by it, your attention is invited to Figure 2, which shows a cross-section of the human ear. The part of the ear (A) which is outside the skull is called the "pinna". The tube-like arrangement (B) leading into the head is called the "canal". The pinna intercepts a wide section of the areas of compression and rarefaction which approach it. It so directs the movement of air particles toward the canal that the compression at the canal entrance is greater than if the pinna did not exist. In like fashion, an approaching area of rarefaction tends to rarefy the air in the canal to a greater degree than if the pinna were absent. This is because the pinna prevents the air particles behind it from moving into the area of rarefaction as this approaches the canal entrance, therefore the particles in the canal itself tend to move backward into the approaching area of rarefaction to a greater extent than if the pinna were absent. The over all result is that the presence of the pinna makes an appreciably greater difference in air pressure between the compression and rarefaction areas, and we shall see that this means increased loudness.

At the end of the canal is a stretched tissue which we call the tympanic membrane. The space immediately behind the membrane contains air, and is connected to the back part of the throat by the Eustachian tube. When the air is still on both sides of the membrane, the pressure is the same on both sides. When an area of compression arrives in the canal the particles of air close to the outer side of the membrane are pushed together. This pressure pushes the membrane in against the normal steady air pressure existing behind the membrane. When an area of rarefaction approaches the membrane (called the ear drum), the pressure at the outside of the drum becomes less than the normal pressure on the inside, and the drum bulges outward. We see then that the ear drum bulges in and out for every pulsation consisting of an area of compression and an area of rarefaction.

The ear drum separates the outer ear from the middle ear, which is a chamber containing three odd-shaped bones. These bones form a system of levers to transmit the bulging motion of the ear drum to another membrane which separates the middle ear and an inner ear. Beyond this point we need not go, except to say that any movement of the membrane which acts as the door of the inner ear causes impulses to pass along certain nerves to the brain which interprets them.

This sensation is called "hearing". The greater the difference in pressure between the peak of compression and the peak of rarefaction of air at the ear drum, the greater will be the sensation of hearing produced in the brain, and we interpret this as loudness. That action should be fairly easy to understand because we can compare it with the sensation of feeling, for instance. We know that if something touches us lightly we barely "feel" it, but if the something that touches us exerts greater pressure the "feeling" increases up to the point where it may become painful. It is strange but the sensation of hearing has its pressure limit also, because as the pressure difference of the air pulsation becomes greater and greater a point is reached where the sensation of loudness of hearing is overpowered by an actual sensation of pain.

THE ELECTRIC EAR

A microphone has sometimes been called an electric ear, and there is some reason for this, as we can see by a study of Figure 3. Here we have an arrangement similar to that of Figure 1, with the ear replaced by the microphone. This also has a stretched diaphragm which can be compared to the tympanic membrane of the human ear. As an area of compression arrives at the front side of the diaphragm the air particles close to it will tend to bulge it inward, because behind the diaphragm the air is at rest and at the same pressure as the air in front would be if there were no pulsations. When an area of rarefaction approaches the diaphragm, the air particles close to its front move away slightly, decreasing the pressure on that side. The normal pressure of the air behind the diaphragm therefore makes it bulge outward toward the source of sound. This bulging of the diaphragm in and out causes an alternate compression and expansion of

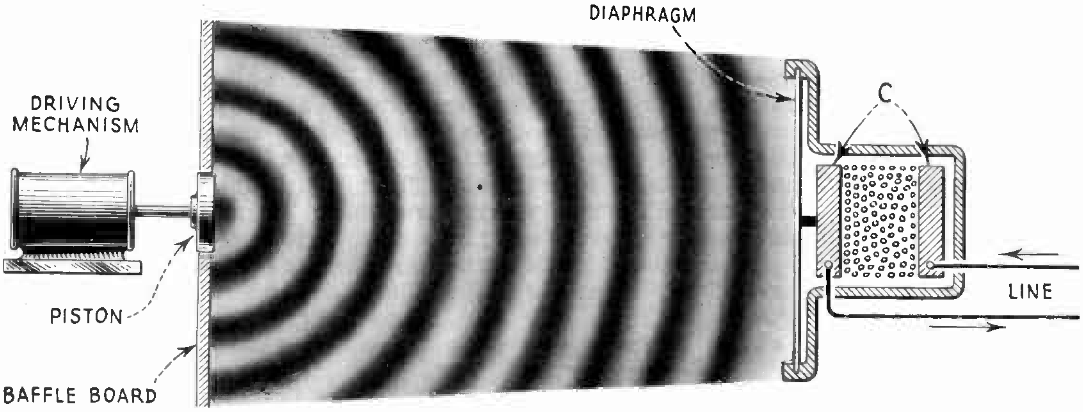

Fig. 3 - A microphone responds to sound pulsations.

the carbon granules which lie between the two carbon contacts "C", because the left hand one of these is attached directly to the center of the diaphragm. The current pulsations along the line thus caused by the air pulsations can be compared to the impulses along the nerves connecting the inner ear and the brain.

This comparison is presented to you to emphasize the fact that the air pulsations can cause an actual movement in space of things such as diaphragms and other flat objects, which either are freely suspended in space, or which are supported on their edges, but flexible enough to bulge in and out easily. We can therefore expect that pulsations can be caused by making a generally flat body move back and forth in the otherwise still air, or by making a thin fixed body bulge in and out by applying mechanical forces near its center.

This is proved to be true by the complete telephone system shown in Figure 4. The microphone at the left changes air pulsations (AP) into pulsations in an electric current. A transformer (L) changes the pulsations into an alternating current which is passed through the coils (J) of the telephone receiver at the right. Here we have a round metal diaphragm (K) supported at its edge and which is attracted toward the permanent magnet (I). This attraction is a steady one, and the diaphragm does not move, just so long as no current passes through the coils around the magnet.

Such a current flow will occur whenever an air pulsation arrives at the microphone. The magnet then has a greater or lesser attracting power for the diaphragm. This results in the diaphragm bulging inward more or less from its normal position.

It is clear that this effect is the same as that of the piston used in preceding illustrations, and air pulsations (AP) are caused by the vibrating diaphragm.

SOUND PRODUCTION

The audible pulsations of the atmosphere which constitute sound are always produced by what Newton refers to as a "tremulous" body, but which we in modern times refer to as a "vibrating" body. This may be stretched skin, as in the drum; a thin metal plate, as in the cymbal; a pair of stretched pieces of flesh, as in the human voice; a string that is bowed, as in the violin; or a thin wooden reed, as in the clarinet.

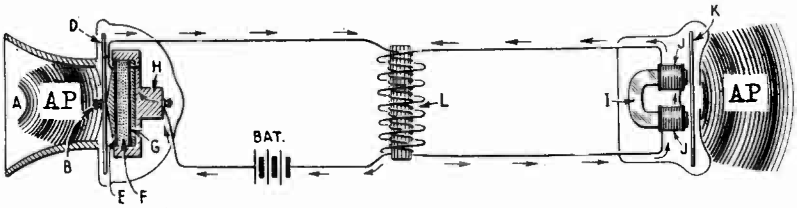

Fig. 4 - Sound pulsations and a telephone system.

Whatever the physical shape or composition of the vibrating body, its sole purpose is to cause those recurring pulsations of the air which we know as sound. The pulsations are useful to us only when they arrive at the ear as alternate areas of compression and rarefaction of air or some other gas or liquid which is capable of establishing an intimate contact with the surface of the ear drum.

A pulsation may be communicated along a solid substance such as a steel rod or a stone, but in general we may limit our consideration to the use of air and water, because these are practically the only gas and the only fluid which ever contact the ear drum.

A pulsation in air travels at the rate of about 1100 feet per second. A pulsation in water travels at the rate of about 4400 feet per second. The velocity of sound becomes important in some cases where we wish to measure the distance between a source of sound and the place where it causes the sensation of hearing. A case of this kind concerns the type of lighthouse or lightship in which a bell is struck below the surface of the water as shown in Figure 5. The pulsations travel through the water in all clear directions at a velocity of 4400 feet per second. If a microphone is placed close to the bell, the pulsations can also be changed into electric current pulsations with practically no time delay due to travel through intervening water or air. The electric pulsations are applied to a radio transmitter and received on a ship practically simultaneously with the striking of the bell, due to the high velocity of radio waves, about 186,000 miles per second. However, the pulsations through the water medium take an appreciable and measurable time to travel outward. It is not a difficult feat to measure the time between the arrival of the "sound" by radio substitution and the arrival of the actual sound pulsations by water. This time in seconds, multiplied by the velocity of sound through water (4400 feet per second) gives the approximate distance that the receiving ship is from the sound source.

The designers of certain musical instruments, particularly the organ, are greatly interested in the velocity of sound in air, because they must know the time required for a pulsation to travel along a pipe of a given length.

PERIOD OF A PULSATION

Any motion or action which continually repeats itself and always in the same time, is said to be periodic. The motion of the bob of a pendulum is periodic, and so is the motion of the earth around the sun. In either case the point on which we fix our attention describes the same path again and again; it furthermore completes its

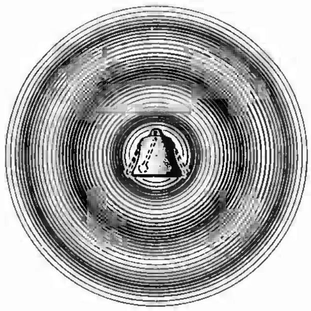

Fig. 5 - Sound pulsations in water.

traversing of the path in the same interval of time. This interval of time we refer to as its period. For instance, consider the piston of Figure 1. If we give it a rapid motion to and fro at regular intervals of time the air pulsations produced will cause the sensation of hearing to appreciate them as a musical note. If the motion of the piston is irregular and non-periodic, we interpret the sound produced as noise.

The piston may move slowly at some points of its path and rapidly at others; it may even partially retrace its motion a bit. These peculiarities will affect the nature of the pulsation and also the sensation produced to some extent, but if the vibration of the piston, however complicated, is repeated regularly in equal intervals of time, its motion is said to be periodic. The ear drum will of course be made to have a motion that is periodic; the period will be the same as that of the piston. The number of complete to and fro vibrations executed per second by a body is called the frequency of its vibration. The maximum movement of the vibrating body from its position of normal rest is called the amplitude of its vibration. Let us not overlook the fact that, while the frequency of vibration of the ear drum is the same as the frequency of pulsation of the air and the frequency of vibration of the piston, the amplitude of pulsation of the intervening air decreases with increasing distance from the source to the ear drum. This decreasing amplitude of pulsation corresponds to a decreasing loudness in hearing the sound as the ear moves away from the sound source.

DOPPLER'S PRINCIPLE

When a source of sound is being carried toward or away from a person who is listening, there is an apparent alteration of the frequency of the pulsations produced. If the person is standing in a railroad station as a fast express rushes through with its whistle blowing, it seems that the pitch of the note changes as the engine passes. The same holds for the engine hum of a speedy motor car travelling along a road and passing a listener on the side of the road.

If the train is travelling toward the observer, the sound pulsations get crowded up into smaller space, and when the train is going in the opposite direction, the sound pulsations get spread out in space, as shown in Figure 6. On the approach, a sound pulsation leaves the whistle at a uniform air speed of about 1100 feet per second, and is well on its way by the time the next pulsation leaves the whistle. Meanwhile the whistle itself has been moved closer to the observer, so the second pulsation is appreciably closer in a forward direction to the first one than if the two pulsations had originated from an engine standing perfectly still. These pulsations travel at a uniform speed through the air, but more of them per second

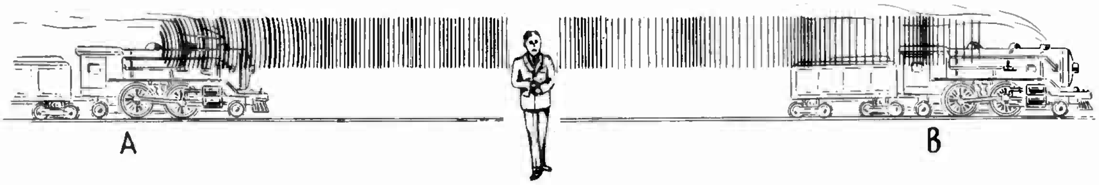

Fig. 6 - Pictorial representation of "Doppler's Principle".

arrive at the ear of the listener on the station platform than arrive at the ear of a person riding in the train at a fixed distance from the whistle. (See A in Figure 6.) The frequency of the whistle sound will remain the same for a person riding on the train, regardless of where the train is. Now when the train has passed the listener on the ground, each pulsation to the rear starts from the whistle at a point in space appreciably removed from where the preceding one started, and the distance between the successive areas of compression to the rear is greater than if the train were standing still. Therefore fewer pulsations will arrive at the ear of the stationary listener than would be the case if the train were standing still and pulsation had exactly the same distance to travel to him. (See B in Figure 6.)

The name "Doppler's Principle" is applied to this phenomenon. Since the frequency of pulsation is identical with the pitch of the musical tone which is sensed by an observer, we can see that there is plenty of room for argument between the best of friends as to the pitch of the whistle of an engine, if the engine is travelling rapidly between two nearby railroad stations at each of which one friend is standing. To the man at the rear station, the note will be of lower pitch than the true pitch of the whistle; to the man at the station ahead, the note will be of a pitch higher than the true one. And each would be right, because after all each is interested in what particular sensation of hearing is produced at his own ears.

GRAPHING A PULSATION

We have referred to an area of compression and a succeeding or preceding area of rarefaction as making up a single pulsation. This does not mean that in the first area the particles are crowded uniformly together and therefore at a uniform pressure. Nor does it mean that in the second area the particles are uniformly scattered from their normal positions, and therefore at a uniform pressure below the normal. There is actually a gradual variation in pressure throughout the pulsation, and it is easier to realize this by the use of graphs.

We have two quantities that are uniform as regards our purposes, and they are time and distance. The three quantities that are to be considered as variables are the position of a particle, the density of particles, and the pressure. The relation between these must be obvious. It would be possible for us to graph the forward and backward displacement of a particle from its position of rest with respect to a uniform time axis, but this is not customary. The density of particles and the pressure are directly related in the case of a gas, so we may consider either one as the variable whose action we wish to study. The uniformly changing quantity against which we will graph the variable can be either time or distance.

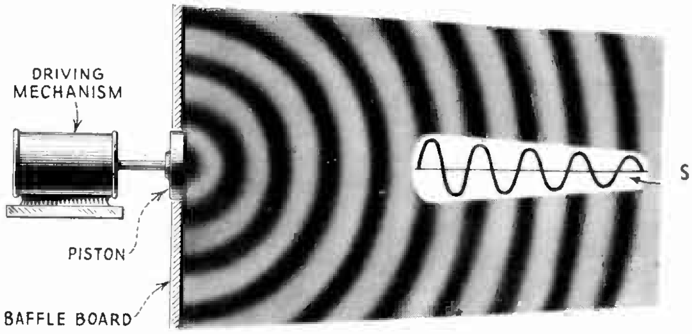

Fig. 7 - Graph of pulsation amplitudes at varying distances from source.

In Figure 7 is shown a cross-section of the air in which pulsations exist. As before, the compression of air particles is shown by the dark bands as contrasted with the light bands representing rarefaction. In the graph, the horizontal ordinate is distance, and the vertical ordinate is pressure. It could just as well be density, as the pressure is directly related to the density of air particles at the point where the pressure is measured. If we had sensitive meters to measure the air pressure along the straight distance line shown pointing away from the source, we would have values of pressure, at a given instant, which could be plotted along the line to form the graph which is shown. Pressures greater than normal would be graphed above the line; pressures less than normal would be graphed below the line.

If the measurements are made at points sufficiently close together, the resulting graph would look very much like a sine wave of alternating current. The area of compression corresponds to the positive half of a cycle, and the area of rarefaction corresponds to the negative half of a cycle. Actually there is no such thing as a negative air pressure. The pressure curve has as its reference line the value of air pressure. The pressure curve has as its reference line the value of air pressure existing in that vicinity when no pul sations occur, that is, when there is no motion of air particles with respect to each other. The pressure graph can be better compared to a graph of current in the plate circuit of an amplifying vacuum tube, where there exists a steady flow of current at all times when the proper voltages are applied, but which current rapidly increases somewhat and then decreases somewhat when an alternating voltage is applied to the grid input side of the tube. While operating as a linear amplifier, the tube plate current never decreases to zero. Likewise in the air which is the medium of sound transmission the rarefaction never even approaches the zero pressure which we call a perfect vacuum. In fact, the difference in pressure between the compression peak and the rarefaction peak is tremendously small compared to the actual normal pressure in the open air. Sound represents a very small percentage change in the air pressure, and therefore its measurement is always a difficult problem.

The fact that the maximum pressure change of a pulsation gets less and less as it travels outward from the source (piston) is shown by the decreasing height of the pressure graph peaks as the measuring point is moved along to the right, or farther from the source. It can be reasoned that when the areas of compression and rarefaction have proceeded a great distance the differences in pressure from the normal are so small that the ear cannot distinguish between them.

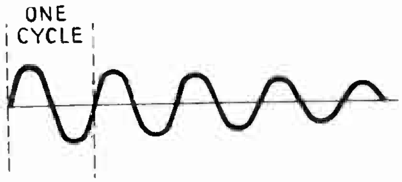

Fig. 8 - Graph illustrating cycles of sound pulsations.

Thus the sound would become inaudible due to dissipation caused by length of travel.

THE BAR

Pressure is the total force exerted on an area divided by the number of area units. In sound we use a pressure unit called the "bar", and it represents a force of one dyne per square centimeter of area.

CYCLE

A "cycle" of the piston may consist of one forward movement, a return to center position, a movement backward from center and a return to center a second time. Observing Figure 8 it appears that the pulsation thereby produced constitutes one cycle of sound. This consists of a beginning point at normal air pressure, an area of compression, a return to normal pressure, an area of rarefaction, and a return to normal pressure again. This is shown by the section of the curve included between the dotted lines. Then another cycle begins. A single cycle may be considered to begin at any point on the pressure curve and end with the corresponding point which begins another complete repetition of the act.

The graph of Figure 8, it must be remembered, shows pressure values at various distances but for a fixed instant of time. We could just as well make a graph corresponding to the pressure changes at a fixed point in space but for different instants of time. This would be based on rapid readings taken of a pressure meter placed at a definite distance from the source. The readings would be timed accurately so the values of pressure could be plotted at the correct place along the time axis of the graph. This is based on an assumed ability of the meter to follow accurately the changes in pressure. Practically such a graph can be made only by a photographic record of pressure against time. This new graph would have a uniform height for all its peaks, because the amplitudes of succeeding pulsations would not differ at a fixed point in space, so long as the amplitude of vibration of the sounding body does not change. There will be no falling off in amplitude of succeeding peaks as shown in Figure 8, which occurs because that graph shows pressure at increasing distances.

An inspection of Figure 9 will emphasize this difference. In A of the figure there are indicated 20 areas of compression and 20 of rarefaction, and they alternate regularly, giving 20 complete pulsations. These are plotted against time in the graph above, showing that the frequency is 20 cycles per second. In B of the figure the corresponding information is given for a frequency of 40 cycles per second.

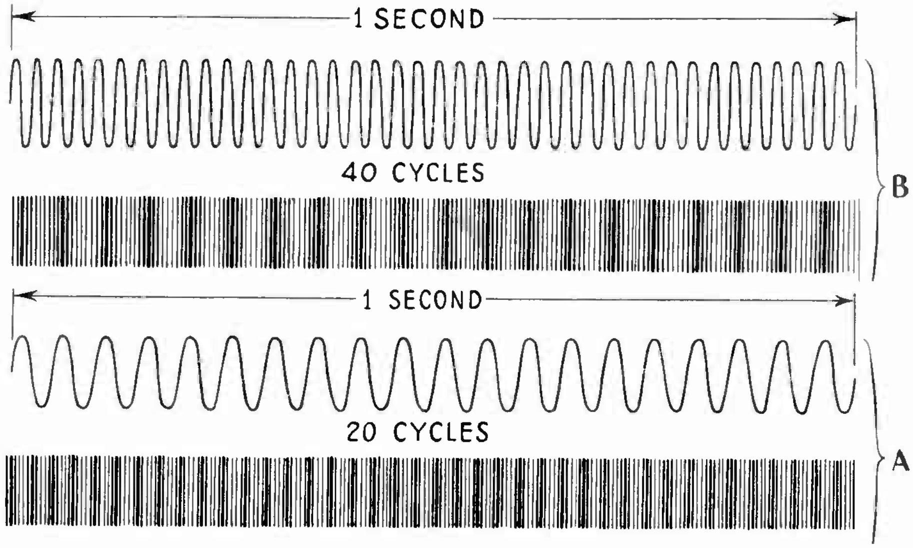

Fig. 9 - Graphs showing uniform amplitudes of pulsations.

INTERFERENCE - BEATS - RESULTANT TONES

In any elastic medium it is possible to have more than one periodic motion happening at a time. This applies to light waves, water waves, and even to air pulsations. Its occurrence in the case of water has probably been noticed by everyone, but will be explained here because of a certain similarity to sound.

Suppose that you have a quiet pond of water with a narrow channel leading out of it into another quiet pond. By dropping stones or using a plunger it is possible to start regular waves radiating from the spot where the plunger is working. Suppose we have two such plungers working at some distance apart, each developing a group of waves which move with the same velocity and are the same distance apart in their groups. If the waves are so timed that a wave-top of one group arrives at the exit channel at the same instant of time as a wave-top of the other group, the combinations of these elevations will produce a wave higher than either of the original waves. In the same way, the trough of one wave group will match with the trough of the other group to produce a resultant trough which is deeper than either. Now suppose that two equal waves, one from each group, arrive at the channel just one-half a wave-length apart. The elevation of the wave of one group will be offset by the trough of the wave of the other group. In the same way succeeding waves have their depressions filled up by the elevations of the other wave-group and the surface of the water will remain smooth. This shows us why the word "interference" is used to describe the phenomena.

The waves of one group may arrive at such a time with respect to the other group that the elevation of one wave occurs somewhere in between the elevation and the trough of the other group wave. In this case the combination will provide waves whose maximum elevation is something less than the sum of the two separate wave elevations.

Likewise the combination will provide a trough whose depth is less than the sum of the two separate wave troughs. Each wave system causes a motion of the area which is traversed by both. Sometimes the motions are in the same direction, and add; sometimes the two motions are in opposite directions, and the actual motion of a particle of water is equal to the difference of the two motions it would have had separately. When the channel, or common area, has

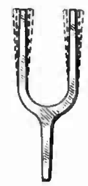

Fig.10 - Tuning fork used to illustrate periodic vibrations.

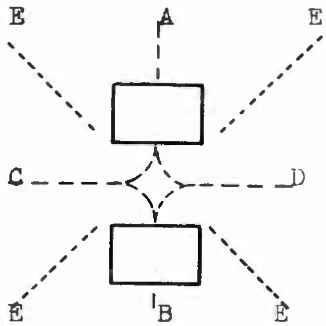

Fig.11 - Top view of the prongs of a tuning fork showing lines of compression, rarefaction and silence.

been passed, each wave motion continues as it would have done if the other wave motion had never been present.

We have a good example of interference between sound pulsations in the case of a simple tuning fork, shown in Figure 10. If one or both prongs are plucked or struck with a padded hammer they will vibrate with a periodic motion for some time before coming to rest. Compressions are started in front of the prongs when they move, and rarefactions behind them. When the prongs move toward each other a compression will be formed between them and this will be propagated out to each side, at right angles to the direction in which the prongs are moving. A rarefaction is started behind each prong and this is propagated out from each prong in the direction opposite to which it is moving. Figure 11 will make this clearer, being a top view of the fork. When the prongs return to their normal positions of rest, their momentums carry them beyond and each compresses the air in front of it, causing compressions to be propagated in the direction in which they are moving. A rarefaction will then be created between the prongs which will be propagated sideways at right angles to the direction of motion of the prongs.

When compressions are being propagated along lines A and B, rarefactions are being propagated along lines C and D. When rarefactions are being propagated along lines A and B, we find compressions being propagated along lines C and D. We can expect to find that the compressions and rarefactions will combine to give us normal pressure along some lines which bisect the right angles formed by the lines A, B, C, and D. It is easy to prove the truth of this by causing the fork to sound, and rotating it about an axis parallel to the prongs. The sound dies out in four directions from the center of the fork, as shown by the lines each marked E.

The pulsation frequencies along lines A, B, C and D are identical because they are caused by the same vibrating body. The "lines of silence" consist of a series of points in space where an air particle is subjected to two equal and opposite forces, and therefore does not "pulse".

BEATS

Subjecting an air particle to forces of different directions is also done when two separate vibrating bodies are sounding close together. Their frequencies may of course be different. At any instant of time the pressure at some point will depend on the direction and amount the particles would have been displaced if the two pulsations had occurred separately.

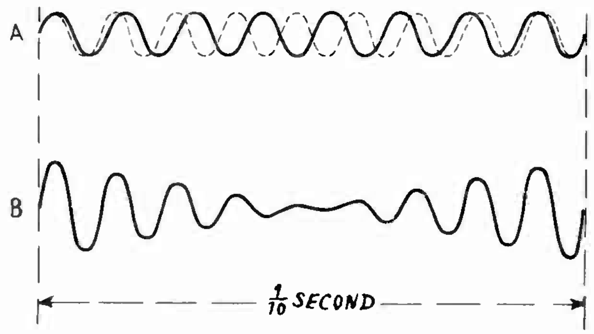

Fig. 12 - Graphs of two sound pulsations of different frequency and the resulting combined throb or beat pulsation.

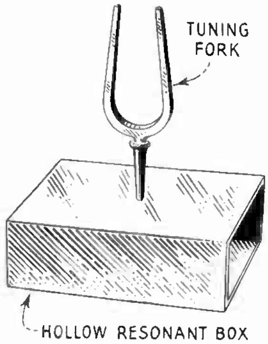

Fig. 13 - Tuning fork mounted on a hollow box to increase the amplitude of sound waves.

In Figure 12, A gives the pressure-time graph of an 80-cycle pulsation (dark line) and a 90-cycle pulsation (dotted line). In B is shown the net pressure effect due to the presence of both pulsations in a single medium. The left peak is due to the combination of the two pressure peaks at the left of A. The right peak in B is due to the two pressure peaks at the right of A. In the middle of B it is seen that the pressure wobbles weakly along for some time. This is caused by the fact that in A several peaks of the 80-cycle pulsation are nearly offset or cancelled out by several peaks, in the opposite direction, of the 90-cycle pulsation.

The effect is that the two pulsations at 80 and 90 cycles combine to cause a throbbing or alternate swelling and diminishing at the rate of (90-80) or 10 cycles per second. This is shown by B of Figure 12, where in 1/10 second, there is a gradual change in the peaks from maximum to minimum to maximum again. This represents one complete cycle of events in air pressure in 1/10 second. The frequency of the throb, or beat, is therefore 10 cycles.

We find the more general use of the term beat when the throbbing is at a rate which can be counted, as in tuning a piano. Here the procedure is to tune one string to the exact frequency of some portable frequency standard, such as a tuning fork. The tuning is accomplished by changing the tension on the string until its frequency is close to that of the fork. Then as the string is tuned closer, the number of beats between the string and the fork will grow less and less. When there is probably one beat per minute between the two frequency sources, they may be considered to have identical frequencies. The next step is to tune some second string to the first one; and this uses a definite count of beats between harmonic frequencies generated by the various strings. This will be better understood after you have covered the subject of tone quality and modes of vibration.

RESULTANT TONES

The term beat is used to apply particularly to the waxing and waning at very low frequency which compares with the beating of drums, etc., of which the ear recognizes each blow as a separate pulsation. This occurs where the pulsation frequency is less than about 15 per second. When the difference in frequency of two strong pulsations is more than 15, the increase and decrease in pressure at that frequency is sensed by the ear as a third musical tone. As far as the ear can sense, the third tone is there just as much as if it had been produced by a third vibrating body. This combination tone is referred to also as a resultant tone, a different tone, or a Tartini's tone.

RESONANCE AND DAMPING

A tuning fork is usually mounted on a hollow box or sounding board as shown in Figure 13. The effect of this is to reinforce the tone, that is, to increase the amplitude of the sound waves. It does this by presenting a larger surface to the air, and when the vibrations of the fork are transmitted to the sounding board and set it into vibration, it causes waves of greater amplitude to be sent out because it moves more air due to its greater surface. For this same reason stringed instruments are provided with a hollow, resonant body usually of wood and the sound waves which go out into the air really come from this vibrating body which in turn is set into movement by the vibratory motion of the strings. The piano has a large sounding board over which the strings are stretched and which vibrates when the strings vibrate. The comparatively large surface which the sounding board presents to the air produces a sound wave of considerable amplitude.

The part of a musical instrument which is the original source of the vibrations is sometimes referred to as the "tone-generator", and the body having a wide surface which acts to increase the pulsation amplitude is called the "resonator". This brings us back to the subject of vibratory periods and introduces us to an extension of that phenomenon.

SYMPATHETIC VIBRATIONS

It is a well-known fact that almost every object or body has a natural vibratory period, and this means that there is a certain frequency to which it responds more readily than any other frequency. This property of a body is forcibly brought to our attention at times by its action in a room where music is being played, for as notes of a certain frequency are struck, an object such as a vase or picture will suddenly commence vibrating and emit a loud rattle. This is due to the fact that the natural spring or resiliency of the body or object is such as to cause it to move back and forth at the exact moment when the areas of compression and rarefaction in the sound wave reach it and aid its backward and forward movement. This same effect of properly timed impulses is seen in the action of a person pushing a child on a rope swing, for the swing has a natural period of movement due to the length of its ropes. If it is given a slight push, allowed to swing back and is pushed again as it starts forward very little energy is required to get the swing into motion having a large amplitude or in other words to make it swing high. If the pushes are not applied at the right moment the motion of the swing will be retarded instead of helped.

This happens if the person on the ground pushes forward a fraction of a second before the swing has returned to the near end of its travel; the push is then opposite to the direction of movement of the swing. The energy in the pushing effort is partly wasted in stopping or slowing down the swinging. If the push is applied just after the swing has stopped at one end of its path, and has started forward again, the energy of a push will be effectively applied toward increasing the speed of the swinging child, which makes it swing higher than before.

If the pushing effort is stopped and the swing allowed to come to rest of its own accord, this happens because the energy of the swinging mass is slowly dissipated in overcoming air resistance and sometimes friction at the top of the ropes. If the child keeps his feet hanging low as he passes close to the ground, the dragging effect of his shoes on the ground increases the resistance, consuming more energy per swing, and bringing it to a stop much sooner. This decreasing of the amplitude of oscillation is called "damping". The damping is proportional to the rate of decrease of amplitude of successive swings.

The tuning fork shown in Figure 13 is mounted on the resonant box for a reason which should be clear. The fork itself vibrates very feebly. It also has a very low rate of damping, which means that the vibrations continue, after the first plucking or striking, for quite a length of time. A certain amount of energy has been stored up in it with the original distortion of its shape. If the mechanical energy can be transferred into sound energy at a faster rate, the amplitude of the early pulsations will be greater, but the vibrations of the fork will die out sooner. This is accomplished through the use of the resonant box. Its construction is such that its air column would naturally vibrate by itself at a frequency very nearly the same as the fork. The fork transfers some energy of its vibrations just by resting on the box. Energy is also transferred directly through the air, which should be clear from our study of the effect of a sound pulsation on the stretched diaphragms, etc. The walls of the box are made to bulge in and out slightly. Air pulsations are caused at the same frequency. The box resounds and is therefore said to be "resonant" at the frequency of the fork.

A well-known method by which this effect of sympathetic vibration in a body is shown is that of two tuning forks which have the same period of vibration or frequency. When one fork is struck and set into vibration it sends out pulsations which by means of successive tiny pushes and pulls start the other fork into vibration. This action of the areas of compression and areas of rarefaction in the pulsation is easily understood by reference to Figure 14 which shows pulsations produced by one fork acting upon another fork tuned to the same frequency. The dark bands represent areas of compression and the light bands areas of rarefaction. The sound is produced by fork A and travels through the air to fork B. The first area of compression to arrive at B pushes the prongs of the fork to the right and as the natural spring effect of the prongs returns them to normal, the area of rarefaction follows and pulls the prongs to the left, thus completing one cycle of movement. As the prongs start to return again to normal the next area of compression arrives and pushes them to the right past normal, and the succeeding area of rarefaction pulls the prongs again to the left. This continues as long as the sound wave from A exerts its force upon fork B. The latter is finally swung into visible vibration.

Suppose small pieces of metal or even of sealing wax are added to the ends of the prongs of fork B. This added weight or mass causes it to vibrate naturally, when struck, at a lower frequency than before. If fork A is now sounded, fork B will vibrate very weakly if at all. If more weights are added, fork B will not respond at all to the pulsations caused by fork A. The reason for this is simple. Perhaps the first few areas of compression and rarefaction would make fork B vibrate very slightly. Succeeding pulsations from fork A, however, would arrive so poorly timed with respect to the natural vibrations of fork B that the latter would be "stopped in its tracks". This compares with the poorly timed impulses given to the swinging of the child, previously described.

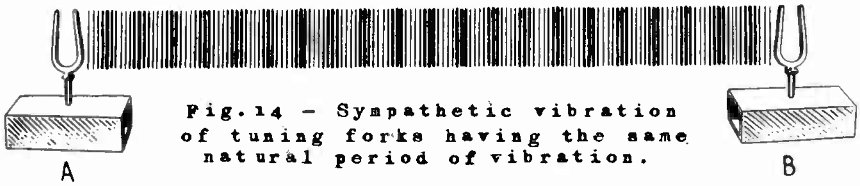

Fig.14 - Sympathetic vibration of tuning forks having the same natural period of vibration.

A tuning fork has a very low damping, which is to say that the energy imparted to it is expended very slowly in vibrating. The energy received from one pulsation lasts a long time, and if succeeding pulsations are not accurately timed to it the bucking effect results. The fork is therefore very sharply resonant.

It is interesting to note what happens if each fork is separately struck, when mistuned by the addition of weights to one. The energy given to each fork is imparted with a single blow, and is usually sufficient to keep it vibrating for some time, even though each fork is subjected to the air pulsations arriving from the other fork. The two forks now vibrating freely due to the hammer blows received will produce pulsations of different frequencies, and a listener would perceive the beats due to the phenomenon of interference.

If two forks accurately tuned to the same frequency are struck simultaneously, the sound waves of one will reinforce the sound waves from the other and a louder tone will be heard due to the fact that the areas of compression join each other to produce areas of greater compression; the areas of rarefaction join to produce areas of greater rarefaction thus creating a sound wave of greater amplitude and consequently greater sound.

This may not seem to fit in with the description of water waves in the paragraphs on INTERFERENCE. There it was stated that equal water waves of the same frequency might either add to their effects or might balance out and nullify each other. This would depend on whether the crests of the waves arrived at a point at the same time, or whether the crest of one arrived at the same time as the trough of the other. In the case of the water waves, we assumed that each wave group was being originated by a separate plunger that was being supplied with power which was so timed as to give it the same frequency as the other plunger, Therefore the plungers were not vibrating freely and one plunger would not be moved by water waves from the other.

In the case of the sound pulsations from the tuning forks, they vibrate due to single impacts of a hammer which immediately give up some energy to the prongs, and these continue to vibrate at the same frequency, but freely and independently of the hammers which have been laid aside. Each fork is resonant to the pulsations started in the air by the other fork. This transfer of energy from each to the other makes them "lock in", which may be compared to men marching along who not only make the same number of steps per minute (same frequency) but also keep step left and right (same phase).

FREQUENCY RANGE OF HUMAN HEARING

The sensitiveness of the ear to certain frequencies varies in different people so that sounds which are audible to one person cannot be heard by another at all. This failing makes itself evident in

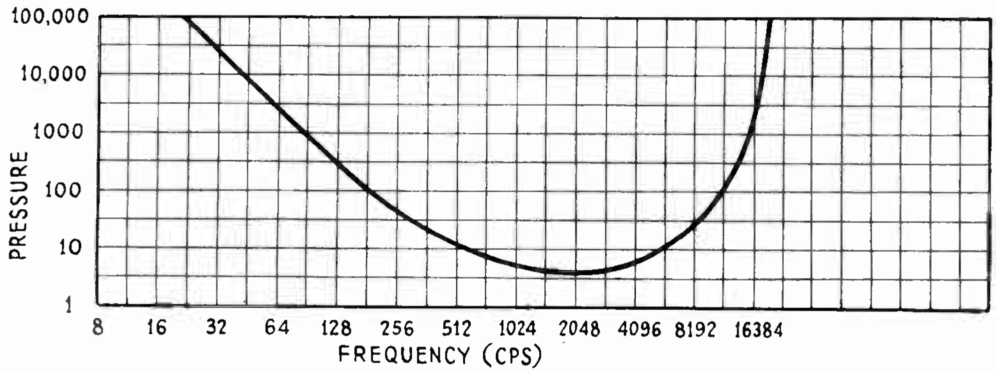

Fig. 15 - Sound pressure for human hearing depends on pulsation frequency.

the narrowing down of the band of frequencies that are audible. That is, a person with normal hearing can hear sounds with frequencies from 20 c.p.s. (cycles per second) at the lower limit to 16,000 c.p.s. at the upper limit. It is thus said that the audible band of frequencies for that person is from 20 to 16,000 c.p.s. It must be evident that the ability to hear well depends to a great extent on the elasticity or "limberness" of the ear drum, for if the eardrum is elastic it moves with the slightest movement of air caused by a sound pulsation. The eardrum is more elastic in youth than in old age, and in fact there is a gradual hardening of the eardrum with age just as most of the rest of the body hardens and grows less elastic with age. As age increases then the audible band of frequencies grows narrower and a person cannot hear sounds of as high or as low a pitch as he could when he was younger. The chart in Figure 15 serves to illustrate this point somewhat.

First let us say that in order to hear any difference between the volume or intensity of one sound as compared with another sound there has to be a certain difference in pressure that the sound pulsation exerts upon the eardrum. This difference in pressure must be great enough or the ear will not be affected to a degree sufficient to enable it to recognize that there is any difference in the loudness of the sounds. The difference in pressure necessary to make the change in loudness noticeable varies for the different frequencies so that while it takes a change of air pressure of only 3/10ths of 1 per cent to enable the ear to recognize a difference in loudness at frequencies from 500 to 4000 c.p.s. it takes many times as much difference in pressure at frequencies lower than 500 and higher than 4000 c.p.s. As seen by the chart in Figure 15 it takes almost 100,000 times as much pressure to make the ear notice a difference in loudness at about 20 c.p.s. as it does at 2,000 c.p.s. Now, inasmuch as the sensitiveness of the ear to sound depends to a certain degree on the flexibility and response of the eardrum to the pressure of sound waves, it is evident that as a person grows older and the eardrum stiffens somewhat, and thereby becomes less sensitive, the person will first lose the ability to hear the lowest and highest frequencies so that the audible band of frequencies for that particular person will narrow down from both ends. If a person is growing deaf through the action of age upon the eardrum, for instance, we would expect that as he grew older he would first fail to hear the frequencies at the lower and upper limits of normal hearing, say 20 to 30 c.p.s. and 20,000 to 15,000 c.p.s., then as he grew older possibly he would not be able to hear a range greater than from 60 to 6000 c.p.s. and so on until probably the last frequency he would be able to hear before he went entirely deaf would be about 2,000 c.p.s. at which frequency the ear is most sensitive. So much for the human ear and its normal range.

FREQUENCY RANGE OF THE HUMAN VOICE AND MUSICAL INSTRUMENTS

Figure 16 is a very interesting chart showing the frequency range of various musical instruments and the human voice. At the bottom is seen a representation of a standard piano keyboard with some dark keys added to carry the range beyond that of the piano. Immediately above the keyboard are letters by which the various keys on the piano are known, as A, B, C, D, E, F, and G after which they start all over again. The numbers directly above the letters refer to the frequency of vibration of each note and as can be seen extends from 26.667 cycles for the lowest key to 4096 cycles for the highest key on the piano keyboard and up to 8192 cycles for the highest note shown on the chart.

The pitch frequencies marked for the various piano keys are those based on the tuning of middle C to 256 cycles per second, which is the physicists standard of pitch. Pianos are actually tuned for ordinary playing to either the "international" or the "concert" pitch, which are respectively based on 435 and 440 cycles for the A note immediately to the right of middle C. The average organ range is from 16 to 4138 cycles although an organ pipe has been made that will produce a note vibrating at 15,600 cycles.

It is interesting to note the various ranges covered by singers. A base voice ranges from about 80 to 342 cycles; baritone from 96 to 384 cycles; tenor, 128 to 480 cycles; alto, 171 to 683 cycles and soprano from 240 to 1152 cycles. The chart shows how the ranges of these various voices overlap so that each voice is able to reach a considerable number of notes within the next range. In fact, there are several notes that are common to all the voices shown. Running up the left side of the chart are brackets labeled, "human voice", "stringed instruments", "percussion instruments", and "wind instruments." Each instrument has a clearly defined range of frequencies which it is able to produce and it is seen that there is considerable overlapping of ranges in this instance also. Now the thought probably occurs to you that if a certain note, say middle C which vibrates at 256 cycles, is in the range of several musical instruments and the human voice, there must be something else that takes place in order to make the various instruments sound differently. Following up from middle C at 256 cycles on the chart we find that it is in the range of the human voice, eight stringed instruments, nine wind instruments and the harmonica. Therefore there are nineteen sound sources which produce a note vibrating at 256 cycles and yet not two of the instruments sound the same. For instance, when middle

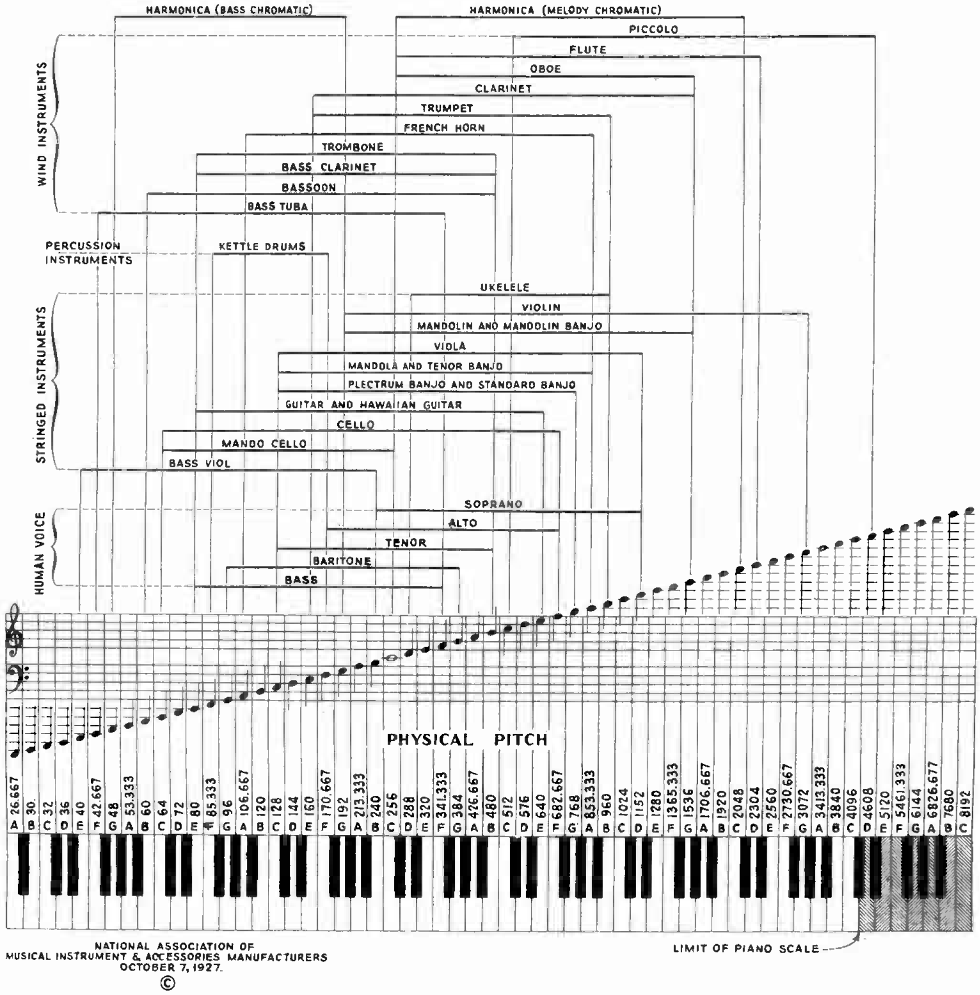

Fig.16 - Frequency range of the human voice and musical instruments.

C is struck on the piano you can tell instantly that it is a piano note and not a violin note although both are vibrating at 256 cycles.

MODES OF VIBRATION IN STRINGS AND TONE QUALITY

The answer is in the harmonics or overtones which accompany the fundamental frequency of every note and these harmonics differ for each instrument so that a distinct quality of sound is given to each note by the addition of the harmonics which are always present. This presence of harmonics is shown in simple form in Figure 17. If a stretched piano string is struck at its center point it will vibrate as a whole as shown in Figure 17(A) and produce the fundamental tone. If you now place your finger on the middle of the string and then strike each half separately the string will vibrate in two parts as shown in Figure 17(B) and will continue to maintain this form of vibration even after the finger is removed. The tone heard will be of a higher pitch than the fundamental, in fact its frequency will be just twice that of the fundamental as each half of the string vibrates twice as rapidly as the string would vibrate as a whole.

If the string is stopped at two places, dividing the string into three sections of equal length, the vibrations will be as shown in Figure 17(C) when each section is struck individually. Each section vibrates at a rate determined by its length; the common frequency will be three times the fundamental produced by the open unstopped string. In Figure 17(D) is shown the mode of vibration in five equal sections, the common frequency being five times the fundamental. The string can be made to vibrate at other frequencies which are integral multiples of the fundamental, such as four, six, seven, eight, etc.

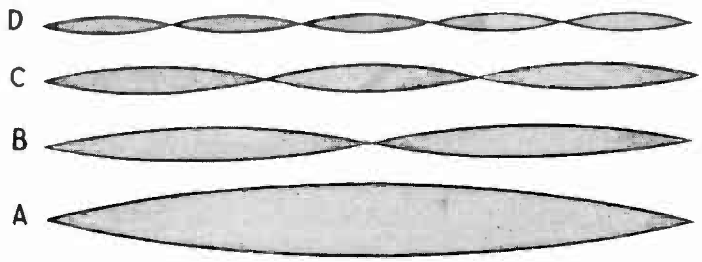

Fig. 17 - Graphic representation of modes of harmonic vibration.

We find various names applied to the several frequencies which can be produced by a string or other vibratory body. It is unfortunate that there continues to be a disagreement between the purely artistic members of the musical profession and those other members, more far-seeing, who treat the production of music as a branch of science without losing their appreciation of the resulting sensation.

In the following table the contrast is shown between the various methods of naming the frequencies. As a concrete example a frequency of 220 cycles for the fundamental is assumed.

Shown in	Freq.	Ratio to Fund.Freq.	Terminology Used	
			Scientific	Artistic
Fig. 17A	220	1	Fundamental and 1st Harmonic	Fundamental
17B	440	2	2nd Harmonic	1st Harmonic 1st Overtone
17C	660	3	3rd Harmonic	2nd Harmonic 2nd Overtone
---	880	4	4th Harmonic	3rd Harmonic 3rd Overtone
17D	1100	5	5th Harmonic	4th Harmonic 4th Overtone
---	1320	6	6th Harmonic	5th Harmonic 5th Overtone
and so on				

Now these harmonics can be produced without the trouble of stopping the string movement at certain places. In fact, a string seldom vibrates in only the fundamental mode. This means that the string vibrates as a whole and also in sections at the same time. The difference between musical instruments lies largely in just what sections their vibratory bodies break up into, and at what relative amplitudes.

Let us consider the first three harmonics, shown in Figure 17, (A, B, and C) and draw the pressure-time graphs of the air pulsations produced. In Figure 18, let us assume that graph A is caused by a tuning fork which is producing sound pulsations at a certain frequency. Then we start a second tuning fork vibrating which produces pulsations as graphed in B, at twice the frequency of those graphed in A. These two sounds both exist in the air at the same time. The pressures combine to produce a pulsation which could be graphed as in D. If we now start a third fork vibrating which produces pulsa-

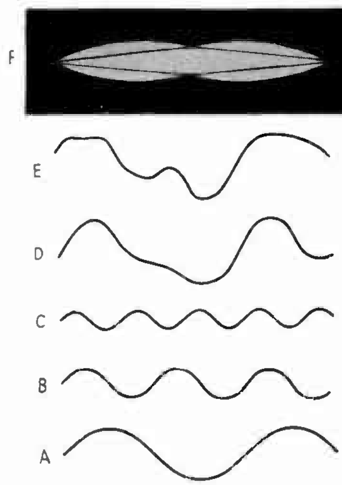

Fig. 18 - Composite effect of vibrations in several modes.

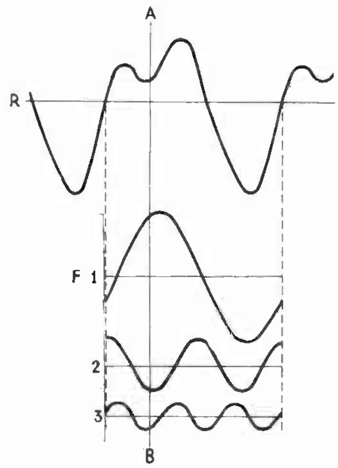

Fig. 19 - Graphic analysis of a violin note.

tions as graphed at C, having three times the frequency of those graphed in A, we find that the pressure conditions will be further modified and can be graphed as in E.

By careful inspection you will be able to see how the addition of pulsation B to pulsation A lifted or lowered the graph of A at certain points to make it as shown at D and how the added effect of pulsation C altered pulsation D in certain places to change its graph to E. The effect on the ear of such a pulsation as shown at E is that of a fundamental with the pitch of A and in addition added quality or "richness" of sound due to the harmonics. It should not require much of a stretch of the imagination to visualize in your mind a piano string vibrating with the effect of the fundamental and the second harmonic so that in vibrating it looks as shown at F. Thus, if this be the form a piano string takes when vibrating and you have learned to associate with it the sound produced by a piano then whenever any string vibrates in that particular form you will recognize by the quality of sound produced that it is a piano note. And so it is with the various string and wind instruments. The certain quality that enables the ear to recognize one from the other is brought about by various combinations of harmonics added to the fundamental. The tone pitch of a string is due largely to its length; the longer it is the slower it vibrates, which produces a low frequency sound wave. As the length of the string is decreased it vibrates more rapidly and the higher becomes the frequency of the tone it emits.

The action of pulsating air may be photographed to show the graph form which it produces. When a violin note is "photographed" by this process it produces a form as shown in R, Figure 19, which when analyzed into its component parts shows that it is composed of the fundamental F and the 2nd and 3rd harmonics designated as 2 and 3 in the same figure. It can be seen in this figure how the two valleys on the line A-B put a dip in the fundamental making it look as shown on the same line A-B in the resultant curve R. It is easier to see the effect of superimposing a harmonic on a fundamental pulsation by assuming that F in Figure 20 is the fundamental and H the harmonic. The resultant pulsation graph is seen to be in the form as shown at R.

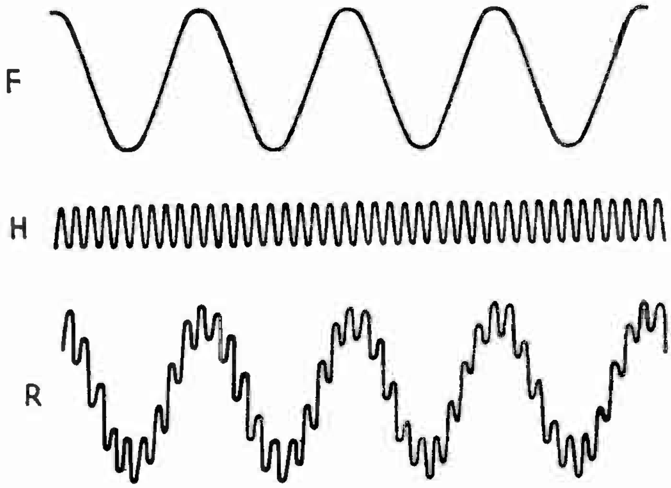

Fig.20 - Graphic representation of a harmonic superimposed upon a fundamental pulsation.

Before going further the student should realize that the shape of the graph of a combined pulsation produced by several independent pulsations depends on three factors:

1. The frequencies of the component pulsations
2. Their relative amplitudes
3. Their phase relation.

The latter may be described as the relation in time between the occurence of normal air pressure (before compression begins) for the several components. In Figure 18 all three graphs (A, B, C) begin a cycle at the same instant of time. In Figure 19, for the period of time shown, the fundamental graph cycle begins at less than normal air pressure (below the line), the second harmonic graph cycle begins at a compression peak, (above the line) and the third harmonic graph cycle begin at normal air pressure (on the line). As far as the ear is concerned, there is practically no difference in the sensation produced with different phase conditions for these various harmonics. However, the photographed records may be radically different in shape. A resultant graph must be broken up into its components (analyzed) to determine what is the true cause of a musical effect.

MODES OF VIBRATION OF AIR COLUMNS IN PIPES

The production of air pulsations by wind instruments is due to the air columns within them which are caused to vibrate by various methods. In the reed type of wind instrument a slender flexible reed opens and closes the entrance to the air column admitting little puffs of air which set it into vibration. The clarinet, oboe, and saxaphone are instruments of this type while the cornet, trombone, and bass horn are examples of instruments that require the vibration of the lips against a cupped opening to produce a vibrating air column. To produce notes of various pitch, a variety of devices are used to vary the length of the air column. The slide trombone, for instance, lengthens its air column by means of a sliding tube, the cornet by means of keys which stop up certain sections of its tubular construction and the clarinet by keys which open new paths through which the air escapes. The particular quality which each wind instrument displays is dependent upon the fact that its air column vibrates as a

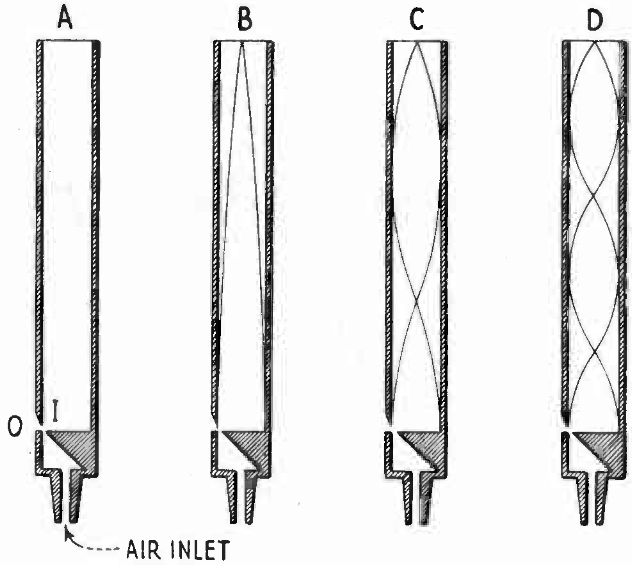

Fig.21 - Modes of vibration of air columns in organ pipes.

whole to produce the fundamental tone and also in parts to produce the harmonics. This is more clearly understood by referring to Figure 21 which shows how sound is produced by a closed organ pipe and how its air column vibrates as a whole and also in sections to produce the characteristic quality of tone which we recognize as organ music. In A the air enters through a pipe at the bottom and a puff of it passes through the opening into the tube at l. This puff of air travels up the pipe as an area of compression and when it reaches the closed end of the pipe it rebounds or is reflected back down the tube. When it reaches the opening at I it pushes the jet of air which is entering the pipe out towards O causing an area of compression to be sent out into the air. When the compression area that pushed the jet of air out of the pipe has passed, a rarefaction area follows it, the jet of air again passes into the pipe causing another compression area to pass up the pipe where it is again reflected from the closed end, travels back and pushes the air jet out through O again.

This happens over and over again as long as air passes up through the inlet. The sound is caused by the intermittent puffs of air sent out at O and the frequency of the sound is determined by the number of puffs emitted per second. It takes a certain length of time for the compression areas to travel up the pipe to its closed end and back again and this length of time governs the frequency of the note which the pipe produces. Thus it can be seen that the longer the pipe the greater the length of time it will take the areas of compression to travel twice its length and the fewer puffs of air will be sent out per second at orifice O. It follows then, that the longer the pipe the lower the frequency of the sound produced by it. This conclusion is well demonstrated by the fact that an organ pipe producing a tone of 16 cycles is over 32 feet in length and weighs 1278 pounds while one of the smallest pipes ever made produces a tone of 15,600 cycles, has an effective sound producing length of $\frac{1}{4}$ inch, and weighs a matter of ounces.

The characteristic tone of a closed organ pipe is produced by the air column within it vibrating as a whole as shown in Figure 21(B) and in sections as shown for the third harmonic in C and for the fifth harmonic in D, and so on. If the organ pipe were open at the end opposite the air inlet, it would have been able to vibrate at all the harmonics, both even and odd; the closed pipe provides only the odd ones. Also the pitch of an open pipe fundamental tone is an octave above the pitch of a closed pipe of the same length.

The exquisite richness of the organ tone is due to the fact that in addition to the fundamental tone there are a number of harmonics. This condition is shown in graph form in Figure 22 where R is the graph of air pulsations, F is the fundamental and graphs 2 to 11 are the harmonics. The vertical dotted lines show the limits of one cycle of the pulsation R and the fundamental F. The proper way to look at this is that the pulsation R is the resultant form of the fundamental pulsation F when the ten higher harmonics have acted upon it to change its shape. It can be seen in this figure that the second harmonic is twice the frequency of the fundamental, the third harmonic three times the frequency of the fundamental and so on up to the eleventh harmonic which is eleven times the fundamental frequency. The set of curves shows also that in general the amplitude of the pulsations decreases as the frequency of the harmonics increases so that the amplitude of the eleventh harmonic is but a small fraction of the amplitude of the second harmonic. Any recurring graph, no matter how complex, may be analyzed by certain formulae and found to consist of a certain combination of fundamental and harmonics.

A COMPLEX TONE MEETS A DIAPHRAGM

Now you might very well say at this point that you don't understand how a body such as the diaphragm of a microphone or loudspeaker can move in two ways at the same time as it would have to do to follow or to make a sound pulsation as seen in R of Figure 20. Let us look at an edge view of a diaphragm as seen in Figure 23. The solid line represents the diaphragm at rest, while the dotted lines represent an exaggerated idea of the amplitude of movement of the diaphragm when a pulsation strikes upon it. The diaphragm is pushed out of its normal position by the area of compression and, in effect, pulled in the opposite direction out of normal by the area of rarefaction. A pulsation with a fundamental frequency of say 27 cycles, would cause the diaphragm to move back and forth to the dotted line positions 27 times per second. During the same interval of time let us assume that the second harmonic at 54 cycles per second is also acting on the diaphragm. Then, while the diaphragm is moving to the dotted line positions shown it will move backward and forward a little twice due to the 54 cycle pulsation while it is moving back and forth once due to the 27 cycle pulsation. Let us demonstrate the possibility of

Fig. 23 - Edge view of a diaphragm.

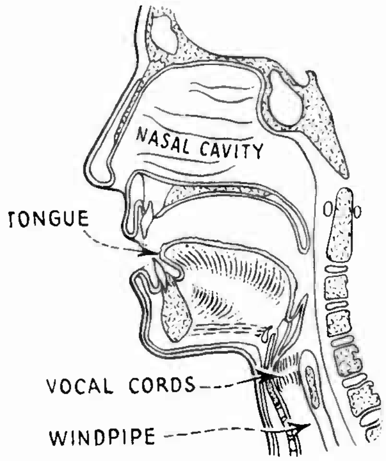

Fig. 25 - Cross-section view of the human voice organism.

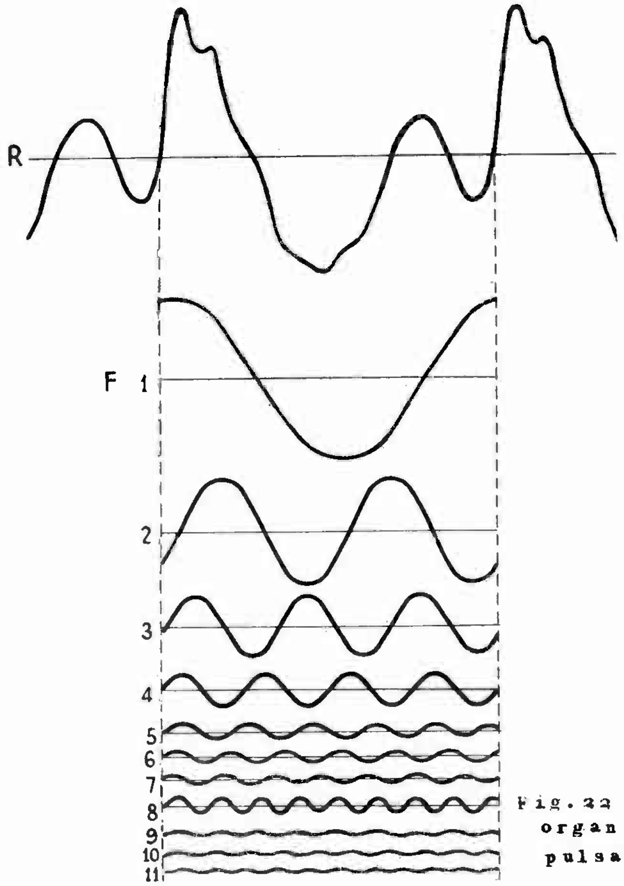

Fig. 22 - Graphic representation of an organ note showing the fundamental pulsation with all the harmonics.

this by laying the diaphragm in a horizontal position as shown at A, Figure 24, comparing the movement of its center point with the movement of a man walking over a series of hills, as seen in B. We all know that due to the action of walking a person's body rises and falls a trifle as he walks so that if we looked steadily at his head as he walked along on smooth ground we would see it describe a path somewhat in the fork of a sine wave with an amplitude of say two inches. This would look like the line C in Figure 24 if the man were walking on level ground but if he were walking over a series of ridges as shown at B then the path his head would follow would look like the line in D which looks considerably like the resultant wave R in Figure 20. The center of the diaphragm A shown by the dot at the middle of the line can describe a path exactly as shown at D if the diaphragm were moved along at the same rate of speed as the man. The line corresponding to the hills could be produced by a 27 cycle pulsation and the line corresponding to the rise and fall of his head during walking could be produced by the 216 cycle pulsation which is its 8th harmonic. The resultant pulsation in air would provide the graph shown in D, and this would also represent the displacement in space of the center point of the diaphragm. The pulsation graphs we have studied so far have all been produced by musical instruments or tuning forks and most of them have been curves of simple sounds. A simple sound is one that has few harmonics as for instance the tuning fork whose tone is composed chiefly of the fundamental and approaches the standard of what is known as a pure tone because no harmonics are present. There are very few vibrating bodies that produce pure tones, most of them adding harmonics to the fundamental.

THE HUMAN VOICE

The voice is produced in a manner different from either the tuning fork or the organ pipe but it, too, requires something that vibrates in order to produce sound. The action by which a human voice is produced is easily understood by referring to Figure 25 which is a cross-section illustration of a human head. In the action of pro-

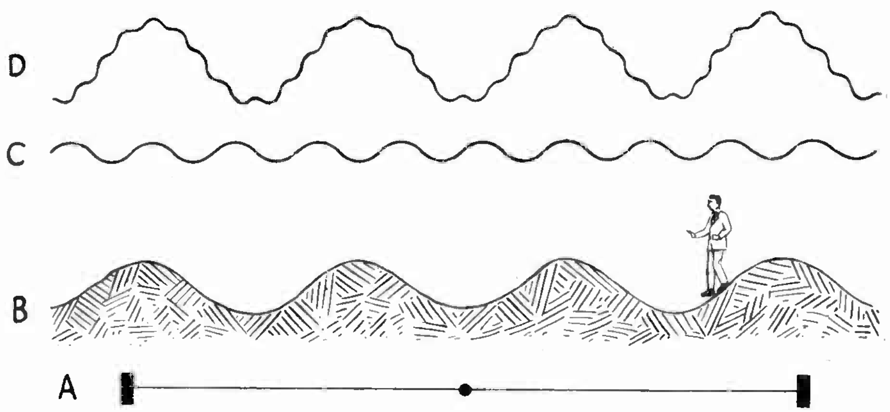

Fig. 24 - Graphic representation of composite pulsations of a diaphragm.

ducing sound, the air is forced up the windpipe by the lungs and passes by the vocal cords which are muscular ledges or flaps, setting them into vibration which causes air pulsations to pass up through the mouth and out into the air. There are cavities in the head that resonate with the component frequencies of the pulsations to provide a certain quality that makes one person's voice sound different from that of another person. By placing the tongue in various positions and changing the shape of the mouth and throat by muscular action words and sounds of different pitch and quality are produced. Each voice has a certain range of frequencies which it can produce and this range varies with different persons and between men and women. The range of fundamental frequencies covered by the human voice is from 80 to 1200 cycles, but it should be understood that this range cannot be covered by one person's voice. It includes the frequencies from the lowest note sung by a bass singer to the highest note reached by a soprano.

REFLECTION

Sound may be reflected from surfaces which are too firm to give way to the pressure changes of a pulsation. If the surface is far from the sound source so much time may have elapsed before the return effect that the direct sound reaching the ear from the source will have died out completely. The reflected pulsation arrives at the ear drum when the latter has ceased vibrating, and gives the impression of a separate sound; we call this an echo.

If the reflection of sound occurs in a room it may be a process of repetition from one wall to another and so on, until it finally dies away. The time interval between the direct sound and a reflection of the sound may then be so small that the ear does not distinguish it. The impression is had of being surrounded or wrapped up in a sound effect which should have come and gone quickly. This continuation of sound is called reverberation. A certain amount of it is desirable because it gives naturalness and a certain aliveness to the sound. Too much reverberation prevents separate sound effects from being distinguished from each other, bringing confusion and lack of intelligibility.

REFRACTION

In brief this applies to a change of direction of a sound as it passes from one medium to another, as when it enters and leaves a wall between two rooms. This may be compared to the bending of light waves as they pass through glass, water or other medium having a density different from that of air.

DISPERSION

The reflection of sound heretofore described applied to surfaces which were generally flat. If the reflecting surface is rough and irregular the reflection will be in many directions, and the sound is said to be scattered or dispersed.

ABSORPTION

We have so far discussed decreasing intensity of sound only as it was caused by the distance of travel of a pulsation. We find another cause for an intensity decrease, and it is based on a change of sound energy into heat energy. This happens when a sound is partly reflected from a surface material which is slightly porous to air particles. As the particles next to the surface move forward under increased pressure, they cause friction with the particles of the material against and into which they are trying to move. This reduces the amplitude of their movement, and the energy of pulsation is partly transferred into heating the material and the air particles themselves. This temperature increase is not a measurable quality; the thought is presented to you merely to make clear what happens to sound energy when rugs and curtains are placed on the floor and walls of a room.

A REMINDER

In a lesson that deals with fundamentals of such importance as those of SOUND, a particular effort must be made by the instructing staff to present the subject in a clear and easily understood manner. To that end we have consistently adhered to the use of the word "pulsation" throughout this lesson. You are again informed that common practice in the sound industries has established the use of the word "wave". Other lessons on the subject of sound will tend to use the latter word. In studying them you may have a cause to refer back to what you have learned in this lesson. In doing so, interpret the meaning of the popular word "wave" as being the same as that of "pulsation" as used here.

EXAMINATION QUESTIONS

1. Through what mediums may sound be propagated?

2. Explain how sound travels.

3. How does sound vary the current in a telephone circuit?

4. Explain how a beat is produced?

5. What is the meaning of the word "Amplitude" as used in sound?

6. What is meant by the "third harmonic"?

7. What is meant by "frequency"?

8. What is the frequency of a pulsation caused by reflection from a wall or other large flat surface?

9. What may cause a reflected pulsation to be much less in amplitude than the original pulsation, considering them at some point in space close to the reflecting surface?

10. What differentiates the tone of one musical instrument from that of another instrument, even when they have the same frequency?

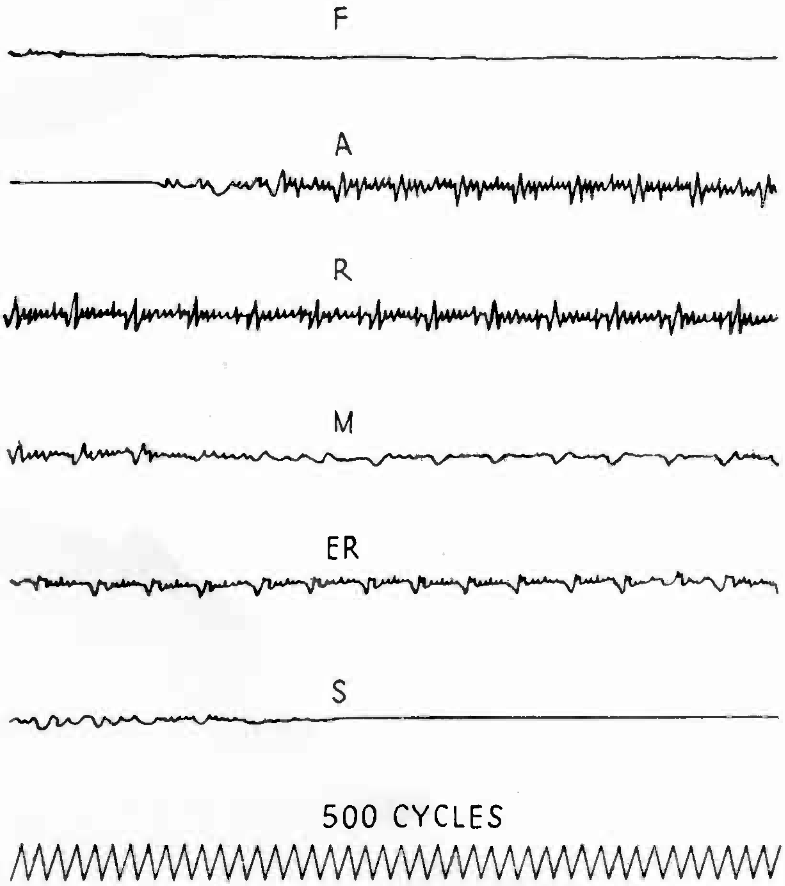

Chart showing frequency analysis of the spoken word, "farmers".

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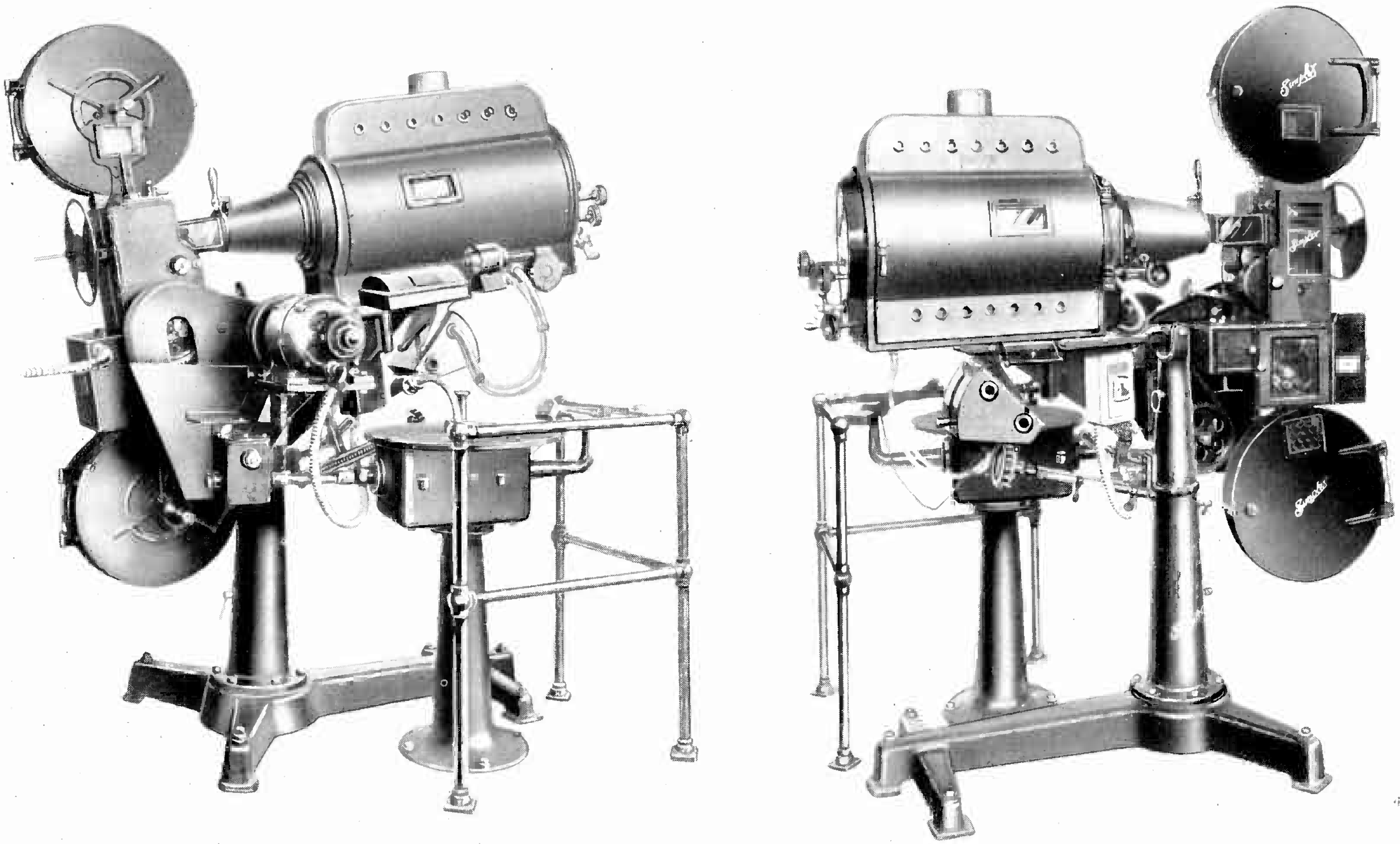
Foreword

It is a well recognized fact that the successful operation of any machine depends upon the ability and knowledge of the operator. Usually, the manufacturer has no responsiblity for, or control over, the selection of the operator, and therefore cannot be responsible for the ability of that operator. On the other hand, the ability of the operator is directly dependent upon his knowledge of the machine, and it is the responsibility of the manufacturer to make available such information concerning his product as is necessary for its intelligent operation.

In presenting this book, RCA PHOTOPHONE, INC. aims not only to present a comprehensive description of its apparatus, but also to give in elementary terms an understanding of the operation of this apparatus. Such technical information as may prove of assistance in the understanding of the various operational procedures is given, but deeply involved technical discussions have been avoided as far as possible.

In addition to explaining the "how" and "why" of the operation of PHOTOPHONE equipment, it is also our aim to give this information in such a fashion as to enable the projectionist to intelligently recognize, locate and remedy such minor defects as might occur during the operation of the equipment, and make whatever minor adjustments which may become necessary for the proper operation of the equipment.

To those whose previous training does not qualify them for an exact understanding of the theory involved, we wish to state that it is not necessary to understand in detail this theory in order to have a practical working knowledge of the apparatus. Such theoretical discussions as may be found in this book serve merely to explain the reasons *why* certain things are done.



Frontispiece—Simplex projector with RCA Photophone film and disc sound attachments. The Type PS-1 sound head and Type PT-2 turntable are illustrated

CHAPTER I

NATURE OF SOUND

1. **Definition of Sound.**—There are various definitions of sound. Therefore at the start it is well to have an understanding as to the definition of the word as used in this and in the succeeding chapters of this book.

Sound can be considered as a series of vibrations of the air of such frequency, or pitch, that it is audible to the human ear.

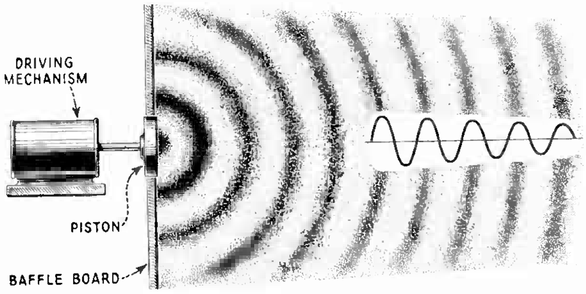


Figure 1—Generation of sound waves

Sound is sometimes defined as an audio sensation in the ear. Such a definition requires a person to be located in the vibrating air before sound can exist, and is therefore inconvenient in a discussion of sound reproduction.

(A) PRODUCTION OF SOUND

2. **Production of Sound.**— Sound is produced when air is set into vibration by any means whatsoever, provided that the frequency of vibration is such that it is audible, but sound is usually produced by some vibrating object which is in contact with the air. If we take a string, such as used on a banjo or similar instrument, stretch it taut between two fairly solid supports a few feet apart and pluck it, sound is produced which dies down in a fairly short time. When the string is plucked it springs back into position, but, due to its weight and speed, it goes beyond its normal position, oscillates back and forth through its normal position, and gradually comes to rest. As the string moves forward it pushes air before it and compresses it, also air rushes in to fill the space left behind the moving string. In this way the air is set into vibration. Since air is an elastic medium, the disturbed portion transmits its motion to the surrounding air so that the disturbance is propagated in all directions from the source of disturbance.

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

If a light piston several inches in diameter, surrounded by a suitable baffle board several feet across, is set in rapid oscillating motion (vibration) by some external means, sound is produced. The air in front of the piston is compressed when it is driven forward, and the surrounding air expands to fill up the space left by the retreating piston when it is drawn back. Thus we have a series of compressions and rarefactions (expansions) of the air as the piston is driven back and forth. Due to the elasticity of air, these areas of compression and rarefaction do not remain stationary but move outward in all directions. (See Figure 1).

3. **Propagation of Sound.**—If we could measure the atmospheric pressure at many points along a line in the direction in which the sound is moving, we would find that the pressure along the line at any one instant varied in a manner similar to that shown by the wavy line of Figure 1; or, if we set up a pressure gauge at one point and could watch its variations, we would find that pressure varied at regular in-

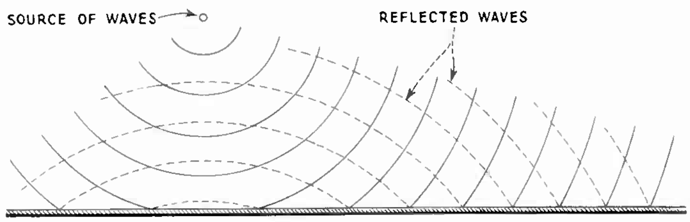


Figure 2—Reflection of waves from a plane surface

tervals and in equal amounts above and below the average atmospheric pressure. Of course we could not actually see the variations of the gauge because of the high rate at which they occur.

We *can* see wave motion in water, however, which is very similar to sound waves with the exception that water waves travel on a plane surface, while sound waves travel in all directions. You are all fairly well familiar with what happens when a pebble is dropped into a still pool. Starting at the point where the pebble is dropped, waves travel outward in concentric circles, becoming lower and lower as they get farther from the starting point, until they are so small as not to be perceptible, or until they strike some obstructing object. If the pond is small it will be noticed that the waves which strike the shore will be reflected back. If the waves strike a shore that is parallel to the waves, they will be reflected back in expanding circles. If the waves strike the shore at an angle they will be reflected at an equal angle. (See Figure 2.)

If the waves strike a concave (hollow) shore line the reflected waves will tend to converge (focus) to a point. (See Figure 3.) The solid lines show the direction of the original waves, and the dotted lines show the direction and focusing of the reflected waves. Focusing of waves results in their reinforcement, which may cause them to build up to a considerable proportion at one point.

If you can picture the same kind of wave motion in air, with the exception that the air waves expand as concentric *spheres* instead of *circles*, you will have a fairly good picture of a sound wave as it travels through the air. Sound waves are reflected in a manner similar to water waves, causing echo and reverberation. If the sound waves focus at a point, loud and dead spots are produced. These terms are explained in more detail in Chapter XII.

Wave motion has certain definite characteristics; these characteristics determine the loudness, frequency (or pitch) and tone of the sound.

4. Loudness.—Loudness (or amplitude) is determined by the amount of difference in pressure between the maximum compression and the maximum rarefaction. This corresponds in water waves to the vertical height of the crest above the trough of the wave. (See Figures 4 and 1.)

5. Frequency.—*Any one of a series of variations, starting at one condition and returning once to the same condition is called a "cycle."*

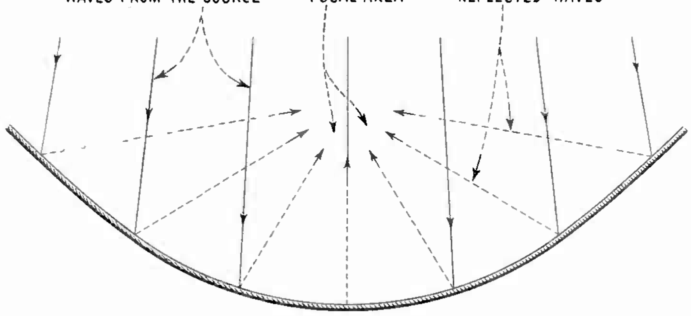


Figure 3—Reflection of waves from a curved surface

If we should fix our attention at some point on the surface of water in which waves exist, we would notice that at one particular point the water will rise and fall at regular intervals. At the time at which the wave is at its maximum height the water begins to drop, and continues until a trough is formed, when it rises again to its maximum height. Therefore, if we notice all the variations of height which one point on the surface of the water goes through in the formation of a wave we will have witnessed a "cycle" of wave motion.

The number of cycles a wave goes through in a definite interval of time is called the "frequency." Therefore the number of times the water rises, or falls, at any point in one minute would be called the frequency of the waves per minute, and we would express the frequency as a certain number of cycles per minute.

In sound, the number of waves per minute is large, and it is more convenient to speak of the frequency of sound waves as the number of waves per second, or, more commonly, as the number of cycles per second. Thus, a sound which is produced by 256 waves a second is called a sound of a frequency of 256 cycles. *When speaking of sound, "cycles" always mean "cycles per second."* Considered from the standpoint of travelling waves, frequency is determined by the number of complete waves passing a certain point in one second, and this, of course, is equal to the number of vibrations per second generated at the source.

In the same way, when a racer goes once around the race track and returns to the starting point, he completes a "lap," which, in this case, is just another name for a "cycle."

Figure 5 is a chart showing the range of frequencies covered by the human voice in singing and by the various musical instruments. This chart represents the relation between the musical scale and the piano keyboard, giving the frequency of each note in terms of complete vibrations, or cycles, according to the standard used in scientific work, *viz.*—the scientific scale based on middle C at a frequency of 256 cycles. The shaded keys are not included on a standard piano keyboard. The piano keyboard covers nearly the entire range of musical notes and extends from 26.667 cycles to 4,096 cycles. The piccolo reaches two notes beyond the highest note of the piano. The extreme organ range, not shown on the chart, is from 16 cycles to 16,384 cycles, scientific or "physical pitch," as it is usually called. Musical instruments are tuned to the international pitch which is based on middle A at a frequency of 440 cycles.

Music seldom utilizes the full keyboard of the piano, the extremely high notes and extremely low notes being seldom used. Therefore a reproducing device which reproduces all frequencies from 50 to 4000 cycles would be satisfactory in reproducing musical notes. However, there is another factor which enters into the consideration. This factor has to do with tone.

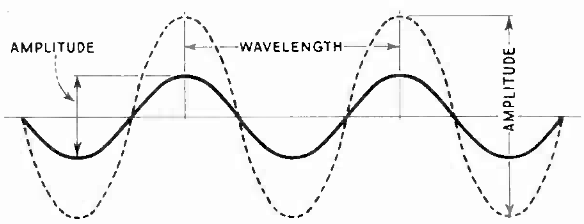


Figure 4—Properties of wave motion

6. Tone Quality.—The terms "quality" or "tone" of sound are used particularly with reference to music. A pure note of a given pitch always sounds the same and the frequency of this note is termed its "fundamental" or "pitch frequency," but you are all familiar with the fact that notes of the same pitch from two different kinds of instruments do not give the same sound impression. This difference is due to the presence of overtones, sometimes called harmonics. Let us consider again the case of a taut string which is plucked to set it into vibration. If the string is plucked at its exact center, it will vibrate as a whole and give a very nearly pure note; but if it is plucked at some other point, say one-third of the length from one end, it will vibrate as three parts as well as a whole, and a change of tone will be noticed. If the string is plucked indiscriminately, various tones will be heard, all of the same pitch.

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

The frequency of an overtone is always some multiple of the pitch frequency; that is, the second overtone has twice the frequency of the pitch note, and the third overtone, three times the frequency, etc. Overtones of twenty times the frequency of the pitch note are present in the sounds of some musical instruments, but overtones of this order are important only when the pitch note is low, because the frequency of the twentieth overtone of even a moderately high note would be beyond the ability of the human ear to detect. Overtones give character and brilliance to

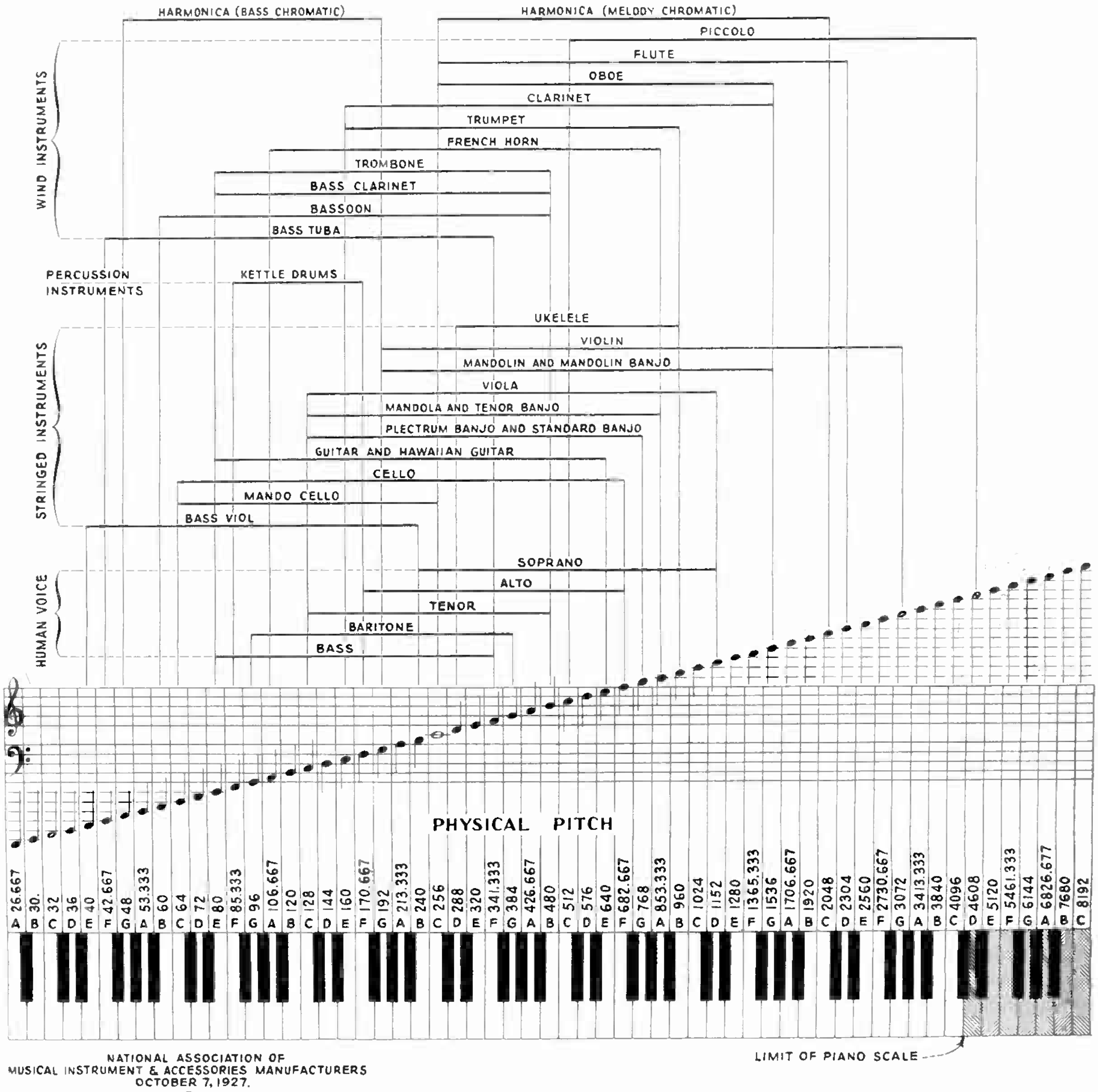


Figure 5—Range of musical instruments and the human voice

music, and their presence in reproduced sound is necessary if naturalness is to be attained. A reproducing device which reproduces frequencies from 50 cycles to 6000 cycles will cover very well all the notes and overtones necessary for naturalness and distinctiveness.

In singing, the range of notes covered is from 80 to 1200 cycles, but this range cannot be covered by one person's voice. The frequency of 1200 cycles does not represent the highest frequency used in singing, because overtones of several times the frequency of the note are always present in the human voice. The presence of the overtones gives the pleasing quality to songs. This quality of the singing voice is called "timbre." The timbre of the voice transmits the emotions of joy, sadness, etc., from the performer to the audience, and therefore is very important in the enjoyment of vocal music.

7. **Wave-length.**—Frequency in wave motion is related to wave-length. The wave-length of a water wave is the distance between the crest of one wave and the crest of the next wave. This distance remains the same as long as the wave continues, even though the wave becomes so small as to be hardly perceptible. All waves produced do not have the same wave-length. A small pebble dropped into a pond will produce a wave of short wave-length, but a large stone will produce a wave of correspondingly longer length. In sound the wave-length is dependent upon the frequency of the source. Similarly, in sound the wave-length of a sound wave is the distance between the point of maximum compression of one wave to the point of maximum compression of the next wave. These facts are illustrated graphically in Figures 4 and 1. Sound travels at different speeds in different substances, thus it travels at a much higher speed in water and steel than in air. We are interested only in sound travelling in air, where it travels about 1100 feet a second. An illustration of the fact that time is required for sound to travel from one place to another is shown by a steam whistle at a distance of several hundred yards. If it is observed when blown, it will be noticed that the steam can be seen coming from the whistle a considerable length of time before the sound of the whistle is heard. Sounds of all frequencies, or pitches, travel at the same speed. Therefore if we divide the speed at which sound travels by the frequency, we will obtain the wave-length of the sound wave.

8. **Speech.**—The sounds of speech are divided into two classes, vowels and consonants. The vowel sounds are used in the pronunciation of the letters "a," "e," "i," "o," "u," and sometimes "y," in the formation of words. These letters are also used in combination to indicate other vowel sounds. The pitch frequencies of the vowel sounds in male voices range from 110 cycles to 140 cycles. For female voices the range is from 230 to 270 cycles. The characteristic frequencies, or overtones of the vowel sounds, however, reach frequencies of 3300 cycles. So important are these overtones that the pitch frequency can be entirely eliminated without noticeably changing the sound sensation produced on the human ear. The full range of frequencies used in vowel sounds is from 110 cycles to 4800 cycles.

The pitch frequency of the vowel sounds are produced when air is blown through the vocal cords. The vocal cords are two muscular ledges in the air passage of the throat. When these muscles are taut there is a narrow slit between them, which sets the air passing through into oscillation. The sound produced by the vocal cords is changed by the cavities of the mouth. The shapes of the cavities continuously change as a person speaks, making it possible for him to produce a wide variety of sounds, all of very nearly the same pitch frequency.

Consonant sounds are usually produced without the aid of the vocal cords. Most of these sounds are produced by the lips and teeth, as in the pronunciation of "th," "s," and "f." The range of frequencies covered by consonant sounds is from 200 to 8000 cycles, but most consonant sounds have frequencies of less than 6000 cycles.

9. **Hearing.**—The actual mechanism of hearing is not very well understood, but certain facts regarding the ability of the ear to register sounds of various frequencies has been determined very accurately. The range of frequencies which the average person can hear is from about 20 cycles to 17,000 cycles, but a comparatively large amount of sound energy is required before the ear can detect sound of extremely low or extremely high frequencies. The ear is most sensitive to frequencies between 500 cycles and 7000 cycles; also, the ear is most sensitive to changes of pitch and changes of intensity of sound in this same band of frequencies.

(B) SOUND AS A FORM OF ENERGY

10. **Matter and Energy.**—The recording and reproduction of sound involves the use of energy in many forms, and matter in general. Everything with which we come in contact in our daily life is in some way related to energy and matter.

Matter is anything which has size, shape and weight, that is, anything capable of occupying space. All matter is believed to consist of small particles, called molecules, which are in rapid motion, but travel only through very short distances. Matter is believed to hold its shape due to the mutual attraction of the particles.

There are three classes of matter, solids, liquids and gases. In solids the particles are relatively close together and, although the particles are in motion, the motion is of a very orderly nature, and considerable force is required to separate them or change the order of their motion. In liquids the motion of the particles is still very orderly, but the particles slide over each other with less difficulty, and they move at greater speeds than do the particles of solids. In gases the particles move more or less at random, and can be considered as knocking one another around, which gives the gas a tendency to expand as pressure is released. The gases of the air are compressed by the weight of the air above, and as we go farther up from the surface of the earth the air is less dense.

Energy is work, anything that arises as the result of work, or anything which can be converted into work. Such a statement is not clear in itself, but it will serve as a starting point for a discussion of energy. For greater clarity, energy can be classified into many different forms, the most common of which are mechanical energy, sound energy, heat energy, electrical energy, light energy and chemical energy.

Energy cannot be created or destroyed, but one form of energy can be converted to other forms. A good example of the conversion of energy from one form to others is the generation and use of electrical energy. The energy of coal is chemical. When coal is burned the chemical energy is transformed to heat energy, which changes water to steam. The steam confined in a boiler builds up a pressure. This steam under pressure is used to drive turbines mechanically coupled to the generators which convert the mechanical energy to electrical energy for distribution.

The electrical energy is converted into various forms as required, such as heat energy to heat flat irons, water heaters, waffle irons, etc.; mechanical energy by electric motors for driving various machines, trains, etc.; light energy for artificial lighting; or into chemical energy for plating metals, charging storage batteries, etc.

Since reference will be made to the various forms of energy later on, a brief discussion of the most important forms of energy is given below.

(*a*) *Electrical Energy.*—The generation of electricity by mechanical means is accepted by all of us as a fact. The ease with which electrical energy can be converted into other forms, and the ease with which it can be transmitted from one place to another had led to its wide use in our modern times. Electricity plays a very important part in the recording and reproduction of sound pictures, and a fundamental knowledge of the behavior of electricity is necessary for a clear understanding of the processes involved. Therefore a brief discussion of the principles of electricity will be given later.

(*b*) *Light Energy.*—Light is anything which affects the sensation of sight. It may seem peculiar to consider light as a form of energy, since it was said that energy was anything which arose from work, or which could be converted into work, or was work itself. It cannot be shown very easily that light is work, but it is easy to see that light may arise as a result of work, as, for example, the red hot sparks that fly from a high speed saw in cutting steel. In this case a great deal of heat is generated. The heated material emits light depending on the degree of temperature. Another interesting feature of light is the fact that practically all of the energy which exists on the earth came here as light from the sun. It is this light energy from the sun which produces our winds, and gives us rain and the resultant water power.

These effects are commonly attributed to the heat of the sun's rays, but heat does not travel through a vacuum as evidenced by the "Thermos" bottles in every day use. Practically no heat arrives at the earth directly from the sun, but is produced at the surface of the earth by the effect of the light rays. This gives us a striking example of the transformation of energy from one form to another. When the light from the sun strikes the earth, the surface of the earth is heated, which, in turn, heats the surrounding air. Heated air is lighter than cold air and rises, thus setting the air in circulation and producing winds. The warm air evaporates water from the surface of the earth (oceans, lakes, rivers, etc.), and rising warm air currents carry the evaporated moisture up with them until they come in contact with the cooler upper layers of air and are cooled. Cold air cannot hold as much water vapor as warm air so that, when the warm air is cooled, the water vapor contained in it condenses and falls as rain. Some of this rain falls on portions of the earth's surface of high elevation, and the energy of the water due to its elevated position is available for turning water wheels for the generation of electric power.

(*c*) *Heat Energy.*—Heat, as pointed out above, is another form of energy, and a certain amount of it is produced whenever work is done in any form as a sort of by-product of the work itself. This is usually considered as a loss of energy except where it is produced for a definite purpose.

Frictional losses in machinery result from the transformation of mechanical energy to heat energy. If the bearings are not kept lubricated so as to reduce this loss, the bearing surfaces will heat up and become pitted if not entirely destroyed.

Also, whenever an electric motor is run or electrical energy is transmitted a loss occurs in the wire leads, which is called a "resistance loss." Therefore it is necessary to use wire large enough to prevent high losses and excessive heating. In the case of an electric flat iron or other heating device, the transformation of electrical energy to heat energy is not considered a loss because it is produced for a useful purpose.

(*d*) *Chemical Energy*.—The chemica energy which a substance has is contained in it by virture of its chemical composition. It is rather difficult to understand what chemical composition has to do with work, but it is easy to understand that chemical energy can be converted into work. Such a conversion takes place in a gasoline, oil, or steam engine when the chemical energy of its fuel is converted into work for driving automobiles, motor boats, ships, etc.

(*e*) *Mechanical Energy*.—There are two kinds of mechanical energy—potential energy and kinetic, or dynamic, energy.

Potential energy exists by virtue of the position or condition of matter. An example of potential energy stored in matter by virtue of its position is a mass elevated to a position from which it can do work when lowered, such as a reservoir of water at an elevated position, which can be made to turn water wheels at a lower elevation for driving machinery. An example of potential energy by virtue of condition is a compressed gas which can be made to perform work when released, or a rarefied gas (vacuum or partial vacuum) which can also be made to do work. A common example of this is the wind shield wiper of an automobile where the wiper motor is worked from the vacuum tank.

Dynamic energy exists in moving bodies. It requires work to set a mass of matter in motion and likewise to stop it once it is set in motion. An example of kinetic energy is water flowing in a pipe. If we consider again an elevated reservoir supplying water to a water wheel, we will remember that the energy of the water when it was in the reservoir was potential energy. The water is piped to the water wheel, and at a point just before it comes in contact with the wheel it has no longer any potential energy, although its energy has not yet been used in turning the wheel; but the potential energy which was in the water in the reservoir has been converted to dynamic energy or energy of motion.

In order to obtain a clearer understanding of the difference between potential and kinetic energy, let us for a moment consider the two principal types of old time water wheels used by the miller in grinding flour. One type of wheel—the "overshot" wheel—contained a row of boxes, or "buckets," around the rim of the wheel. The axis of the wheel was horizontal, and the location of the wheel was so chosen that water from a higher elevation could be directed by means of a trough so as to fall into the buckets at the top of one side of it. The weight of the water in these buckets caused the wheel to turn. In this case the energy to rotate the wheel arose directly out of the potential energy stored up in the water by virture of its elevation.

On the other hand, we may consider the operation of an "undershot" wheel. This type of wheel was similar in its location and mounting to that of the "overshot" wheel described in the previous paragraph, but, instead of "buckets," a number of "paddles" were located around the rim of the wheel, and, instead of water being directed over the wheel, it was caused to flow under the wheel is such a way as to strike the paddles. The kinetic energy of the swiftly moving water, upon being brought to bear against the paddles, rotated the wheel.

(*f*) *Sound Energy.*—Sound is not usually considered as a separate form of energy but as a variety of mechanical energy. You will remember that under "Mechanical Energy" it was stated that both compressed gases and rarefied gases contained energy by virtue of their condition, and we stated that this energy could be converted into work. Sound, being an alternate succession of compression and rarefactions of air, is a particular form of energy which is capable of doing work, such as driving the membrane of the ear to produce the sensation of hearing, or driving the diaphragm of a microphone to produce electrical impulses. Likewise, sound waves drive the diaphragm of an Ediphone machine, which, in turn, drives the cutting point that makes a record on a wax cylinder. This is similar to the method used in making the old type of phonograph records. In the new method the sound is picked up with a microphone and converted into electrical impulses which are amplified before being converted to mechanical impulses for cutting the record.

CHAPTER II

ELEMENTS OF ELECTRICITY

(A) MAGNETISM

11. Discovery of Magnetism.—You are all probably more or less familiar with magnetism and its mysterious behavior. It is not our purpose to try to explain this mystery, but rather to state the simple laws of magnetism, so that you may better understand the operation of the electrical devices of reproducing equipment.

It was known to the ancient Greeks that certain "stones," found in a region of Asia Minor called Magnesia, had the peculiar property of attracting to themselves small bits of iron, and that when two of these "stones" were brought near one another there was sometimes present a force which tended to draw them together, and at other times the force present tended to keep them apart. The Greeks called the "stones" "magnets" after the country where they were found.

It was later found that when one of these magnets was hung, suspended by a string, one portion always turned towards the north. Some of the Mediterranean merchants used these magnets to aid them in navigation. As a result of this use the magnets were termed "leading-stones" or "lode-stones."

A still later development arose as a result of the discovery that a piece of iron or steel when rubbed against a magnet acquired its properties to a somewhat less degree. It would pick up other bits of iron or steel, attract or repel another bit of iron similarly treated, and would take up a definite position north and south when freely suspended. Such a piece of iron or steel is said to be "magnetized." The Italian navigators as early as the tenth century utilized the tendency of a magnetized steel needle to place itself north and south. Their first compass consisted of a horizontal card attached to a cork in which was mounted a magnetized steel needle. The edge of the card was marked with "the points of the compass," and this whole unit was floated in a bowl of water the edge of which was marked in line with the keel of the ship.

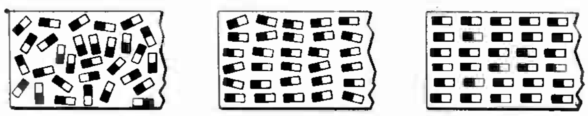
The original magnets or "lode-stones," which were not really stones, but were instead a combination of two iron "ores," are called "natural magnets"; and magnets made by rubbing pieces of iron or steel against "natural magnets" (or by any other means) are called "artificial magnets."

In examining the action of any magnet, it will be found that in at least two positions its magnetic properties will be much more pronounced than at others. These points are termed the "poles" of the magnet.

The space surrounding a magnet in which its influence may be observed is termed the "magnetic field."

12. The Nature of Magnetism.—Magnetism and electricity are peculiarly related. *It has been found that every time a loop of wire located in a magnetic field is moved in such a way as to change the strength of the field with respect to the coil, an electric current will flow in the loop; and also, that whenever an electric current flows in a wire, the wire is surrounded by a magnetic field.* These two facts will be amplified in the succeeding paragraphs.

If several turns of wire are wound around an iron rod, and an electric current from a battery is passed through the wire, the iron rod becomes magnetized as shown by its ability to pick up iron filings, tacks, etc. If the rod is of soft iron, practically all of the magnetism will disappear when the flow of the current is stopped. If the rod is of hardened steel, an appreciable amount of the magnetism will remain after the flow of the current has ceased and the piece of steel so treated becomes a permanent magnet. If one end of such a rod is brought close to a magnetic compass, it will attract one end of the compass needle toward it. If the opposite end of the



(a) (b) (c)

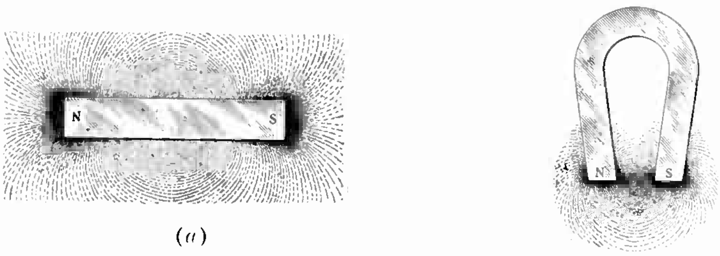
Figure 6—Molecular construction of unmagnetized and magnetized material

rod is brought near the compass, it will attract the other end of the compass needle. Since a magnetic compass is itself a small permanent magnet, the behavior just described shows the effect of one magnet on another.

In order to study the action of magnets a little more, bring together the ends of two magnetized steel rods which attract the same end of the compass needle, and it will be found that they repel each other; but, if the ends of the two rods which attract opposite ends of the compass needle are brought close together they will be strongly attracted to each other, proving that opposite ends of a magnetized iron rod act differently when brought near one end of another magnet. The pole of a magnet which attracts the end of the compass needle which normally points north is called the south pole of the magnet, and conversely the pole of a magnet which attracts the end of the compass needle which normally points south is called the north pole of the magnet. From the above discussion this general rule is formed: ——*magnetic poles of like polarity repel each other, and magnetic poles of opposite polarity attract each other.*

An iron rod can be considered as being made up of a large number of small permanent magnets. When the iron rod is not magnetized, the tiny magnets will be arranged in a random fashion such as shown in Figure 6 (a). If a wire is wound around the rod and a current is passed through the wire from a battery, the tiny magnets which compose the iron will arrange themselves in a manner similar to that shown in Figure 6 (c), thus aiding the electric current in producing a magnetic field. When the flow of current is stopped the tiny magnets will return to very nearly their original position, and most of the magnetism will be gone if the rod is of soft iron; but, if the rod is of hardened steel, the little magnets will remain more nearly in the position shown in Figure 6 (b), after the flow of current has been stopped. It takes a stronger current to produce a magnet of the same strength using a hardened steel rod than it does if a soft iron rod is used, but hardened steel retains its magnetism after the magnetizing current is stopped. This leads us to believe that it is more difficult to change the position of the little magnets in hardened steel than in soft iron.

If iron filings are sprinkled on the surface of a sheet of paper placed directly over a magnet, the filings will arrange themselves in a pattern similar to that of Figure 7 (a). If the rod is bent into the shape of a horseshoe, we have what is called a horseshoe magnet, and the pattern formed by iron filings over such a magnet will be as shown in Figure 7 (b). It will be noticed that the iron filings arrange themselves in curved lines connecting the north and south poles of the magnet, and that the lines of the horseshoe magnet are concentrated within a small area. These lines represent lines of force which are assumed to exist between the poles. Figure 7 shows that the lines of force are more numerous and more concentrated when the poles are close together. If a piece of soft iron is placed between the poles, touching one pole but not the other, so as to reduce the air gap between them, the lines of force in the gap will be still further increased. This shows that the number of lines of force varies with the air gap between the poles, and the number of lines of force increases as the air gap is made smaller. In other words, the iron serves as a path of low resistance for the magnetic lines of force as compared with the resistance offered by air. This can be shown more readily by passing a current through a coil of wire and noting the strength of the magnetic field produced, and then noting the increase of the strength of the field when an iron rod is inserted through the coil.



(a) (b)

Figure 7—Magnetic fields

It should also be noted that the coil of wire, without the iron rod through it, behaves exactly like an iron magnet in attracting the needle of a compass when an electric current from a battery passes through the coil. It is important to have a fairly good idea of magnetic lines of force because this property of magnetism will be referred to repeatedly in later discussions.

(B) ELECTRICITY

13. Nature of Electricity.—As stated in Chapter I, all matter is composed of small particles called molecules. These molecules themselves are composed of smaller particles which have positive and negative charges of electricity. Some of the negative charges, called "electrons," are more or less free to move. Normally a molecule consists of an equal number of positive and negative charges. If one electron is taken away, the molecule is said to be positively charged; or, if a molecule has one more electron than normal, it is said to be negatively charged. Likewise, if a neutral body has one or more electrons removed from it, the entire body is said to be positively charged or, if electrons have been added, it is said to be negatively charged. If either a positively charged or a negatively charged body is brought near a neutral body (one without charge), there will be an attractive force between them; or, if a negatively charged body is brought near a positively charged body, there will be an attractive force between them. On the other hand, if a positively charged body is brought near another which is also positively charged, or, if a negatively charged body is brought near another negatively charged body, there will be a repelling force between them. In other words, *bodies having like electrical charges repel each other, and bodies having unlike electrical charges attract each other*. The reason that a neutral body is attracted by a charged body is that, although the neutral body is neutral within itself, it is not neutral with respect to the charged body, and the two bodies act as if oppositely charged when brought near each other.

If an electrically charged body, such as a metal sphere, is connected by a wire to a neutral body, such as the earth, a charge will flow between the neutral body and the sphere so as to equalize the charge on the two bodies. This flow of electric charges is known as an electric current. The moving charges themselves are called "electrons" and are always negative.

The flow of an electric current can be understood most readily by considering the molecules of which all matter is composed. As stated before these molecules are made up of equal positive and negative charges (protons and electrons). Some of the negative particles (electrons) are more or less free to move. The number of free electrons and the freedom with which they can move depends upon the substance. Good conductors of electricity, such as copper, have large numbers of free electrons which move with comparative ease, and the application of energy (chemical, magnetic, etc.) in the proper form will cause some of the electrons to move from one molecule to another in a direction from a point of low to a point of high "potential"—as electrical pressure is called. This flow of electrons constitutes an electric current. New electrons to take the place of those which have traveled away from the point of low potential are supplied from the source of potential (battery, generator, etc.). In other words, the source of potential acts as a pump driving electrons into the point of low potential, and pumping them out of the point of high potential.

To explain further, if a copper wire is connected between the terminals of an electric battery, electrons will move from one molecule to another. As one molecule receives an additional electron, it passes another on to the next molecule. Under the conditions just stated, the current flows out of one terminal of the battery through the wire, and back through the battery in a continuous circuit until the circuit is broken or opened. Besides this relaying of the electrons by the molecules the electrons themselves drift along the wire a few feet a minute. An idea of the number of electrons required to produce even a small value of electric current will be gained from the fact that it is necessary for billions of electrons to be in motion through a small electric lamp every second to light it.

[In the early days of the discovery of electricity certain terminals of electric batteries were termed positive and negative and the current was said to flow from the positive (+) to the negative (—). In view of later discoveries this assumption is incorrect but has persisted nevertheless. The fact that electric currents are said to flow from plus to minus, positive to negative, or high potential to low potential, when as a matter of fact the reverse is true gives rise to a great deal of confusion. It is important that you remember this fact, *while current is said to flow from positive to negative, it actually flows from negative to positive.*]

14. Ohm's Law.—In some substances the electrons are so strongly attracted to their corresponding protons that it is impossible to move them by means of the potentials we are using. These substances are known as "non-conductors." In various stages between what are termed "conductors" and "non-conductors" are materials in which the electrons are comparatively hard to move, but which will carry a current depending upon the amount of electrical pressure applied. All conductors offer fairly low "resistance" to the flow of electric current. Metals as a rule have comparatively low resistance, while non-metallic substances such as porcelain, wood, glass, etc., offer a very high resistance to the flow of electric current.

The resistance offered by a wire is in proportion to its length and cross-section. That is, a wire of a certain material which is twice as long as another wire of the same diameter and material will have twice the resistance. Two wires of the same material and of the same length will offer different resistances to the flow of current if the areas of their cross-sections differ. If one wire has one half the area of cross-section as the other, it will offer twice the resistance to the flow of the current.

The flow of an electric current in an electrical circuit is very similar in its action to the flow of water in a water system. To have a flow of either water or electricity, it is absolutely necessary to have first a pressure. Without pressure there is never any flow. In electrical circuits the pressure is called "potential," and it is measured in units called "volts." Since the unit of potential is called a volt, potential itself is quite often called "voltage." If a pressure is applied to water in an open pipe line by means of a pump, the amount of water which will flow through the pipe depends on two things, first, the pressure; and second, the size of the pipe, which determines its resistance to the flow of water through it. If a certain pressure is applied to the pipe line, a certain flow of water will result. If this pressure is doubled, the rate of flow will be doubled; and, on the other hand, if the pressure is cut in half, the rate of flow will be halved. In like manner, if the size of the pipe is doubled the rate of flow will be doubled; and if the size of the pipe is decreased, the water will flow at a decreased rate in direct proportion to the decrease in the size of the pipe.

The same thing is true of electrical circuits. If the current through an electrical circuit at a certain voltage is measured, and then the voltage is doubled, the current reading will also be doubled. It can also be observed that, provided the pressure is kept constant, and, instead, the size of the conductor is varied either in length or in cross section, the current will change also. Increasing the length of the conductor or decreasing its cross-sectional area will decrease the current, since this will increase the resistance. All other things being equal, if the resistance of a circuit is cut in half, the current will be doubled; and if the resistance is cut to one-third of its original value the current will be trebled, and vice versa; that is, three times the resistance will result in one-third of the current, etc. These facts were first presented as a definite rule by a man named Ohm, which resulted in the use of his name as applied to the unit of resistance. The unit of current is known as the ampere. *The value of an ohm of resistance was so chosen that it would require an electrical pressure of one volt to force an electric current of one ampere through it.*

If any two of the three factors mentioned above (voltage, current, and resistance) are known, the third factor may be found from one of the following equations:—

$$E = RI, \quad I = \frac{E}{R}, \quad and \quad R = \frac{E}{I},$$

where E represents the voltage, R the resistance in ohms, and I the current in amperes.

If a valve is placed in the pipe line, the flow of water can be restricted. In the same manner the flow of electricity can be restricted by placing a resistance in the circuit. If the resistance is made variable, the current can be changed at will. A variable resistance of this type is known as a rheostat.

If the water pipe is tapped at various points at different distances from the pump, and the water pressure is measured between these points while water is flowing through the pipe, the pressure of the water will be found to vary in proportion to the distance of these points from the pump measured along the pipe. A resistor carrying an electric current and tapped at various intervals has a similar effect, that is, if the voltage is measured between one end and the different taps, the voltage will vary from one point to another. A resistor used in such a manner is known as a potentiometer. Potentiometers of the simplest variety are usually made of "resistance wire" wound on a form, and are provided with a sliding arm which permits contact with the resistor at any point throughout its length. With such a device any desired fraction of the impressed voltage can be "tapped off" by simply moving the sliding arm.

15. The Production of Electricity by Contact.—All electricity is basically the same, no matter how produced. Static electricity gains its name from the manner in which it is produced; *i. e.*, by rubbing together two insulating materials, such as a glass rod and piece of silk. When two different materials are rubbed together and then separated, they are both found to be electrically charged. One of the materials is charged to the opposite polarity from the other. This is caused by the electrons of one of the substances being rubbed off and gathered by the other. Since the materials are insulators, the charge does not flow off and they remain electrically charged. The charge is therefore said to be "static." If touched by another substance they will discharge to it a portion of their charge. If touched to the earth they will give up their entire charge. Electricity produced in this manner has very little value because of the inefficiency of its generation, although it may be very annoying when produced where it is not wanted, as in the case of belt driven machinery, or in nature in the form of lightning.

16. **The Production of Electricity by Chemical Action.**—Electricity can be generated by chemical means. Examples of electricity generated in this manner are shown in the use of (so called) dry batteries, wet batteries and storage batteries.

Two different substances, such as copper, zinc, carbon, etc., immersed in a dilute solution of acid, constitute an electric cell. The two solid substances are called "plates" and the acid solution is called the "electrolyte." The plates extend above the solution for making external connections. If the two plates are connected together by means of a conductor a current will flow through the connection. The energy is furnished by the action of the acid on one of the plates, which is eaten away as the current circulates. The current will continue until a plate is entirely eaten away or the active element of the acid is used up. In order to renew the cell it is necessary to replace the consumed plate and the acid solution. A common example of such a cell is the ordinary "dry" cell with zinc and carbon plates. The acid solution, instead of being liquid, is a paste formed by impregnating absorbent material with the acid solution. If the direction of current through such a cell is reversed, neither the acid nor the plate will be restored, so that such a cell can not be used as a storage battery. This type of electric cell is called a "primary cell."

In certain types of cells the original condition can be restored, after the cell has been discharged, by forcing current through it in the opposite direction to that in which it delivers current. In such a cell neither plate is eaten by the acid, but the chemical compositions of the plates change, and, although the acid is weakened as the cell discharges, it is restored to its original strength when the cell is recharged. This type of cell is known as a "storage cell." The commercial name "storage battery" is derived from the fact that several cells are arranged together to form a "battery" of cells. A storage battery does not actually store electricity, but stores energy by chemical means which is readily changed to electrical energy when the proper external connections are made to the battery.

17. **The Production of Electricity by Rotating Machinery.**—Electricity can be produced dynamically, *i.e.*, from motion and this method is always used when a large amount of electrical power is desired. It is produced in this manner by means of

rotating machines called "generators" or "dynamos." In order to understand how electricity is produced by such a machine it is necessary to know something about the relation between electricity and magnetism.

In the discussion of magnetism it was stated that a magnetic field surrounded a magnetic pole, and that this field consisted of imaginary lines of force which extended from one pole to another. If a loop of wire is placed in the field in such a manner that some of the lines of force pass through the loop, nothing occurs as long as the loop is held stationary and the magnetic field kept at a constant strength, but, if the number of magnetic lines of force which pass through the loop of wire is changed, a voltage will be generated in the loop in proportion to the change in the number of lines through the loop in a second of time. The number of lines of force which pass through the loop can be changed by changing the position of the loop with respect to the magnet or by varying the strength of the magnetic field, but, if the position of the loop is changed without changing the number of lines of force through it, no voltage will be generated.

If the loop is closed, current will flow in the loop whenever a voltage is generated in it. Thus we have the prerequisites for electric power, namely, current and voltage. If a loop of wire is rotated in a magnetic field in such a manner that the number of lines of force through the loop is continuously changing in number, an alternating current is generated. In order to change the alternating to direct current a mechanical device known as a "commutator" is used. The production of electric power by generators will be discussed in more detail in Chapter III.

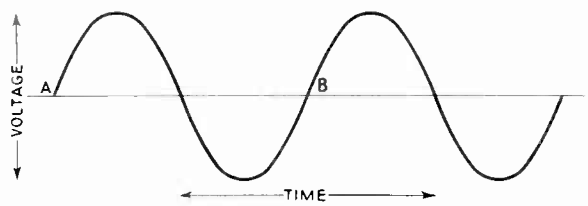


Figure 8—Representation of alternating voltage

18. Alternating and Direct Currents.—In speaking as we have above, of "alternating" and "direct" current, the problem immediately presents itself — just what is meant by these terms "alternating" and "direct" as applied to electricity? What is termed *a "pure direct current" is a very steady, even flow of current in one direction,* such as is obtainable from a battery.

An alternating current, on the other hand, flows first in one direction, dies out completely, and then flows in the opposite direction. This reversal of the current is not an immediate or instantaneous one, but is a gradual change from one condition to another, similar to the action of wave motion described in Chapter I. The current, beginning at zero, gradually builds up to a maximum value whereupon it dies down to zero, and then reverses in direction and builds up to a similar maximum value in this opposite direction. If we were to draw a figure to represent this action it would be similar to Figure 8. In this figure, the distance along the horizontal line represents the interval of time during which measurements of current or voltage are taken. Distances measured vertically indicate the value of voltage or current at the time indicated by the corresponding horizontal distance at which the vertical measurement was made. This curve shows that the voltage, beginning at "A," increases to a maximum value and then falls to zero. The fact that the voltage is in the reverse direction in the next period is indicated by the portion of the curve drawn below the zero line. This does *not* indicate that the voltage is less than zero, but shows only that it is reversed. After building up (or down, as shown by the curve) in this reverse direction, the voltage falls (shown by a rise in the second loop of the curve) until it reaches zero again at "B." This action (shown from "A" to "B") represents that of a single cycle of alternating voltage or current. Each cycle consists of two pulsations in opposite directions. Figure 8 illustrates two complete cycles. The number of times per second that this action, as represented from "A" to "B," takes place is called the frequency of the voltage, or current, and is expressed as a certain number of cycles. The frequency of most power systems is 60 cycles, meaning that the current flows back and forth 60 times (120 pulsations) per second. Frequencies of 25, 40, or 50 cycles are supplied by some power

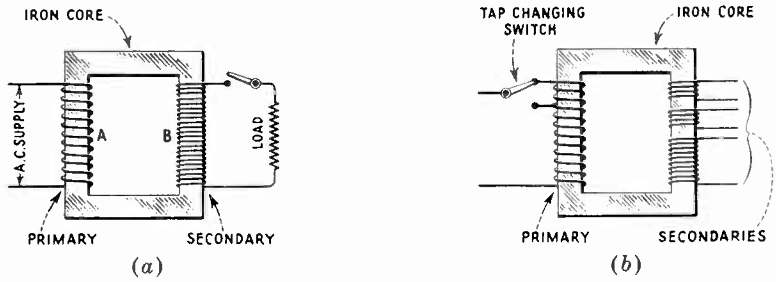


Figure 9—Transformer connections

companies, necessitating the use of different equipment from that supplied for use on 60 cycle systems. The reasons for these differences will be explained later.

Direct current is more suitable for certain purposes than alternating current, and, conversely, alternating current is better suited for other purposes. Direct current motors are used when variable speed is required, such as in street cars, elevators, etc. For most other purposes AC motors are usually preferable because of their greater simplicity. Direct current is required for vacuum tube amplifiers. The DC required for this type of apparatus can be obtained from batteries, motor-generator sets or rectifiers. A rectifier is a device for changing AC to DC without, ordinarily, the use of rotating machinery.

Alternating current is best adapted for the transmission of electric power because of the ease with which it can be changed from one voltage to another. This is important because electric energy cannot be transmitted efficiently long distances except at high voltages. Therefore, it is necessary to raise the voltage for transmission and reduce it again where it is used and, at present, no simple method has been devised for changing DC voltages up and down for transmission purposes. A common device for changing AC voltage is known as a transformer.

19. Transformers.—A transformer usually consists of two separate windings on an iron core (See Figure 9). It was stated at the beginning of this chapter that when a current is passed through a wire a magnetic field is formed around the wire, and if an iron bar is placed in such a field it is magnetized. Magnetic lines of force were described. These lines extend through the iron as well as through the air, and they form in closed loops, parts of the loops being in the iron and parts of them being in the air. If the entire path is in iron, *i.e.*, if we have an iron ring, the number of lines of force are increased because it requires less magnetizing force to produce lines of force in iron than in air. Earlier in this chapter it was stated also that if the lines of force which passed through a loop changed in number, a voltage would be generated in the loop.

Referring to Figure 9 (a), if an alternating voltage is applied across the terminals of coil "A" an alternating current will pass through the coil. The current will set up lines of force through the iron, and the number of lines of force set up will be proportional to the current in the coil at any instant. Since the current is constantly changing, the lines of force will be constantly changing also. Coil "B" is a series of loops connected together, so we should expect to have a voltage generated in coil "B" when an alternating current was flowing in coil "A," and such is the

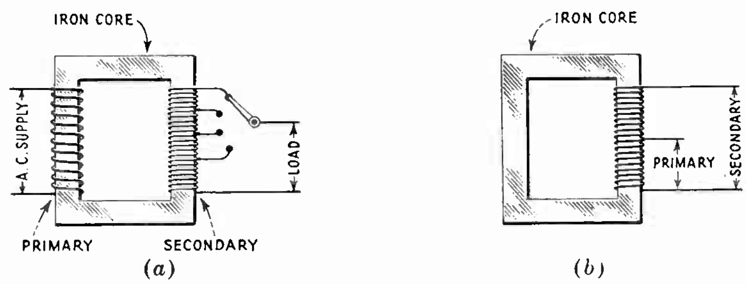


Figure 10—Transformer connections

case. If coil "B" is closed through an external circuit similar to that marked "Load," current will flow in the load circuit. Coil "A," or the coil to which the alternating current is supplied from an outside source, is called the primary. Coil "B," the coil in which the voltage is generated by the transformer action, is called the secondary of the transformer. Instead of having only one secondary winding, any number (within practical limits) can be used so as to supply several circuits at different voltages as shown in Figure 9 (b).

The voltage generated in the secondary winding depends on the ratio of the number of turns of the secondary compared with the number of turns of the primary. If the secondary has twice as many turns as the primary, it will have twice the voltage of the primary, or if it has one-half the number of turns of the primary, it will have only one-half the primary voltage. It is therefore possible to obtain any desired voltage within quite a wide range.

If the primary voltage is less than the secondary voltage, the transformer is called a step-up transformer, and if the primary voltage is greater than the secondary it is called a step-down transformer. Some transformers are provided with a tapped primary [See Figure 9 (b)], for the purpose of adjusting the transformer to the supply voltage. By using the proper tap, the ratio of the number of secondary turns to the number of primary turns is adjusted to give the proper secondary voltage when the supply voltage is too high or too low. When it is desirable to have the secondary voltage variable over a considerable range the secondary is sometimes tapped [as in Figure 10 (a)]. A transformer may have several secondary windings all insulated from each other [Figure 9 (b)], and the voltage generated in each secondary winding will be independent of the voltage generated in the other secondary windings; in other words each secondary winding behaves as though the other secondary windings were not present. Another type of transformer called the auto-transformer is sometimes used. In this transformer both the primary and secondary windings use some turns in common. The same laws regarding the voltage ratio of the windings hold for the auto-transformer as for transformers where the windings are entirely separate. As shown in Figure 10 (b), the primary uses only a fraction of the total number of turns while the secondary uses all the turns of the winding. This condition could just as well be reversed. The connections used depend upon the voltage change desired.

The figures used in conjunction with this discussion of transformers show the primary and secondary windings on different legs of the iron core. In practice the windings may be as shown, but they are usually wound one on top of the other. One method is about as good as the other so far as operation is concerned, and all the statements made regarding transformer action are true for transformers in which the primary and secondary are on the same leg of the core, as well as when they are on separate legs.

Transformers used to transform the voltage of power circuits are known as "power transformers." Transformers used to change the voltage of speech frequencies are known as "audio transformers." The electrical action in both types is the same. The difference arises from the difference of the frequencies involved and the use to which the transformers are put. A power transformer should not be used on circuits of lower frequency than that for which it was designed unless the primary voltage is reduced a corresponding amount, that is, a 60 cycle transformer with a 110 volt primary should not be used on a 110 volt, 25 cycle circuit, because it would become over-heated and burn out.

20. Impedance.—If a 110 volt DC circuit was connected to a 110 volt primary of a power transformer, the transformer would probably burn out immediately, and the current would be over twenty times the current for which the primary was wound. Therefore, it is evident that direct current and alternating current behave differently in certain types of circuits. It was implied in the discussion of Ohm's law that resistance alone limited the current in DC circuits, but it is evident from the behavior of DC in transformers that there is some other property that limits the alternating current in a transformer circuit. This property of the transformer circuit which limits the alternating current is known as impedance.

Impedance is the name given to that property of any electrical circuit which limits the current flow in the circuit when a voltage is applied to its terminals, and is made up of three factors: resistance (already described for DC circuits under Ohm's law), inductance, and capacity.

The pure resistance of a circuit to an alternating current is the same as to a direct current.

Inductance does not affect a direct current but has considerable effect on an alternating current. When a current flows in a conductor a magnetic field is formed around the wire in proportion to the strength of the current. If the conductor is in the form of a coil, a strong magnetic field is produced, and, if the coil is wound on an iron core, an even stronger magnetic field is set up. When a magnetic field is created the number of lines of force through the coil producing the field must increase, but if the number of lines of force through the coil is increased, a voltage will be generated in the coil. The generated voltage opposes the applied voltage and prevents the current from increasing rapidly. This property of a circuit which prevents a rapid change of current is called inductance. Inductance can be considered as an electrical inertia. From this discussion we see why the rapidly changing alternating current does not reach a destructive value in a transformer, while the steady direct current increases rapidly to a value limited only by the pure resistance of the circuit. Coils wound for use in circuits to offer a high impedance to an alternating current while offering a low resistance to a direct current are called "inductors" or "reactors." Such devices are used in certain types of amplifiers, or in the filter circuits of socket power units used to supply the DC voltage for the amplifiers.

The third type of impedance is capacity, and the device used in obtaining this type of impedance is called a condenser. A condenser will not pass direct current but passes alternating current in proportion to the frequency of the applied voltage. Condensers are used in the filter circuits of socket power units and, when so used, act as reservoirs to absorb ripples in the direct current and thereby smooth out its flow. Condensers are also used to prevent the flow of direct current while passing the desired alternating current, and when used in this manner they are called by-pass condensers.

CHAPTER III

MOTORS AND CONVERTING EQUIPMENT

(A) GENERAL THEORY

21. **Generation of Electricity by Rotating Machinery.**—It was explained in the previous chapter that when a current is passed through a wire, a magnetic field is set up around it, and that a voltage is generated across a loop of wire placed in a magnetic field if the number of magnetic lines of force included within the loop are changed. The magnitude of the voltage generated depends upon the rate at which the number of lines of force through the loop are changed, *i.e.,* if a change of ten lines of force per second produces a certain voltage, a change of twice ten, or twenty, lines per second produces twice the voltage. The total number of lines through the loop at the time of the change has no effect upon the voltage generated. Specifically stated, this means that the same voltage is produced in a coil when the number of lines is changed from 100 to 120 in one second, as when the number of lines is changed from 1,000 to 1,020 in one second, because the rate of change of the number of lines through the loop is the same (20 lines per second) in each case.

The direction of the generated voltage depends upon the direction of the lines of force through the loop, and upon whether the number of lines of force through the loop are increasing or decreasing.

The process of following through the different changes of position of a rotating loop so as to determine the nature of the generated voltage in it, is complicated and not easily understood. The generation of a voltage in a loop can be more readily understood if the sides of the loop are thought of as cutting the lines of force. When so considered the voltage generated is proportional to the number of lines of force cut per second, and the direction of the voltage generated depends upon the direction in which the sides of the loop cut the lines of force.

Figure 11 shows a magnetic field in which there is a loop of wire. The magnetic lines of force flow from the north pole to the south pole in parallel lines across the air gap between the poles. In (a) a loop of wire is shown in a position such that one side of the loop is cutting the lines of force in one direction, and the other side of the loop is cutting the lines in the other direction. The direction in which the loop is turning is shown by the arrow at the crank. Under this condition a voltage is generated in side "A" so as to cause current to flow in the direction shown by the arrow at that side of the loop. Side "B" of the loop cuts the lines of force in the opposite direction, therefore the voltage generated in side "B" causes a current to flow in the opposite direction, as shown by the arrow at that side of the loop. The voltage generated in the sides of the loop causes a current to flow into one side and out of the other. In order for a current actually to flow through the loop, a connection would have to be made between the rings shown in the drawing. The drawings do not show an external connection, but the arrows indicate the direction the current would flow if an external connection was made. When the loop is in such a position as to be at right angles to the lines of force, as shown in (b), there will be no voltage generated in the loop, because the sides of the loop do not cut any lines of force when in this position. The same thing is true when the loop is rotated through a half turn, and side "B" is at the top and side "A" at the bottom. Therefore there is no voltage generated in the loop for two positions during each revolution. When the loop is in the position shown in (c), one half turn from position (a), the voltage generated in side "B" is such as to cause the current to flow into that side of the loop, and the voltage generated in side "A" is such as to cause a current to flow out of that side of the loop. Thus the direction of flow of the current through the loop reverses as it changes its posi-

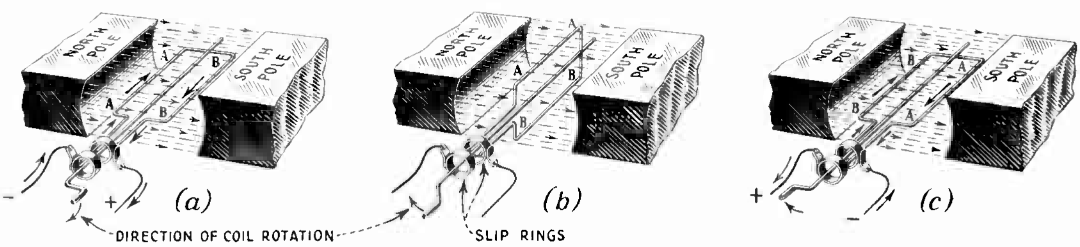


Figure 11—Operation of AC generator

tion from (a) to (c). When the sides of the loop are in the positions shown in (a) and (c), the number of lines of force cut for a given amount of rotation is greater than when the loop is in any other position. As the loop rotates from position (a) to position (b) the number of lines cut for equal amounts of rotation gradually becomes less until, at position (b), no voltage is generated, because when the loop is in position (b), the sides of the loop are moving along the lines of force instead of cutting them. From this it is seen that the voltage is continuously varying in magnitude and twice during each revolution the voltage is zero; also, the voltage changes direction twice for each revolution. The current generated by such a machine is called an alternating current because it alternately flows in one direction and then in the other. Two rings, one connected to each side of the loop, are provided, together with wiping contacts called "brushes" to permit external connections to the loop while it is in rotation. The rings are called "collector rings," or "slip rings." These rings are usually made of copper or brass, but iron is sometimes used. They are insulated from the shaft and from each other. The brushes are usually made of carbon or a combination of carbon and some metal.

A DC generator is the same as an AC generator except in the manner of collecting the generated current. Figure 12 shows a simple DC generator consisting of a magnetic field, one loop, and a collector ring split into two parts. These parts, called "segments," are insulated from the shaft and from each other. One segment is connected to one end and the second segment to the other end of the loop. This type of collector is called a "commutator." As in the case of an AC generator, brushes are mounted so as to make a wiping contact with the split ring and permit current to be drawn from the generator as it rotates. The brushes are mounted so that they change contact from one segment to the other when the loop is at right angles to the lines of force as shown in (b) of Figure 12. It will be remembered from the discussion of the alternating current generator that, when the loop is in this position, there is no current generated in it. Therefore, shorting of the loop, caused by the brushes making contact with both segments at the same time, will do no damage because there will be no current flowing. When the loop is in the position shown in (a) the current will flow in at the left-hand brush and out at the right hand brush. When the loop is in position (b) no current will flow because no voltage

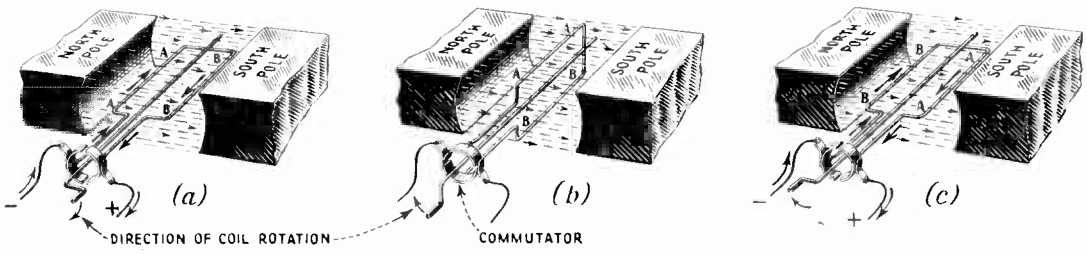


Figure 12—Operation of DC generator

is generated in the loop. When the loop is in position (c) the current again flows in at the left-hand brush and out at the right-hand brush. The current that flows in the loop changes in direction as the loop changes from position (a) to position (c) as it did in the AC generator, but the brush connections also change when the loop is rotated, that is, side "A" of the loop is connected through the commutator to the left-hand brush when the loop is in position (a), and is connected to the right-hand brush when the loop is in position (c), so that the net result is that the current always flows in at the left-hand brush and out at the right-hand brush.

The current flowing in the load circuit of such an arrangement just described, with only one loop and two segments, is pulsating (continually varying in magnitude), but flowing always in the same direction. In practice, a large number of loops and segments are used so as to give a fairly constant DC voltage. The loops are connected in series in such a way that the generated voltage is the sum of the voltage generated in nearly all of the loops. The brushes are of such size as to short circuit two or three of the segments, which short-circuits two or three loops. These loops occupy a position as shown in (b) of Figure 12 when they are short-circuited, and very little, if any, voltage is generated in them. However, the current through the loops must change in direction as they pass under the brushes, and an arc will form at the brushes unless they make a firm, even contact. For this reason it is important that the brushes fit the commutator snugly, and that the commutator is kept clean.

22. **Motors.**—The operation of a motor is the same as that of a generator except that the current of a motor flows in the opposite direction through the machine from that in which it flows when the machine runs as a generator; that is, the current flows in one direction with respect to the generated voltage in a generator, and in the opposite direction with respect to the generated voltage in a motor. The current flows into the motor through the positive brush and out at the negative brush. The current of a generator flows out of the positive brush and in at the negative brush. The reason for this is the fact that the generated voltage of a motor is always in opposition to the applied voltage, but never quite as great. Therefore, the applied voltage forces a current through the motor against the electrical pressure offered by the generated voltage.

When a current is passed through the armature winding of a motor, a magnetic field is created in it which has a north and south pole. These poles are attracted by one pole of the motor field and repelled by the other, causing the armature to rotate. In the case of an alternating current machine the field rotates according to the frequency of the alternating current, and the windings follow this field around.

In the case of a DC machine, as the winding rotates the commutator rotates, and the windings through which the current flows is continually changing. The magnetic poles of the revolving windings are always kept at a fixed angle with respect to the field poles and a steady rotating force is maintained. As each portion of the armature winding reaches a position where the field poles produce no turning effect, the commutator action is such as to disconnect these coils, and to connect others which are in a position where a turning effect may be had.

23. **Commercial Motors and Generators.**—Motors and generators, as they are built for use, do not look anything like the illustrations shown in Figures 11 and 12. These illustrations show the action of the machines, but the machines themselves are built in a considerably different form. The field poles of a commercial machine are not "permanent" magnets, but are "electro-magnets" consisting of a field-winding on an iron core. The current for the field-winding is supplied from some source of direct current. In the case of a DC generator, this current is usually supplied by the generator itself, and in the case of the DC motor the field current is supplied from the same source as the current that runs the motor. AC motors are more complicated in their action although the same principles are involved. The explanation of the process is very involved and will not be taken up here.

Figures 11 and 12, show a loop rotating in a magnetic field. In practice a large number of loops are used and they are mounted on an iron core. This iron core reduces the length of the magnetic field in air, and therefore makes it easier to create a strong magnetic field. The space between the rotating iron core carrying the rotating windings and the poles is called the air gap. This air gap varies with the design and size of the motors. For small machines it is sometimes only a few thousands of an inch, while for large generators the air gap may be several inches wide. The rotating part of motors and generators is called the "rotor." In all DC machines and in some AC machines, it is often called the "armature" of the motor or generator. Strictly speaking, the armature is that part of the machine wherein the magnetic field rotates with respect to the windings.

24. Voltage Control of Generators.—As stated earlier in this chapter, the voltage generated in a conductor which is moved through a magnetic field depends upon the number of lines of force cut by the conductor in a second of time. There-

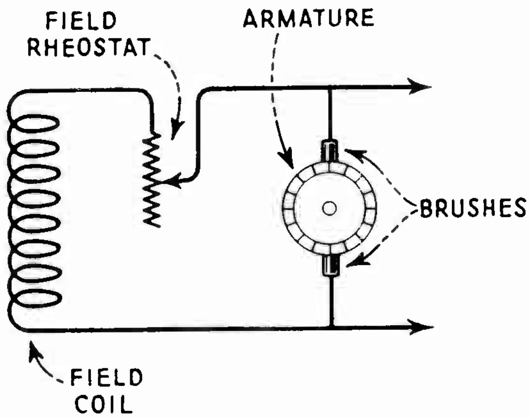


Figure 13—Field control of DC motors and generators

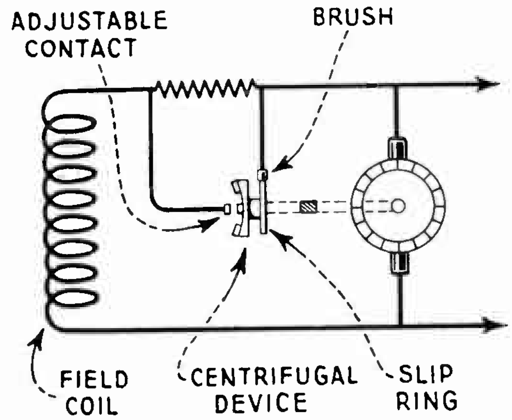


Figure 14—Wiring diagram illustrating operation of speed control device

fore if the speed with which the conductor cuts the lines of force is increased, the voltage generated will be increased. There are two ways of increasing the number of lines of force cut per second by a conductor; one is to speed up the movement of the conductor, and the other is to increase the number of lines of force.

The speed of generators is usually constant, and the voltage is regulated by changing the field strength (increasing or decreasing the number of lines of force in the field). The field strength is controlled by the current in the field winding, and this current is controlled by putting resistance in series with the field winding. See Figure 13. This resistance is made variable, and the device for changing the resistance is called a "rheostat." When resistance is "cut out" of the field circuit, the current increases so that that number of lines of force are increased, and the generated voltage increases in proportion to the increase of the magnetic lines of force of the field. The voltage of a generator is decreased by increasing the resistance in the field circuit, and thereby decreasing the field current.

25. Speed Control of a DC Motor.—While a DC motor is rotating, it generates a voltage in the same way that a voltage is generated in a DC generator. The generated voltage is in the opposite direction as the applied (line) voltage, but not quite equal to it. The voltage which causes a flow of current through a motor is the voltage difference between the line voltage and the generated voltage of the motor. If the line voltage is 110 volts and the generated voltage of the motor is 105 volts, the difference of voltage (110—105, or 5 volts) is used in causing a current to flow in the motor. The resistance of a motor is rather low, and, as a result, a fairly large value of current will flow through the motor armature for a slight difference of voltage between the line voltage and generated voltage of the motor. The generated voltage of a motor, like the voltage of a generator, depends upon the speed of the motor and the number of lines of force in the field poles. The speed of the motor automatically regulates itself so that the generated voltage will allow just enough current to flow through it to produce the necessary torque (turning power) to keep the motor running. If a braking force is applied to the motor, it will slow down a little so as to allow more current to flow to increase the torque. If the number of lines of force in the field of the motor is increased, the motor does not need to run at as high a speed to produce the necessary generated voltage, and the motor slows down. If the number of lines of force in the motor field is decreased, the motor must speed up to produce the necessary generated voltage. Therefore, if a rheostat such as described for regulating the voltage of a DC generator is used in the field circuit of a motor, the motor can be made to "speed up," or "slow down," by changing the amount of resistance in the field circuit. See Figure 13. When the resistance of a motor field circuit is decreased, the motor "slows down" and if the resistance is increased, the motor will "speed up." Therefore, the use of a variable resistance in the field circuit is a very practical method of controlling the speed of a DC motor.

26. Rating of Motors and Converting Equipment. — Motors are rated in horse-power (hp.) or kilowatts (kw.). One horse-power is equal to approximately three-quarters of a kilowatt.

A kilowatt is a thousand watts, and a watt is a unit of electric power. The number of watts of power in a DC electric circuit, or in an AC circuit of pure resistance, is equal to the product of the voltage across the circuit and the amperes through the circuit.

DC generators are usually rated in kilowatts.

AC generators and converters are usually rated in kilovolt-amperes (kv-a). The kv-a of a circuit is the product of the volts and amperes divided by 1000. For example: An AC machine that will deliver 20 amperes at 440 volts has a rating of 20 multiplied by 440 and divided by 1000, or 8.8 kv-a. In DC circuits or in AC circuits of pure resistance the kv-a. and kw. are the same, but in some AC circuits this condition does not hold, and the product of the voltage and current is not equal to the watts of power delivered to, or taken from the circuit. In all such cases, the product of volts and amperes is always greater than the watts of power. The reason for this is very complicated and will not be taken up here.

Usually motors and converting equipment are rated also in volts and in amperes. The rating in amperes should never be exceeded, even though the machine may not be delivering its rating in horse-power or kilowatts, because the heating (which is the limiting factor) depends upon the current through the machine.

(B) PROJECTOR DRIVE MOTORS

27. DC Projector Drive Motors.—The DC projector motor is a standard shunt-wound direct current motor. Figures 15 and 16 show a picture of this motor, the motor terminal and resistor box, and the controller or drum-switch. This motor is supplied with RCA Photophone installations where direct current is the standard supply at the theatre, or in theatres where alternating current is the standard supply but variable speed motors are required. A suitable AC to DC motor generator

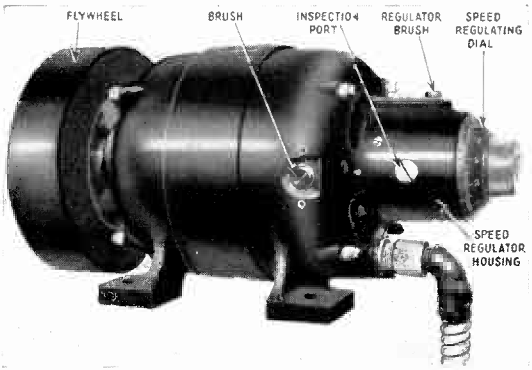


Figure 15—DC projector drive motor

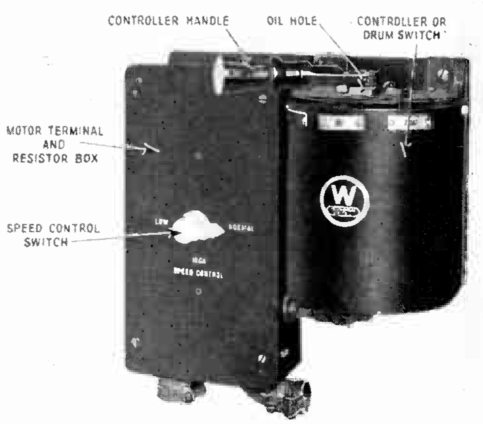


Figure 16—Controller for DC projector drive motor

set is used to supply the direct current for these motors when they are used in AC districts. A description of this motor-generator set is given in section 33.

As stated in section 25 the speed of a DC motor can be varied by changing the resistance of the motor field circuit. A three-position speed-control snap-switch on the motor terminal and resistor box gives a speed control by this method of three steps—"High," "Normal" and "Low." Sound film should always be run with the switch in the "Normal" position. The motor speed may be varied when desirable when using silent film by using the "High" or "Low" position. A close adjustment of the speed can be had for any position of the three-position switch by means of the dial adjustment on the motor. The adjustable dial is a part of a centrifugal speed-control switch shown in Figure 17. This switch consists of an adjustable stationary contact; a fly-weight operated moving contact; a slip ring and a brush, for making an electrical connection to the moving contact; and a circuit closing contact spring and stud, which make a connection to the fixed contact.

The action of this device can best be explained by referring to Figure 14. One end of a resistor in the field circuit of the motor is connected to the moving contact through the slip ring and brush. The other end of the resistor is connected to the stationary contact. As the motor speeds up, the fly weights move out (away from the shaft) and bring the moving contact closer to the stationary contact. When the motor reaches a certain speed the moving contact touches the stationary contact, and the resistor in the field circuit is short-circuited. The position of the contacts under this condition is shown in the right-hand drawing of Figure 17. This allows the current in the field circuit to increase and the motor "slows down." When the motor slows a little, the contacts open and the resistance is again con-

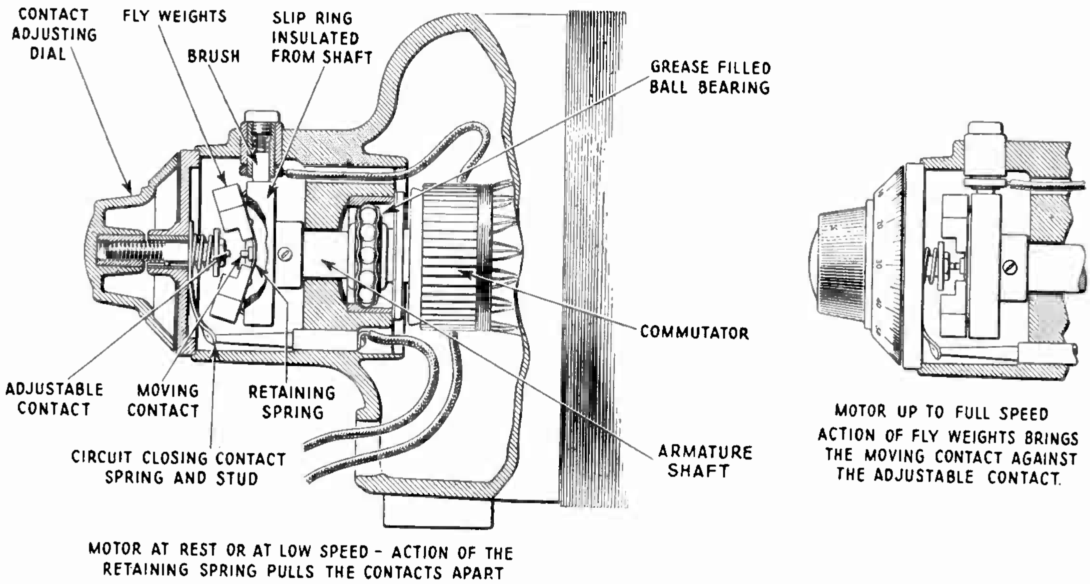


Figure 17—Automatic speed-control device for DC projector drive motor

nected in the field circuit, decreasing the field current which increases the speed of the motor. This continues, the contacts opening and closing very rapidly, and the motor rotates at a practically constant speed. The position of the stationary contact can be varied. It can be moved in or out by rotating the dial at the end of the motor. If the dial is rotated in a clockwise direction it moves the stationary contact closer to the revolving contact, a connection is made between the two at a lower speed, and the motor will run at a slower speed. If the dial is rotated in a counter clockwise direction the contacts are moved further apart, and it then becomes necessary that the motor run at a higher speed before the contact is closed and the motor is held at this higher speed.

When the motor speed is properly adjusted for a film speed of 90 feet per minute, the dial-reading opposite the white line nearest the white dot on the top of the speed-regulator housing should be carefully noted and preserved for ready reference, so that the dial may be quickly and accurately reset in case it is accidentally disturbed. The dial figures are for calibration only, and do not indicate either motor or film speed.

The dial of the speed regulator can be calibrated by counting the number of revolutions per minute of the turn table. When properly set, the turntable should make thirty-three and one-third revolutions per minute. It can be set approximately by counting the revolutions for one minute, but for accurate setting the revolutions should be counted for at least three minutes. The table should make one hundred revolutions in three minutes.

To operate the motor for sound-on-disc or sound-on-film, see that the snap-switch on the motor terminal and resistor box is in the "Normal" position and that the speed regulator dial is set at the proper reading. The motor is then operated by means of a three-position drum switch or controller. See Figure 16.

To start the motor, the controller handle is moved from the center or "Off" position to the extreme left. To stop the motor, the controller handle is simply returned to the "Off" position. The controller handle should never be placed on the extreme right, or "Brake," position, except when it is necessary to make an emergency stop. Using the "Brake" position every time the projector stops causes excessive wear on the mechanism, and this position should not be used unless absolutely necessary. When the switch is in the "Brake" position, the motor field is connected to the line while the motor armature is disconnected from the line and is short-circuited. The coasting motor then acts as a generator with a heavy load, and comes to a sudden stop. If it is necessary to use the brake, be sure to return the controller handle to the "Off" position, since in the "Brake" position the motor field is connected to the power line and will get excessively hot in a short time. During normal operation the fan on the end of the armature cools the field windings. When using this control switch, turn the handle to the desired position quickly to reduce arcing within the switch.

Improper operation of the centrifugal speed-control device will result in "wows," and may be caused by a dirty slip ring, a pitted brush, or a burned switch contact. The brush may be removed for inspection by removing the brush-holder cap. When replacing the brush make sure that the curvature of the brush fits the slip ring.

The switch contacts and the slip ring are accessible by removing the dial. This is done by removing three screws which hold it to the motor housing. These screws are under the dial, and are accessible by rotating the dial so that the notch uncovers the screw-heads. The fly-weight and slip ring mechanism is held on the motor shaft by a set screw which is accessible by removing the large plug screw on the left-hand side of the motor housing.

Do not remove any parts without first opening the main line switch, to the projector. Setting the drum to the "Off" position is not enough.

A fly-wheel is mounted on the motor shaft. The purpose of the fly-wheel is to keep the motor running smoothly by preventing sudden changes of speed.

Inside of the motor casting is a heavy fan which rotates with the armature shaft. The purpose of this fan is to cool the motor windings. *Be sure to keep fingers out of the end of the motor castings while the machine is in operation.*

The motor runs on ball bearings which are packed in grease and require no attention other than a yearly renewal of this grease. This will be taken care of by the service man. *Do not attempt at any time to oil the DC motor.*

If the motor fails to start look for blown fuses in the DC supply line.

If the motor runs at excessive speed, inspect the centrifugal switch for dirty or burned contacts. If this switch does not close, the motor will run at too high a speed.

If trouble is experienced at any time with the switch contacts of either the drum-switch or the three-position speed-selector switch, the covers may be removed (after opening the main line switch) and the contacts inspected for burned points. It is advisable to coat the contacts of the drum-switch with vaseline, which will allow the switch to turn more easily and reduce the wear on the contacts. The bearing of the drum-switch has an oil hole as shown in Figure 16. It should be oiled about once a month with a good grade of machine oil.

28. Synchronous Motors.—A 220 volt, 60 cycle, 3 phase, synchronous motor is used as standard equipment on PG-1, 2, 3, 4, 6, 7, and 8 equipments when the proper power is available.

The speed of a synchronous motor depends upon the frequency of the power supply. It is called a synchronous motor because it runs at a speed corresponding to the speed of the generator. These motors can be built to run at different speeds by building the motor with different numbers of poles. A synchronous motor which has two poles will run at 3600 r.p.m. (revolutions per minute) on a power supply whose frequency is sixty cycles per second. A four pole motor would run at 1800 r.p.m. and a six pole motor at 1200 r.p.m. The synchronous motors used in RCA Photophone equipment have four poles and run at 1800 r.p.m. on a 60 cycle circuit.

The action of this motor is as follows:—When a three-phase alternating voltage is applied to the winding of a three-phase motor, a magnetic field is created which rotates at a constant speed (if the frequency of the power supply is constant). The speed of the rotation of the magnetic field is such that it passes over two poles for every complete cycle of alternating voltage. Therefore, in a four pole motor, two cycles are required for each complete revolution of the magnetic field around the motor.

The rotating magnetic field mentioned above does not refer to a rotation of mechanical parts, but a rotation of magnetic lines of force. These magnetic lines of force are set up by the current in the stator windings. Each phase has a separate winding for each pair of poles. The phase windings are spaced successively around the circumference of the stator so that the three windings (phase windings) cover two poles (which is one-half of the circumference in the case of a four-pole machine). The voltage waves of the separate phases are not in unison but follow one another at equal time intervals. As the phase windings successively produce magnetic lines of force in different parts of the stator the effect of a rotating field is produced.

Synchronous motors are highly satisfactory for use in driving projectors equipped for sound reproduction, because of the extremely uniform speed which they maintain. The reason these motors maintain a very uniform speed is that their speed depends entirely upon the frequency of the power supply and is not effected by voltage variations. The frequency of the power supply is held within very close limits by sensitive governors on the generating equipment at the power house. Furthermore, even though the frequency of the power supply may change from 59 cycles to 61 cycles the change of frequency takes place very slowly due to the great weight of the generating equipment used in power houses. A change of projector motor speed changes the pitch of the reproduced sound, but slight variations of pitch are not discernible if the change of pitch takes place slowly. A rapid change of pitch, even if only a small amount, will cause "wows."

29. **Synchronous Projector Motors.**—Figure 18 shows a synchronous projector drive motor used on RCA Photophone equipments. This motor consists of a three-phase armature wound on the stationary part of the motor, and a rotor that has four equally spaced shallow slots. The rotor also has a winding, which consists of copper bars through the periphery of the rotor and bonded by copper rings on both sides. This type of winding is called a squirrel cage winding because of its similarity to a squirrel cage. This winding does not enter into the action of the motor once it is up to speed, and is useful only for starting the motor. The action of this motor is as follows: When a three-phase alternatingvoltage is applied to the stator (stationary winding) a rotating field is produced. This rotating field drags the rotor along with it, so that the parts of the rotor which form the smallest air gap between the rotor and stator are always in the positions of maximum field strength. This can be demonstrated by placing a horse-shoe magnet under a piece of window-pane glass, and placing on the top of the glass a small oblong piece of steel about as long as the distance between the poles of the magnet. The piece of steel will assume a position so that the distance between its ends and the poles is the shortest. If the magnet is moved the piece of steel will move with it, and, if the magnet is rotated about an axis mid-way between the two poles, the piece of steel will rotate also, so as to

remain always in the same position with respect to the poles of the magnet. This action takes place only when the motor is at synchronous speed. The motor comes up to speed as an induction motor, the action of which will be elaborated on later in this chapter.

If the stator windings are connected directly to the AC lines the motor would come up to speed too rapidly, so as to put undue strain on the equipment, and there would be danger of stripping the gears. Therefore, resistors are added in the line circuit to slow the starting. Either two 40 ohm resistors (one in each of two lines) or three 20 ohm resistors (one in each line) are used.

A fan is mounted on the rotor shaft within the housing to cool the windings.

Oil the motor regularly every day. The oil cups are at each end of the motor housing.

If the motor fails to start, look for blown fuses in the line circuit, or burned out starting resistors. If one of the resistors is burned out, it may be shorted with a piece of wire, but the machine should not be run in this condition any longer than necessary because the high rate of starting would cause undue strain on the equipment.

30. Single-Phase Motors.—There are two types of single-phase motors used with RCA Photophone equipment. They are both induction motors and the main difference between them arises from the different starting methods used. Single-phase induction motors will not start as such, but they will continue to run once they are started. The stators of these motors are wound with four poles as in the case of the three-phase synchronous motors. When a single-phase alternating voltage is applied to such a winding a magnetic field is created which alternates in direction twice each cycle, in the same manner as the alternating current which produces the field, but this field does not rotate as in the case of a three-phase motor. A current is set up in the rotor winding which produces an equal turning force in both directions at the same time, so the motor will not start. But, after the rotor has attained a slight speed, the motor will have a turning torque in one direction because the voltage generated by the rotation of the rotor creates another magnetic field. This magnetic field combines with the field of the stator winding to produce a rotating field, and the motor is kept running. The speed of the motor never reaches synchronous speed, or 1800 r.p.m. in case of a 60 cycle circuit, because a certain amount of slipping of the rotor with respect to the rotating field is required in order to produce a current in the rotor. This difference in speed between synchronous speed and actual speed is called the "slip" of the motor. The "slip speed" is constant for a constant load. Therefore, the motor will run at a constant speed of about 1725 r.p.m. when driving a projector because the load (the friction of the projector) remains constant.

Two different methods of starting are used on the two types of single-phase motors used for projector drive. One is called "repulsion starting" and the other is called "split-phase starting." These methods will be described in the two succeeding sections.

31. Single-Phase Repulsion-Induction Motor. — A repulsion-induction motor is used as a projector drive motor on PG-10 equipment. One of these motors is illustrated in Figure 19. The rotor of this machine contains a commutator and is similar to the armature of a DC motor. The stator is wound with a four-pole single-phase winding. This winding is somewhat similar to the field winding of a four-pole DC motor. The starting device consists of two brushes mounted so as to make contact with the commutator, a resistor to prevent the motor from coming up to

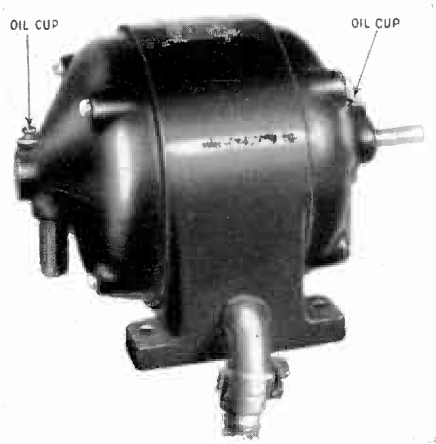


Figure 18—Three-phase synchronous motor for projector drive

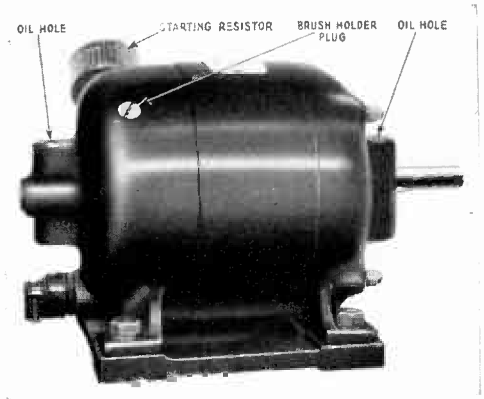


Figure 19—Single-phase repulsion-induction motor for projector drive

speed too rapidly, and a centrifugal mechanism for shorting out the entire commutator after the motor has attained sufficient speed to run as a single-phase induction motor. As stated in section 30 the action of a single-phase induction motor, when its rotor is stationary, has the tendency to turn the rotor in both directions at once. This action, of course, results in no rotation at all, but, if by some means this balance can be disturbed, rotation will result. The brushes short-circuit a part of the commutator so as to unbalance the torque set up by the rotor current. The current in the rotor is due to the transformer action between the stator and the rotor. The unbalancing action caused by the short-circuited portion of the rotor gives a predominance of torque in one direction so that the motor starts to rotate. The direction of rotation depends upon the position in which the brushes are mounted. The running winding will keep the motor running in either direction once it is up to speed. If the brushes were short-circuited through a very low resistance, such as a copper wire, the starting torque would be too great and an excessive strain would be put on the projector mechanism. A resistor of 9 ohms resistance is used to connect the two brushes together through the frame of the motor itself. This reduces the starting torque sufficiently to prevent undue strain on the projector.

Figure 20 is a drawing showing the centrifugal short-circuiting device. The mechanism consists of a stationary plate, a movable plate, a commutator, a short circuiting disc, three fly-weights, separator balls, and a retaining spring. The whole mechanism is mounted on the shaft and rotates with it. When the motor is at rest,

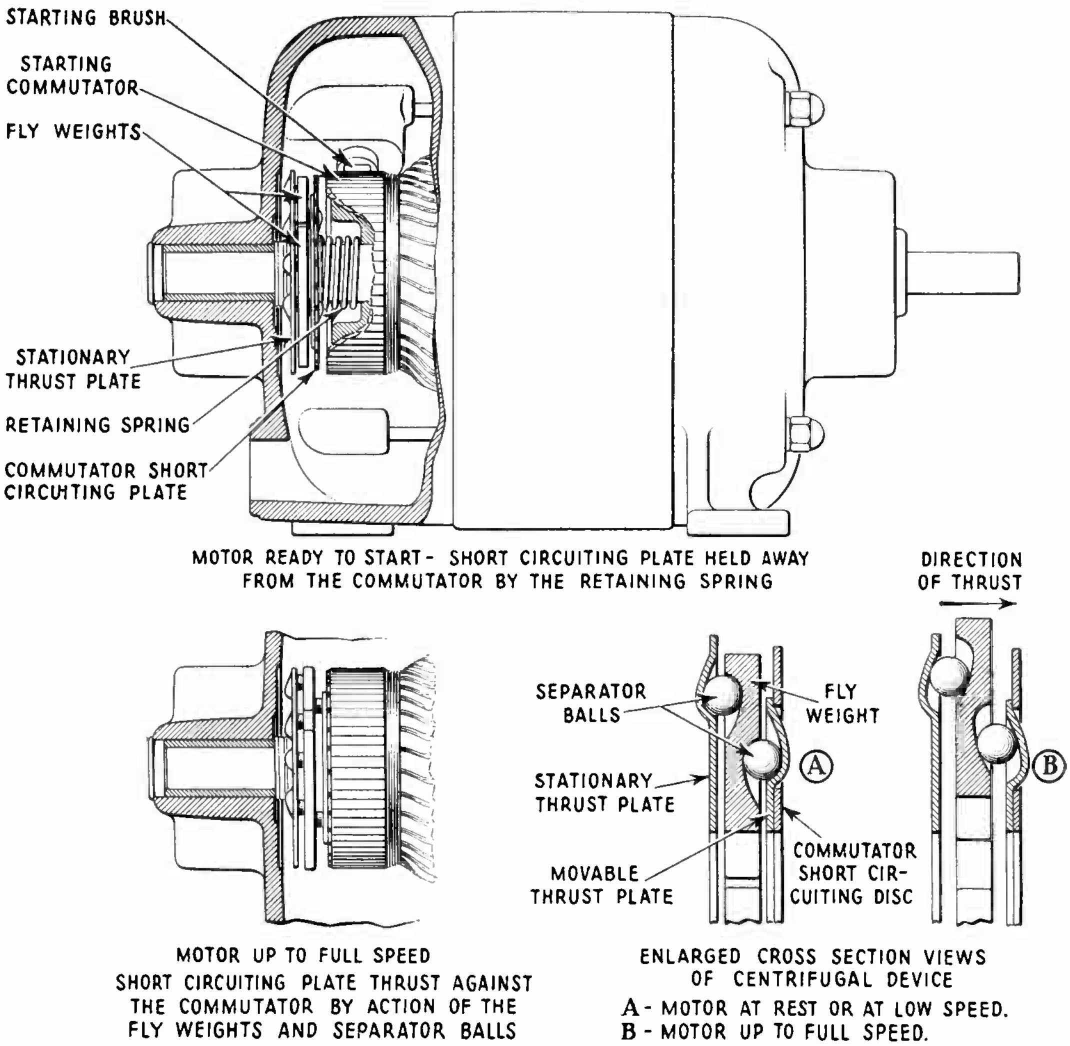


Figure 20—Automatic starting switch for single-phase repulsion-induction motor

the retaining spring forces the commutator short-circuiting disc away from the commutator. The force is transmitted from the spring through steel balls to the fly-weights, and they are forced in towards the shaft, as shown in the upper drawing of this figure. In (A) of the same figure is shown a sectional view of the mechanism under this condition. There is a space of about three thirty-seconds of an inch between the commutator and the commutator short-circuiting disc. When the centrifugal switch is in this position the motor will start as a repulsion motor. As the motor gains speed, the fly-weights are forced away from the shaft. The force is transmitted through the separator balls, which force the movable plate and the commutator short-circuiting disc toward the end of the commutator. When the motor speed is nearly up to normal, the short-circuiting disc makes contact with the end of the commutator, short-circuiting all of the commutator segments, and the motor then runs as a single-phase induction motor. The position of the parts of the centrifugal switch mechanism under the running condition is shown in the lower left-hand drawing of Figure 20. Drawing (B) of this figure shows a cross-sectional view illustrating the action of the fly-weight and the separator balls under the running condition.

If for any reason the centrifugal switch fails to short-circuit the commutator when the motor is up to speed, *do not let the motor run in this condition,* as the resistor will get hot and burn out. Stop the motor at once and see what is causing the mechanism to bind. If the show is in progress, give the motor a slight boost with the crank.

If the motor fails to start, look for blown fuses in the supply circuits.

If the mechanism should bind so as to cause the commutator short-circuiting disc to "stick" in the running position, the motor will hum when the switch is turned on, but will not start. It can be started by cranking the machine, but the mechanism should be repaired at the first opportunity. Keep the motor clean at all times and check the condition of the brushes occasionally.

Oil cups are located at each end of the housing and should be filled daily.

32. Split-Phase Starting Single-Phase Induction Motor.—This motor is used for the projector drive of PG-13 equipment. (See Figure 21.) It is started by means of a split-phase winding which, in conjunction with the running winding, produces a rotating field similar to that of the three-phase motor. The split-phase, or starting, winding is connected in series with a resistor mounted in a box on the end of the motor, and this series combination is connected across the power line through a centrifugally operated switch.

On starting, the centrifugal switch is closed, and both windings function to produce a rotating field which acts upon the squirrel-cage rotor to effect rotation. As the motor comes up to speed the fly-weights of the centrifugal device on the motor shaft travel radially away from the shaft, and in so doing strike a metal pin which operates the switch to disconnect the starting winding.

When the power is turned off, the fly-weights are drawn in towards the shaft by small springs. As the weights are retracted, they strike another metal pin, which closes the switch that connects the starting winding and resistor in parallel with the running winding, to be ready for another start.

There are no brushes or other continually moving contacts anywhere in this motor. The speed of the motor, while not synchronous, is constant and dependent upon the frequency of the power supply. The speed of a four-pole synchronous motor operated on a 60 cycle circuit is 1800 revolutions per minute, but the speed of this induction motor is approximately 1725 revolutions per minute.

The electrical connections to the motor are made in the metal box, in which the starting resistor is mounted, on the end of the motor. Four leads are brought out into this box from the motor, two of which are connected to the running winding and two to the starting winding. The leads from the running winding are connected to the two binding posts provided for power connections, and the starting winding is connected to the left-hand binding post and to the left-hand end of the starting resistor. If these two last named leads are reversed the direction of

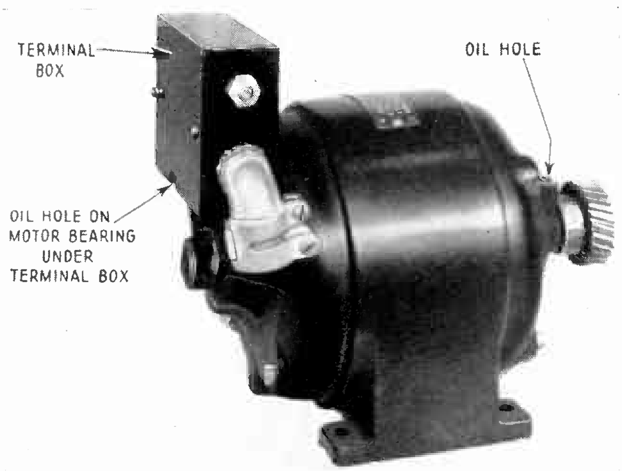


Figure 21—Single-phase induction motor for projector drive (split-phase starting)

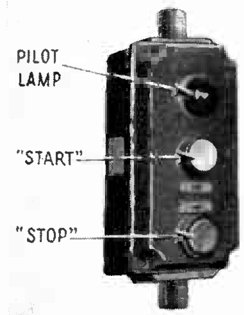


Figure 22—Push - button station for AC to DC M-G set for DC projector motors.

rotation of the motor will be reversed, as such a connection will reverse the "phase relation" between the starting and running windings. The running winding will keep the motor running in either direction once it is up to speed.

This motor utilizes waste-packed bearings which should be oiled about once a week with a medium grade of machine oil. The oil hole for one bearing is underneath the motor terminal and resistor box, and must be reached through the channel provided in the bottom of the terminal box for such a purpose.

(C) CONVERTING EQUIPMENT

33. AC to DC M-G Sets for Driving DC Projector Motors.—An AC to DC M-G set is used to supply DC power for driving projector motors when either 25 cycle or 50 cycle two-phase or three-phase power is the standard power supply at the theatre; or where 60 cycle three-phase power is standard power supply for the theatre, but it is desirable to have a variable speed projector drive motor.

The purpose of the M-G set is solely that of supplying power to the projector drive motor. Two M-G sets are usually supplied for one installation, one of the sets being a stand-by machine for emergency service. See Figure 23.

The equipment consists of two identical M-G sets; two motor starting boxes, one for each M-G set; a generator control panel; and two push button stations, one for each M-G set.

The power for driving the motors is supplied through a three contact, magnetically operated line switch, called a "contactor." Figure 24 is a picture of this switch. It is operated by pushing the "Start" button of the push-button station shown in Figure 22. When the line switch closes, it also closes an auxiliary (holding circuit) contact which is connected across the "Start" push-button so as to keep the operat-

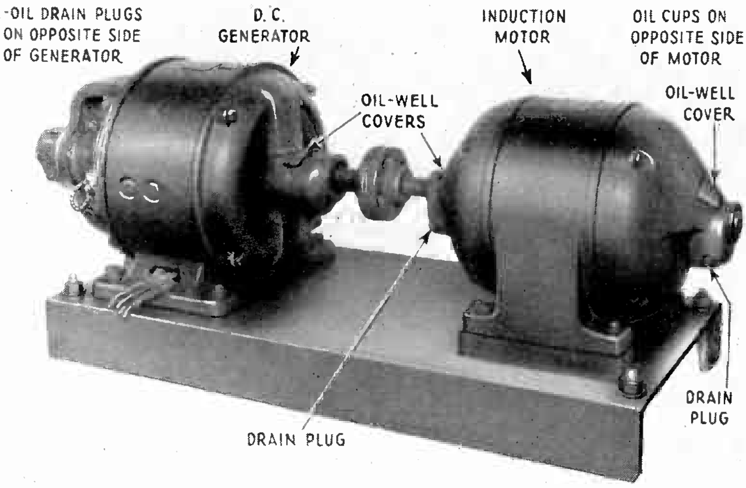


Figure 23—AC to DC M-G set for DC projector drive motors

ing circuit closed when the "Start" button is released. The motor starting boxes do not contain fuses, but contain instead an over-load switch which turns off the power to the motor in case of trouble. If, for any reason, the motor draws excessive current, the heating of a thermo-element in series with the motor line causes a spring to bend and trip a switch which in turn opens the circuit to the operating coil of the motor line switch. It will not then be possible to start the motor until this switch has been reset by hand. The reset is operated by either pulling up a lever which protrudes from the right-hand side of the starting box or by pulling on a string which hangs from the bottom of the box. (There are two styles of starting boxes used and the operations of the reset is the only real difference.)

Porcelain shields called "flash guards" are mounted over the contacts to prevent an arc from occurring between two adjacent switch contact arms or points.

The DC power from the generators is controlled through the generator control panel. At the top of this panel are located line switches for both generators (see Figure 25). Just below, and associated with, each line switch are two 30 ampere fuses for the protection of the DC circuit from serious overload. At the bottom of the panel are two generator field rheostats for controlling the voltage of the generators. A DC voltmeter is mounted at the center of the panel and indicates the DC line voltage (generator voltage).

The operating coil of each DC line switch is in the same circuit as the operating coil of its associated motor line switch, so that the generator line switch closes when the motor is started.

If power is applied to the motor of one of the sets and both of the generator line switches could be closed at the same time, the generator of the other machine would run as a motor, which is not desired. To avoid this, the "Start" button for one motor-generator set opens the line switch for the other generator and vice-versa.

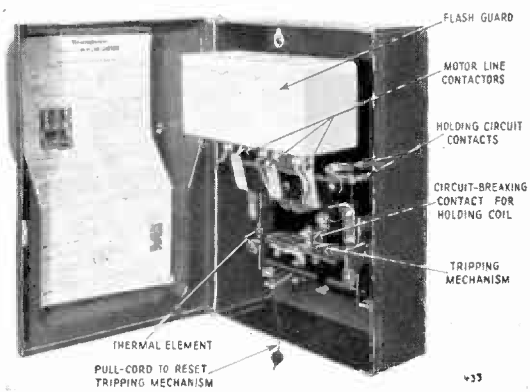


Figure 24—Line switch for AC to DC M-G set for DC projector motors

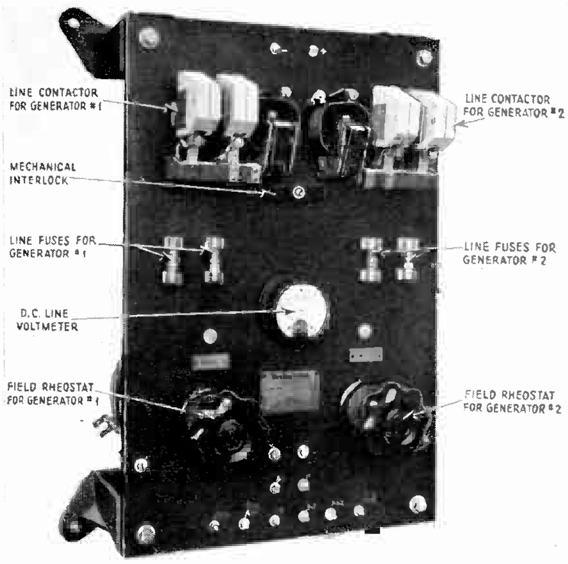


Figure 25—Generator control panel for AC to DC M-G set for DC projector motors

As an additional safeguard, a mechanical "inter-lock" is also added to the panel. This "inter-lock" consists of a bar pivoted between the two contactors (see Figure 25). When one contactor closes, it pushes one end of this bar down, and the other end is pushed up against the other contactor so that it cannot close. On account of these features, in case of emergency it is not necessary to push the "Stop" button of a machine which has been operating. Simply push the "Start" button for the other machine. This will automatically turn off the power to the machine which was being used and start up the stand-by machine.

To adjust the voltage of the DC generators push the "Start" button of one of the push-button stations. Adjust the voltage at the generator panel, by means of the generator field rheostat which is directly below the line switch which is closed, so that the generator panel meter reads 110 volts when two projector motors are running. After the voltage of one generator is adjusted, stop the machine, start the other, and adjust it in the same manner. The generator voltages should seldom require readjustment after they are once set properly.

In each motor bearing and around the motor shaft is a brass ring, the inside diameter of which is considerably larger than the diameter of the motor shaft. This ring rides on the shaft when the motor is running. The lower edge of the ring is dipped in an oil well. Oil adheres to this oil-ring and is carried to the top of the shaft where it is rubbed off by the rotating shaft, thus keeping it oiled while the set is running. The level of the oil in the oil cups on the motor should be inspected once a week and, when necessary, oil should be added to keep them half full.

The generator bearings are similar in operation but different in appearance. A hinged cover permits a view of the oil ring in the bearing, and the oil level is checked by observing the height of the oil in the little oil vent under the hinged

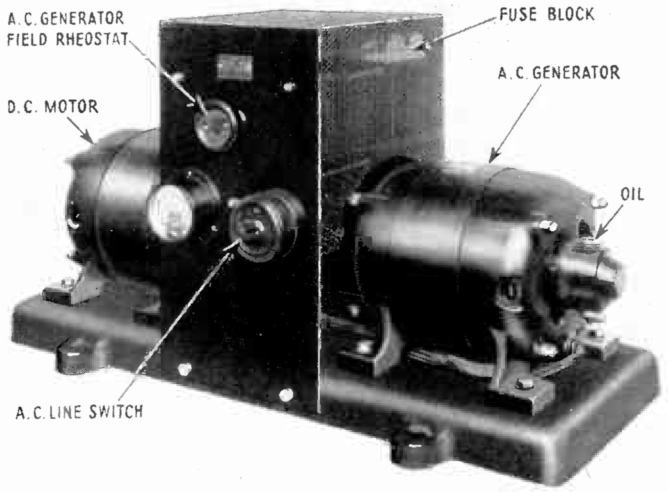


Figure 26—½ k-va. DC to AC M-G set

cover. Check the oil level in these bearings once a week and, when necessary, add oil to hold the level about one-eighth of an inch below the edge of the vent.

If, at any time, the motor fails to start when the push-button is operated, operate the reset device of the motor line contactor to make sure that the thermal relay switch is not open.

If neither of the motor line switches close when their respective starting buttons are pressed, look for blown fuses in the main supply line.

If the motor runs, but there is no reading on the generator control panel voltmeter, check the 30 ampere fuses which are mounted just below the generator line switch which is closed.

If trouble develops on one M-G set and it is necessary to use the other, call this fact to the attention of the service man as soon as possible. *Do not wait until both units are defective before reporting it.*

Keep the sets clean at all times.

Check the condition of the oil in all the bearings at least once a week and add oil when needed. At the same time the machine is oiled, inspect the commutator. If the commutator shows signs of burning or pitting, it should be cleaned off with 00 sand paper.

Several types of AC motors are used with these sets, depending upon the type of power supplied in the theatre (single-phase, two-phase, or three-pase at 110, 220 or 440 volts). The care and operation of all of these types will be the same with the exception of the single-phase motor. This motor is identical in principle with the single-phase repulsion-induction projector drive motor previously discussed. In addition to checking the oil in this motor, the commutator should also be checked, and the same treatment given it as prescribed for the generator commutator.

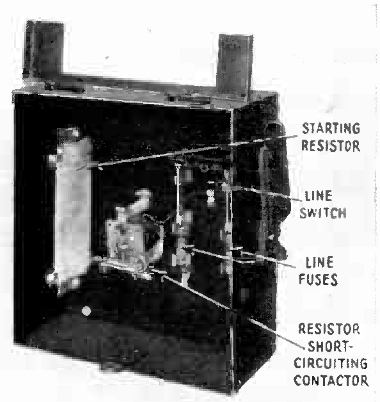


Figure 27—Line starter for ½ k-va. DC to AC M-G set

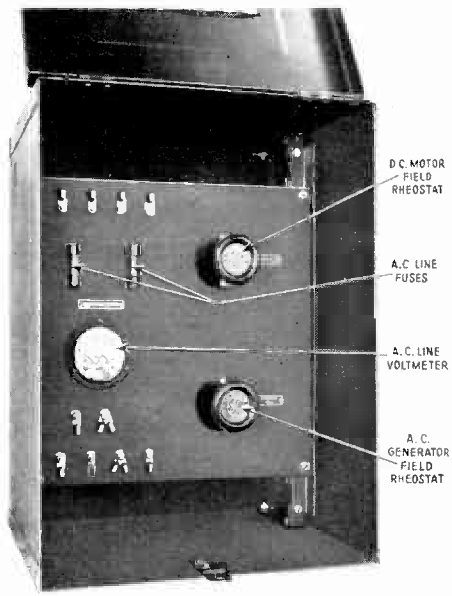


Figure 28—Generator control panel for 1½ k-va. DC to AC M-G set

34. DC to AC Motor-Generator Sets.—In theatres where direct current only is available, it becomes necessary to convert the direct current to alternating current for use in the power amplifiers of PG-3, PG-4, PG-6, PG-7, PG-8 and PG-10 equipments. To do this, some sort of motor-generator set or its equivalent must be used. One of the motor-generator sets used for this purpose is illustrated in Figure 26. This motor-generator set is rated at ½ k-va. The drive motor is located at the left and the generator to the right of the generator control panel. The electrical operation of the motor is similar to that of the DC projector drive motor previously described, except that no speed regulating device is used.

This motor is more powerful than that used for the projector drive motor, and for this reason cannot be connected directly to the power supply line without some special provision being made to prevent an excessively high current from being drawn by the motor upon starting. The starting apparatus used with this motor is illustrated in Figure 27. This starting device consists essentially of a sheet-iron box in which are mounted a line switch for turning the power on and off, a resistor which is connected in series with the motor armature to prevent an overload current from being drawn upon starting, and a contactor which "shorts out" the resistor after the motor has almost reached its normal running speed. The action of this device is as follows:—When the main line switch is closed, a heavy starting current is drawn by the motor. This large current produces what we call a "voltage drop" across the resistor. The connections of the contactor operating coil are made from one side

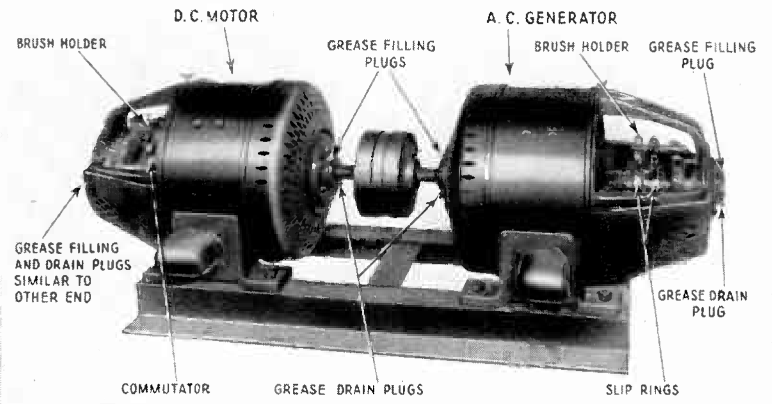


Figure 29—1½ k-va. DC to AC M-G set

of the line to a point between the motor armature and the resistor. When the motor comes up to speed, the current drawn by the motor "falls off." The lesser current reduces the voltage drop in the resistor, and, since there is less loss through the resistor, the voltage across the coil becomes higher which causes the contactor to close and short-circuit the resistor. The terminals of the coil are then connected directly across the line, and, until the main line switch is opened, the operating coil will keep the contactor closed and the resistor short-circuited.

The generator controls are mounted on the control panel between the two machines. On this panel are located a switch for turning on and off the AC power to the amplifiers, a voltmeter for reading the line voltage supplied by the generator, and a field rheostat for controlling this voltage in the same manner as that described in section 24. In back of the generator control panel is mounted a fuse block containing fuses for the AC line from the generator. These fuses may be replaced when necessary by removing the wire mesh cover. This is done by removing the three nuts on the ends of the three bolts seen protruding from the rear of the panel.

Both the DC motor and the AC generator have waste-packed oil wells at each end bearing. The packing of these oil wells should be kept saturated with a good grade of machine oil. A few drops once a week should be sufficient. At the same time that the motor and generator are oiled, it is well to check the commutator on the motor and the generator slip rings to see if they are clean and bright, and inspect the brushes to see that they are not pitted or burned.

The same type and size of motor-generator set, physically speaking, is used for battery charging in some installations. The generator in this case will be an 18 volt DC generator, and the motor will be either an AC or a DC motor depending upon the power supplied to the theatre. This battery charging motor-generator set is described in Chapter V.

A DC to AC motor-generator set of three times the electrical capacity of that just described is used with the type PG-6 equipment. This motor-generator set ($1\frac{1}{2}$ k-va.) is illustrated in Figure 29. The starting box used with the motor of this set is like that used for the M-G set described in a previous paragraph, but two resistors are connected in parallel in the starting box. This is necessary because of the greater starting current required by this larger machine.

The generator control panel used with the $1\frac{1}{2}$ k-va. AC generator is illustrated in Figure 28. This control panel is mounted in a sheet-iron box as illustrated, and contains the field rheostat for regulating the motor speed, and a field rheostat for regulating the AC supply voltage together with AC line fuses and an AC voltmeter for indicating the line voltage. The frequency of the alternating current supplied by the generator depends upon its speed, and consequently the motor field rheostat provides a control of the frequency of the voltage supplied by the generator. This adjustment once properly made by the service man should not be tampered with under any circumstances, since an improper frequency of supply may cause the power transformer in the power amplifier to "burn out". The voltage supplied by the generator should be adjusted by means of its field rheostat to somewhat above 100 volts, and is further regulated at the power amplifier panel by a rheostat provided upon it for such regulation. The meter on the power amplifier panel should read 100 volts. In case the voltmeter on the generator control panel gives no reading while the generator is running, it is usually an indication that the fuses upon the generator control panel are burned out.

As in the case of the $\frac{1}{2}$ k-va. DC to AC motor-generator set, a weekly inspection of the commutator, slip rings, and brushes should be made, but, since the bearings of both machines in this set are run in grease, no oil should be added. These motors require grease about once a year, and this greasing should be taken care of by the RCA Photophone service engineer. The commutator and slip rings of both M-G sets just described should be cleaned when necessary with 00 sandpaper.

35. DC to AC Rotary Converter.—A rotary converter, in effect, is a motor-generator set built on one frame. The same field is used for both the motor and the generator, and the operation of the machine depends upon the generated voltage in any DC motor as described in the beginning of this chapter. The armature has a commutator on one end and is tapped, and connections are brought out to slip rings on the other end. Power is supplied to the direct current end (the commutator end) of the armature. As the machine rotates, an alternating current flows in the armature, and is brought out through the slip rings to the power supply. Such a machine is much simpler in construction and operation than the DC to AC motor-generator sets just described. The rotary converter used with Photophone equipment was specially constructed for such use, as the ordinary rotary converter

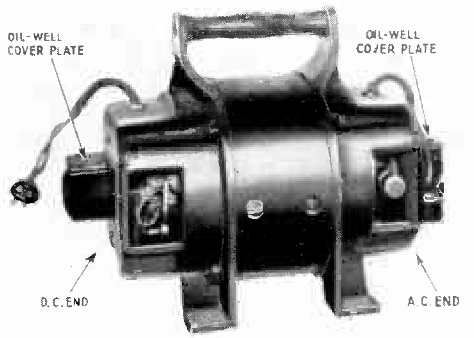


Figure 30—¾ k-va. DC to AC converter

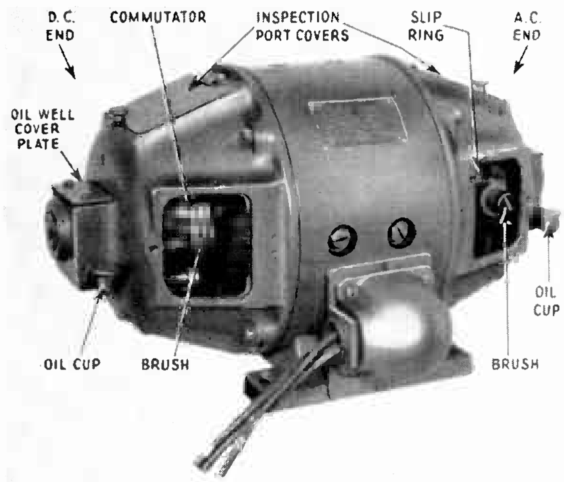


Figure 31—1½ k-va. DC to AC converter

run from a 125 volt DC line would not supply the voltage required by the power amplifier unit.

A rotary converter which may be used in any installation where the ½ k-va. motor-generator set may be used is illustrated in Figure 30. The DC commutator is at the left and the slip rings of the AC end are at the right. To oil the machine, which should be done once a week, it is necessary to remove the oil well covers at each end of the converter by means of the two screws provided. The bearings are waste packed, and the waste should be kept well saturated with oil. At the time of oiling, the commutators and slip rings should be inspected and cleaned if necessary.

In Figure 31 is illustrated the 1½ k-va. rotary converter which may be used in any installation where the 1½ k-va. motor-generator set may be used. This converter is similar to the ¾ k-va. converter except for its size. On account of its increased size a starting box is used. This starting box is the same as that described for the 1½ k-va. motor-generator set. The 1½ k-va. rotary converter has oil ring bearings similar to those described in the discussion of the AC to DC motor-generator sets for DC projector drive motors. The level of the oil in the oil cups should be checked once a week and maintained about 1/8 of an inch from the top of the oil cups. The commutator of the 1½ k-va. converter should be checked weekly and cleaned with 00 sandpaper when necessary. Both converters contain, on the commutator end of the armature, a blower for the purpose of ventilation.

In a number of installations two converters are used, one machine being a "stand-by" for emergency service only. In this case a four pole double-throw switch is used to transfer the power supply from one converter to the other (see Figure 32). Pilot lamps are provided to show which converter is in use.

36. Motor-Generator Set for Types PG-1 and PG-2 Equipments.—The 4-unit motor-generator sets used with the types PG-1 and PG-2 equipments each consist of a 250

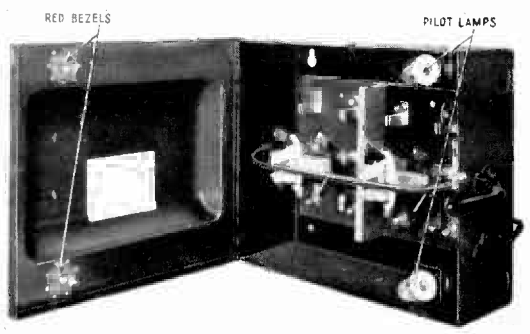


Figure 32—Converter change-over switch

volt DC generator, a 15 volt DC generator, a driving motor, and a 1000 volt DC generator (see Figure 33). The type of motor supplied depends upon the power available at the theatre.

The 1000 volt generator has two 500 volt commutators, one on each end of the armature. These commutators are connected in series, giving a total of 1000 volts. Two 6 volt storage batteries are "floated" across the 15 volt generator. This arrangement gives a very steady DC output for lighting the tubes in the power amplifiers, and for lighting the exciter lamps in the sound head. The storage batteries are necessary because the direct current supplied from a DC generator is never absolutely constant, but varies up and down slightly, depending upon the number of bars in the commutator and the speed with which the generator is rotating. Such variations, called "commutator ripple," will cause a decided hum from the amplifiers if something is not done to prevent it. Dirty commutators may cause a sufficiently bad ripple to produce such a hum in spite of the smoothing action of the batteries. If this occurs, clean the commutator of the 15 volt generator (and in some cases, that of the 1000 volt and 250 volt generators) with fine sandpaper. In order to clean the commutators of the DC machines, it is necessary first to remove the iron shields. *CAUTION: Do not clean the commutators with the power to the motor turned on, or with the main operating switch at the power amplifier panel closed.*

The starting box used with the DC driven four-unit set is similar in operation to that described in section 34 for starting the 1½ k-va. DC to AC motor generator set but instead of a hand operated line switch, an electrically operated line switch or contactor is used (see Figure 35). This contactor is operated by means of push-button switches provided on the amplifier rack panel. A pilot light next to the switch

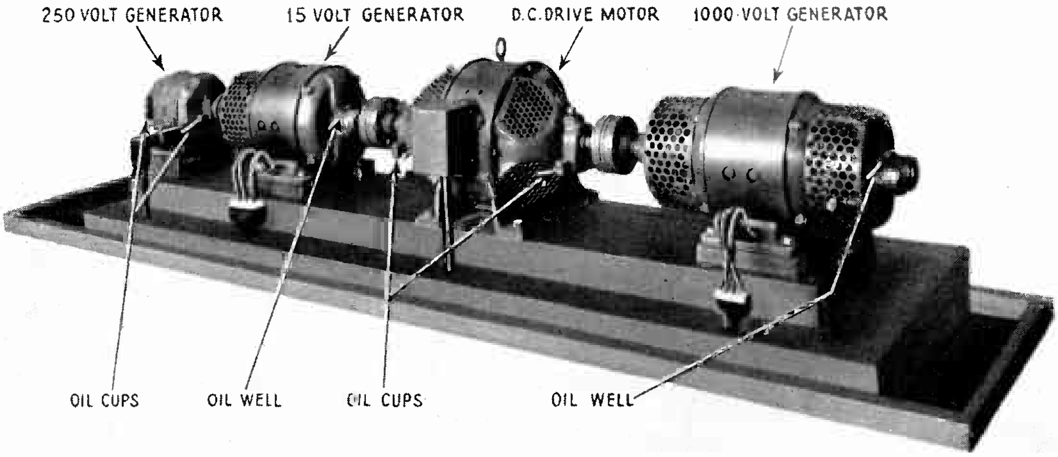


Figure 33—Four-unit M-G set used in PG-1 and PG-2 installations

indicates when the motor-generator set is operating. In the case of the PG-1 equipments two motor-generator sets are used, one being a stand-by equipment for emergency service. Since a pilot light is provided at the push-button operating each motor-generator set, the two pilot lamps also indicate which one of the two sets is running.

The starting switch used with the AC driven four-unit set (Figure 34) is similar in operation to that used with the AC to DC motor-generator set for DC projector drive motors. The description of this last named switch is given in section 33.

These four-unit motor-generator sets are not equipped with individual control panels. All voltages are measured at the amplifier rack, and the details of this will be given in Chapter XIII, "RCA Photophone Equipments." The four-unit motor-generator set with the DC driving motor is oiled as follows:—All four units have oil ring bearings, and the oil cups should be kept filled to within one-eighth of an inch of the top. In the case of the 250 volt machines and the 1000 volt machine, the oil level is checked by lifting up the oil-well covers and observing the height of the oil in the oil vent just below the main opening into the oil well.

The following instructions apply to oiling the AC driven four-unit motor-generator set. All four units have oil ring bearings similar to the unit just described, but all machines have oil cups for checking the oil and for filling. The same instructions as to cleaning the commutator apply in this case as for the machine described above.

The type PG-2 equipment utilizes but one four-unit motor-generator set, but, as this set is similar in all respects to those used with PG-1 equipments, no further description or instructions are necessary.

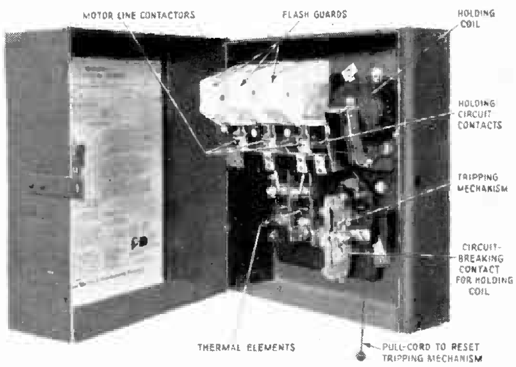


Figure 34—Line switch for AC operated four-unit M-G set

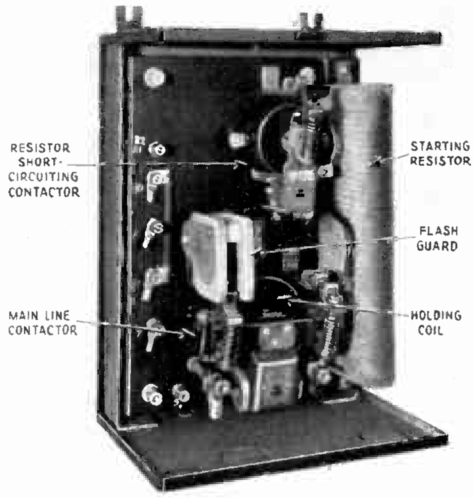


Figure 35—Line starter for DC operated four-unit M-G set

37. **PG-13 Motor-Generator Set.**—All power for the type PG-13 equipment is provided by a three-unit motor-generator set (see Figure 36). The motor-generator set has, besides the motor, a 12-volt DC generator and a 600 volt DC generator. The 12 volt generator furnishes current for the filaments of all tubes, exciter lamps, pilot lights, and for the fields of both the stage and monitor speakers. The 600 volt generator furnishes plate current for all tubes, and also furnishes polarizing voltage for the photo-electric cells. The fields of both generators are excited by the 600 volt machine. Standard equipment is provided with a 110 volt, 60 cycle, single-phase motor. A 125 volt DC motor is used in some cases. Converting equipment is used if neither 125 volt direct current nor 110 volt 60 cycle alternating current is available. When a 125 volt DC motor is used, a suitable starting box is employed. This is similar to the box used in the DC to AC motor-generator set described in section 34. The motor-generator set stands on a felt pad which eliminates noise and vibration, and the entire assembly is covered by a perforated metal case.

The PG-13 motor-generator set is provided with a control board which contains a rheostat for controlling the voltage of the 12 volt generator and a rheostat for controlling the voltage of the 600 volt generator (see Figure 36). This panel also contains a 12 volt meter, a 600 volt meter and a motor switch. Both rheostats are operated through the same control knob. Push in on the knob and rotate in either direction until the needle of the high voltage meter comes to rest at the red line on the dial (600 volts). Then pull out the same knob and regulate the field of the low voltage generator until the needle of the low voltage meter comes to rest at the red line on its dial (12 volts).

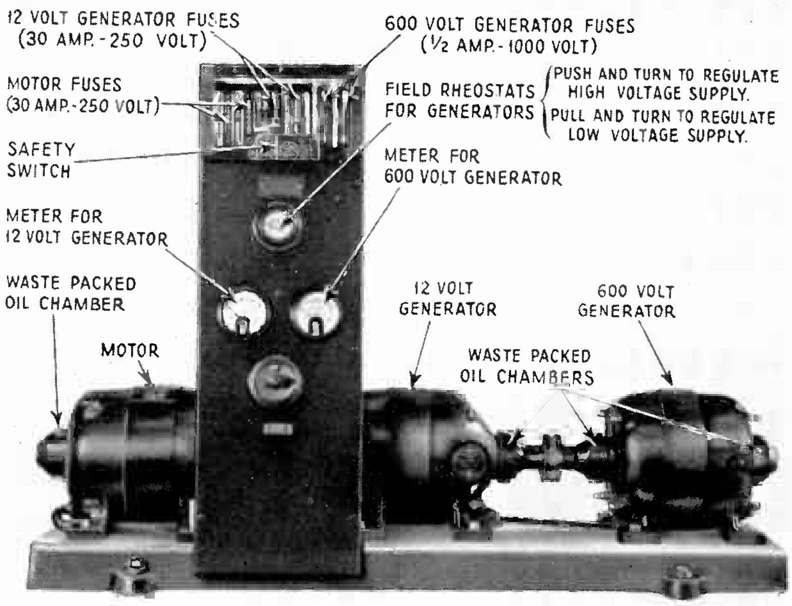


Figure 36—AC operated M-G set for PG-13 equipments

Behind the control panel and mounted as an integral part of it, is a fuse block containing fuses for the motor and for each generator. To replace any of these fuses, it is necessary to remove the fuse cover-plate by unscrewing the knurled knob at the top of the control panel. The removal of this cover plate operates a safety switch so as to automatically disconnect the high voltage fuse (plus 600) from the generator.

The motor-generator set should run freely. See that all bearings are properly lubricated before the set is turned on. The waste in the waste-packed oil cups should be kept saturated with a medium grade of oil. Commutators should be clean, and the brushes should be smooth and should fit the curvature of the commutator throughout the width of the brush. If the brushes do not fit properly, they should be sanded. In sanding brushes use a good grade of 00 sandpaper (*not emery*). The sandpaper should be wrapped tightly around the commutator, and should be drawn under the brush *in one direction only*. Pull the sandpaper past the brush in the same direction that the commutator usually rotates, holding the paper flush down on the commutator. This will grind the brush down so that it has the same curvature as the commutator and will fit snugly against it. Unless the brushes are quite smooth, and the commutators free from dirt, there will be a noticeable generator hum in the loudspeaker.

The 12 volt generator-commutator may be reached for cleaning through a hole in the lower portion of the end casting on the right-hand end. Use 00 sandpaper. Do not clean the commutator while the machine is running. Turn it by hand. Follow the same procedure to clean the commutator of the 600 volt generator.

PG-5 TROUBLE CHART
(Continued)
See section 281

Trouble	Indication	Cause	Remedy
Noisy Operation (Continued)		Loose cable connections.	Check all cable connections and tighten where necessary. Springing the prongs at the cable connection plugs slightly will make them fit snugly.
		Defective photo-cell.	Replace photo-cell.
		Dirty contacts on photo-cell.	Clean the photo-cell contacts with fine sandpaper.
	Disturbance increases when one of the amplifier tubes is tapped lightly.	Defective tube or dirty tube prongs on socket contacts.	Clean tube prongs and contacts. If this does not correct the trouble replace the tube.

PG-5 TROUBLE CHART
(Continued)
See section 281

Trouble	Indication	Cause	Remedy
Low Volume (Continued)	Low volume on one projector only.	Dirty exciter lamp.	Clean the exciter lamp.
		Old exciter lamp.	Replace exciter lamp.
		Optical system out of adjustment.	Adjust the optical system. See operating instruction book.
		Defective photo-cell.	Replace photo-cell.
Poor Quality		Poor Film.	Use good Film.
		Defective photo-cell.	Replace photo-cell.
		Sound gate open.	Close sound gate.
		Optical system out of adjustment.	Adjust optical system. See operating instruction book.
		Defective amplifier tube.	Replace all amplifier tubes.
		Defective UX-281 tubes.	Replace UX-281 tubes.
"Wows"	"Wows" noticeable only when projector is first started.	Cold lubricant in projector bearings and viscous damping device. (Type PP-6A projector only.)	Run projector for 15 minutes before the show starts.
	"Wows" heard after machine has warmed.	Viscous damping device not properly adjusted. (Type PP-6A projector only.)	Adjust the viscous damping device. See section 273.
		Impedance flywheel and roller not turning freely. (Type PP-6B projector only.)	Oil impedance flywheel bearing well with "Three-in-One" oil.
Hum		Hum adjustments not properly made.	Adjust for hum.
		Photo-cell shields not installed.	Install photo-cell shields.
		Defective UX-281 tube.	Replace UX-281 tubes.
Noisy Operation		Dirty film.	Clean film or use a new print.
		Dirty sound gate or constant speed sprocket.	Clean sound gate and constant speed sprocket.
	Frame line or sprocket hole noise, "motor boating".	Guide rollers of sound gate out of adjustment.	Adjust the guide rollers.
	Film weaving in sound gate.	Tension springs of sound gate not properly adjusted. (Type PP-6B projector only.)	Adjust the tension springs of the sound gate. See section 91.

PG-5 TROUBLE CHART

See section 281

Trouble	Indication	Cause	Remedy
No Sound	Exciter lamp of the projector in use not lighted. Exciter lamp in other projector lighted.	Fader switch in wrong position.	Switch the fader switch to projector in use.
		Exciter lamp cables reversed.	Connect exciter lamp cables correctly.
	Exciter lamp of neither projector lighted.	Burned out exciter lamp.	Replace exciter lamp.
	Amplifier tubes and exciter lamp not lighted.	Key operated switch on amplifier not turned "on".	Turn key switch "on".
		Amplifier power cable disconnected.	Connect amplifier power cable.
		Power supply fuse blown.	Replace fuse.
	Amplifier tubes and exciter lamp lighted.	Photo-cell not in place or photo-cell shield not properly installed.	Insert photo-cell and mount shield with opening toward the sound gate.
	Sound from one projector but not from the other.	Defective photo-cell.	Replace photo-cell on projector from which no sound is obtained.
		Defective fader switch.	This equipment can be operated by transferring the projector output cable and exciter lamp cable to change from one projector to the other.
	Amplifier tubes not lighted—Exciter lamps lighted.	Plug out of rectifier unit.	Insert plug.
		Voice coil cable disconnected at the amplifier or loudspeaker.	Connect the voice coil cable.
		Power cable disconnected at the loud speaker. (Very low volume will be obtained).	Connect the power cable at the speaker.
		Fuse blown in the loudspeaker power supply circuit.	Replace burned out fuse.
Low Volume	Very low volume on both projectors.	Power supply to loudspeaker open.	Check cable connections and fuses in power supply circuit.
	Low volume on both projectors.	Defective amplifier tube.	Replace amplifier tubes.
		Defective UX-281 tube.	Replace rectifier tubes.
		Exciter lamp current low.	Regulate the exciter lamp current to obtain one ampere.

For a change-over, turn on the motor of the incoming projector at the sight of the cue and almost immediately afterwards turn on the lamp of this projector, at the same time turning off the lamp on the other projector. A short time afterwards, or as long as the cue dictates, fade over the sound. When the film is run out of the outgoing projector, turn off the motor. This difference in procedure is necessitated by the aforementioned points of difference, and are important. If the projectors are set just far enough apart so that each projector switch can be reached at one time by stretching out the arms when standing between them, these operations are quite easily carried out.

280. **Location of Troubles.**—It is the purpose of the trouble chart to list, in tabulated form, troubles which may possibly occur, and the suggested remedy which in most casts can be effected quickly. The method and procedure are similar to that for other equipments.

The trouble chart is for the purpose of aiding the operator in locating the cause of "no-sound," low volume, poor quality and noisy operation. In case of "no sound," before referring to the chart, check the operating procedure and see that no error was made in setting up, check all cable connections and check to see that the exciter lamp of the "faded in" projector is lighted and that all tubes in the amplifier unit are lighted.

281. **Use of Trouble Charts.**—When using the chart look along the left-hand column for the section corresponding to the type of trouble experienced, then look in the "Indication" column and note if any of the items listed there correspond to the nature of the trouble found. The "Cause" column should then be consulted for the probable cause of the trouble, and the "Remedy" column for the suggested remedy.

converter are used, the larger converter as before and the smaller for the second projector.

When all connections have been made and adjustments checked, turn on the amplifier. Test the exciter lamp for proper position by holding a white card in front of the sound gate. When the filament image is centered in the round spot the lamp is in position. Move it up or down until correctly set, and tighten the thumb screw.

Allow the amplifier to warm up for one minute, as certain of the tubes used require that time before they will function. Give each projector a "click test" by flicking a card in and out of the sound gate with the volume turned up and the projector "faded in." A loud click or thump in the loudspeaker will result. If no sound is heard, consult the trouble chart, section 282.

Next test the amplifier for hum, and adjust so as to minimize it. Since the tube filaments are AC operated, it is necessary to include a hum adjustment. Figure 136 shows the location of the hum adjusters, which consist of potentiometers connected across the filament circuits, and adjustable by means of a slotted screw head. These are turned with a screw driver, either to the right or left, until the hum is at a minimum. The procedure is as follows:—Keep the volume control on zero, and remove the UY-227 tube. Adjust the UX-250 hum adjuster for minimum hum. Replace the UY-227 and remove the UY-224. Adjust the UY-227 hum adjuster for minimum hum. Replace the UY-224 and adjust the UY-224 adjuster.

279. Operation of the Equipment.—Although the portable Photophone equipment is quite different in construction from the theatre equipments, as has been pointed out, the operation is not very different. Since the projectors are quite similar to standard types in the construction of the mechanism, the film is threaded through them in the same way.

Figure 131 shows the Type PP-6A portable projector mechanism with film threaded. Figure 134, showing the sound projecting mechanism, and the film threaded through the sprockets, sound gate and rollers illustrates how this is done on the Type PP-6B projector. The projection mechanism threading is the same as for the other model. Figure 132 shows the sound projecting mechanism of the PP-6A projector. A black line is painted on the center plate as a threading guide.

The operation of the portable Photophone equipment when using sound film is somewhat different from the standard routine of running sound projectors. The main reasons for this are that the motor comes up to speed almost immediately, and the projection lamp is turned on at each change-over, and does not need to be started beforehand as with an arc. In addition to this the fader switch changes the exciter lamp supply as well as the sound output. Because of these things it can be seen that the operation of changing over, starting and stopping must take into account these facts. The procedure is therefore as follows:—

When all the apparatus is in place, insert a projection lamp, an exciter lamp and a photo-cell in each projector and the tubes in the amplifier. The photo-electric cell is placed in its socket just to the right of the sound gate, and the shield is replaced with the hole in it to the left, or towards the sound gate. The two UX-281, the UY-227, UY-224 and UX-250 Radiotrons are placed in the amplifier, in the sockets provided for them. These sockets are labelled to prevent any mistake in the location of the tubes. The UY-224 is mounted inside the shield, as shown in Figure 136. The projection lamp is inserted by pushing it down into its pre-focused socket and giving it a quarter-turn to the right. This socket, and the reflecting mirror behind it, may be adjusted for height. Make sure that the center of the filament and the

Figure 139—Accessories trunk for portable equipment

center of the mirror are in line with the center of the condenser lens, which is fixed in position. With no film in the projector, turn on the light and raise the fire shutter. Focus both projectors on the screen and aim them at the same spot so that the fields of light are exactly superimposed, using the tilting screw under the front of the projector if necessary. Rotate the mirror on its vertical axis to obtain the brightest and most even light on the screen.

Connect all supply cables as indicated in the cable diagram, Figure 138. In most cases the supply will be 110 volts, 60 cycle, alternating current. In places where only direct current is available, the projection lamps must be operated from this, and a small rotary converter, described in section 35, is necessary. When operated with one projector, one 1½ k-va. converter is used. This supplies both the projector and the amplifier. When using two projectors, one 1½ k-va. converter and one ¾ k-va.

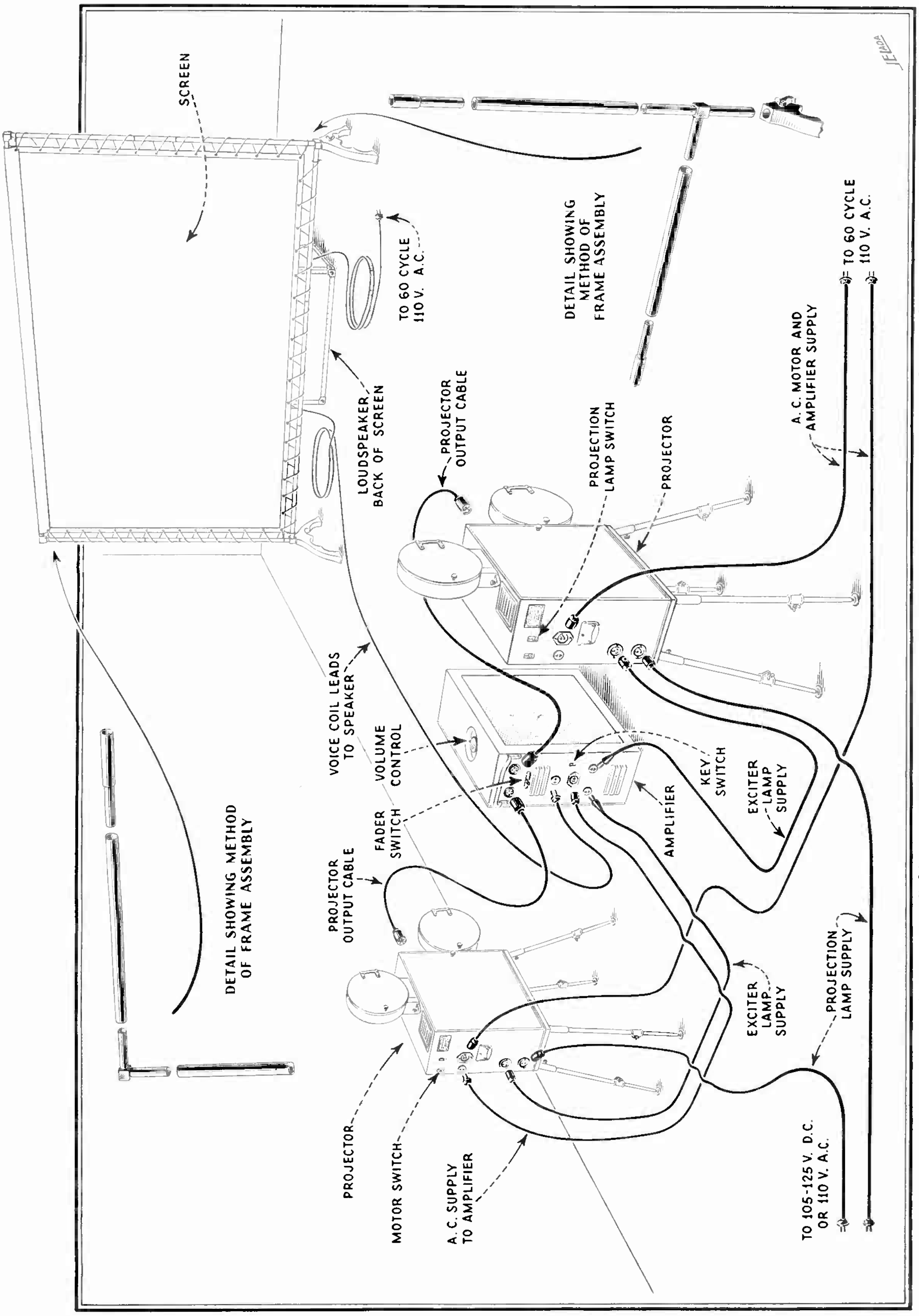


Figure 138—Cable connection and general layout diagram of PG-5 portable equipment

dience. It is collapsible and folds so that it fits compactly into one of the trunks. When unfolded the trunk becomes a part of the support.

The current for the field coil of this unit is supplied by means of a Rectox rectifier unit mounted directly on the baffle. Current for the Rectox is supplied from the 110 volt, 60 cycle, AC source used for the projectors and amplifier. When assembled the unit is similar to the RCA Photophone theatre loud speaker, except that it is smaller.

278. **Setting Up the Equipment.**—The Photophone portable equipment is in every sense portable. Each individual unit is reasonably small in size, consistent with the requirements of the apparatus, and all shipping cases are within the weight limits for baggage. Due to the simplicity of design the operation of setting up and connecting the apparatus so as to place it in readiness for operation takes but a short time.

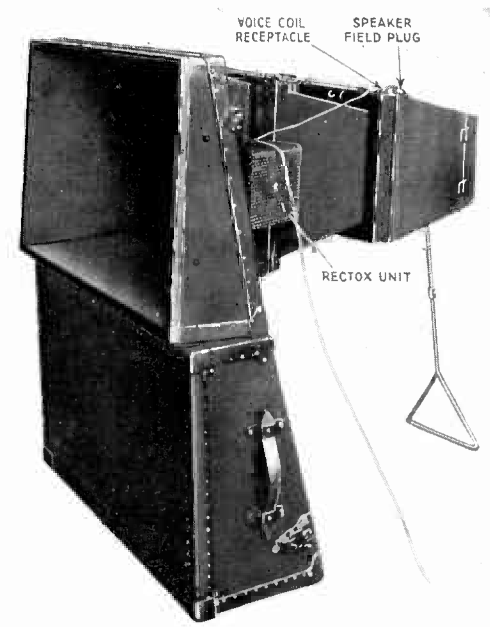


Figure 137—Type PL-26 portable loudspeaker

The projectors are unpacked and mounted on their stands side by side, with the amplifier on the floor near them as shown in Figure 130. This position is in the rear of the room in which the apparatus is to be used, or in the booth, if one is used. The screen and loud speaker are set up at the other end of the room. Figure 138 shows the relative position of all units, and a cable diagram giving the location and proper position for each cable necessary for the operation of tl e equipment. The cables are packed with the projectors and amplifier. The accessories trunk (Figure 139), containing necessary tubes, lamps, tools, film magazines for the projectors, etc., should be conveniently located.

projector; the output for the voice coil leads to the loudspeaker; and the sound input from each of the two projectors. There is also a key-switch provided in case it is desired to lock the equipment electrically. A fader switch permits the changing of the sound from one projector to another, and accomplishes this by changing over from one projector to the other both the input circuit to the amplifier and the exciter lamp supply at the same time. These plugs and switches are all illustrated in Figure 138. A phonograph input jack is located between the input plugs, and permits the playing of non-synchronous records.

The amplifier unit also contains a compensator with a two-position switch, which switches the compensator either "in" or "out". Its purpose is to correct for the ill effects of poor recording. The compensator is discussed in more detail in section 165.

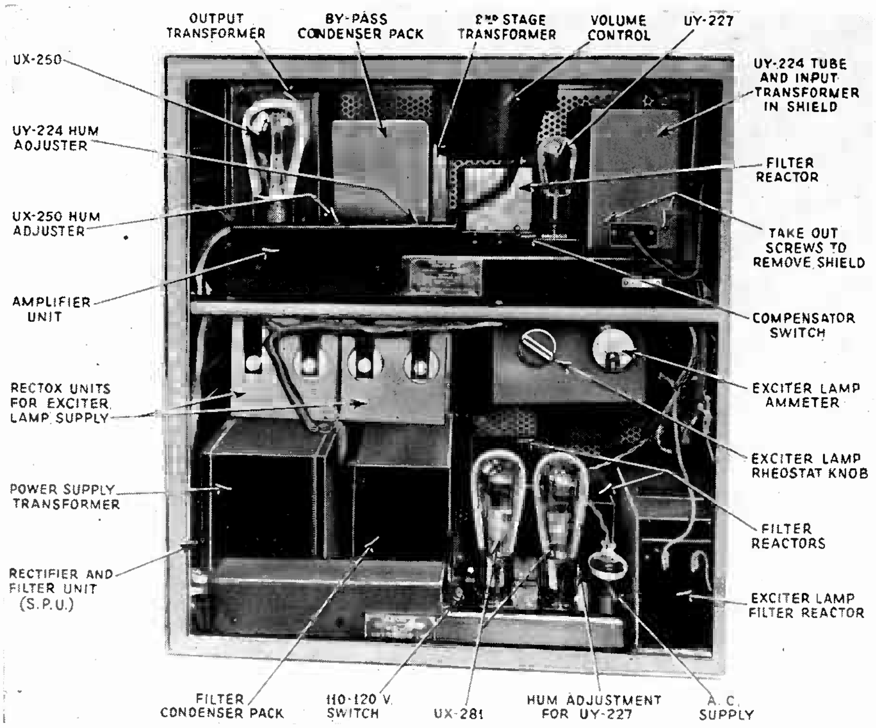


Figure 136—Interior of Type PA-22A amplifier used in the PG-5 equipment

276. The Screen.—The screen provided as a part of this equipment is of light, porous construction and is supported on a collapsible tubular steel frame, which is easily assembled and disassembled. The assembled frame stands as illustrated in Figure 138, and the screen is laced to it by means of a light rope. By adjusting the lacing, all wrinkles can be removed and a perfectly flat surface obtained. The dimensions of the screen are about seven by nine feet. This unit is packed complete in one of the trunks (or packing cases).

277.—The Loudspeaker.—The loudspeaker provided with this equipment, illustrated in Figure 137, is an eight inch dynamic cone type with a directional baffle. When set up it is placed behind the screen, and is aimed through it toward the augrid of the UY-227 Radiotron, and the output of the UY-227 tube is impedance transformer coupled to the grid of the UX-250 Radiotron. The output of the UX-250 is impedance-transformer coupled to the voice coil of the loudspeaker. The volume control consists of a variable resistance connected across the input to the amplifier.

A power unit, utilizing two UX-281 tubes, supplies the necessary voltages for the filaments, grids and plates of the amplifier tubes. This power unit also supplies the polarizing voltage for the photo-cell, and contains a special Rectox rectifying unit, which furnishes current at 1 ampere, 27 volts for the exciter lamps in the pro-

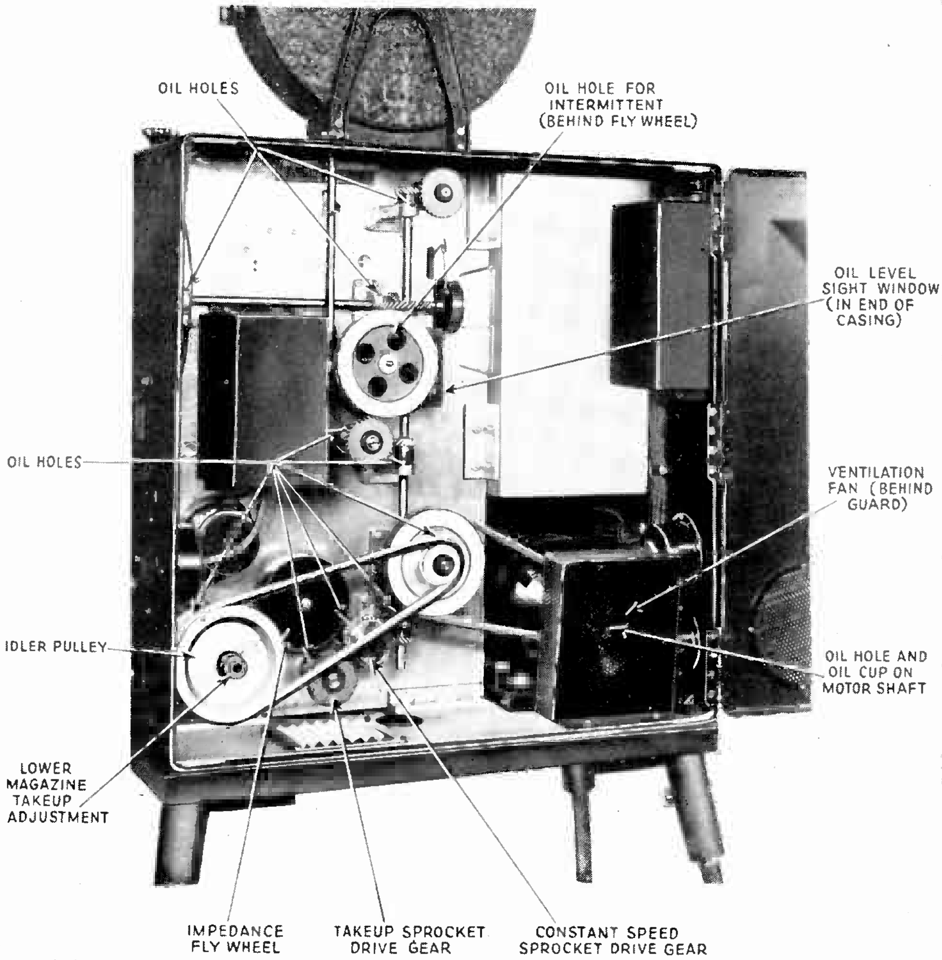


Figure 135—Drive side of Type PP-6B portable projector

jectors. The volume control dial is mounted on the top of the amplifier, and is countersunk flush with the top. All other switches and plugs are mounted at one end, and a hinged door forms one side of the cabinet, thus giving easy access to the interior. Figure 130 shows the amplifier in place with two projectors. Figure 136 illustrates the interior, showing the location of the tubes and amplifier parts.

The receptacles on the end of the amplifier provide for an input of 60 cycle alternating current at 110 volts; the output voltage for two exciter lamps, one for each

The viscous damping grease cup, where used, should be filled with genuine Alemite grease, and the grease cup given a half-turn down each time the projector is put into use, or once for every two hours of continuous running.

Pad rollers provided with oil holes, guide rollers on the sound gates and fire trap rollers should receive one drop of light machine oil for each day's use. Apply with a tooth-pick.

After lubrication, all excess oil should be wiped off of the projector mechanism. Particular care should be taken to see that no excess oil is left on the pad rollers, lateral guide rollers, idler rollers, and fire trap rollers, because these parts come in contact with the film. If oil should get on the film it would impair the picture and sound reproduction.

In addition to the oiling noted in the foregoing paragraphs attention should be given to the gears, racks, and pinions of the projector mechanism which are not oiled by means of oil holes. An occasional drop of oil on these moving parts will increase the life and improve the performance of the projectors.

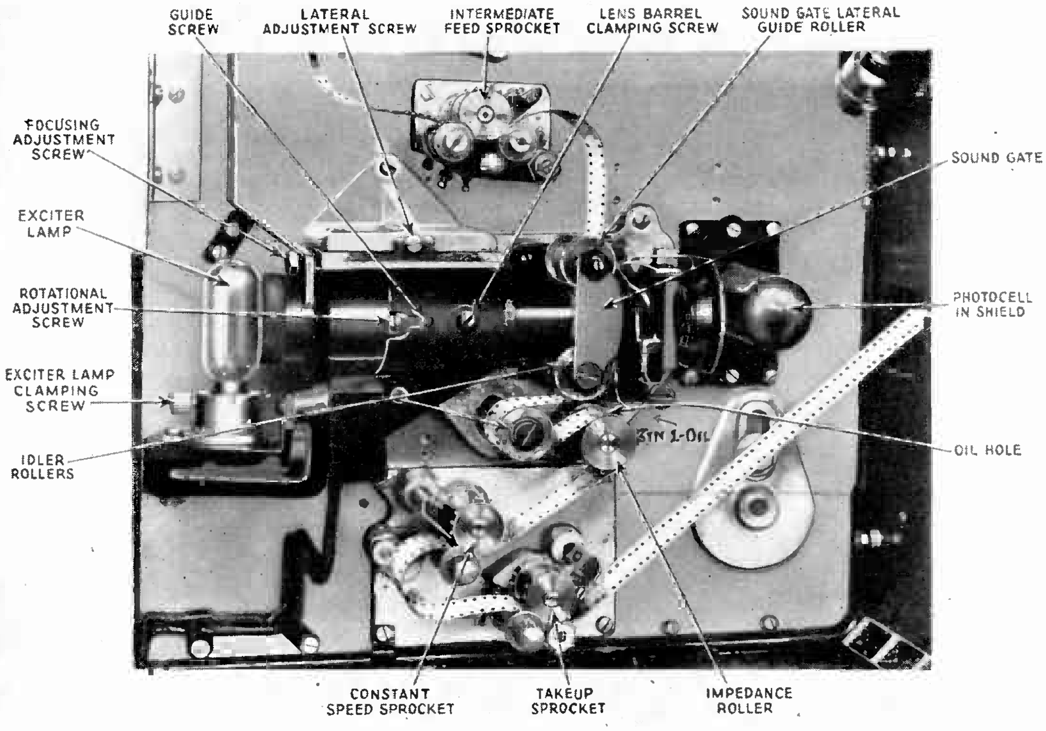


Figure 134—Sound reproducing mechanism of the Type PP-6B portable projector

275. Description of Amplifier.—The amplifier for the PG-5 equipment operates on any 110 volt, 50 to 60 cycle alternating current supply, available almost everywhere. Converters are available where DC must be used. See section 35. No batteries are required. It is housed in a metal cabinet and is connected to the projectors, loudspeaker and source of supply by easily connected cables. The amplifier proper consists of two stages of voltage amplification and one power stage. The output of the photo-cell transformer is auto-transformer coupled to the grid of the UY-224 screen grid Radiotron. The output of this tube is impedance coupled to the

274. **Lubrication of Projector.**—The necessary lubrication of the projector is quite simple and is easily done. The necessary points of lubrication can be classified under four headings:—the motor, the intermittent, the shaft bearings, and miscellaneous parts. Use a good grade of light machine oil except where otherwise noted.

The motor is provided with two oil cups and two oil wells, as illustrated. Two or three drops of light machine oil for each week's use is sufficient. The oil wells should be refilled with fresh vaseline every month or two, depending on the amount of use to which the projector is submitted.

The intermittent is lubricated through an oil hole in the top of its casing. The intermittent should be kept supplied with light machine oil so that the level in the

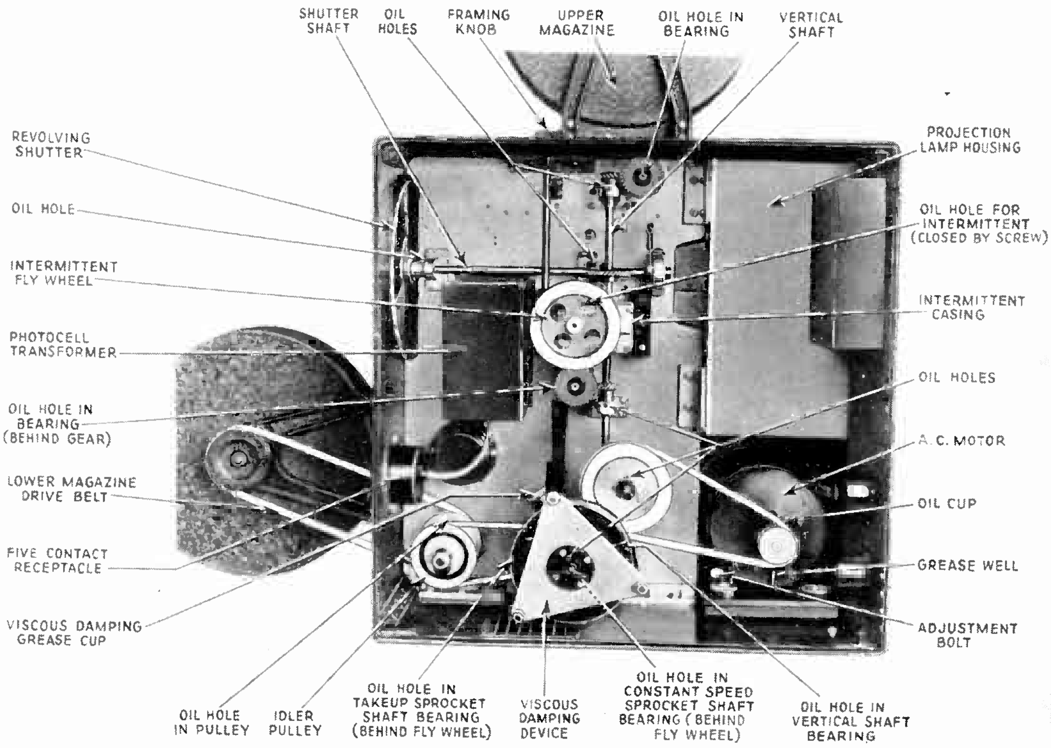


Figure 133—Drive side of Type PP-6A portable projector

casing about covers the window located in the side of the intermittent casing. On some of the projectors this oil hole is accessible by turning a knurled cap so as to make the hole in the cap coincide with the hole in the tube on which it is mounted. On other projectors a round headed machine screw must be removed for oiling. The oil holes should be kept closed to prevent loss of oil. *Do not let the intermittent mechanism run dry.*

All shaft bearings illustrated in Figures 131, 133, 134 and 135 should receive a drop or two of light machine oil for each show, or every two hours of continuous running. The impedance fly-wheel shaft bearing should be lubricated with Three-in-One oil only. Use a few drops for each day's use. See Figure 134.

proximately four sprocket holes from the lower loop and must be provided for when threading. A loop of from eight to ten sprocket holes is satisfactory. Figure 134 shows a close-up view of the operating side of this mechanism with film threaded. Figure 135 illustrates the drive side, showing differences of construction and lubrication as compared to the drive side of the other model, shown in Figure 133.

The sound optical system used is similar to that described and illustrated in section 90 and Figure 64. Lateral, horizontal and focusing adjustment screws are provided, as with the other types, and the exciter lamp has a vertical adjustment, described in section 278.

The standard Photophone UX-868 Photocell is used in the portable projector. In the illustrations it is shown covered by a metal shield, which protects it from extraneous light. The light beam from the optical system passes through a hole in

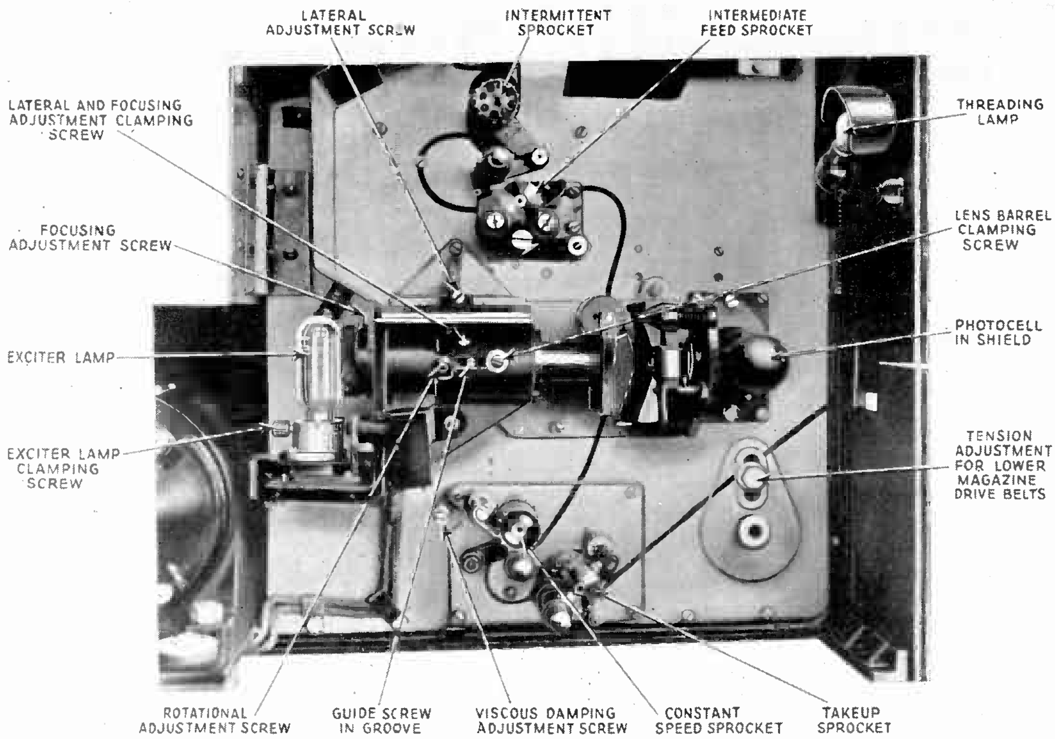


Figure 132—Sound reproducing mechanism of the Type PP-6A portable projector

the shield onto the cell after passing through the sound track on the film. The photo-cell terminals lead to an input transformer located in the projector, and this is connected by a cable to the amplifier.

The exciter lamp operates at 27 volts, 1 ampere and derives its direct current from a Rectox rectifier in the amplifier. The exciter lamp current is controlled by means of a rheostat (See Figure 136). It is possible to burn out the exciter lamp if the rheostat is not properly set. It is, therefore, important that the knob be set to the extreme counter-clockwise position before the amplifier power is turned on.

projector is shipped from the factory. The smaller of the two pulleys is for use in case the projector is used on a 60 cycle supply. It is important that the right pulley be used, otherwise the film speed will be incorrect.

The lower part of the projector contains the sound reproducing mechanism. This may be one of two types, each of which correspond in most respects to those used on RCA Photophone theatre equipments. The Type PP-6A uses the mechanism shown in Figure 132, the drive side of which is illustrated in Figure 133. This is similar to the mechanism used on Types PG-1 to PG-10 Photophone equipments, and has been completely described in Chapter VIII. The constant speed sprocket on this

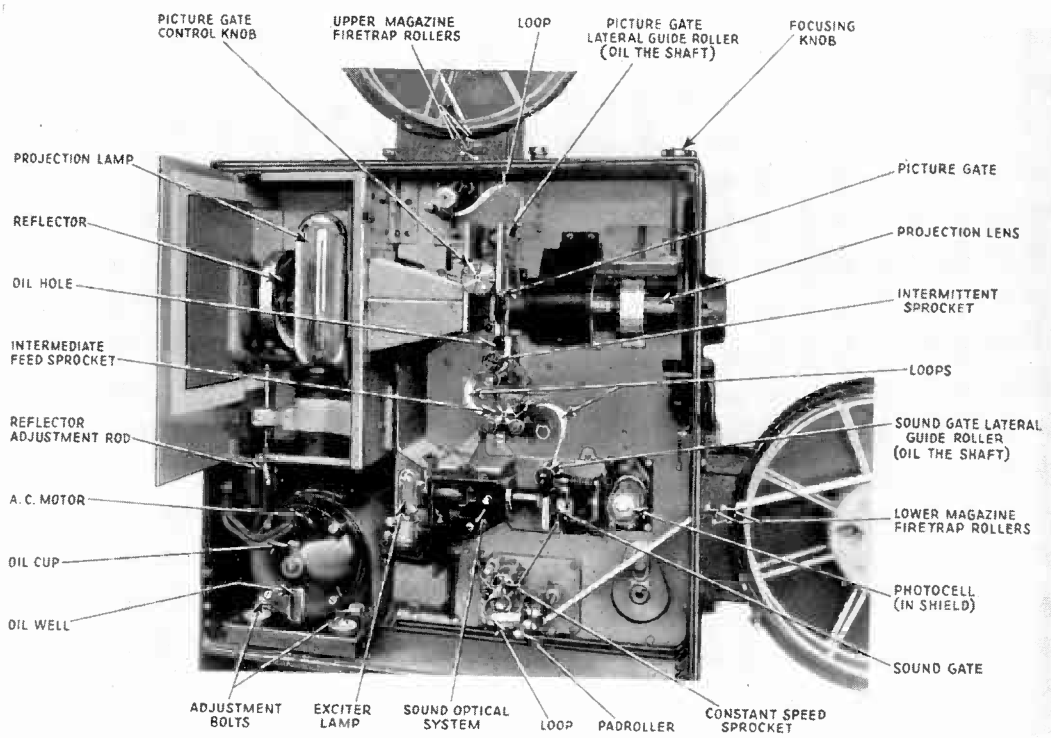


Figure 131—Operating side of Type PP-6A portable projector

projector is controlled by the viscous damping device described there and in section 71. The damping device is lubricated and adjusted in the same way as that in the other sound heads, except that the adjustment screw and grease cup are located as shown in Figures 132 and 133. The sound gate used is similar to that illustrated in Figure 62 and described in section 91.

The other type of projector (PP-6B) uses an impedance roller and fly-wheel in conjunction with the constant speed sprocket to maintain constant film speed, and the sound gate illustrated in Figure 66 and described in section 99. Due to the rapidity with which the projector motor comes up to speed, there would be danger of the film breaking in bringing the impedance flywheel up to speed, if no provision were made to lessen the strain. This is taken care of by driving the constant speed sprocket through a coil spring. The coiling of the spring while running takes ap-

As will be seen in Figure 131, the projector mechanism combines both a picture projecting mechanism, similar in principle and construction to a standard projector, and a sound reproducing mechanism similar to the larger Photophone sound heads.

The projection lamp is a 1000 watt incandescent lamp operated at 110 volts, and is contained in a fire-proof lamp housing, in a pre-focused socket which insures its proper position in relation to the reflector and condenser lens. The standard "quarter size" projection lens projects a picture covering the screen, about nine feet wide, at forty feet. Longer focus lenses are available for longer throws.

The intermittent movement is similar in action to those on standard projectors, but of slightly different construction. Figure 131 shows film threaded in the projec-

Figure 130—The projectors and amplifier used with the PG-5 portable equipment

tor, illustrating the similarity to larger projectors. The framing and focusing knobs are located on the top of the projector, thus making it unnecessary to open the projector doors when running.

The projector is driven by means of a one-eighth horse power, single-phase, 110 volt AC motor, operating at 50 or 60 cycles. An adjustable belt drive transmits the power to the projector mechanism, the adjustment being effected by moving the motor until the proper tension is secured. The adjustment bolts illustrated are used for this purpose.

Projectors intended for use on 50 cycle power supply systems are supplied with two motor pulleys. The larger of the two pulleys is for use when the power supply available is 110 volt, 50 cycle. This pulley is mounted on the motor shaft when the

CHAPTER XV

TYPE PG-5 PORTABLE EQUIPMENT

272. **General Description.**—The PG-5 Portable Equipment, although similar in function to all Photophone reproducing equipments, is quite different in design and purpose. Since the main consideration has been portability, without attendant loss of quality of reproduction, the appearance and construction of the various parts is therefore quite unlike the theatre equipments.

The projector is specially designed, combining both projection and sound reproducing mechanisms, and is a very compact unit. The amplifier is a self-contained unit which needs only a standard 110 volt, 50 or 60 cycle, AC supply, and furnishes all voltages necessary for its operation without the use of batteries or motor-generator sets. A portable screen and loud speaker are supplied with each equipment.

The equipment can be used in districts where 125 volt DC is the standard power supply, but converting equipment is required to change the DC power to 110 volt, 60 cycle power. Converters can be supplied for this purpose.

The entire equipment is quickly set up or repacked. A completely portable set including two projectors, an amplifier, loudspeaker, screen and accessories packs into six trunks, the total weighing about 920 pounds. Several schedules are supplied, so that either one or two projectors and a completely portable or semi-portable loudspeaker are available.

Each trunk has been specially designed, carefully fitted and padded to withstand vibration and handling in shipment. An accessories trunk contains the projector film magazines, a double set of amplifier tubes, a supply of projection and exciter lamps, tools, film cement and a film rewinder and splicer.

The screen is quickly assembled from parts which fit very compactly into its trunk, and the speaker also is designed to be quickly unpacked and placed ready for operation.

273. **Description of Projector.**—The Photophone portable projector used in PG-5 equipments accommodates standard film, sound or silent, and projects it at a film speed of 90 feet per minute. The entire mechanism is enclosed in a steel cabinet, on which are mounted the two 1000 foot film magazines, removable for packing. It rests on telescoping legs about thirty inches from the floor, and a tilting screw on the mounting frame placed under the front of the projector provides for centering of the picture on the screen. The angle of projection can also be altered by adjusting the front and rear telescoping legs. See Figure 130.

It is specifically recommended that a spare parts kit for the particular installation be kept on hand, and that its supply of spare parts (with particular reference to fuses and Radiotrons) be maintained. These kits are obtainable from RCA Photophone and contain spare parts which may be required for emergency repairs.

270. **Summary of the Daily Maintenance Requirements.**—The following is a list of things which should be done every day:—

(a) Fill grease cup of the viscous damping device with Alemite grease. Screw down one turn for every four hours of running in both the sound heads and the turntables. See sections 71 and 92.

(b) Oil projectors, turntables, chains, motors, and M-G sets and converters where used.

(It is very important to see that the equipment receives sufficient oil, but care should be taken to see that the bearings are not drenched, particularly in the sound head, as oil may be thrown on the film and on the optical system. Take no chance of dry bearings, but do not drench them with oil.)

(c) Run the projector 15 minutes before starting the show.

(d) Clean sprockets and sound gate, taking particular pains with the constant speed sprocket.

(e) Polish condenser lenses in optical system. Keep the sound head clean.

(f) Check exciter lamp adjustments and see that exciter lamps are all clean.

(g) Check the storage batteries for state of charge, and cleanliness.

(h) Check the voltages at the amplifier panels.

(i) Check sound from each projector by means of the card "test", and scratch needle of each turntable pick-up before each show.

(The click test is made by passing an opaque card in and out through the exciter lamp beam at each sound gate alternately. With the amplifier turned "on" and all switches properly set for sound-on-film operation, a click in the loudspeaker should be heard.

With all switches properly set for sound-on-disc, scratch the needle in each pick-up alternately. A scratching noise should be heard in the loudspeakers.)

(j) Test all power amplifiers with the "click" test by plugging the monitor into one at a time.

(k) Test both voltage amplifiers with the "click" test.

271. **Some Things Which Should Not Be Done:**—

(a) Do not put any thing but oil on the drive chains.

(b) Do not turn "off" the voltage amplifier before turning "off" the power amplifier.

(c) Do not fade to the starting projector too soon.

(d) Do not try to adjust the optical system.

(e) Do not forget to close the sound gate when using sound film.

(f) Do not forget to keep the aperture of the sound gate clean.

(g) Do not use reels with small sized hubs when using the large size take-up pulley as the small hub will not take up the film fast enough, and the film will pile up in the lower part of the sound head. When using a reel with a small hub use the two inch pulley. The five inch pulley should be used with large hubbed reels.

power line. If the motor still fails to start when these conditions have been checked and it is certain that power is actually entering the charger, check the fuses inside of the cover. See Figures 26 and 39. These figures show the location of the generator fuses only, but the motor fuses are similarly mounted.

(b) *In DC installations,* failure of the DC motor to start may be due to:—

Any of the troubles listed above for the AC motor except that there are no motor fuses inside of the cover.

Worn brushes. Replace the worn brushes with the spares.

Very dirty commutators. Clean with "00" sandpaper.

Care must be taken when starting the DC charger at the line starting box to close the switch rapidly. If it is not closed rapidly, and one contact of the switch closes a few moments before the other, the operation of the line starter is lost.

(c) *Generator troubles.* These troubles are of course common to either the AC or DC motor-generator chargers. A considerable variation in the reading of the ammeter located on the control panel of the charger unit is usually caused by worn or dirty brushes in the generator or loose connections. Remove these brushes and replace or clean them and also clean the commutator with a very fine grade of sandpaper such as "00" (*Never use emery cloth on a commutator.*) Tighten any loose connections found.

See also sections 53 and 56.

268. Tungar and Rectigon Battery Chargers.—Theatres that are equipped with the Tungar or Rectigon chargers may experience the following troubles at one time or another:—

(a) If, when the battery charger is turned "on," the Tungar or Rectigon bulbs fail to light, make sure that the main power supply from the street main into the building is closed, and that AC voltage is actually obtained at the charger. If this is O.K. replace the bulbs with new ones of the same rating. If this does not correct the trouble call the RCA service engineer.

(b) Should the tubes light up and the ammeter not show any charging current, make sure that the four-pole battery switch is in the proper position for charging. If this does not correct the trouble, check the fuses in the battery circuit, and if still no charging current is shown by the ammeter, replace the rectifying tubes. If no charging current is obtained after all available tubes have been tried, call the service man.

See also sections 57 and 58.

(D) ROUTINE MAINTENANCE AND TESTS

269. General Discussion.—Although the primary purpose of this chapter is to deal with troubles, it would not be complete unless something was said regarding the prevention of trouble. Many of the troubles which are experienced by projectionists can be prevented if the equipment is properly taken care of and checked over periodically.

The maintenance requirements of the various parts of the equipments were covered in the chapters describing the parts so that only a summary will be included here.

turned to the "Off" position. Be sure to keep your fingers out of the end casting of the motor at the fly-wheel end. This is dangerous as there is a fan inside of this opening and injury may result.

264. **AC to DC Motor-Generator for DC Projector Drive Motors.**—The motor starting boxes for this set do not contain fuses, but contain instead an overload switch which turns "off" the power to the motor in case of trouble. If, for any reason, the motor draws excessive current, this overload switch will trip. It will not be possible to start the motor until the overload switch has been reset by hand. The reset is operated by pulling up a lever which protrudes from the right-hand side of the starting box, or by pulling a cord hanging from the box. If at any time, the motor fails to start when the push buttons are operated, operate this reset to make sure that this switch is closed. In an emergency it is not necessary to push the "Stop" button of the machine that is operating, just push the "Start" button of the other. This stops the motor generator that is running and starts the other.

If the machines run but no voltage reading is obtained at the DC voltmeter, check the fuses on the front of the generator control panel. Also note if the selector switch on the front of the panel is closed for the proper generator that is running. See section 33.

265. **DC to AC Motor-generator Sets.**—If the DC to AC motor-generator set fails to start when the motor line switch is closed, look for blown fuses in the line starter box. See section 34.

In case of the ½ k-va set, if the set runs and no AC power is available at the power amplifiers and a reading is obtained on the AC voltmeter at the M-G set, the indication is that the fuses under the mesh cover of the set (see Figure 26) are blown. The mesh cover can be removed by removing the three nuts at the end of the tie rods at the back of the panel.

In case of the 1½ k-va set the AC line fuses are mounted just above the AC voltmeter on the generator control panel (see Figure 28). If one of these fuses should burn out, no reading will be obtained on the AC voltmeter when the M-G set is running.

CAUTION.—A DC motor field rheostat is mounted on the generator control panel of the 1½ k-va M-G set. The setting of this rheostat should not be disturbed by the projectionist.

266. **DC to AC Converters for SPU Equipments.**—Very little trouble will be experienced with these machines and, if there is a spare, in case of trouble change converters. If this does not remedy the trouble, check the AC fuses in each supply line and if they are O.K. and the converter is running but no voltage is obtained in the amplifier, check the fuses in the amplifier itself.

267. **Motor-Generator Battery Chargers.**—Theatres that employ the motor-generator chargers may encounter any of the following difficulties:

(a) *In AC installations,* failure of the AC motor to start may be due to:—

No power on the supply line. Main power line switch open. Blown fuses in the

(C) TROUBLES ON PROJECTOR DRIVE MOTORS AND AUXILIARY EQUIPMENT

262. **AC Projector Drive Motors.**—Should the AC motor fail to start check the following:

(a) AC line switch open.

(b) Blown fuses in AC line.

(c) Defective switch. There is a possibility that a burned out switch contact on the projector is preventing current from reaching the motor. Do not turn "off" the motor switch until the motor has reached full speed unless it is absolutely necessary, as this causes an arc in the switch. After some time such an arc is likely to ruin the switch contacts completely.

(d) A burned out resistor in the three-phase motor line. Bring the projector up to running speed by cranking it with the power turned "on" and, if the motor will keep the projector running, it usually is a sign that one of the resistors in the AC line has opened, probably burned out. Of course, if the two resistors have burned out, which should never occur, the motor would not drive the projector under any condition. Should the condition be found where the motor will not run unless it has been cranked up to synchronous speed, it can be temporarily fixed by "shorting out" the defective resistor, but the equipment should not be left in this condition for any length of time, as the machine will come up to speed too quickly and too great a strain on the mechanism will result.

(e) A burned out resistor in any single-phase AC motor line must be replaced before the equipment can be operated. Notify the RCA Photophone service engineer.

(f) If excessive vibration occurs, check all bolts to see that the motor is bolted tight to the base, and also make sure that the drive sprockets have not slipped out of alignment. See sections 28 and 29.

See also sections 31 and 32.

263. **DC Projector Drive Motor.**—If the DC projector motor fails to start look for the following troubles:—

(a) DC line switch "off".

(b) Blown fuses.

(c) Dirty switch contacts.

If the drum type switch is used, make sure that the contacts in the switch are clean and bright. Dirty or pitted contacts can cause much trouble.

If the motor picks up to a speed much in excess of normal, look for dirty contacts in the centrifugal switch.

If excessive sparking is noticed at the commutators of DC motors or generators, coating the brushes very lightly with tallow will greatly help to reduce it. Keep the commutators clean. When brushes become excessively worn, replace them with new ones. With proper care the motor will give very little trouble. Never oil the DC motor. See section 27.

CAUTION.—Never leave the drum control switch in the "Brake" position. The brake may be used to stop the motor when necessary, but must be immediately re-

261.

PG-13 EQUIPMENT TROUBLE CHART

See Section 254

Trouble	Indication	Cause	Remedy
No Sound		Volume control not set correctly.	Set volume control correctly.
	M-G set not running.	Open in the power supply line.	Check for open switches in the power supply line. Replace any fuses which may be burned out. See Figure 36.
	Amplifier tubes and exciter lamps fail to light. Reading obtained on low voltage meter of M-G set.	Fuse blown in low voltage generator circuit.	Replace fuse and if it blows again, check for short on low voltage line. See section 248, and Figure 36.
	Amplifier tubes and exciter lamps light. Reading obtained on high voltage meter of the M-G set.	Fuse blown in high voltage generator circuit.	Replace fuse, and, if it blows again, replace the UX-250 tubes in the amplifier unit and again replace the fuse. See Figure 36.
	Amplifier tubes and exciter lamps light. Fuses of M-G set OK.	Defective UX-112A tube.	Replace all UX-112A tubes with tubes known to be good.
Low Volume		Defective UX-112A tube.	Replace all UX-112A tubes.
	One or more UX-250 tubes do not light.	Burned out UX-250 tubes.	Replace burned out UX-250 tubes.
		Defective UX-250 tube.	Replace all UX-250 tubes.
Noise or Motor-Boating		Loose connections.	Inspect all connections and tighten where necessary.
		Poor ground connections on projectors.	Clean and tighten connections.
		Defective "C" batteries.	Replace "C" batteries.
Hum		Dirty commutators on generators.	Clean the commutators. See section 37.
Whistling Sound		Defective or unmatched UX-250 tubes.	Replace the UX-250 tubes with matched tubes.
		Microphonic UX-112A tube.	Tap tubes lightly to determine which tube is defective, and replace defective tube.

260. PG-2 EQUIPMENT TROUBLE CHART

See Section 254

Trouble	Indication	Cause	Remedy
No Sound		Switches or rheostats on amplifier rack set incorrectly.	Set switches and rheostats to their correct positions.
	Amplifier tubes and exciter lamps fail to light.	Fuse blown in 15 volt generator circuit.	Replace fuse. If fuse blows again check for short-circuit on the "A" supply line. See section 247.
	Tubes of one power amplifier unit fail to light when those of other do light.	Defective lever switch on power amplifier panel.	Operate with the power amplifier unit which is OK.
	Tubes of power amplifier light but no reading is obtained on the plate current milliammeters.	Open in the 1000 volt generator circuit. Burned out fuse in 1000 volt circuit.	Replace burned out fuse. If the fuse blows again open both lever switches on the power amplifier panels, replace the fuse and close lever switches one at a time. If the fuse blows when one of these switches is closed, the indication is that there is a short-circuit in the power amplifier associated with the switch. Operate with the other power amplifier alone. Replace the tubes in the defective power amplifier, and check operation when convenient.
	All amplifier tubes light. No reading at jack labelled EB123X-100.	Fuse blown in 500 volt circuit.	Replace burned out fuse. If the fuse burns out when replaced, replace all the tubes of the voltage amplifier and replace the fuse in the 500 volt generator again.
Noise or Hum	Hum from the monitor and stage speakers.	Dirt and acid on top of the storage batteries.	Clean the storage batteries.
		Fuse blown in battery circuit.	Replace the fuse.
		Reverse current relay stuck open.	Notify the RCA service engineer.
		Storage batteries gassing.	Decrease charging rate of the storage battery.
		Dirty commutators on the generators of the M-G set.	Clean the commutators. See section 36.
	Hum from monitor only.	See "Hum," section 259.	
Whistling Sound	Readings of the plate current meters on the power amplifier panels not equal.	Plate currents of power amplifier tubes not properly adjusted, or defective tube.	Balance the readings if possible. Replace the tubes if balancing is not possible or does not eliminate the noise. See section 183.

259. PG-1 EQUIPMENT TROUBLE CHART

See Section 254

Trouble	Indication	Cause	Remedy
No Sound		Switches or rheostats on amplifier rack set incorrectly.	Set switches and rheostats correctly.
	Sound can be obtained from one amplifier rack and not from the other.	Defect in amplifier rack equipment.	Operate using the good amplifier rack. Check all tubes, meter readings, and fuses of the defective rack as soon as convenient. See section 176.
	Motor-generator sets associated with both amplifier racks fail to start.	Open in power line circuit to motors of M-G sets.	Check all line switches in the power circuit. Replace fuses if blown.
	Fuses in the low voltage generator circuit blow as indicated by the amplifier tubes and exciter lamps failing to light.	Short circuit in "A" supply circuit.	Change over to other amplifier rack. If fuses blow on this rack also the indication is that the short is in the exciter lamp circuit of the projector. See section 246.
	Tube in voltage amplifier fails to light.	Tube burned out.	Change to other amplifier rack and replace tube when convenient.
Low Volume		Defective tube in the voltage amplifier.	Change to the other amplifier rack and replace all the voltage amplifier tubes when convenient.
Noise or "Motor-Boating"	Noise obtained when using either amplifier rack.	Loose ground connections on the projector.	Clean and tighten the projector ground connections.
	Noise obtained from one amplifier rack only.	Loose connection on the amplifier rack.	Operate using other amplifier rack. Inspect all connections and tighten where necessary.
		Defective "C" batteries.	Operate using other amplifier rack. Replace "C" batteries as soon as convenient.
Hum	Hum heard from both stage and monitor speakers.	Dirty commutator on M-G set.	Change to other amplifier rack. Clean commutators. See section 36.
	Loud hum heard from monitor speaker only.	Defective UX-280 tube (or Rectox unit) on monitor speaker.	Replace UX-280 on monitor speaker. Where the Rectox unit is used, turn off the AC power to the monitor and notify the RCA service engineer.
Whistling Sound	Readings on plate current meters of power amplifier not balanced.	Unbalanced plate currents of power amplifier tubes.	Balance plate current readings. If this does not correct the trouble change to the other amplifier rack. Replace the power amplifier tubes when convenient.

SPU AMPLIFIER TROUBLE CHART
(Continued)
See Section 254

Trouble	Indication	Cause	Remedy
Low Volume (Continued)	No sound from one power amplifier as shown when monitor speaker is plugged in.	Power amplifier fuse burned out.	Replace burned out fuse.
		Tubes burned out in power amplifier.	Replace burned out tube.
		Defective power amplifier unit.	Operate without the defective unit.
Poor Quality	Poor quality from more than one power amplifier unit.	Defective voltage amplifier.	Change to other voltage amplifier if available. If only one voltage amplifier is used, replace all tubes with matched pairs of new tubes.
	Poor quality from one power amplifier, others OK.	Defective power amplifier unit.	Operate without the defective unit. Check all tubes when convenient.
Hum	Loud hum heard from stage and monitor speakers.	Defective or burned out UX-281 tube in power amplifier unit.	Check for power amplifier causing the hum (using monitor speaker and jacks.) Replace defective UX-281 tube.
	Loud hum heard from monitor speaker only.	Defective UX-280 tube (or Rectox unit) on monitor speaker.	Replace UX-280 on monitor speaker. Where the Rectox unit is used, turn off the AC power to the monitor and notify the RCA service engineer.
Noise or "Motor-Boating"		Dirt and acid on top of the storage batteries.	Switch to the other battery and clean the dirty ones.
		Gassing storage battery.	Do not use a storage battery sooner than one hour after charging except in an emergency.
		Loose storage battery terminal connections.	Clean and tighten connections.
		Poor ground connections on the projector.	Clean and tighten connections.
	Low plate voltage readings at metering panel of voltage amplifier.	Noisy or old "B" batteries.	Replace the "B" batteries.
		Noisy or old "C" batteries.	Replace the "C" batteries.
Whistling Sound	Whistling sound heard when the monitor speaker is plugged into one power amplifier and not when it is plugged into the others.	Defective or unmatched tubes.	Replace the UX-250 tubes in the power amplifier which whistles. If whistling continues replace the UX-281 tubes. See section 251.

258.

SPU AMPLIFIER TROUBLE CHART
See Section 254

Trouble	Indication	Cause	Remedy
No Sound		Switches or rheostats set incorrectly on amplifier or input control panel.	Set switches and rheostats to their proper positions.
		Output fader in the "Off" position or wrong one being used. (These are used in PG-6, PG-7 and PG-8 equipments only.	Use the proper output fader and set it in the correct position.
	Sound can be obtained from one voltage amplifier but not from the other.	Defective voltage amplifier.	Operate using good voltage amplifier. Check tubes of defective unit when convenient.
	Both tubes of one voltage amplifier stage do not light.	Burned out tubes.	Replace tubes which do not light.
	No reading at a plate voltage jack of the metering panel.	Open "B" battery connection.	Reconnect "B" battery.
	Voltage amplifier tubes and exciter lamps do not light.	Dirty contacts on the battery switch.	Snap the switch back and forth several times to clean the contacts.
		Dirty contacts of change-over switches. PG-3 equipment only.	Snap the change-over switches back and forth several times to clean the contacts.
		Burned out fuse in four-pole battery switch box.	Turn switch to other battery and replace burned out fuse. See section 245.
	Fuses in four-pole battery switch box burn out when replaced.	Short circuit on "A" battery line.	Check for short circuit. See section 245.
	AC voltmeter on power amplifier panel reads zero.	AC supply circuit open.	See that all line switches are closed. Replace line fuses if they are blown.
	AC voltmeter indicates proper voltage but amplifier tubes fail to light.	Fuses in power amplifier burned out.	Replace fuses. If they continue to blow, operate without this amplifier if possible. Reset voltage to 100 volts. If only one power amplifier is used, replace all tubes. See section 249.
Low Volume	Low filament voltage as measured at the metering jack.	Storage battery discharged.	Switch to the other storage battery.
		Voltage amplifier defective.	Change to the other voltage amplifier if available.
		Tube burned out in voltage amplifier.	Replace burned out tube.

257.

FADER CIRCUIT TROUBLE CHART

See Section 254

Trouble	Indication	Cause	Remedy
No Sound	No sound from either the pick-up or photo-cell of one projector, but sound obtained from the other projector.	Defective fader relay or fader potentiometer.	Clean contacts of the fader relay or potentiometer. See sections 242 and 243.
		Defective "Film-Disc switch	Clean the contacts of the "Film-Disc" switch.
	No sound from either projector but sound obtained from non-synchronous phonograph.	Defective fader relay or fader potentiometer.	Clean the contacts of the fader relay or fader potentiometer. Look for broken connections.
		Dirty contacts in plugs in input control panel.	Clean the contact pins.
		Loosely inserted plugs in input control panel.	Insert plugs all the way.
Noise		Vibration of loosely inserted plugs in input control panel.	Insert plugs all the way.
Noisy Fading	Noise noticed only when operating the fader potentiometer.	Dirty fader potentiometer contacts.	Clean the fader potentiometer contacts. See section 242.
Cross-talk on a PG-10 equipment		Dirty contacts on fader relay.	Clean fader relay contacts. See section 243.

256. **SOUND-ON-FILM TROUBLE CHART**

See Section 254

Trouble	Indication	Cause	Remedy
No Sound		"Film-Disc" switch set in "Disc" position.	Set "Film-Disc" switch in the "Film" position.
		Fader in the "Off" position or set for wrong projector.	Set fader to the proper position.
	Exciter lamp ammeter reads zero when exciter lamp rheostat is turned on.	Exciter lamp burned out or not properly turned into position.	Turn another lamp into operating position.
	Exciter lamp lighted but no light at photo-cell.	Sound gate aperture completely clogged.	Clean the sound gate aperture.
		Defective photo-cell.	Insert new photo-cell.
	No sound from photo-cell of either projector, sound from pick-ups.	Open photo-cell polarizing battery leads.	Reconnect battery leads.
Poor Quality	Fluttering sound from loud speakers.	Poor sound film.	Use good film.
		Dirty sound gate.	Clean gate thoroughly.
		Dirty constant speed sprocket.	Clean constant speed sprocket.
		Dirty or scratched film.	Clean film or use a new print.
		Defective photo-cell.	Use new photo-cell.
		Sound gate open.	Close sound gate.
"Wows"		Dirty sprockets.	Clean sprockets thoroughly.
		Worn constant speed sprocket.	Replace worn sprocket.
		Viscous damping device out of adjustment.	Check carefully, and make whatever adjustment is necessary. See section 92.
Unequal Volume from Projectors		Weak photo-cell.	Replace photo-cell.
		Poor exciter lamp.	Turn another exciter lamp into position.
		Dirty sound gate aperture.	Clean sound gate aperture.
	Inequality of volume not very great.	Un-matched photo-cells.	Adjust exciter lamp currents to compensate for inequality of photo-cells. See section 237.
Noise or Motor Boating	Noise noticeable on both projectors when operating from sound-on-film but not from disc.	Noisy photo-cell battery —Battery voltage low.	Replace photo-cell battery.
	Film weaves noticeably.	Guide rollers out of adjustment.	Readjust guide rollers. See sections 90 and 250.
	Light ray passes through the sprocket holes or frame lines.	Optical system out of adjustment, or film weaves as above.	Adjust guide rollers. If trouble continues, notify RCA service engineer.

255.

SOUND-ON-DISC TROUBLE CHART

See Section 254

Trouble	Indication	Cause	Remedy
No Sound	Motor-boating (frame line) noise only, if exciter lamps are lit.	"Film-Disc" switch set in the "FILM" position.	Set "Film-Disc" switch in the "DISC" position.
		Fader in the "OFF" position or set for wrong projector.	Set fader to the proper position.
	Sound obtained from one projector but not from the other.	Defective pick-up.	Replace pick-up from which no sound is obtained. See section 229. Make sure that the pick-up contacts are clean and tight.
		Defective "Film-Disc" switch.	Clean contacts of "Film-Disc" switch.
Low Volume	Low volume from one projector only, other O. K.	Pick-up defective.	Clean contacts on pick-ups. Use new pick-up if other projector gives decidedly better results. Reset pick-up equalizer. See section 231.
Poor Quality	Excessive scratch.	Poor discs.	Use good discs.
		Dirty discs.	Use clean discs or clean those in use.
	Good sound from one projector and not from the other.	Defective pick-up on one projector.	Replace defective pick-up. See section 229.
Pick-Up Needle Jumps the Groove		Warped records.	Use good records.
	Binding noticed upon swinging tone-arm by hand.	Tone-arm binding.	Investigate trouble and correct.
		Bottom of pick-up striking the face of the record.	This trouble will arise only through the use of short needles. Use longer needle, or do not insert needle all the way into its socket.
	Pick-up jumps when starting.	Turntable not level.	Level the turntable.
"Wows"	"Wows" noticeable only when starting with cold projector.	Grease of viscous damping device cold. Projector mechanism stiff due to cold oil.	Run the projector for 15 minutes before the show.
	"Wows" continue after projector has warmed.	Viscous damping device out of adjustment.	Adjust viscous damping device. See section 71.
		Turntable coupling out of line.	Line up turntable.

In case no sound is obtained from the pick-up of one projector, turn "on" the exciter lamp when the projector is running and throw the "Film-Disc" switch to the "Film" position, and see if sound (frame line noise) can be obtained from the photo-cell. If sound can be obtained from the photo-cell, use the "SOUND ON DISC TROUBLE CHART," section 255.

In case no sound can be obtained when operating from sound-on-film, switch the "Film-Disc" switch to the "DISC" position and rub the needle of the pick-up. If sound is obtained from the pick-up, use the "SOUND ON FILM TROUBLE CHART," section 256.

In case no sound can be obtained from either the film or disc, switch the fader to the other projector and test both the pick-up and photo-cell for sound. The photo-cell can be checked for sound by passing a card up and down between the sound gate and the photo-cell housing with the exciter lamp lighted. If sound can be obtained from one projector but not the other, use the "FADER CIRCUIT TROUBLE CHART," section 257.

In case no sound can be obtained from either projector but can be obtained from a non-synchronous pick-up, use the "FADER CIRCUIT TROUBLE CHART," section 257.

In case no sound can be obtained from either projector or the non-synchronous pick-up, use the trouble chart which corresponds to the type of amplifier equipment used.

In case abnormal sound is obtained from one or both pick-ups and the sound-on-film reproduction is normal, use the "SOUND-ON-DISC TROUBLE CHART," section 255.

In case abnormal sound is obtained from one or both projectors when using sound film, and the sound from disc is normal, use the "SOUND ON FILM TROUBLE CHART," section 256.

In case of noisy fading or cross-talk, use the "FADER CIRCUIT TROUBLE CHART," section 257.

In case abnormal sound is obtained from both disc and film of both projectors use the trouble chart corresponding to the type of amplifier equipment used.

first then on the load side. If light is obtained at the load side of the fuses it is a sign they are not blown. Continue this procedure until the "open" in the line is found.

Do not attempt to test fuses in this manner in circuits rated at more than 220 volts.

(B) TROUBLE CHARTS

253. General Discussion.—The following charts are for the purpose of aiding the projectionist in locating and correcting troubles which may occur on RCA Photophone equipments.

Seven charts are provided. The particular chart to be used in case of trouble depends upon the nature of the trouble and the type of equipment used.

The first chart covers trouble with sound-on-disc and is limited to troubles that might occur in the pick-ups, pick-up circuits and turntable mechanism. This chart should be used when trouble is encountered in the operation from sound-on-disc, when tests indicate that the rest of the equipment is performing satisfactorily. (Section 255.)

The chart for troubles from sound-on-film is for use in locating trouble due to defective sound heads, photo-cell circuits, or exciter lamp circuits, when the rest of the equipment is operating satisfactorily. (Section 256.)

The third chart is for use in case it is found that the trouble is in the input circuit to the voltage amplifiers, as indicated when no sound can be obtained from either disc or film of one or both projectors when the rest of the equipment is operating satisfactorily. (Section 257.)

The trouble chart for SPU equipments is for use in locating and correcting trouble in SPU equipment amplifiers, and should be used when no sound or poor sound is obtained from both disc and film on PG-3, 4, 6, 7, 8 and 10 equipments. (Section 258.)

The other charts are for use in locating troubles on PG-1, PG-2 and PG-13 equipments (Sections 259, 260 and 261).

Before referring to any of these charts make certain that trouble is not due to a "slip-up" in operation by checking over to see that all switches and rheostats are properly set.

If sound can be obtained from the monitor speaker but not from the stage speaker, the trouble is obviously due to a fault in the leads between the amplifiers and the speakers or due to the stage speakers not being plugged in, or, in the case when only one speaker is used, the fault may be in the speaker itself. See section 228.

254. Use of Trouble Charts.—To determine which trouble chart to use make the following tests, after checking over to make sure no "slip-up" has been made in the operation.

(d) Loose connections to dry batteries.

(e) Poor ground connection on the projectors. Clean and tighten.

(f) Noisy photo-cell polarizing battery (in SPU equipment). Check for low voltage.

(g) Noisy or old "B" batteries in the voltage amplifier circuits (in SPU equipments). Check for low voltage.

(h) Optical system out of adjustment in such a way that the light ray passes through the sprocket holes of the film, or through the frame lines of the picture.

(i) Defective "C" batteries. Check for low voltage.

(j) Guide rollers out of adjustment. The guide rollers in the sound gate shoe should rotate freely. There should not be any side play in the outside roller, but it should not bind on the gate shoe. If this guide roller is loose or out of position, the film will weave in and out through the gate, thereby causing "motor-boating" (frame line or sprocket hole noise), and the reproduction will be very poor when using sound film.

251. **Whistling Sound When Using Either Sound Film or Discs.**—When an unusual whistle occurs in the PG-13 and SPU equipments, it is usually a sign that one of the UX-250's has become defective—not burnt out, but the filament emission may have dropped. When the UX-250's are greatly unbalanced in plate current, it is usually indicated by a whistle. If this occurs, it is necessary to determine which power amplifier it is that is whistling. Insert the monitor plug in each monitor jack until the whistle is heard in the monitor speaker. This will indicate that it is the amplifier into which the speaker is plugged that is whistling. The UX-250 tubes should be removed from this amplifier, and replaced with a set of matched tubes from the theatre's spare supply. Of course, in the case of a PG-4, PG-8, PG-10 or PG-13 there is only one power amplifier, rendering it unnecessary to go through this procedure to determine which amplifier is whistling. If replacing the UX-250's does not stop the whistle, put in a new set of UX-281 rectifier tubes. In most cases, replacing the tubes in the power amplifier will stop this whistling, but if the whistle continues after all the above mentioned things have been done, it is possible that the whistle may come from the voltage amplifier. Tap gently each tube in the voltage amplifier, one at a time, to ascertain if any are excessively microphonic. If any of the tubes are abnormal in this respect, replace both tubes in the stages containing a defective tube with two new tubes. A whistle may be caused by unusually low "B" batteries.

252. **Test Lamps.**—It is very handy to have a test lamp in the booth. Where there is 220 volts as well as 110 it is well to have two testers, one with a single bulb of 25 watts capacity for testing fuses and speaker field continuity. The other tester, with two 110 volt lamps wired in series, is used for testing 220 volt circuits.

To test for blown fuses with the lamp tester start at the main power switch. Hold the leads one on each side of the line—if the bulb lights, all fuses, etc., from that point to the power house are O.K. If it does not light, it is a sign that power is not reaching that point. If O.K. test at the next fuse block. Test on the power side turn the exciter lamp switches to their "On" positions, one at a time. If the fuse blows when one of these switches is turned "on" the indication is that the short-circuit is in the exciter lamp circuit of the projector whose exciter lamp control switch causes the fuse to "blow." As in the case of the PG-1, the equipment can be operated for sound-on-film from one projector and for sound-on-disc in case of a short-circuit in the exciter lamp circuit of one projector, by leaving the exciter lamp switch associated with the defective projector in the "Off" position.

248. **Short-circuit on the "A" Supply Line of a PG-13 Equipment.**—In case of a short-circuit on the "A" supply line of a PG-13 equipment, a fuse will "blow" in the low voltage generator circuit, and the filaments of the amplifier tubes and the exciter lamps will not light.

To isolate the short-circuit, turn the exciter lamp rheostats on the projectors to their "Off" positions and replace the blown fuse. If the fuse "blows" before the exciter lamps are turned "on" the indication is that the short circuit is either in the filter unit or in the amplifier unit. If the fuse does not blow when the exciter lamp rheostats are in their "Off" position, turn "on" the exciter lamps one at a time. The exciter lamp circuit which causes the fuse to "blow" should be left turned "off" so that the equipment can be operated from disc as usual or from sound-on-film from the projector the sound circuits of which are O.K.

249. **Type PK-1 Power Amplifier Tubes Fail to Light.**—If the Type PK-1 power amplifier tubes fail to light, check the fuses in the AC line. If there is a reading on the volt-meter located on the front of the power amplifier control panel, the line fuses have not blown. In this case, check the fuses mounted in the amplifier unit. These fuses should never be more than 6 amperes rated capacity. If the fuses continue to blow and the installation has more than one power amplifier, turn "off" the amplifier that is causing the fuses to blow and operate on the others.

In the PG-10 equipments there is a cartridge fuse mounted on the rear of the power amplifier control panel of the amplifier, Type PA-21A. This fuse should never exceed 6 amperes rated capacity. In case the power amplifier tubes fail to light, check this fuse. If it is blown, no reading will be obtained at the voltmeter.

In the PG-4, PG-8 and PG-10 equipments only one power amplifier is used and an attempt should be made to correct the trouble immediately. Replace all the tubes with tubes known to be in good condition and try the amplifier again. If the tubes do not light or the plates of any of them should become red hot, the indication is that the unit is defective and cannot be used.

250. **Noise or "Motor-Boating" When Using Either Sound Film or Discs**—Noise or "motor-boating" may be due to any of the following causes:—

(a) Dirt and acid on top of the storage battery. Switch to the other battery and clean the dirty one.

(b) Gassing storage battery. Do not use a storage battery sooner than one hour after charging, unless in an emergency.

(c) Loose storage battery terminal connections. Clean and tighten.

position and make the same test again. If the fuses do not "blow" under this condition, the equipment can be operated from "disc" but not from "film," except that it can be operated from "film" using the other projector only.

Of course, the above tests can not be made as outlined if no plugs are used in the input control panels, but a similar test can be made by turning the exciter lamp rheostats to their "Off" positions instead of disconnecting the plugs. Under this condition the procedure is the same except that the rheostats are turned "on", one at a time, instead of reconnecting the plugs.

246. Short-circuit on the "A" Supply Line of a PG-1 Equipment.—In case of a short-circuit on the "A" supply line of a PG-1 equipment the fuse in the 15-volt generator circuit will blow, and the filaments of the voltage amplifier tubes, the power amplifier tubes and the exciter lamps will not light. Since the PG-1 has a complete duplicate amplifier and power supply equipment, it will be necessary to isolate the defect immediately unless the short-circuit is in the exciter lamp circuit of one of the projectors.

In case the fuses blow in the low voltage generator circuit of one of the motor-generator sets, change over to the other amplifier rack. Leave the input switches on the input panel in their "open" positions until the input switches of the rack being shut down have been "opened." Then, as the last operation of putting the rack to be used into operation, "close" its input switches one at a time. If the short-circuit is in the exciter lamp circuit of the projector, the fuses of the 15-volt generator circuit will "blow" when one of the lever switches is closed. The defective projector is indicated by the input switch which causes the fuse to "blow." In case of a short-circuit in the exciter lamp circuit of one projector, the equipment can still be operated for sound-on-film from one projector only and for sound-on-disc. To do this, turn the exciter lamp rheostat of the defective projector to its "Off" position and operate the remainder of the equipment in the usual way.

247. Short-circuit on the "A" Supply Line of a PG-2 Equipment.—In case of a short-circuit on the "A" supply line of a PG-2 equipment the fuses in the 15-volt generator circuit will "blow." To isolate the defective part of the equipment turn the exciter lamp switches to the "Off" positions, open the lever switches on the power amplifier panels and replace the "blown" fuse. If the fuse blows again before any of the amplifier rack switches are closed, the indication is that the short-circuit is either in the voltage amplifier or in the storage battery circuit. The storage battery circuit can be opened by removing the upper of the two 50 ampere fuses in the low voltage generator circuit. See Figure 118. If necessary, the equipment can be operated with the battery disconnected, but an appreciable hum may be heard from the loud speaker. If the fuse does not blow when replaced, close the lever switches of the power amplifier panels one at a time. If the fuse "blows" when one of these switches is closed, the indication is that the short-circuit is in the power amplifier unit with which the switch is used. In this case leave the lever switch of defective power amplifier open and operate using one power amplifier.

If closing the power amplifier lever switches does not cause the fuse to blow, or switches. These should be switched back and forth several times as the trouble may be due to dirty contacts which may be cleaned by operating the switches.

In case of SPU equipments, if the tubes of the voltage amplifier and the exciter lamps in the projector do not light, the trouble may be due to a discharged storage battery. This can be checked by changing the four-pole double-throw battery switch to the other position. If changing over the battery switch does not cause the tubes to light, the indication is that there is a short-circuit or open circuit in the "A" battery line.

Of course this test cannot be made on the PG-1, PG-2, and PG-13 equipments. In case the voltage amplifier tubes and the exciter lamps fail to light on these equipments, the fuses in the low voltage generator circuit should be checked. If the fuses burn out immediately when replaced, the indication is that there is a short-circuit in the low voltage generator circuit.

245. **Short-circuit on the Voltage Amplifier "A" Battery Line of SPU Equipments.**—In case of a short-circuit on the voltage amplifier "A" battery line, the tubes of the voltage amplifier, the pilot lamps, and the exciter lamps of the projector will not light. If the short-circuit is between the storage battery and the four-pole battery switch, the tubes and lamps will light when the battery switch is changed to the other position. (In no case should the storage battery be left short-circuited. If opening the battery switch does not clear the short-circuit the batteries should be disconnected at the battery terminals.) If the tubes and lamps cannot be lighted check the fuses in the four-pole battery switch box. If changing the position of the four-pole switch does not permit the tubes and lamps to be lighted, check the fuses in the four-pole battery switch box. If they are "blown," test for the location of the short-circuit as follows:—Turn the battery switch "off" and disconnect the plugs to the input control panel. Insert new fuses to replace those "blown" and turn the battery switch "on." If the fuses burn out make the same test with the other voltage amplifier in the circuit, and reconnect the plugs on the input control panel, one at a time, and note under what conditions the fuses burn out. The trouble will be found to be in the part of the circuit which "blows" the fuses when connected.

If fuses "blow" when either voltage amplifier is connected in the circuit and the plugs are out of the input control panel, the indication is that the "short" is either in the connection between the four-pole switch and amplifier rack or in the cables connected to a plug of the input control panel. However, it is very improbable that such a short-circuit should occur.

If the fuses "blow" when one of the voltage amplifiers is connected and not when the other voltage amplifier is connected, the short is in the voltage amplifier unit which is connected when the fuses blow.

If the fuses do not "blow" until one of the plugs is reconnected to the input control panel, the indication is that the "short" is between the particular plug which causes the fuses to "blow" when it is reconnected, and the projector, or in the projector itself. The most probable location of such a "short" is in the projector itself. If the fuses "blow" when one of the plugs is reconnected to the input control panel, leave the plug in and turn the exciter lamp rheostat associated with it to its "Off" as a loss of volume will be the result of any defect in their adjustment. The proper check and adjustment of exciter lamps in the RCA sound head attachment is outlined in section 89.

Exciter lamps should not be used after they have become excessively dark, but should be replaced. The darkening of the interior surface of the glass not only is detrimental in itself in that it greatly reduces the amount of light available, and thereby decreases the volume of sound, but also is an indication that the lamp is nearing the limit of its "life," i.e., it is about to burn out.

All finger marks should be wiped off the lamp immediately. If the lamp becomes hot while greasy finger marks are upon it, they will be hard to remove later. The condensing lens on the optical system should also be kept clean at all times. The turret in which the exciter lamps are mounted should not be allowed to become loose. If the exciter lamp turret is loose it will be difficult, if not impossible, to keep the exciter lamp focused during the operation of the machine. The large nut at the top of the turret should be tightened if the turret becomes loosened.

241. **Aperture Mask Not Completely Effective.**—If trouble is experienced with white light on the screen when running Movietone prints, this can very easily be corrected by adjusting the guide rollers in the "Simplex" head just above the aperture. If this roller is adjusted correctly, there will be no white light on the screen at any time.

242. **Noisy Fading When Using Sound Film or Discs.**—If clicks are heard when moving the fading potentiometer, it may be due to dirt on the contact points. The contacts may be reached for cleaning by removing the knob and taking the four screws out of the escutcheon plate. Immediately behind this plate are the contacts. They may be cleaned with a very fine grade of "crocus" cloth or sandpaper, and then wiped off with a soft cloth. A soft cloth moistened with Carbona is very good for cleaning these contacts or those of any kind of relay.

243. **Cross-Talk on PG-10 Equipments.**—Should cross-talk develop, that is, if sound is heard from both projectors at the same time, it will usually be found that dirt has collected on the contacts of the relay fader. These contacts may be cleaned very easily by sliding a small card or heavy paper between the contacts. The purpose of this relay is to "short" the output of the projector that is not being operated and, therefore, if dirt collects on the relay points the relay cannot serve its purpose, and sound may be heard from both projectors.

244. **Voltage Amplifier Tubes Fail to Light.**—If some of the voltage amplifier tubes fail to light while others in the same unit do light, the indication is that the unlighted tubes are burned out, and should be replaced; but if none of the tubes of of a voltage amplifier unit light when the amplifier is turned "on," the indication is that the fault lies somewhere in the "A" supply line (storage battery leads in case of SPU equipments).

If two voltage amplifiers are included in the equipment and the tubes of one amplifier will light when turned "on," but the tubes of the other unit will not light when it is turned "on," the indication is that the trouble is in the change-over switch "wows" continue after the lubricant has been warmed by running, check the viscous damping device as described in section 71.

235. No Sound When Using Sound Film.—No sound when using sound film may be due to a burned out exciter lamp, sound gate light aperture completely clogged, or a defective photo-cell. To determine whether the aperture is clogged or not, place a card between the sound gate and the photo-cell housing. A round circle of light should be obtained at this point. If light is obtained on the card and no sound is obtained, the indication is that the photo-cell is defective and should be replaced.

236. Low Volume When Using Sound Film.—Low volume when using sound-on-film may be due to any of the following:—incorrect exciter lamp current, dirty or old exciter lamp, exciter lamp out of focus, sound gate aperture partly clogged, or a defective photo-cell.

237. Unequal Volume From Projectors When Using Sound Film.—If unequal volume is obtained from the two projectors when using sound film, the projector giving the lowest volume should be checked for trouble. See section 236. If no cause is found for low volume the output of the projectors should be balanced by adjusting the exciter lamp currents. To do this, adjust the exciter lamp current of the projector giving the lowest volume to its usual value and adjust the exciter lamp current of the other projector to give an equal volume; then, if necessary, increase the setting of the volume control.

238. Poor Quality From Sound Film.—Poor quality of sound from sound film may be due to any of the following causes:—poor sound film, dirty sound gate, dirty film, dirty constant speed sprocket, or a defective photo-cell.

Poor quality of sound is often blamed on the equipment when the fault is in the film itself. On the other hand, dirt on the film or on the sound gate will ruin the quality of sound from a good recording.

A defective photo-cell can spoil the quality of the reproduced sound.

A photo-cell can be spoiled by misuse. It is important that the photo-cell should not be exposed to strong light at any time, whether the polarizing voltage is applied or not. They should be handled gently and not jarred. When no film is in the projector, the circle of light from the exciter lamp can be seen on the photo-cell. This circle should be located at the exact center of the plate in case of the UX-868 Photocell or in the center of the window in case of the UX-867 Photocell. Dirty prongs on the photo-cell may also cause trouble. These can be cleaned readily with fine sandpaper.

After carefully checking all other possible causes of poor sound it may be assumed that the optical system is out of focus; in which case the RCA Photophone service engineer should be notified.

239. "Wows" When Using Sound Film.—If "wows" are noticeable when running sound-on-film, it may be due to dirty sprockets or due to the constant speed sprocket being excessively worn (teeth undercut). Improper adjustment of the viscous damping device will also cause "wows" and should be checked carefully. See section 92.

240. Exciter Lamps.—It is very important that the adjustment of the exciter lamps be checked by the projectionist before beginning the show at least once a day,

coil and field current are obtained and the speakers do not operate, call the service man, but usually it will be found that, if no sound issues from a speaker, one of the leads is open. It is quite possible that the trouble may be found in one of the plugs.

229. **Defective Pick-Up.**—When sound can be obtained from one pick-up and not from the other, the most probable cause of failure to obtain sound is that the pick-up itself is defective. This should be checked by replacing it with a new pick-up. When removing a pick-up, loosen the set screw which holds it to the tone arm just enough to free it and pull the pick-up straight out. (*Do not remove the set screw entirely, or the fine wires in the pick-up will be broken when the pick-up is removed.*)

230. **Low Volume When Using Discs.**—If the volume obtained from both projectors is low when using discs the indication is that the voltage amplifier is defective. Switch to the other voltage amplifier if one is available. Check the voltages of the voltage amplifier.

If the volume from one pick-up is low while the other is OK the indication is that the pick-up is defective. Replace the pick-up.

231. **Unequal Volume from Pick-Ups.**—If a greater volume is obtained from one pick-up than from the other, the volume level should be equalized. The volume of the sound from the two pick-ups can be equalized by means of a potentiometer mounted in the "Film-Disc" box except in the case of the PG-10 and PG-13 equipments where the potentiometer is located in the terminal box on the side of the turntable. Two different types of potentiometers are used. One consists of resistance wire wound on a tube with a movable contact which can be slid along the wire. The other is built like an ordinary radio potentiometer, with a resistance wire wound on a circular form and a movable arm for adjusting the point of contact. This arm is fastened to the shaft of the device and the shaft is slotted for the insertion of a screw driver blade.

To adjust for equal volume on two pick-ups use two records of the same selection and start both at the same time. Then fade from one projector to the other and adjust one of the potentiometers until the volume obtained from both pick-ups is the same.

232. **Pick-Up Needle Jumps the Groove.**—If the pick-up needle jumps the groove the trouble may be due to:—warped discs, turntable not level, tone-arm binding, or the bottom of the pick-up striking the records due to the use of short needles.

233. **Poor Quality When Using Discs.**—Poor quality when using discs may be due to poor discs, dirty discs, or a defective pick-up. The pick-up can be checked by testing with a record known to be good. If the quality of the sound from one projector is normal while the sound from the other is not, the trouble is probably due to a a defective pick-up.

234. **"Wows" When Using Discs.**—"Wows" when using discs may be due to the lubricant of the viscous damping device being too heavy. In cold booths where the Alemite grease might become hard, it is advisable to run the projectors for fifteen minutes before the show to warm the lubricant to the normal temperature. If the

loudspeaker. The photo-cell and its circuit can be tested by the method outlined above. If sound can be obtained from one projector and not from the other, the indication is that the defect is in the fader relay or fader potentiometer (depending on which device is used on the equipment) or in the "Film-Disc" switch. The reason for this conclusion is, that it is not probable that both the pick-up and photo-cell would fail at the same time.

A similar procedure should be followed if trouble develops when operating from sound-on-film.

If it is found that sound cannot be obtained from either projector, the indication is that the trouble is in the voltage amplifier or power amplifier. The voltage amplifier can be checked by changing over to the other voltage amplifier if one is available. If a second voltage amplifier is not available, but a non-synchronous turntable attachment is, the amplifiers can be checked by plugging the non-synchronous turntable input plug into the jack provided, and listening for sound while scratching the needle of the turntable pick-up. If sound can be obtained from the non-synchronous turntable and not from the projectors, the indication is that the amplifiers are O.K. and the defect is in the fader relay or potentiometer.

If no sound can be obtained from either of the projectors or from the non-synchronous turntable, the indication is that the trouble is in one of the amplifier units. If a second voltage amplifier is available and it is possible to get sound from one but not the other, the fault will be found to be in the voltage amplifier unit from which no sound can be obtained. Of course, in this case it will not be necessary to repair the defective unit immediately, but it should be checked over at the first opportunity.

If only one voltage amplifier unit and one power amplifier unit is used with the equipment, no simple tests can be made to isolate the defect to one of them. In this case it will be necessary to check over both units for defects. If two power amplifier units are used, it is reasonable to assume that both of them will not develop a defect at the same time. Therefore, if no sound can be obtained from either power amplifier units the indication is that the defect is in the voltage amplifier unit; and, if sound can be obtained from one power amplifier unit and not from the other, the indication is that the power amplifier from which no sound can be obtained is defective.

228. **No Sound From the Stage Speakers—Sound OK at the Monitor Speaker.—** In case no sound is obtained at the stage and the sound is OK at the monitor speaker, the trouble must be somewhere in the line leading from the amplifier rack to the stage speakers. Where stage plugs are used, it is possible that these plugs have not been inserted, or when being inserted one of the contacts may have become broken. Check speakers for field continuity by removing each of the field plugs at the speakers one at a time and by inserting the leads of a 100 volt test lamp which should not be over 25 watts capacity. (See section 252.) If light is obtained at this point the field continuity is O.K.

The voice coil supply circuit continuity may be checked at each speaker by using a pair of head phones across the incoming voice coil leads. If sound at the voice part of the equipment causing the trouble should be isolated by systematic tests. The method of making such tests will be outlined later in this chapter.

When the part of the equipment causing the trouble has been isolated, it is usually a fairly simple matter to remedy the fault. The more probable causes of trouble in the various parts of the equipment will be discussed in separate sections.

Should there be any difficulty in locating or correcting the cause of the trouble, the RCA Photophone service engineer should be notified immediately. In the meantime the projectionist should do what he can to get the equipment back into normal operating condition.

The trouble charts included in this chapter should be used as an aid in locating faults. Several charts are used, each one covering a part or type of equipment.

226. **Checking For Errors in Operation.**—If no sound is obtained when starting, or when "changing-over" from one projector to the other, check for any of the following errors:—

(a) Switches or rheostats set incorrectly on the amplifier panels. (While checking the switches and rheostats of the amplifier, inspect the tubes of the voltage and power amplifiers to see that they are all lighted.) See sections 244 and 249 if any or all of the tubes of an amplifier unit fail to light.

(b) "Film-Disc" switch set in the wrong position.

(c) Fader switch set for the wrong projector, or fader potentiometer set in the "off" position or for the wrong projector.

(d) Output fader in the "off" position or wrong one being used. (Output faders are used only on PG-6, PG-7 and PG-8 equipments).

(e) Loudspeakers not plugged in at the stage. (If "no sound" is due to the stage speakers being disconnected, sound can still be heard at the monitor speaker.)

If in checking over the routine operation no error is noted, the trouble would probably be due to some defective part, and the next thing to be done would be to isolate that defective part. To do this, systematic tests should be made.

227. **Systematic Tests for Locating a Defective Part.**—Usually the most effective method of locating a defective part is by determining to what extent the equipment is still operative. If, when operating from "sound-on-disc", no sound is obtained when starting or changing from one projector to the other, the first thing to be done, after checking to determine if an error has been made in the operating procedure, is to find out if sound can be obtained by using the photo-cell circuit. To do this, change the setting of the "Film-Disc" switch to the "Film" position, light the exciter lamp, and pass a card up and down between the sound gate and photo-cell. If a thumping sound is heard, the indication is that all the equipment except for the pick-up or pick-up circuits is functioning properly, so that it is only reasonable to assume that the trouble is either in the pick-up itself or in the "Film-Disc" switch.

If no sound is obtained from either the pick-up or photo-cell circuit, the other projector should be "faded in" and tested. The pick-up and its circuit can be tested by stroking the needle point with a finger and listening for a plucking sound in the

CHAPTER XIV

TROUBLE SHOOTING

(A) GENERAL DISCUSSION

224. Introduction.—The RCA Photophone equipment has been ruggedly designed with a view to reducing the required maintenance to a minimum. Complicated mechanisms and mechanisms requiring delicate adjustments have been avoided as much as possible. However, no matter how well equipment containing as many inter-related parts as that required for "talking-movie" reproduction is designed, trouble may develop during the operation of the equipment.

Troubles which develop during operation can be reduced to a minimum, if not entirely eliminated, if the equipment is properly taken care of and checked over frequently and thoroughly.

Cleanlines and neatness are of prime importance in the prevention of trouble. Dirty equipment is certain to give trouble. Dirty sound heads will cause distorted reproduction and loss of volume, and may be the cause of "no-sound". Dirt on storage batteries will cause noisy reproduction and shorten the life of the battery. Dirty commutators will cause a hum in the loud speakers. Dirty exciter lamps, photo cells, or lenses will cause distortion and lessened volume.

Care should be exercised, when cleaning the equipment, to prevent disturbing the adjustment of the various parts of the apparatus. This is particularly true of the optical system, which is delicately adjusted and should not be disturbed when the sound head is cleaned.

Even with the best of care troubles may develop occasionally which require immediate correction, and, although such emergencies should seldom occur, it is important that the operator be ready to meet them with a definite plan of action.

It is the purpose of this chapter to state briefly the requirements of proper maintenence, to outline the procedure to be followed in case of trouble, and to state the more common causes of trouble and the method of correction. It is recommended that the operator study carefully those parts which apply to the particular type of equipment which he is operating.

225. General Discussion.—The troubles which may be experienced with RCA Photophone equipments depend upon the type of equipment used, but there are some which might occur with any of the equipments.

Probably the most common of the troubles experienced are those which are due to "slip-ups" in the operation. Therefore, it is important to check over the operating procedure before looking elsewhere for the trouble.

After making certain that the trouble is not due to a "slip-up" in operation, the

600 volt generators would increase appreciably, especially that of the 600 volt generator. After replacing the burned out fuse, watch the tubes carefully for abnormal appearance and inspect them for shorts between the elements. If the plate of any tubes should become red hot stop the M-G set immediately and replace the tube.

A further discussion of the troubles which might occur with this equipment is set forth in Chapter XIV.

knob. This adjustment is made at the time of installation with the aid of special instruments, and should not be touched except by an RCA Photophone installation or service engineer.

If the picture has not been cued previously, it will be well to start with no compensation. This means that the compensator dial will be turned as far as possible in a clockwise direction and will point to the figure 40 on the dial. This compensator has been provided to compensate for lack of intelligibility due to poor recording. If the recording consists of music only, it will be found most desirable to run with the compensator set at 40. If, on the other hand, the recording contains speech, it may be found necessary to lower the compensator setting. If the speech sounds "boomy" and is not intelligible, the compensator should be reduced gradually until the speech is cleared up. *Never run the compensator lower than is absolutely necessary* for intelligible reproduction. If the compensator is run at too low a setting, the quality will be greatly impaired and the sound will be "tinny", because of a lack of volume on low notes.

The volume control potentiometer is located on the amplifier. The volume of sound from the loudspeaker should always be kept just as low as is consistent with intelligible reproduction. See section 163.

223. Troubles on PG-13 Equipment.—If a bad hum develops, it is an indication that the commutators of the generators are dirty or pitted. This can be avoided if the machines are inspected before use. See section 37.

If the amplifier goes "dead" inspect the tubes for burned out filaments or abnormal appearance. If the tubes appear to be in good condition they should all be replaced with tubes which are *known* to be in good condition. Always keep a full set of replacement tubes ready for emergency use.

If the filaments of the tubes fail to light, while the proper voltage reading is obtained on the low voltage meter of the motor-generator set panel, check the 12 volt generator fuses of the motor-generator set. See Figure 36 for their location. If one of these fuses should burn out while operating, the readings of both meters will increase appreciably.

If no sound can be obtained from the equipment even after the tubes light and have been checked and found to be O. K., check the 600 volt fuses of the M-G set. (See Figure 36 for the location of these fuses.) If one of these fuses should burn out during operation, "no sound" would result and the voltages of the 12 volt and

"ON" position. As soon as the motor-generator set is up to speed the voltages should be adjusted by means of the rheostats which are located on the motor-generator control panel. Each meter has a red mark indicating the correct reading. It may be desirable to have the volume control set at zero when starting the motor-generator set. If the volume control is set above zero it may be found that there is a "rushing" noise in the loud speaker when the generator set comes up to speed.

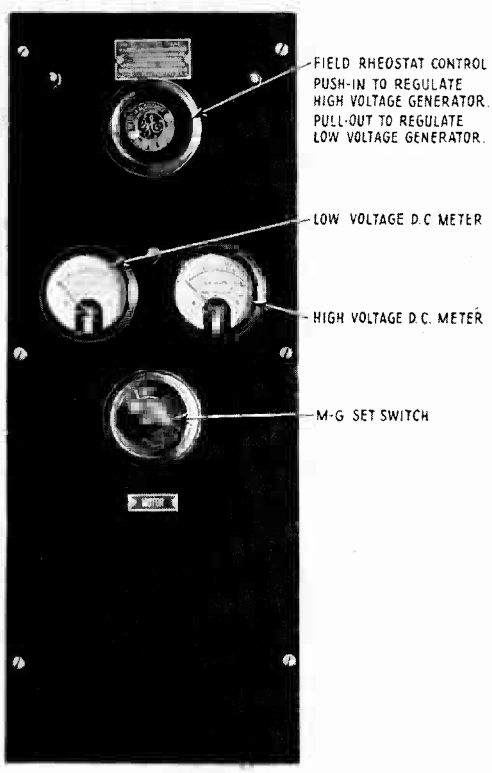


Figure 129—Control panel for motor-generator set used in PG-13 equipments

The "Film-Disc" switch should be set for the desired reproduction and the fader switch should be thrown to the machine which *is not* to be "started up." As soon as the machine is up to speed, the fader switch should be thrown to the machine which has just been started.

The PG-13 equipment is provided with a "compensator" which is built as a unit of the amplifier itself. The initial adjustment of the compensator, to suit its characteristics to that of the individual amplifier with which it is associated, is made by changing the position of the taps provided immediately below the compensator control and for each generator. See Figure 36. The motor-generator set stands on a felt pad which eliminates noise and vibration, and the entire assembly is covered by a perforated metal case. Two lines of conduit run from the generator to the amplifier. The power line runs directly to the motor-generator set.

The PG-13 equipments use two types of sound heads, one (Type PS-14) for the Powers 6B projectors and one (Type PS-16) for the Simplex projectors. These sound heads are considerably different from those used on the other types of equipments and are described in section 99. The turntable used is the PT-10 described in section 73.

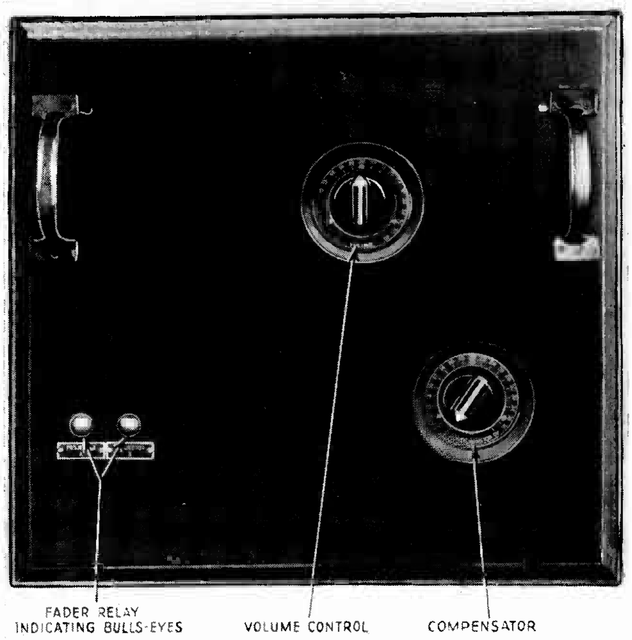


Figure 128—Type PA-29A amplifier panel (See also Figure 127)

Only one stage speaker is used with the PG-13 equipment, and although it is of a slightly different design from the other types of speakers its performance is practically the same. While one speaker is standard equipment, two or four are sometimes used. This speaker is the Type PL-22.

222. Operation of the PG-13 equipment.—Before starting the PG-13 equipment see that the motor-generator set bearings are well oiled and that the commutators are clean.

The operation of the PG-13 equipment is simplicity itself. The entire equipment is placed in operation by turning the motor-generator starting switch to the

All power for the PG-13 equipment is provided by a three-unit motor-generator set. There are no batteries except three small "C" batteries which are mounted on the filter unit. The motor-generator set has, besides the motor, a 12 volt generator and a 600 volt generator. See section 37. The 12 volt generator furnishes current for the filaments of all tubes, exciter lamps, pilot lights and for the field of both the stage speaker and the monitor speaker. The 600 volt generator furnishes plate current for all tubes and also furnishes polarizing voltage for the photo-electric cells.

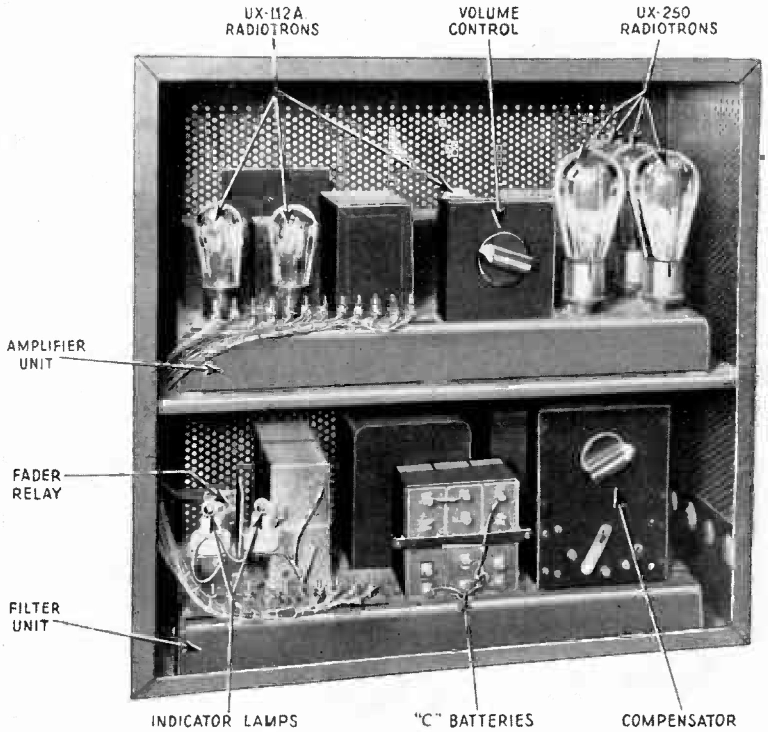


Figure 127—Type PA-29A amplifier and filter assembly used in PG-13 equipments

Both generators are excited by the 600 volt machine. Standard equipment is provided with a 110 volt, 60 cycle, single-phase motor. A 110 volt direct current motor is used in some cases. Converting equipment is used if neither 110 volt direct current nor 110 volt, 60 cycle alternating current is available.

The motor-generator set is provided with a control board which contains two rheostats, one for controlling the voltage of the 12 volt generator and one for controlling the voltage of the 600 volt generator. Both rheostats are operated by means of one rheostat control handle. See Figure 129. This panel also contains a 12 volt meter, a 600 volt meter and a motor switch. Behind the control panel and mounted as an integral part of it, is a fuse block containing fuses for the motor chronous disc, set the input changing switch (see Figure 126) in the "PROJECTOR" position. When operating a non-synchronous turntable, set the switch in the "SPECIAL" position.

The volume level in the theatre should be controlled by means of the volume control on the voltage amplifier control panel.

220. Troubles on the PA-21A Amplifier Rack Equipment.—Since only one voltage amplifier and one power amplifier is used with this equipment it is important that its operation be checked before the show starts. As in the case of the other equipments, defective tubes may be the cause of no sound, or poor sound. However, if the tubes are found to be in good condition at the time the show starts there will be little chance of them failing during the show. Always keep a full set of tested tubes handy for emergency use.

(C) PG-13 EQUIPMENT

(Small Theatre Equipment—Motor Generator Operated)

221. Description of the PG-13 Equipment.—The PA-29A amplifier used in this equipment has been built as a very compact unit. The entire amplifier measures less than 25 inches square by 12 inches deep. It is designed for wall mounting and is placed in a sheet metal cabinet, so that it presents a very neat appearance. Inside the amplifier cabinet there are two shelves. Both the voltage and power amplifiers which are built into a single unit, were described in section 141. This unit (Type PA-41) is located in the upper compartment of the amplifier cabinet as shown in Figure 127.

In the lower compartment of the cabinet, there is a filter unit (Type PA-42) which is provided to eliminate all hum from the loudspeaker. The fader relay and a compensator are mounted as a part of this unit. All connections from the outside are made direct to the filter unit and there is an interconnecting cable between the filter unit and the amplifier unit. There are no direct external connections to the amplifier unit. The amplifier unit and filter unit are readily accessible by removing the front cover of the amplifier cabinet.

The volume control is mounted on the amplifier unit and the compensating unit is mounted in the filter unit. The dials of the volume control and compensator extend through an opening in the cover of the amplifier cabinet. Both the volume control and the compensator are provided with name plates and graduated dials. See Figure 128. Besides the volume control and compensator dials, the front of the amplifier cabinet contains two bulls-eyes behind which pilot lamps are mounted which serve to indicate which projector is connected to the amplifier. In one end of the amplifier cabinet there is a jack for plugging in a special input circuit, such as a non-synchronous phonograph, etc.

below the right-hand indicator bulls-eye. This two-position switch is used to connect the input of the voltage amplifier to either the projector circuits or to the non-synchronous turntable. The positions for each connection are noted on a name plate just below the switch.

218. Description of the PA-21A Power Amplifier Control Panel.—The power amplifier control panel of the PA-21A amplifier is similar to the power amplifier control panels used on the PA-20A amplifier but differs in several details.

The rheostat knob near the center of the panel is for AC line voltage control and the meter in the upper right hand corner of the panel indicates the voltage of the AC power supplied to the amplifier unit. The operating voltage is 100 as in the case of the other SPU equipments.

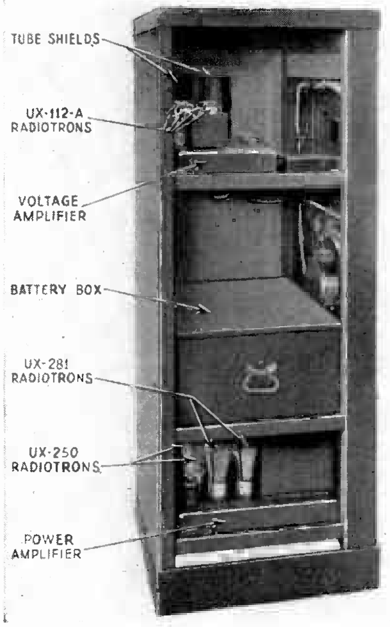


Figure 125—Side view of Type PA-21A amplifier rack used in PG-10 equipments

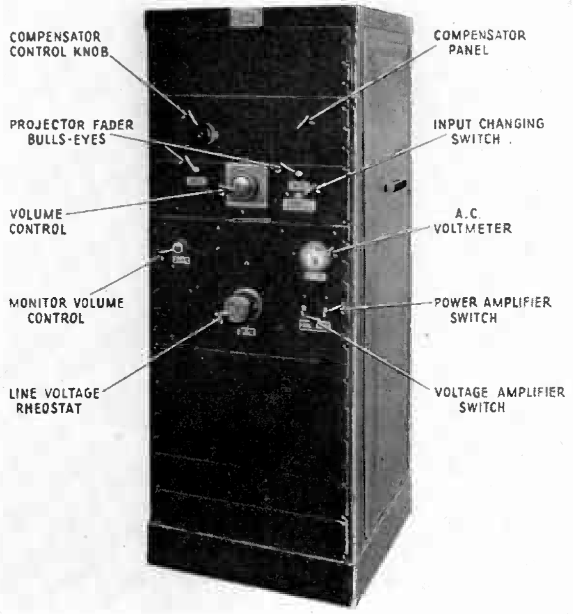


Figure 126—Front view of Type PA-21A amplifier rack used in PG-10 equipments

The two switches mounted below the AC voltmeter are used to turn "on" and "off" the power to the voltage and power amplifiers. The switch on the left is used to control the filament current to the voltage amplifier, and the switch on the right is used to control the AC power to the power amplifier unit.

The knob in the upper left-hand corner of the panel is the monitor speaker volume control knob, and is used to control the volume output of the monitor speaker, but does not affect the volume in the theatre proper. The monitor speaker is wired in permanently at the terminal board.

219. Operation of the PA-21A Amplifier Rack Equipment.—To put the amplifier rack equipment into operation, turn both switches on the power amplifier control panel to their "ON" positions. If operating from sound-on-film or from the syn-

amplifiers be checked before the show starts, and a complete set of tubes, which have been previously tested, be kept at hand for emergency replacement. Testing the equipment before the show starts may forestall trouble which might otherwise occur during the show.

See also Chapter XIV.

215. General Description of the PG-10 Equipment.—The PG-10 equipment differs from the other SPU equipments in several ways. The most noticeable of these is that no input control panel is used. The volume control is mounted on the amplifier rack. The relay fader control and the exciter lamp rheostats and ammeters are mounted on the projectors.

The PS-5, PS-6 or PS-8 sound heads are used with the PG-10 equipment, according to the make of projector used. These sound heads are described in sections 97 and 98. The turntable used is the PT-7, described in section 72. The amplifier rack furnished is the Type PA-21A, described below.

Only one voltage amplifier and one power amplifier is used with this equipment, as this equipment was designed for the small theatre.

216. Description of the PA-21A Amplifier Rack Equipment.—Figure 125 shows a side view and Figure 126 shows a front view of the PA-21A amplifier rack equipment.

A type PA-12B voltage amplifier is used with this equipment and is mounted near the top of the rack. This amplifier is slightly different from the voltage amplifiers used on other SPU equipments and is described in section 139.

The type PK-1 power amplifier unit used with this equipment was described in section 140. This is the same type of unit as is used on the other SPU equipments.

The compensator panel which is mounted near the top of the rack is of the same type as used on the other equipments. The panel just below the compensator panel is the voltage amplifier control panel, and the panel below the voltage amplifier control panel is the power amplifier control panel.

217. Description of the PA-21A Voltage Amplifier Control Panel.—The volume control, which is mounted at the center of the voltage amplifier control panel, is similar to the volume control used on the PG-1 and PG-2 equipments and gives twenty steps of equal volume change.

Two indicator lamps, one on each side of the control knob, indicate which projector is "faded in" to the voltage amplifier. The fader switch is relay-operated from controls on the projectors. The relay itself is mounted on the rear of this panel and is readily accessible for cleaning by removing the left-hand side-cover of the rack.

When used, the non-synchronous turntable is wired in permanently to the voltage amplifier through an input changing switch. This switch is mounted just

The voltage amplifier control panel, with the volume control, output fader and indicator lamp, is the same as that used on the PG-6, but the output fader is not used, because the equipment has only one voltage amplifier. The output fader should be left in its maximum position at all times.

The power amplifier control panel is similar to the power amplifier control panels described in section 204, except in two details. The PA-18B power ampli-

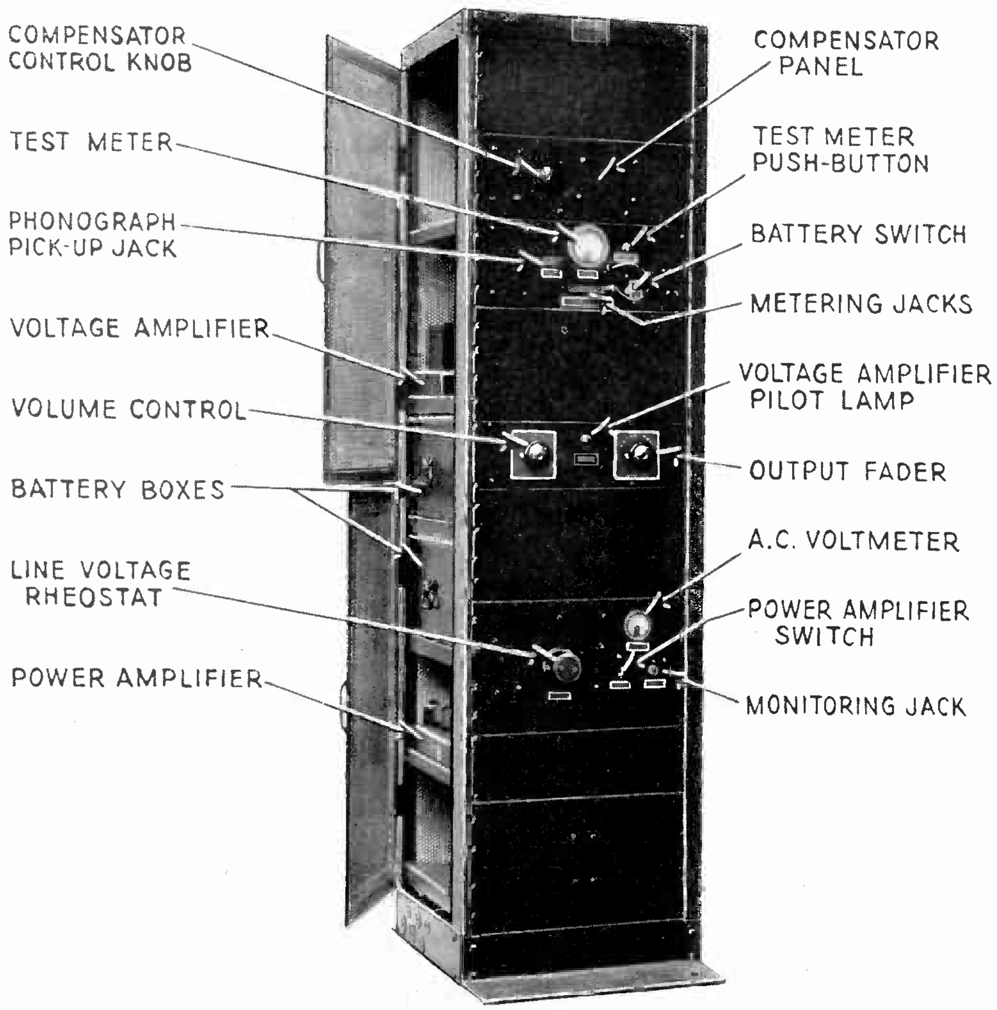


Figure 124—Type PA-18B amplifier rack used in PG-8 equipments

fier panel has only one power switch and one monitoring jack. The operation of the panel is, however, the same as the operation of the PA-20A power amplifier panels. See section 206.

No main line switch is used on the PA-18B amplifier rack equipment.

214. Troubles on the PG-8 Equipment.—Since there is only one voltage amplifier unit and one power amplifier unit used with this equipment, it is important that the

Each power amplifier unit has a separate set of two fuses in the AC power line. These are usually located near the AC line plug close to the amplifier unit. These fuses should be checked if the tubes of an amplifier unit fail to light. Use Edison plug fuses no larger than 6 amperes for replacement.

Refer also to Chapter XIV.

209. **General Description of the PG-7 Equipment.**—The PG-7 equipment is similar to the PG-6 equipment except in the number of power amplifiers used, only two of these units being used in the PG-7 equipment, this equipment being designed for medium sized theatres. The voltage amplifier units and power amplifier units are mounted on the same rack, which is designated as the Type PA-17B.

210. **General Description of the PA-17B Amplifier Rack Equipment.**—Figure 123 shows the arrangement of parts on the PA-17B amplifier rack. The second panel from the top is the compensator panel. The third panel is the voltage amplifier metering panel which is identical to that used in the PG-6 and described in section 202. Below the metering panel and arranged in the order named are, No. 1 voltage amplifier control panel, the voltage amplifier switching panel, and No. 2 voltage amplifier control panel. These panels are identical to similar panels described in section 202. The voltage and power amplifiers used are two Type PA-12A and two Type PK-1 units, respectively.

Only one power amplifier control panel is used on the PA-17B amplifier. This panel is the third from the bottom of the rack and is similar in all respects to the power amplifier control panel described in section 204. The "AC LINE" switch mounted on the panel just above the power amplifier control panel is used to turn the AC power "on" and "off" of both power amplifier units.

211. **Operation and Troubles on PG-7 Equipment.**—The operation of the PG-7 equipment is identical to that of the PG-6 equipment and the comments on troubles of PG-6 equipments apply equally well to the PG-7.

212. **Description of the PG-8 Equipments.**—The PG-8 equipment is a small theatre equipment, and is similar in every respect to the Type PG-7 with the exception that the Type PA-18B amplifier rack is used. This rack is similar to the PA-17B amplifier except that only one voltage amplifier unit and one power amplifier unit are used.

213. **Description of the PA-18B Amplifier Rack Equipment.**—Figure 124 is an illustration of the PA-18B amplifier rack showing the location of parts. It will be noticed that the panel equipment is the same as that used on the PA-17B except that there is less of it. As in the other equipments described, the compensator panel is located near the top of the rack. The metering panel is the same as that used on the PG-6 and PG-7 equipments. This panel has four metering jacks which were described in section 202, but only three of the jacks are used in the PG-8 equipment. The third jack from the left labelled "NO. 2 PLATE V" is not used, as only one voltage amplifier unit is used with this equipment.

208. Troubles on the PA-20A Power Amplifier Rack Equipment.—If one amplifier unit of the power amplifier rack becomes noisy or "dead", it will not be apparent in the operating booth unless the monitoring speaker happens to be plugged into the de-

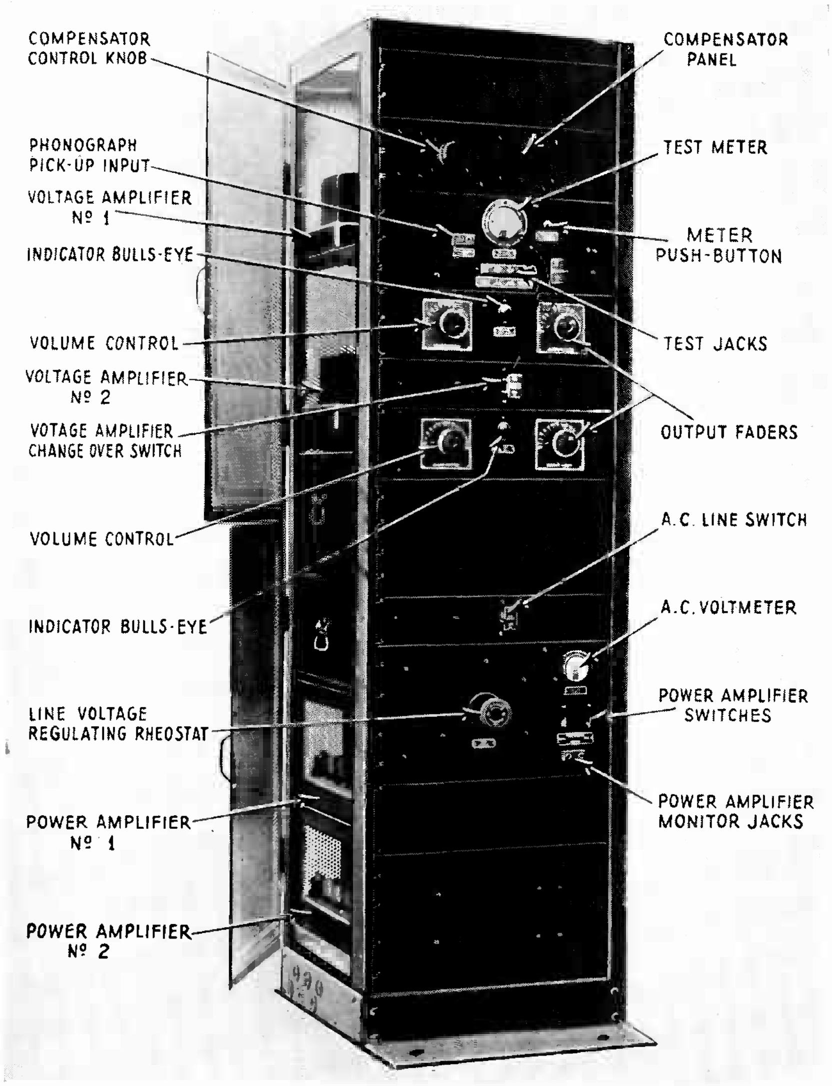


Figure 123—Type PA-17B amplifier rack used in PG-7 equipments

fective unit. Therefore, in case of complaint, check all units by plugging the monitoring speaker successively into each of the units. When the defective unit is located, turn it "off" by means of its individual power switch and check the tubes by replacing them with tubes known to be in good condition. Be sure, also, to readjust the line voltage to its companion amplifier to 100 volts.

the meter push-button and read the lower scale of the meter. A reading of 12 volts should be obtained, which is the voltage of the storage battery. When the meter is plugged into the jack labeled "NO. 1 PLATE V", a reading of from 115 to 135 volts should be obtained on the upper scale of the meter. Similarly a reading of between 115 to 135 volts should be obtained when the meter is plugged into the jack labeled "NO. 2 PLATE V". These two jacks measure the plate voltages of the voltage amplifiers No. 1 and No. 2 respectively. If the reading obtained from either jack is less than 115 volts the indication is that the battery connected to the corresponding voltage amplifier is weak and should be replaced.

The jack labeled "PHOTO CELL PLATE V" is used to check the plate voltage of the photo-cell. A reading of from 80 to 90 volts should be obtained from this jack if UX-868 Photocells are used with the equipment. If UX-867 Photocells are used a reading of between 170 and 200 volts should be obtained. A reading of less than 80 volts in case the UX-868 Photocells are used, or less than 170 volts in case UX-867 tubes are used, indicates that the photo-cell batteries are weak and should be replaced.

To put the voltage amplifier equipment into operation, set the voltage amplifier change-over switch to the position corresponding to the voltage amplifier to be used, and turn the battery switch "on". The filaments of the tubes in the voltage amplifier and the pilot lamp on its control panel should then light.

In case it should be necessary to change from one voltage amplifier to the other while in operation the following procedure should be used:—Set the volume control of the amplifier to be used to approximately the same setting as that of the one in use. See that the output fader control knob of the amplifier to be used is in the "OFF" position. Turn "OFF" the output fader of the amplifier being used. Snap the change-over switch to the amplifier to be used, and turn the output fader control knob of this amplifier to its maximum position. This can be done in less than a second with a little practice and provides a noiseless transfer.

206. Operation of the PA-20A Power Amplifier Rack Equipment.—To put the power amplifier equipment into operation, see that all the individual amplifier switches are in the "ON" position, and turn the main "AC LINE" switch to its "ON" position. Adjust the AC line voltage of both control panels to 100 volts as indicated by the AC voltmeter, and check the output of each amplifier by plugging the monitoring speaker into each of the monitoring jacks. After checking all of the units, leave the monitoring speaker plugged into one of the monitoring jacks.

207. Troubles on the PA-19A Voltage Amplifier Rack Equipment.—In case trouble develops on one voltage amplifier while the equipment is in operation, switch over to the other voltage amplifier as outlined in section 205, and when convenient check the tubes of the defective amplifier by replacing them with tubes known to be in good condition.

202. **Description of the PA-19A Voltage Amplifier Metering Panel.**—The test meter mounted near the top of the metering panel is a DC voltmeter. The meter has two scales, the upper scale is used in making voltage measurements up to 250 volts, the lower scale, used in conjunction with the meter push-button, measures voltages up to 25 volts. The double jack to the left of the meter is a phonograph pick-up jack, and is used for making a connection from a non-synchronous turntable to the input of the voltage amplifier. The first jack on the left is for use, in conjunction with the meter, in measuring the voltage of the storage battery. The second jack from the left is used for measuring the plate voltage of the voltage amplifier, and the third jack from the left is used to measure the plate voltage of the other voltage amplifier. The jack on the right is for checking the plate voltage of the photo-cell.

203. **Description of the PA-19A Volume Control Panels.**—These two panels are identical. One is used to control the volume when using one voltage amplifier and the other is used to control the volume when using the other voltage amplifier. The bulls-eyes at the centers of these panels indicate which voltage amplifier is in use. The knobs on the left are volume control knobs and the knobs on the right are the output fader controls. These output faders are used, when changing from one voltage amplifier to the other, to prevent a loud popping noise incident to changing over. They consist of variable resistances in the output circuits of the voltage amplifiers.

204. **Description of the PA-20A Power Amplifier Rack.**—Figure 122 shows the arrangement of parts on the PA-20A power amplifier racks. The four power amplifier units mounted on the back of this rack are of the PK-1 type and were described in section 140. These amplifier units are arranged in two groups of two units each for the purpose of control, but each amplifier unit can be turned "on" and "off" separately. The two units at the top comprise one group and the two lower units make up the second group.

The switch on the second panel from the top is an AC power line switch for turning "on" and "off" the power of the entire rack.

The third panel from the top is the control panel for the amplifier units No. 1 and No. 2. The rheostat knob near the center of the panel is used to control the AC line voltage input to the amplifiers. The meter in the upper right-hand corner is an AC voltmeter for indicating the voltage of the power input to the amplifier units. The two switches below the meter are single-pole power switches for turning the power "on" and "off" of each amplifier unit separately. The two jacks below the switches are monitoring jacks and are used for monitoring the output of each amplifier separately.

The fourth panel from the top is another power amplifier control and is identical to the one just described. It is used to control the power amplifier units No. 3 and No. 4.

205. **Operation of the PA-19A Voltage Amplifier Rack.**—Before starting the PA-19A voltage amplifier rack equipment, check the voltages at the metering panel. With the test meter plugged into the jack labeled "FILAMENT VOLTAGE", press

for emergency use. Testing the equipment before the show starts may forestall trouble which might otherwise occur during the show.

200. General Description of the PG-6 Equipment.—The PG-6 equipment is the largest of the partially SPU operated equipments and is used in large theatres. It uses PS-1 sound heads and PT-2 turntables. Two amplifier racks are used; one (Type PA-19A) contains two Type PA-12A voltage amplifier units, and the other (Type PA-20A) contains four Type PK-1 power amplifier units. See sections 138 and 140. Only one voltage amplifier unit is used at a time and the power amplifier

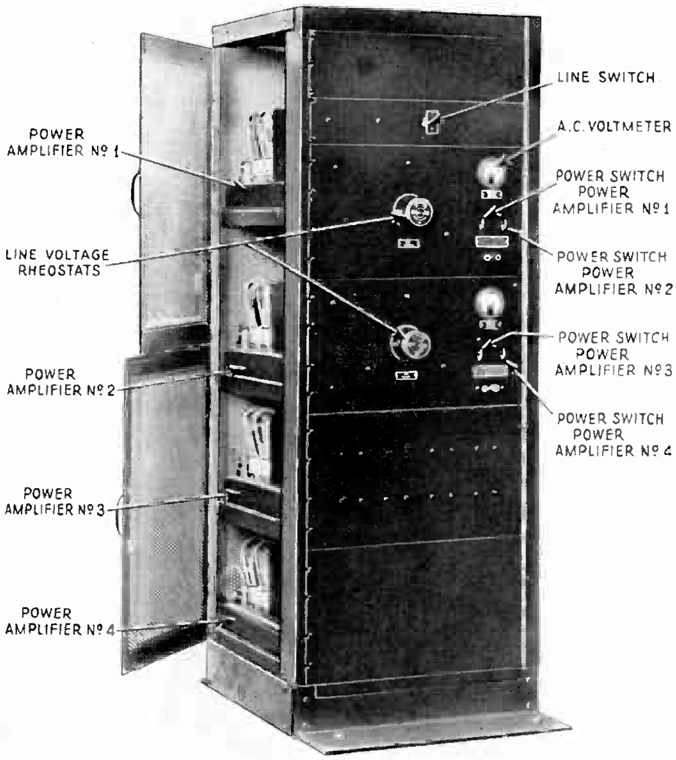


Figure 122—Type PA-20A power amplifier rack used in PG-6 equipments

units may be used individually in case of emergency. The volume control is mounted on the voltage amplifier rack instead of on the input control panel. This input control panel (the Type PA-16B) is described in section 110.

201. Description of the PA-19A Voltage Amplifier Rack.—Figure 121 shows the arrangement of parts on the PA-19A voltage amplifier rack. The top panel is the compensator panel. The second panel from the top is a metering panel. The third and fifth panels are alike and are voltage amplifier control panels, one for each of the two separate voltage amplifier units. The fourth panel from the top is a switching panel used for switching the input and filament supply from one voltage amplifier to the other. The two voltage amplifier units are mounted in back of the five upper panels. The battery boxes for the amplifiers are mounted in back of the two bottom panels.

cells are used in the equipment. If the voltage is less than 80 volts the photo-cell batteries should be replaced. If UX-867 Photocells are used, a reading of between 170 and 200 volts should be obtained. If the voltage is less than 170, the photo-cell batteries should be replaced.

The voltage amplifier is turned "on" by turning the battery switch to the "ON" position. When this is done the filaments of the voltage amplifier and the indicator lamp to the left of the test meter should light.

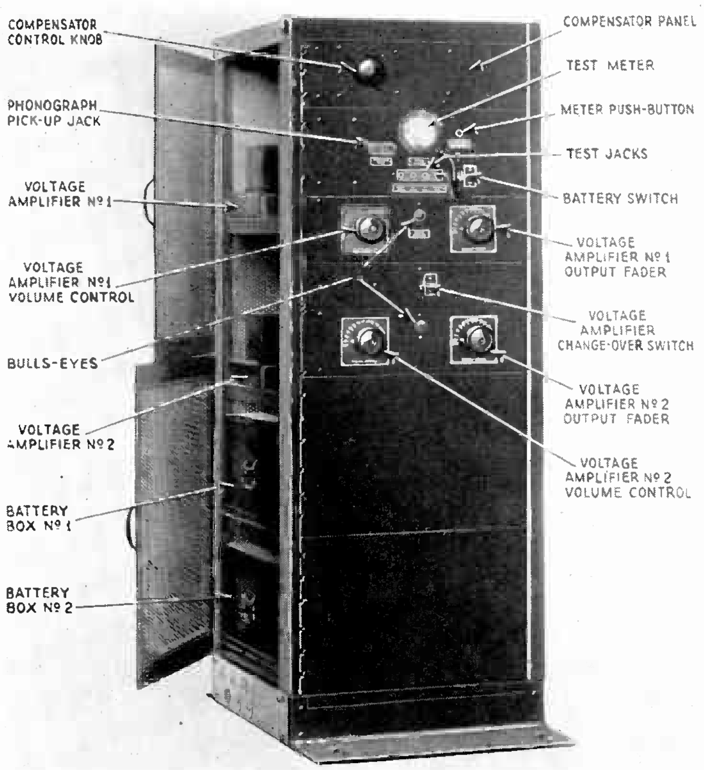


Figure 121—*Type PA-19A voltage amplifier rack used in PG-6 equipments*

The power amplifier is switched "on" by turning the power amplifier switch to the "ON" position. The monitoring speaker should be plugged into the monitoring jack on the power amplifier panel.

199. Troubles on the PG-4 Equipment.—The troubles which may be experienced with the PG-4 equipments are similar to those discussed for the PG-3 equipments in section 193. See also Chapter XIV.

Since there is but one voltage amplifier and one power amplifier included in this equipment it is very important that the amplifiers be kept in good condition. It is advisable to keep a supply of tubes, which have been previously tested, ready this equipment) is mounted to the rear and a little above the power amplifier control panel. The power amplifier unit is mounted back of the bottom panel.

196. **Description of the PA-18A Voltage Amplifier Control Panel.**—The meter at the top of the voltage amplifier control panel is a test voltmeter. This meter has two scales, the upper scale indicates DC volts up to 250 volts and the lower scale indicates DC volts up to 25 volts. The meter push-button to the right of the meter is used in conjunction with the 25 volt scale.

The indicator lamp to the left of the meter lights when the voltage amplifier is turned "on".

The switch on the left-hand side of the panel is used for opening and closing the storage battery circuit to the filaments of the voltage amplifier tubes and the exciter lamps on the projectors.

The three metering jacks mounted directly below the meter are used in conjunction with the test meter, for checking the voltage of the storage batteries and dry batteries. The jack on the left is used to check the voltage of the storage battery, the center jack is used to check the voltage of the "B" batteries of the voltage amplifier, and the jack on the right is used to measure the voltage of the photo-cell polarizing battery.

The double jack to the right of the metering jacks is a phonograph pick-up jack for connecting the output of a non-synchronous phonograph to the voltage amplifier.

197. **Description of the PA-18A Power Amplifier Control Panel.**—The rheostat a little to the left of the center of the power amplifier control panel is for regulating the AC line voltage to 100 volts as indicated by the AC voltmeter in the upper right-hand corner of the panel. The switch below the voltmeter is used for turning "on" and "off" the AC power to the power amplifier. The jack below the meter is the monitoring jack used for connecting the monitor speaker to the output of the power amplifier.

198. **Operation of the PA-18A Amplifier Panels.**—Before starting the equipment, check the voltages at the voltage amplifier metering jacks. When the meter is plugged into the jack labeled "FILAMENT VOLTAGE", press the meter push-button and read the lower scale of the meter. The correct reading, 12 volts, is the voltage of the storage batteries. *Do not press the meter push-button when the meter is plugged into any other than the "FILAMENT VOLTAGE" jack.* The reading obtained, on the upper scale, when the meter is plugged into the jack labeled "PLATE VOLTAGE" is the voltage of the voltage amplifier plate supply "B" batteries. This voltage should be between 115 volts and 135 volts. If the voltage reading is less than 115 volts the indication is that the plate supply "B" batteries should be replaced. When the meter is plugged into the jack labeled "PHOTO CELL PLATE V" a reading of between 80 to 90 volts should be obtained if UX-868 Photo-

uses one Type PA-18A amplifier rack which consists of one Type PA-12A amplifier (see section 138) and one Type PK-1 power amplifier (see section 140). Except that only one voltage amplifier unit and one power amplifier unit is used, the PG-4 equipment is very similar to the PG-3.

195. General Description of the PA-18A Amplifier Rack.—Figure 120 shows the arrangement of the parts of the PA-18A amplifier rack. The second panel from the top is the compensator panel with the compensator control knob. The voltage ampli-

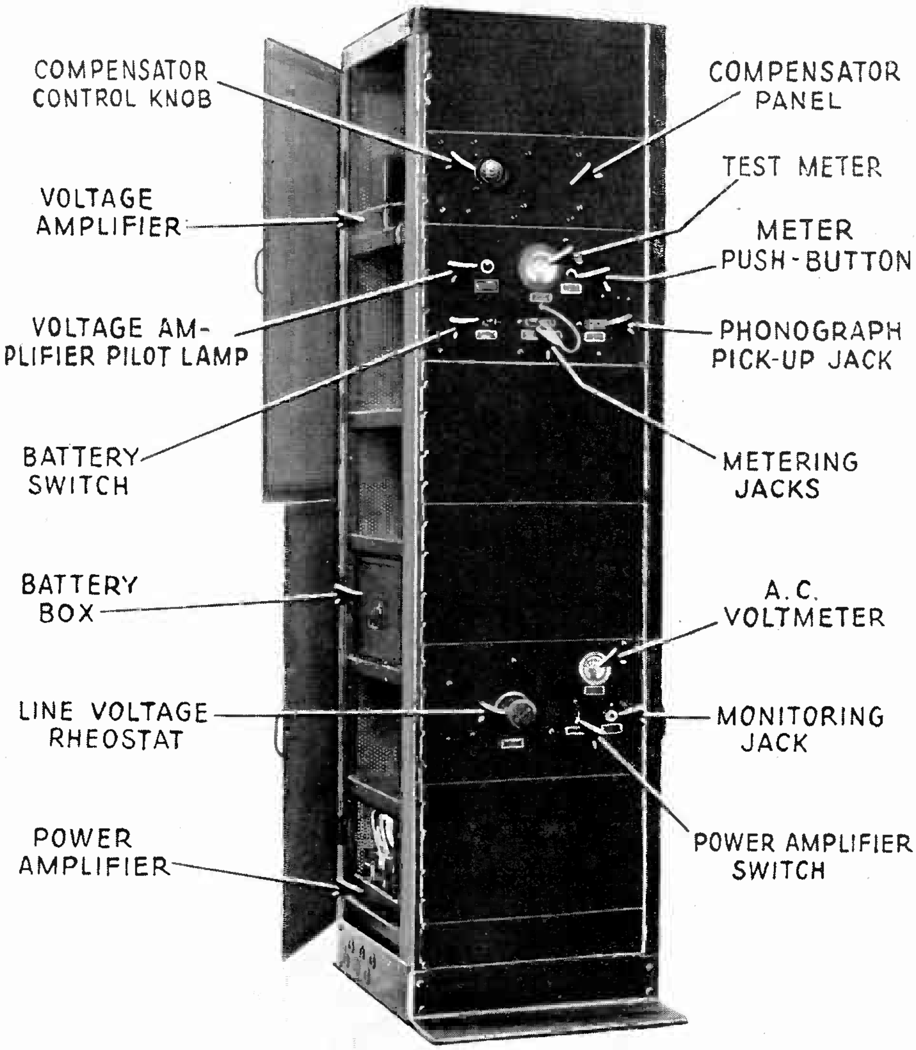


Figure 120—Type PA-18A amplifier rack used in PG-4 equipments

fier unit is mounted back of this panel. The panel below the compensator panel is the voltage amplifier control panel. This panel is very similar to the PA-17A voltage amplifier control panel except that fewer parts are used. The panel next to the bottom is the power amplifier control panel. The battery box (only one is used with photo-cell batteries should be replaced. If UX-868 Photocells are used, a reading of from 80 to 90 volts should be obtained when using the "PHOTO CELL PLATE V" jack. In this case a reading of less than 80 volts indicates that the photo-cell batteries should be replaced.

To operate the voltage amplifier, turn the battery switch "ON". The filaments of the voltage amplifier tubes and the exciter lamps on the projectors should then light. One of the voltage amplifier indicator lamps will light, indicating which voltage amplifier is connected. To change from one voltage amplifier to the other, switch all three voltage amplifier switches and make certain that they are all either in the "NO. 1" or in the "NO. 2" position. If any one switch is set in a different position from the others "no sound" will result. Switch the output change-over switch first, and then switch the other change-over switches as nearly simultaneously as possible, otherwise a severe popping noise will be produced in the loudspeakers.

192. **Operation of the PA-17A Power Amplifier Control Panel.**—Turn both power amplifier switches "ON" and adjust the AC line voltage to 100 volts by means of the line rheostat. The AC voltmeter indicates the line voltage. The performance of both power amplifiers should be checked by plugging the monitor speaker into each monitor jack. After checking both amplifiers the monitor speaker should be left plugged into one of the monitor jacks.

193. **Troubles on PG-3 Equipments.**—Trouble from "run down" dry batteries can be prevented by periodically checking their voltages as outlined in section 191.

Should one voltage amplifier give trouble during operation, switch over to the other voltage amplifier, and, when convenient, check the tubes of the defective amplifier by replacing them with tubes known to be good. If the trouble cannot be readily located notify the RCA service man.

Should trouble develop on one of the power amplifier units, it will not be apparent in the operating booth if the monitor is plugged into the good amplifier. Therefore, both amplifiers should be checked in case of complaint. If one amplifier goes "dead" the speakers connected to it will also go dead. In such a case turn "off" the defective amplifier, and, unless it is obvious that some other defect is causing the trouble, check all tubes in the amplifier by replacing them with tubes known to be good. In case the output of one amplifier is noisy and the other is O.K. turn "off" the noisy amplifier and check the tubes.

If it becomes necessary to turn "off" one of the power amplifiers be sure to readjust the line voltage to 100 volts as before.

For a more complete description of the troubles which may be experienced with the PG-3 equipments, see Chapter XIV.

194. **General Description of the PG-4 Equipment.**—The PG-4 equipment is designed for small or medium sized theatres. Like the PG-3 it has a separate input control panel which is usually mounted between the two projectors. The equipment

The double jack at the left of the panel is used for making a connection between a non-synchronous turntable and the amplifier equipment.

At the center of the panel below the meter are four metering jacks. The jack on the left is for measuring the voltage of the storage battery. When using this jack press the meter push-button. The second jack from the left is for use in measuring the plate voltage of voltage amplifier No. 1. The third jack from the left is for measuring the plate voltage of voltage amplifier No. 2 and the jack on the right is for measuring the polarizing voltage of the photo-cell. The purpose of these measurements is to check the condition of the dry batteries.

In a row along the bottom of the panel are four snap-switches. The switch on the left is the battery switch for opening and closing the storage battery circuit to the amplifiers and exciter lamps. The second switch from the left is used to switch the output of the photo-cells or turntables from the input circuit of one voltage amplifier to the input circuit of the other voltage amplifier. The third switch from the left is for changing the volume control connections from one voltage amplifier to the other. The switch on the right is for changing the connections between the output of the voltage amplifier and the input of the power amplifiers from one voltage amplifier to the other. These three change-over switches should all be in either the "No. 1" position or "No. 2" position, as indicated on the name plates beneath the switches.

190. **Description of the PA-17A Power Amplifier Control Panel.**—The rheostat knob for controlling the AC line voltage input to the power amplifiers is located at the center of the power amplifier control panel. The rheostat is in series with one of the AC power lines and allows adjustment of the voltage of the AC power input to 100 volts. The AC voltmeter in the upper right-hand corner of the panel indicates the alternating voltage supplied to the power amplifier units. The two switches below the meter are for switching "on" and "off" each power amplifier independently. The two jacks below the switches are monitoring jacks. One jack is provided for each amplifier, so that they can be monitored separately.

191. **Operation of the PA-17A Voltage Amplifier Control Panel.**—Before starting the equipment check the voltages at the voltage amplifier control panel, by means of the test meter and jacks. The reading obtained from the "FILAMENT VOLTAGE" jack, while pressing the meter push-button, should be 12 volts as read on the lower scale of the meter. *Do not press the meter push-button when taking readings from any other than the "FILAMENT VOLTAGE" jack.* A reading of 115 to 135 volts should be obtained when checking either the "NO. 1 PLATE V" or the "NO. 2 PLATE V" jack. A reading below 115 volts indicates that the "B" batteries are weak, and should be replaced. A reading of 170 to 200 volts should be obtained from the jack labeled "PHOTO CELL PLATE V" if UX-867 Photocells are used with the equipment. A reading below 170 volts is an indication that the

188. Voltage and Power Amplifiers Used in PA-17A Amplifier Racks.—The type PA-12A voltage amplifiers used with this equipment are described in section 138, and the type PK-1 power amplifiers used are described in section 140.

189. Description of the PA-17A Voltage Amplifier Control Panel.—Near the top the voltage amplifier control panel is a test voltmeter. This meter has two scales,

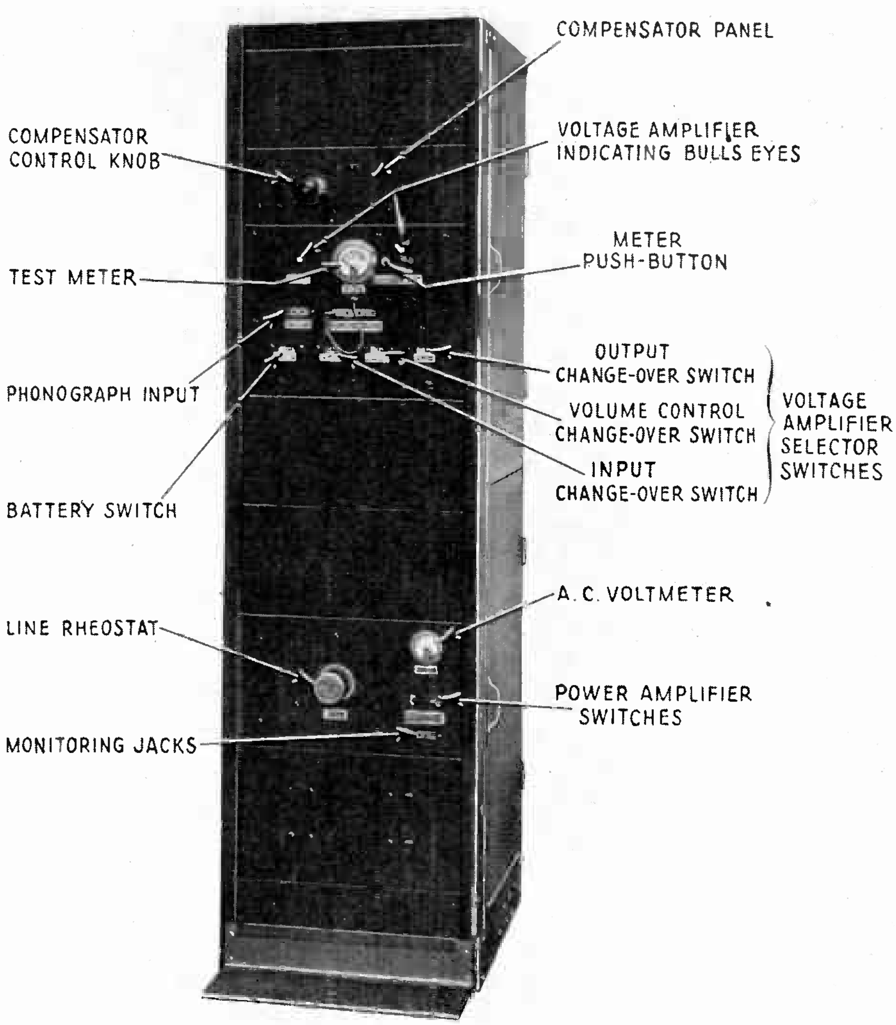


Figure 119—Type PA-17A amplifier rack used in PG-3 equipments

the upper scale reads up to 250 volts and the lower scale to 25 volts. To use the 25 volt scale it is necessary to press the meter push-button to the right of the meter. There are two indicator lamps, one on each side of the test meter, which indicate which voltage amplifier is turned "on".

designation SPU stands for socket power unit. This designation is given to the power amplifier units which obtain their plate and grid voltage supply from rectified alternating current. The rectifying devices are built into the power amplifier units, making each of these units complete in itself.

The voltage amplifiers of these equipments receive their plate and grid voltage from dry batteries mounted in battery boxes in the amplifier racks.

The DC power for lighting the filaments of the voltage amplifier tubes and the exciter lamps is supplied by Type MVJ-13 storage batteries. These batteries were described in Chapter IV. For instructions as to the care of these batteries see section 50.

The differences between the various SPU operated equipments is mostly in location of the controls and the number of amplifier units used. These equipments will be described separately and their differences pointed out.

186. General Description of the PG-3 Equipment.—The PG-3 equipment is for use in medium sized theatres. This equipment uses the PS-1 sound heads, PT-2 turntables, one PA-16A input control panel, one PA-17A amplifier, PL-11 loudspeakers, and necessary power supply apparatus. The voltage amplifiers are battery operated and the power amplifiers are socket power operated.

The Type PA-17A amplifier is a double channel arrangement; that is, two separate voltage amplifiers are used with the necessary switches for changing readily from one voltage amplifier to the other, and two separate power amplifier units are also used, but these are intended for simultaneous operation, each amplifier being connected to separate sets of speakers. See sections 138 and 140.

The current for lighting the filaments of the voltage amplifier tubes and exciter lamps is supplied by a pair of MVJ-13 storage batteries. Two pairs of these batteries are included in the equipment, together with suitable battery charging equipment. These batteries are more fully described in Chapter IV.

A separate input control panel is used in this equipment and is usually mounted between the projectors. This panel was described in section 110.

187. Description of the PA-17A Amplifier Rack.—Figure 119 shows a front view of this rack. As shown in the figure, the rack has seven panels. The top panel is blank, the second panel is the compensator panel and has one knob for the compensator control. The third panel is the voltage amplifier control panel. The two voltage amplifier units are mounted directly behind these three top panels. The two battery boxes are mounted behind the fourth and fifth panels. The sixth panel is the power amplifier control panel, and behind it is mounted one of the power amplifier units. The other power amplifier unit is mounted behind the bottom panel.

VOLTAGE AMPLIFIER PANEL METER READINGS				
Jack Designation	Reading	Multiplying Factor	Meter Reading	Actual Value
ECX5	"C" bias of voltage amplifier	5	6 to 6.4	30 to 32 volts
IP1X1	Plate current of tube No. 1	1	3.3 to 4.5	3.3 to 4.5 milliamperes
IP2X1	Plate current of tube No. 2	1	0.3 to 0.95	0.3 to 0.95 milliamperes
IP3X5	Plate current of tube No. 3	5	2.5 to 5	12.5 to 25 milliamperes
ILAX1	Exciter lamp current of Projector A	1	5 or 7.5	5 or 7.5 amperes
ILBX1	Exciter lamp current of Projector B	1	5 or 7.5	5 or 7.5 amperes

As in the case of the PG-1, the plate current milliammeters for indicating the plate current of the UV-845 tubes should be equalized, that is, the reading of the milliammeter labeled "IP BACK TUBES" on the power amplifier panel should equal the reading of the milliammeter on the same panel labeled "IP FRONT TUBES." The plate currents are controlled by means of the grid bias controls located at the bottom of the amplifier panels. These controls are labeled "BACK TUBES IP CONTROL" and "FRONT TUBES IP CONTROL". The readings of each milliammeter should be approximately 130 milliamperes. If one tube is burned out, the milliammeter in its circuit would read 65 milliamperes. *Do not attempt to equalize the readings with one tube burned out.*

When the voltages have been checked and properly adjusted the amplifier equipment is ready for operation except for turning "on" the stage loudspeaker switch.

184. Troubles on the PG-2 Equipment.—The troubles which might occur on this equipment are similar to those which were discussed in section 177 for PG-1 equipment.

Section 177 applies equally well to the PG-2 equipment with the exception that in case a UV-845 burns out in the PA-5 amplifier the milliammeter reading will drop to half its normal value.

The location of the fuses of the PA-5 amplifier rack is shown in Figure 118. It will be noticed that the PA-5 rack has two 1000 volt fuses, instead of one as used on the PA-1 rack. These two 1000 volt fuses are rated at one-half ampere each. One fuse is in the 1000 volt line to one power amplifier, and the other fuse is the line to the other power amplifier. The location of the fuses at the motor-generator set are the same as described for the PG-1 equipment in section 177.

(B) PG-3, 4, 6, 7, 8 AND 10 EQUIPMENTS

(Partially Socket Power Operated)

185. General Description of the PG-3, 4, 6, 7, 8 and 10 Equipments.—The PG-3, 4, 6, 7, 8 and 10 equipments are all SPU operated. As stated in Chapter X the voltage amplifier panel are in their "ON" positions and that the lever switches or the power amplifier control panels are in their "up" positions, except when only one power amplifier is to be used, in which case one power amplifier lever switch should be left in its "down" position.

To start the motor-generator set turn the starting switch to the "START" position. The indicator lamp to the left of the switch should then light.

Since the voltage of the 15 volt generator cannot be controlled separately, its voltage must be regulated by means of the 250 volt generator control. It is advisable to adjust the 15 volt generator correctly, and let the 250 volt and 1000 volt generators assume their voltage automatically because it is important that the storage batteries be kept properly charged. See section 51. If the 250 volt and 1000 volt generators do not assume approximately their correct voltage when the 15 volt generator is adjusted, notify the RCA Photophone service man.

The following tables give the readings which should be obtained at the various metering jacks. These readings should be checked each time the equipment is started. See section 170 for interpretation of jack designations.

CONTROL PANEL METER READINGS

Jack Designation	Reading	Multiplying Factor	Scale Reading	Actual Value
EAX2	15 volt generator voltage	2	6.5	13 volts
ECX50	250 volt generator voltage	50	5	250 volts
EB123X100	Plate voltage of voltage amplifier tubes 1, 2 and 3	100	5	500 volts
EB47X100	Plate voltage of power amplifier tubes 4 to 7	100	10	1000 volts

Two types of exciter lamps are used with RCA Photophone equipments. One type is rated at 5 amperes and the other at 7.5 amperes. The reading obtained when measuring the exciter lamp currents depends upon the type of lamp used. The exciter lamp currents are adjustable by means of the exciter lamp rheostats on the voltage amplifier panel. This current should be adjusted to a slightly lower value than the rating of the lamps.

The reading obtained for the "C" bias voltage of the voltage amplifier is the voltage of the "C" battery.

plate and filament circuits of the tubes. To the right of this switch are two small knobs, used for grid bias control of the UV-845 tubes. On the right-hand side of the panel is a monitoring jack for "plugging in" the monitor speaker. Below the monitoring jack is a speaker switch, which is connected between the output of the power amplifier and the loudspeakers and is used for turning "on" and "off" the output of the power amplifier.

181. **Description of the PA-5 Control Panel.** — The control panel of the PA-5 amplifier rack is usually mounted between the two power amplifier panels. The knob at the center of this panel is the field rheostat knob for controlling the field current, and therefore the generated voltage, of the 250 volt generator.

Only one field rheostat is used on this equipment. The field current of the 15 volt and 1000 volt generators is supplied by the 250 volt generator, but instead of using a field rheostat for each machine fixed resistors are used with the 15 volt and 1000 volt generators. Therefore it is only necessary to adjust the voltage of one generator, as the voltages of the other two generators will then be automatically adjusted to their correct values. It is advisable to adjust the rheostat to give the proper voltage from the 15 volt generator because this voltage should be adjusted to keep the storage battery properly charged.

The two jacks at the left-hand side of the panel are for use in measuring the plate voltage of the voltage and power amplifiers. The two jacks on the right-hand side of the panel are for measuring the voltages of the 250 volt and the 15 volt generators. The switch in the lower right-hand corner of the panel is for starting and stopping the motor-generator set. To the left of this switch is a pilot lamp which is lighted when the motor-generator set is running.

182. **The PA-5 Loudspeaker Switching Panel.**—The loudspeaker switching panel is usually mounted on the side of the rack. It has six snap-switches. Three of these switches are connected to the output of one power amplifier and the other three are connected to the output of the other power amplifier. They are used to switch off individual speakers or groups of speakers in case of trouble, or in case it is not desirable to operate all of the speakers. These switches are not otherwise used in the operation of the equipment. This panel is not illustrated in the figures.

183. **Operation of the PG-2 Equipment.** — Before starting the motor-generator set see that the commutators are clean and smooth and that the bearings are well oiled. See section **36**.

The voltages of various circuits should be checked whenever the equipment is started up, but before checking the voltages see that all the amplifier rack power switches are turned "on." That is, see that the two exciter lamp switches on the connection from a non-synchronous phonograph to the voltage amplifier. The second jack from the left is for use in measuring the grid "bias" voltage of the voltage amplifier. The two jacks on the extreme right are for measuring the exciter lamp current of both exciter lamps, and three jacks at the center are for measuring the plate currents of the voltage amplifier tubes.

180. Description of the PA-5 Power Amplifier Panels.—The two power amplifier

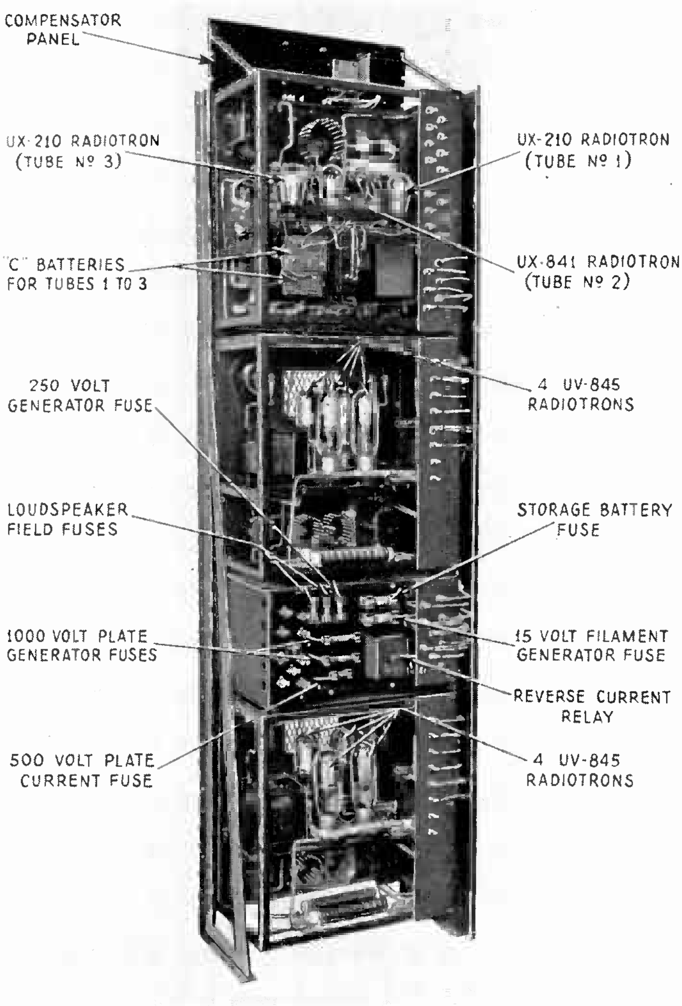


Figure 118—Rear view of Type PA-5 amplifier rack used in PG-2 equipments

panels are identical. The power amplifier units, using four UV-845 tubes each, are mounted to the rear of these panels. At the top of each panel are two plate current meters. They are recessed and protected with a pane of glass, because they are in a high voltage circuit. Holes in each panel, covered with mesh screens, permit an inspection of the UV-845 tubes from the front of the rack. The lever switch mounted in the lower left-hand corner of each panel is used to control the lamps in the upper left-hand corner of the panel labeled "PROJECTOR A" and "PROJECTOR B" indicate which projector is "faded in" to the voltage amplifier. The volume control is at the top of the panel and, like the volume control of the PA-1, it is calibrated from 0 to 40 to give twenty steps of equal volume change. The meter directly below the volume control is a test meter. It is connected by

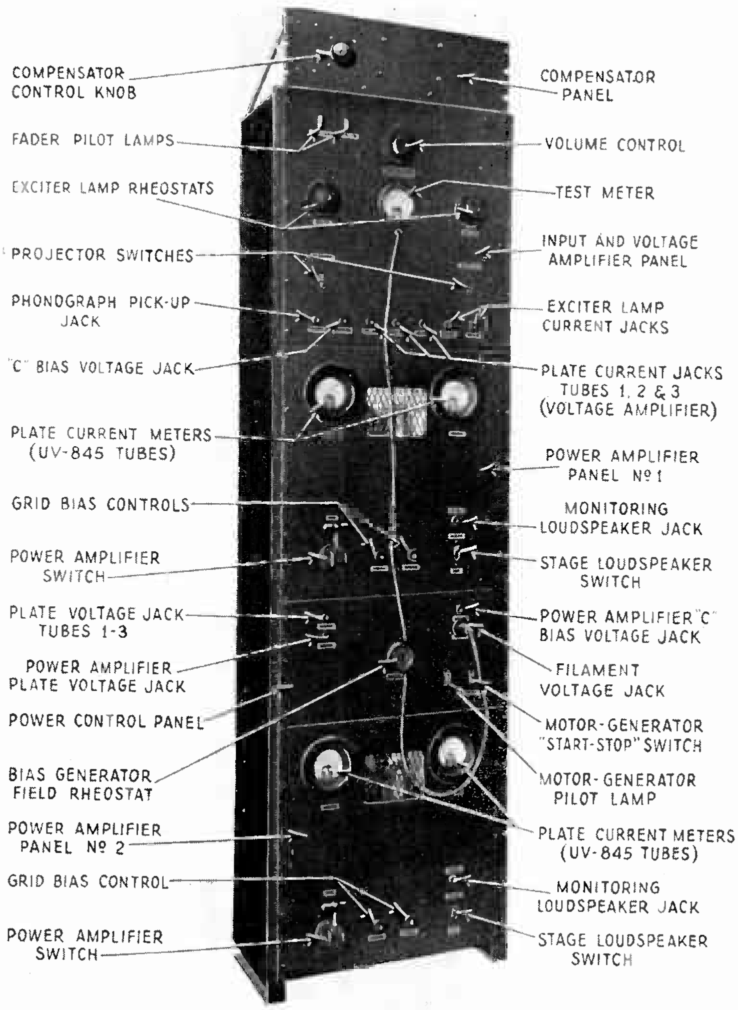


Figure 117—Front view of Type PA-5 amplifier rack used in PG-2 equipments

means of a suitable cord to a jack plug for use, in conjunction with the jacks distributed throughout the rack, in measuring the various currents and voltages. The two rheostat knobs, one on either side of the test meter are used for exciter lamp current control. Directly below each exciter lamp rheostat are exciter lamp switches. In a row along the bottom of the panel are seven jacks. The jack at the extreme left is the phonograph pick-up jack, for use in making an input is burned out. Check the 60 ampere fuses at the back of the panel and the 60 ampere fuse in the low voltage fuse box at the M-G set.

If the filaments do not light and the plate voltages are very low, or give no reading at all, the indication is that a fuse in the 250 volt generator circuit is burned out. Before checking the fuses, make certain that the M-G set is running. If it is running and no readings are obtained, stop the M-G set and check the 10 ampere fuse in the 250 volt line at the back of the rack (See Figure 116) and the 20 ampere 250 volt fuse in the low voltage fuse box at the M-G set.

If the volume level of the loudspeakers drops to a very low value, check the two 5 ampere loudspeaker field fuses at the back of the panel (See Figure 116).

If the storage battery ammeter fails to indicate either charge or discharge when the low voltage generator field rheostat is manipulated, the indication is that one of the 60 ampere fuses at the back of the panel is burned out. If it is found that this is not the case, the trouble will probably be in the reverse current relay, in which case the RCA service man should be notified. If the battery ammeter fails to show charge or discharge, a noticeable amount of hum is liable to be produced in the loudspeakers.

For a further discussion of the troubles which may be experienced with this equipment, see Chapter XIV.

178. **General Description of the PG-2 Equipment.**—The Type PG-2 is a motor-generator operated large theatre equipment. An equipment of this type includes the following apparatus:—Type PS-1 sound heads, Type PT-2 turntables, one Type PA-5 amplifier rack, Type PL-11 loudspeakers, a four unit motor-generator set, and one pair of Type XCR-19 Exide storage batteries. The power output of the amplifier is slightly less than that of the Type PA-1 used in PG-1 equipments.

The amplifier has four panels, exclusive of the compensator panel which is usually mounted on the top of the rack as shown in Figures 117 and 118. The top panel of the rack proper is the voltage amplifier panel. The second panel from the top and the bottom panel are power amplifier panels, and the panel between the two power amplifier panels is the control panel. A small panel with six snap switches is usually mounted on the side of the rack. This panel is a loudspeaker switching panel, and is not illustrated in the figures.

Only one voltage amplifier unit is used with this equipment. Two power amplifiers in two separate units are used together.

179. **Description of the PA-5 Voltage Amplifier Panel.**—This panel, which is the voltage amplifier, a relay fader, projector indicator pilot lamps, exciter lamp rheostats, a test meter, six metering jacks and a phonograph pick-up jack.

The voltage amplifier, mounted on the rear of the panel, differs slightly from those used in the PG-1 equipments and is described in section 136. The two pilot set of the amplifier not in use. Turn the snap switch below the storage battery ammeter to the "ON" position. Close the lever switches on the input panel of the amplifier rack to be used. Switch the loudspeakers from the rack in use to the one to be used. Open the lever switches of the input panel of the rack giving trouble, and stop its motor-generator set.

The following are some of the troubles which may develop:—

(a) A hum may develop due to a dirty commutator on the 1000 volt or 15 volt generator. Occasionally the 250 volt machine may also give this trouble. This trouble can be avoided by keeping the commutators clean at all times. For instructions in cleaning commutators see section 36.

(b) If the plate current milliammeter reading suddenly increases to a great extent when the equipment is in operation, it is a sign that one of the UV-845 tubes has become defective. When this condition is noticed the tubes should be inspected for abnormal appearances. The usual indication is that the plate of one tube has become almost white hot. If a tube burns out it can be readily detected by its failure to light. In this case it will be noticed that the reading of one of the plate current milliammeters will have decreased a little.

(c) If for any reason, one of the tubes in the voltage amplifier becomes excessively "microphonic" a ringing sound will be noticed in the monitor speaker whenever the amplifier panel is gently tapped. This condition should be remedied by immediately replacing the defective tube with a new one.

(d) If sound is heard from both projectors at the same time, it is usually an indication that dirt has collected on the relay fader contact points. The contact points may be readily cleaned by passing a piece of rough paper between the contacts. Do not use sand paper or other abrasive. The location of this relay is shown in Figure 116.

(e) If the plate current of the UV-845 tubes drop to zero while the filaments remain lighted, it is an indication that the circuit of the 1000 volt generator is open. Check the 1000 volt fuses at the back of the panel (see Figure 116). If this fuse is O. K., test the 1000 volt fuses in the fuse box at the M-G set. Two 1000 volt fuses are used in parallel in this box. They are the two long fuses in the box containing three fuses. (Use 2300 volt, 1.3 ampere fuses for replacement.)

If the plate current of the UX-210 tubes drops to zero while the filaments remain lighted check the fuse in the 500 volt line at the back of the panel (see Figure 116) and the 500 volt fuse in the M-G set fuse box. This fuse is mounted in the same box with the two 1000 volt fuses. (Use 600 volt, 1.8 ampere fuses for replacement.)

If the filaments of the tubes and the exciter lamps fail to light, while the plate voltages check O. K., the indication is that a fuse in the 15 volt generator circuit

TEST OF THE PLATE CURRENTS OF THE POWER AMPLIFIER.
(See Section 169.)

Meter Designation	Reading	Multiplying Factor	Scale Reading	Actual Value
IP FRONT TUBES	Plate current of front row of tubes	1	325	325 Milliamperes
IP BACK TUBES	Plate current of back row of tubes	1	325	325 Milliamperes

TESTS OF PLATE CURRENTS AND GRID VOLTAGES OF THE VOLTAGE AMPLIFIER.

Jack Designation	Reading	Multiplying Factor	Scale Reading	Actual Value
IP1X1	Plate current of Tube No. 1	1	3.3 to 4.5	3.3 to 4.5 Milliamperes
IP2X1	Plate current of Tube No. 2	1	0.3 to 0.95	0.3 to 0.95 Milliamperes
IP3X5	Plate current of Tube No. 3	5	2.5 to 5.0	12.5 to 25 Milliamperes
EC12X1	Grid bias of Tubes 1 and 2	1	9 to 9.5	9 to 9.5 volts
EC3X5	Grid Bias Tube No. 3	5	6 to 6.4	30 to 32 volts

When running sound-on-film the exciter lamp current should be checked. The reading to be obtained depends upon the type of exciter lamp used. One type is rated at 7½ amperes and the other at 5 amperes. Adjust the filament current to slightly less than the rating of the lamps used.

TESTS OF EXCITER LAMP CURRENT.

Jack Designation	Reading	Multiplying Factor	Scale Reading	Actual Value
ILBX1	Exciter lamp current of Projector B	1	5 or 7.5	5 or 7.5 amperes
ILAX1	Exciter lamp current of Projector A	1	5 or 7.5	5 or 7.5 amperes

177. Troubles on PG-1 Equipments.—Very little trouble should be experienced with this apparatus. In case serious trouble develops while the equipment is in operation, switch over to the other amplifier. To do this start the motor-generator that the battery is discharging. The purpose of the battery is to filter out the ripple of the DC voltage from the 15 volt generator and is not used to supply current to the amplifier, but it should be kept charged at all times. See section 51.

175. Operation of PG-1 Equipments.—The operation of the PG-1 equipment may seem very complicated at first glance, but it will be found that this is not the case. Before starting the equipment check all oiling points on the motor-generator set. See section 36. Make sure that the commutators are bright and clean, and see that all covers are on the rear of the amplifier racks.

Only one amplifier rack is used at a time. Before starting the motor-generator set, see that the switch below the storage battery ammeter is in the "OFF" position. After the motor-generator set has come up to speed this switch should be snapped to the "ON" position. To start the motor-generator set associated with the amplifier to be used, press the "START" button on the metering panel of that amplifier rack. The pilot lamp to the right of the "START-STOP" switch should light when the motor-generator set is running. See that the two lever switches on the amplifier rack being used are closed (in the "up" position) and the corresponding switches on the other rack are open (in the "down" position). See that the loudspeaker change-over switch on the loudspeaker switching panel is the position which connects the speakers to the amplifier rack being used. When shutting down the amplifier rack, snap the switch located below the storage battery ammeter to the "OFF" position before pressing the "STOP" push-button to stop the M-G set.

176. Checking the Voltages on the PG-1 Equipment.—All voltage and current controls, when once adjusted, should be left in these positions except when a check of the equipment with the meters provided indicates that re-adjustment is necessary. All voltages should be checked before the equipment is put into operation. The voltage of the 250 volt generator should be checked first. See Section 171. The following tables give the necessary information for checking the various currents and voltages.

TESTS OF GENERATOR VOLTAGES.
(Made from Metering Jacks on Metering Panel. See sections 170, 171 and 174.)

NOTE: The charging of the storage battery governs the voltage of the 15 volt generator. See section 51.

Jack Designation	Reading	Multiplying Factor	Scale Reading	Actual Value
ECX50	Voltage of 250 volt generator	50	5	250 Volts
EAX2	Voltage of 15 volt generator	2	6.5 See note above	13 Volts
EB123X100	Plate voltage of tubes 1, 2 and 3	100	5	500 Volts
EB413X100	Plate voltage of tubes 4 - 13 (Voltage of 1000 volt generator)	100	10	1000 Volts

172. **Description of the PA-1 Loudspeaker Switching Panel.**—At the bottom of one rack is a loudspeaker switching panel. The corresponding panel at the bottom of the other rack is blank. The switch in the upper left-hand corner is for switching the speakers from one amplifier to the other. The switch in the upper right-hand corner is for switching the speakers "on" and "off." The row of switches at the bottom of the panel are for switching the speakers "on" and "off" separately or in groups.

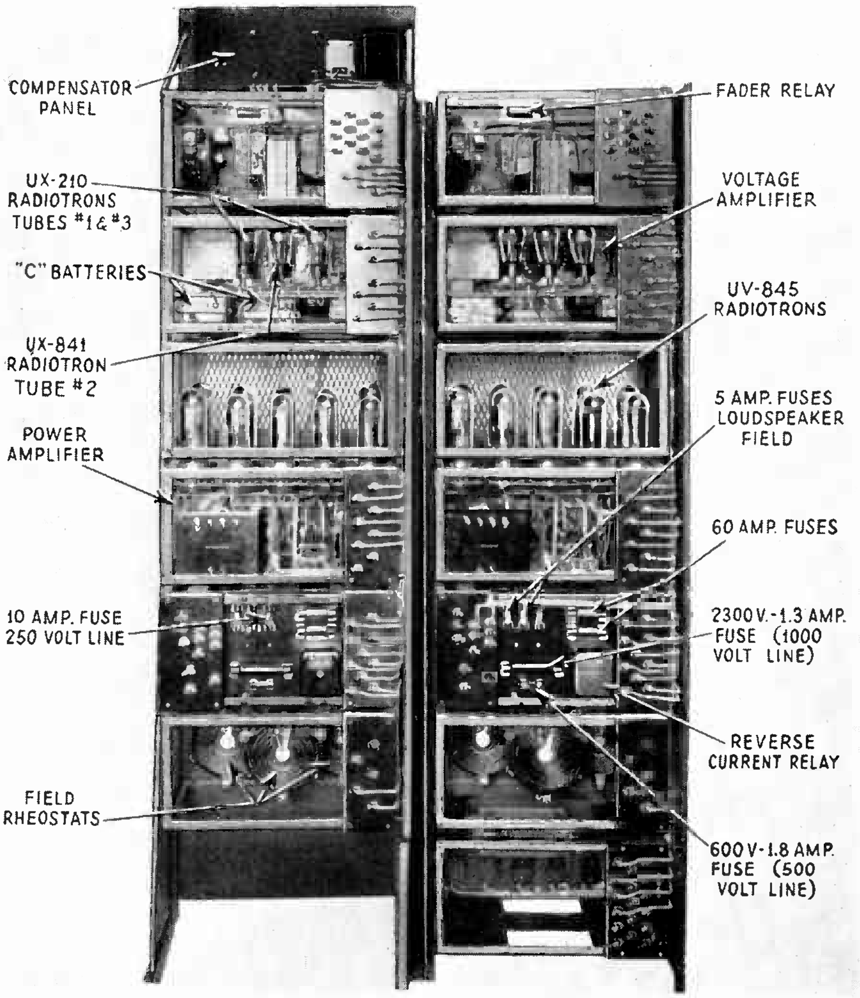


Figure 116—Rear view of Type PA-1 amplifier racks used in PG-1 equipments

173. **PG-1 Motor-Generator Sets.**—The four unit motor-generator sets used with PG-1 equipments are described in section 36.

174. **Storage Batteries Used with the PG-1 Equipment.**—Two Type XCR-19 storage batteries are used with each motor-generator set. These batteries are connected in series to give 12 volts and are connected across the 15 volt generator. The ammeter on the metering panel indicates the battery current, a reading to the right of mid-scale indicates that the battery is charging, and a reading to the left indicates

amplifier and in the field circuit of the 1000-volt generator. Therefore, when this switch is in the "OFF" position, there will be no current through the filaments of the tubes or exciter lamps, and the grid and plate voltages of the power amplifier, and the plate voltage of the voltage amplifier will be reduced to a very low value. This switch can be used to stop the operation of the rack equipment without stopping the motor-generator set, or to charge the storage battery when the amplifier is not in use. To charge the storage battery when not using the amplifier, with the motor-generator set "on", turn the switch to the "OFF" position and regulate the charging rate, as indicated on the storage battery ammeter, by means of the 15-volt generator field control.

In the lower left-hand corner of the panel is a "START-STOP" push-button station for controlling the motor of the motor-generator set. A pilot lamp to the right of the push-button station is lighted when the motor-generator set is running. The push-button station controls an electrically operated motor line switch as described in section 36.

In the upper left-hand corner of the panel are two jacks. One is labeled "EB123 X100." This jack is used to read the plate voltage of the three tubes in the voltage amplifier. The jacks directly below this is labeled EB413X100. This jack is used to check the plate voltage of the UV-845 tubes (tubes 4 to 13). At the right of the panel are two more jacks. One is labeled ECX50. This jack is used to measure the voltage of the 250 volt generator (not the grid bias of the 845 tubes). Although the 250 volt generator is used to supply the grid bias voltage for the UV-845 tubes, the actual grid bias is controlled by means of the grid bias controls described in the preceding section. The other jack on the right-hand side of the panel is labeled "EAX2", and is used to read the voltage of the 15 volt generator. This voltage is also the filament voltage of the UV-845 tubes.

All fuses of the rack are located at the back of this panel. Figure 116 shows the location and sizes of the various fuses used. *Do not remove or replace any fuses without first stopping the motor-generator set used in conjunction with the rack.*

171. **Description of the PA-1 Power Control Panel.**—The second panel from the bottom is the power control panel. Three field rheostats are mounted on the rear of the panel, with their controls brought out to the front. The knob on the left controls the voltage of the 1000 volt generator. The center knob controls the voltage of the 250 volt generator, and the knob on the right controls the voltage of the 15 volt generator.

The field current for all three generators is supplied by the 250 volt generator. It is, therefore, important that the 250 volt generator voltage be correct at all times. This voltage may be checked at the jack on the metering panel marked "ECX50". If it is necessary to adjust this voltage, watch the plate current milliammeters to see that the plate current does not rise above normal. Keep one meter plugged into this jack, when adjusting the voltage of either one of the other two generators. See that this voltage does not change. If it does, correct it before making any further adjustments on either of the other machines.

nation of EB123X100. E stands for "voltage," B stands for "B" or plate supply, 123 means tubes 1, 2, and 3, the X means multiply the meter reading by, and the 100 is the multiplying factor. All EBs are plate voltages. All ECs are grid or "C" bias voltages. All IPs are plate currents, as I stands for current. (The multiplying factors for plate current readings are for giving values of current in milliamperes.)

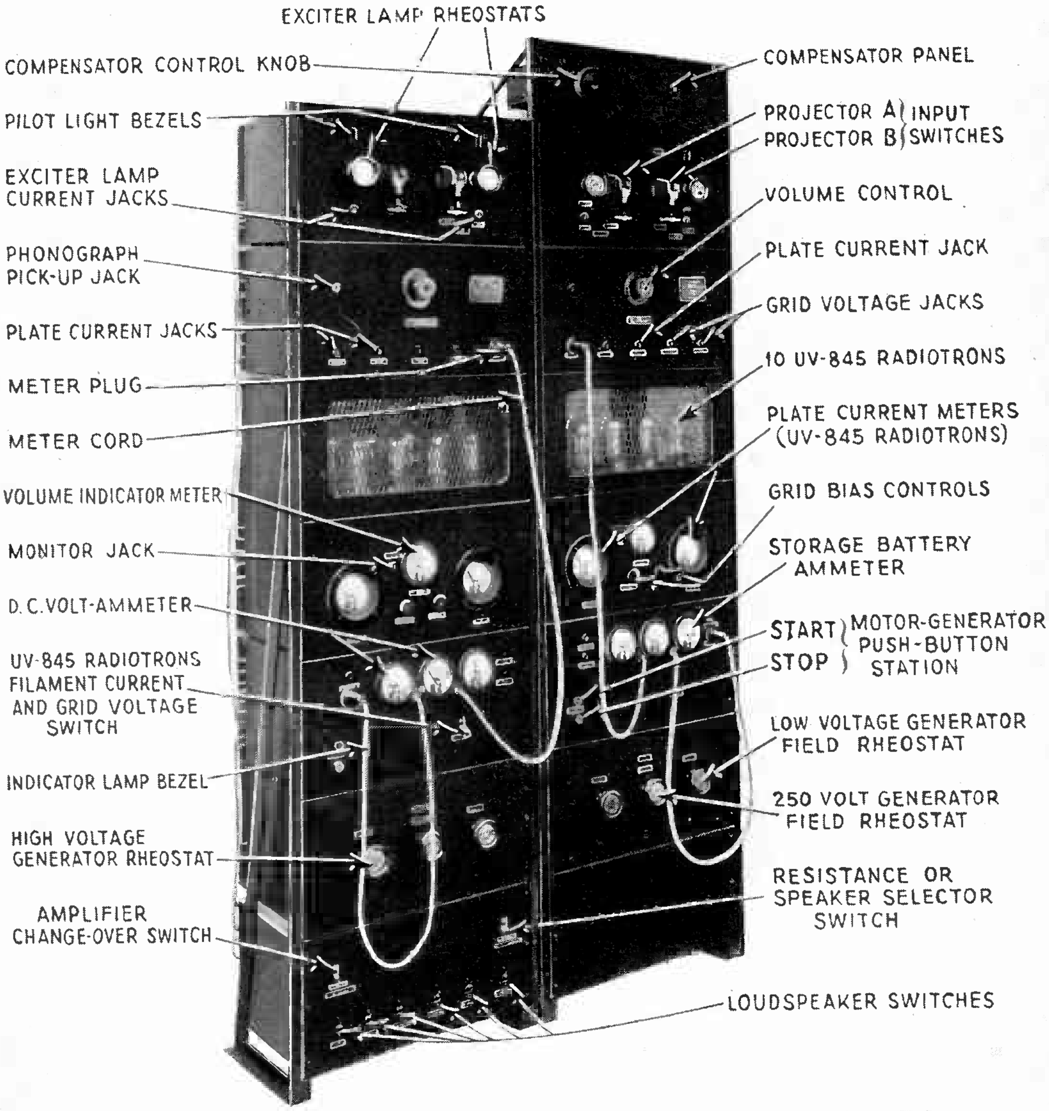


Figure 115—Front view of Type PA-1 amplifier racks used in PG-1 equipments

The meter on the right is for indicating the storage battery current. The zero position is at mid scale, so that the meter indicates the amount of battery current, and whether the battery is being charged or discharged. The switch below this meter is a double-pole switch. The two sides of the switch are in separate circuits, but operate simultaneously. One side is in the filament circuits of the voltage and power amplifiers. The other side of the switch is in the grid bias circuit of the power

The volume control is mounted at the center of this panel. It is calibrated from 0 to 40, and provides 20 steps of equal "gain," so designed that an increase of any one division on the dial gives the same apparent increase of volume as any other division. Along the bottom of the panel is a row of five metering jacks. These jacks, in conjunction with a test meter (to be described later), are used for measuring the plate currents and the grid voltage of the voltage amplifier. A phonograph pick-up jack is mounted in the upper left hand corner of this panel. This jack is used for making a connection from a non-synchronous phonograph to the input of the voltage amplifier.

Small dry batteries are mounted to the rear of the panel, for supplying the "C" bias of the voltage amplifier. See Figure 116.

169. **Description of the PA-1 Power Amplifier Panels.**—The power amplifier uses two panels mounted directly below the voltage amplifier panel. The upper panel has no controls, but has a hole cut into it which is covered with a mesh screen and allows inspection of the UV-845 tubes from the front of the rack. The controls for the power amplifier are mounted on the lower power amplifier panel as shown in Figure 115. For a description of the power amplifier unit see section 137.

The two meters on the outside, to the left and right, are plate current milliammeters for reading the total plate current of each bank of five UV-845 tubes. The plate current of the front bank of tubes is read on the meter to the right, and the current of the rear bank of tubes is read on the meter to the left. These meters are recessed in the panel and are protected by a glass cover, because they are in a high voltage circuit. The center meter indicates directly the voltage across the voice coils of the loud speakers, and indirectly the volume of sound from the loud speakers. The two small controls under this meter are the grid bias or "C" voltage controls. Since the grid bias controls the plate current of amplifier tubes, these controls are used to control the plate current of the UV-845 tubes. The plate current of one bank of tubes should be regulated so as to be equal to the plate current of the other bank. If this is not done a high pitched whistle or some distortion may result.

170. **Description of the PA-1 Metering Panel.**—The metering panel is mounted directly below the lower power amplifier panel. This panel has three meters. The two to the left are exactly alike and are both connected to jack plugs through suitable cords. These meters are used in conjunction with the jacks distributed over the rack for measuring the various voltages and currents of different circuits. The two meters permit two simultaneous measurements from different jacks. These meters can be used on either rack making it possible to make four simultaneous readings if desired.

The name plates on the jacks indicate the circuit to which the jack is connected, and whether the reading on the meter is a voltage reading or a current reading, and a multiplying factor by which the meter reading must be multiplied to obtain volts or milliamperes. For example, consider the jack with the name plate desigalso includes a compensator which is mounted in a different manner but which is electrically the same in its function. See section 222.

(A) PG-1 AND PG-2 EQUIPMENTS
(*Motor Generator Operated*)

166. **General Description of the PG-1 Equipment.**—The PG-1 sound equipment is the largest and most powerful equipment furnished by RCA Photophone, Inc. This equipment uses the PS-1 sound head described in Chapter VIII and the PT-2 turntable described in section 71. Two Type PA-1 amplifier racks are included in each installation, and a separate four-unit motor-generator set is used for each rack. The motor-generator sets supply all the power required by the equipment, except for the grid voltage ("C bias") supply for the voltage amplifiers, which is obtained from small "C" batteries. One amplifier equipment is used at a time, but the spare amplifier can be quickly substituted for the one in use. Four Type XCR-19 exide storage batteries are used.

One amplifier has seven individual panels, and the other has six. The extra panel on one rack is for the purpose of switching loud speakers. In addition a compensator panel is mounted at the top of one of the racks by means of brackets. Figures 115 and 116 show the front and rear views respectively of this amplifier rack equipment.

167. **Input Panel of the PA-1 Amplifier Rack Equipment.**—This panel is mounted at the top of the rack (exclusive of the compensator panel). All the controls for the projector are mounted on this panel. Near the top of this panel are two red pilot lights labeled "PROJECTOR A" and "PROJECTOR B." See Figure 115. These lamps indicate which projector is connected to the amplifier through the relay fader. This relay fader is mounted at the back of this panel and is operated from the fader control switches on the projectors. Directly under the pilot lights are the exciter lamp rheostats for controlling the exciter lamp current. Under the rheostats are jacks for measuring the exciter lamp currents. The jacks are labeled "ILAX1" and "ILBX1" and are used to measure the exciter lamp current of projectors "A" and "B" respectively. At the center of the panel, between the two exciter lamp rheostats are two large lever switches. These switches are used to connect the projector circuits to the amplifier rack, and for shifting the projector circuits from one rack to the other. Each switch controls the circuits to one projector. When the switch handle is in the "up" position the switch is closed, and when it is in the "down" position the switch is open. Both projectors should be connected to the same rack at the same time, that is, when operating the equipment both switches on one rack should be either "open" or "closed." When the switches on one amplifier rack are closed the switches on the other rack should be open. The circuits controlled by each of these switches are: the fader relay control circuits, the exciter lamp circuit, the photo-cell polarizing circuit, and the input circuit to the amplifier.

168. **Description of the PA-1 Voltage Amplifier Panel.** — The voltage amplifier panel is mounted immediately below the input panel. The voltage amplifier, which is mounted on the back of the panel, was described in section 136.

CHAPTER XIII

RCA PHOTOPHONE EQUIPMENTS

164. Introduction.—An RCA Photophone equipment consists of sound head attachments for the projectors, voltage amplifiers, power amplifiers, loudspeakers, voltage supply and control apparatus. Synchronous disc attachments (turntables) are supplied with most of these equipments.

The separate units used, except the compensator panels which are described below, have been described in the previous chapters. The purpose of this chapter is to enumerate and describe the arrangement of the units used, to discuss their inter-relation, and to give operating instructions for the amplifier equipment.

For convenience of discussion this chapter is divided into three parts. The first part will take up the PG-1 and PG-2 equipments, which are motor-generator operated. The second part takes up the PG-3, 4, 6, 7, 8 and 10 equipments, which are partially socket power operated. The third part describes the PG-13, a small theatre equipment using a motor-generator set.

165. Compensator Panels.—Due to the number of recording systems in use and the number of different producers using each system with the consequent differences in recording methods, wide variations in the quality of recording occur. In order to equalize the reproductions of sound from recordings made by different producers, some adjustment is necessary when the sound is reproduced.

This adjustment is termed "compensation" and is made by means of a "compensator" control knob on the amplifier rack.

The control knob is used to compensate for the ill effects of poor recording. It has been pointed out in Chapter I that the proper reproduction of the human voice requires the presence of the higher frequencies much more than that of the lower frequencies. If the recording was not properly done and some of the higher frequencies were not sufficiently recorded, or if the lower frequencies were over-recorded, the blurred effect in the reproduction which results may often be eliminated by turning the control knob counter-clockwise to strengthen the effect of the high frequencies by reducing the amount of low frequencies present. Music, on the other hand, requires the presence of all frequencies for its proper reproduction, and may often be improved by turning the control knob clockwise to increase the amount of low frequencies present.

If the recording was properly done, however, constant manipulation of the compensator knob is unnecessary, and its normal setting is at the point of best reproduction of the average picture.

The compensator (Type PA-39A) is mounted on a separate panel which is standard with all theatre equipments except the Type PG-13. The Type PG-13 equipment

A double wall of fairly light construction will give good sound insulation provided the two walls are not closely coupled mechanically by nails or cross members; that is, provided the walls are kept isolated or separated from each other as much as practicable.

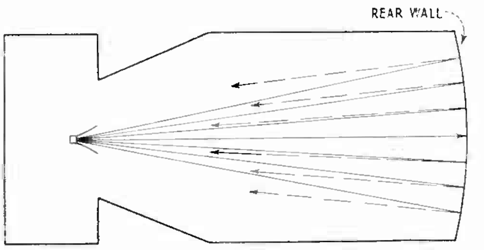


Figure 113—Concentration of reflected sound by curved rear wall of auditorium

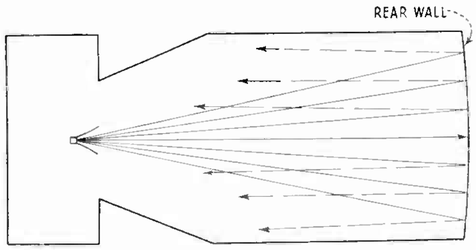


Figure 114—Curvature of wall lessened to avoid concentration of reflected sound

163. The Relation of the Volume Control Setting to Reverberation Effects.—It was stated in section 157 that the sound energy within a closed room is reflected back and forth between the walls until entirely dissipated. The length of time required to dissipate the sound energy produced by a loudspeaker depends upon the amount of sound energy produced, the size of the room, and the amount of sound absorbing material in the room. If there is very little sound absorbing material in the room, a small amount of sound energy will produce a high volume of sound. If the sound energy is quickly absorbed a large amount of sound energy is required to give the desired volume level. If the same volume control setting were used for a nearly empty house as is used for a full house, the volume level would probably be too great, and an undesirable amount of reverberation would be experienced. Therefore, it is a good plan, when operating to a partially filled house, to reduce the volume control setting to give just enough volume so that the sound will be intelligible at the last row of seats used by the audience. This is particularly important when the house is excessively reverberant and where un-upholstered seats are used.

In general very few auditoriums contain a sufficient amount of sound absorbing material unless they have been specially treated. The efficiency of a sound absorbing material depends, not only on the nature of its composition, but also on its thickness, and the way it is installed. Usually a material increases in absorption efficiency, particularly at the lower frequencies, with an increase of thickness and with an increase of air space between the wall and the material. In talking motion picture houses, the most effective placement of absorbing material is usually on the rear and side walls, and the front section of ceiling above the proscenium.

Since the reverberation time depends on the absorption in the room, the reverberation varies considerably with the audience unless the seats are heavily upholstered. The use of heavily upholstered seats is very desirable since it keeps the reverberation and consequently the sound loudness constant, irrespective of the audience present.

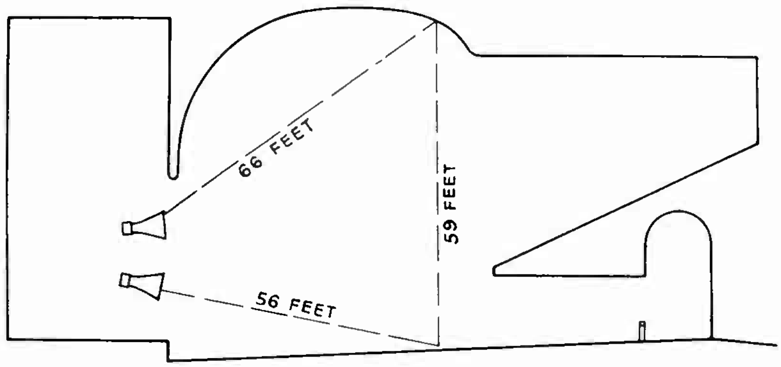


Figure 112—Illustrating production of echo in an auditorium

The absorption treatment of the walls and ceiling inside the operating booth, which has heretofore been neglected, is very desirable. Such treatment would result in the following:— a—reduction of noise in the booth; b—reduction of noise transmitted to the auditorium; c—increased working efficiency in the booth; and d—possibility of the complete control of the volume by the operator because of the improved hearing conditions in the booth.

162. Transmission of Sound.—A theatre with good acoustics has its walls insulated against the transmission of outside noises into the auditorium. The transmission of sound is of two kinds, aerial and structural. Small openings due to doors, windows, port holes, etc., transmit sound to a great degree. Thus, all the joints between walls, doors, windows, etc., should be made as air-tight as possible.

Transmission of sound through structures, such as the noise from vibrating motors and machinery, can be minimized by using massive walls and floors, and by separating all vibrating bodies from their supporting structures with sound insulating materials such as cork, felt, lead, and rubber, used singly or in combination.

Massive walls are not always necessary to obtain sufficient sound insulation.

by dispersing or scattering the sound wave in several different directions. The treatment for echo is particularly important when using directional loudspeakers since such speakers direct the sound in a concentrated beam, and oftentimes good volume distribution is sacrificed because the speaker can not be set to cover all the audience without directing some of the sound toward the echo producing wall.

Like reverberation, echo causes blurred speech and music.

160. Resonance.—The phenomenon of resonance, or the ability to vibrate best at certain frequencies, may occur in structures or in the air in rooms. Structural resonance usually is not harmful unless the resonant body is mechanically connected to the source of sound; for example, many musical string instruments have the vibration of their strings reinforced by a resonant body of wood which is mechanically connected to the strings.

Resonance in air chambers, such as the rear orchestra section under a balcony, alcoves, foyers, etc., does not occur very often unless such chambers are bare of furnishings and have hard reflecting surfaces.

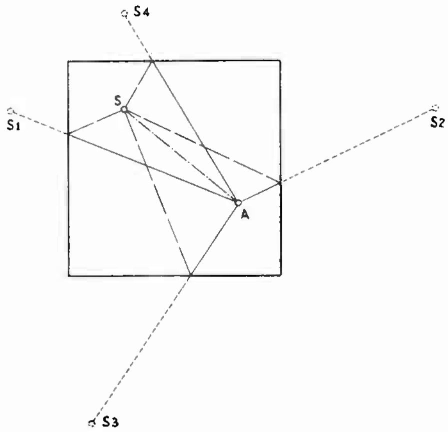


Figure 111—Similarity of reflection of light and sound

161. Absorption of Sound.—The blurring and distortion effect on speech and music caused by reverberation, echo and resonance has already been pointed out. Of these defects, excessive reverberation is the most common in auditoriums. We now come upon methods for curing these defects.

Echo and resonance can oftentimes be overcome by changing the shape of the surfaces producing them. Likewise reverberation can sometimes be minimized by reducing the size of the room. Changing the shape and size of theatres, however, is not often feasible, particularly after the building has been constructed. Thus, the most common method of cure is to increase the absorption of the ceiling, walls, floor, seats, etc.

The amount of sound which a material will absorb depends on its porosity and on its ability to vibrate as a whole. In general, materials absorb mostly due to their porous nature. Thus plaster, cement, brick, marble, and wood surfaces, etc., absorb less than 5% of the sound energy which strikes them, while felt-like materials, plush drapes, carpets, heavy upholstered seats, people's clothing, and all the special sound absorbents made out of mineral rock wool, cane fibres, wood fibres, corn shreds, seaweed, asbestos, etc., absorb over 25% and a few absorb over 70%.

the sound at the listening point. Translating this time interval in terms of the path difference between the two sounds, that is, the difference between the total lengths of their paths in traveling from source to listening point, the path difference should not be greater than 56 feet. Figure 112 shows how this condition may exist. The path of the reflected ray is 66 + 59 or 125 feet, which is 69 feet longer than the direct path. The reflected ray, although from a different loudspeaker, can be considered as coming from the same source.

An echo may sometimes consist of several distinct rapid repetitions of the original sound, in which case it is called a "multiple" or "flutter" echo. In this case the sound reflects back and forth between the smooth parallel walls. An echo usually can be distinguished very easily by making a sharp report in the room such as a hand-clap. When hands are clapped between parallel walls sometimes a dozen or more successive reflections (flutter echo) can be distinguished. Special sound ray apparatus using a sharp beam of sound is sometimes found necessary in locating troublesome echoes.

Echo is most generally encountered in large rooms, particularly those with bar-

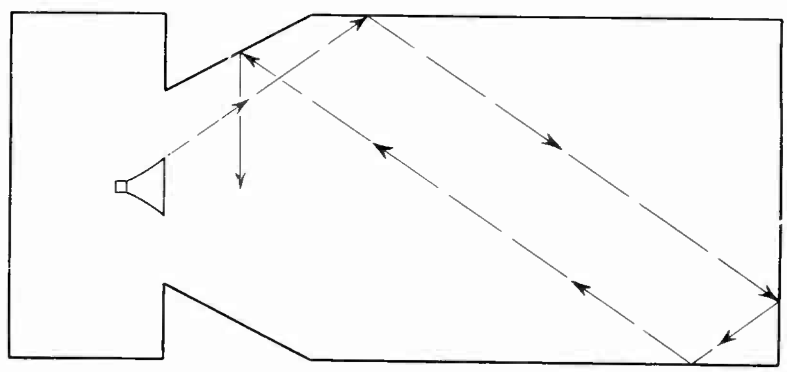


Figure 110—Reflection of sound in an auditorium

rel vaulting domes and other smooth curved surfaces. Architectural design often calls for curved surfaces with radii of curvature equal to the major dimensions of the auditorium, for example, the radius of curvature for a curved rear wall is usually equal to the length of the room. (See Figure 113.) The effect of such a surface is to throw the sound back to the source at S1 and create serious echo. Besides, such a surface, since it concentrates the sound so greatly, gives rise to non-uniform loudness of sound, forming loud and dead spots.

In general, flat surfaces are to be preferred to curved ones, but curved surfaces of a radius of twice, or greater than twice, the major dimension of the theatre will not usually give serious trouble. (See Figure 114.)

The echo effect of a surface may be reduced by changing its shape, by treating it with a sound absorbing material, or by both. Breaking up smooth surfaces with irregularities, such as coffering, pilasters, doorways, box tiers, etc., minimizes echo observer is stationed at A he will see the object and hear the direct sound, not only at S but he will see the images and hear the reflected sounds also from the image sources S1, S2, S3, and S4. These images form the first reflections and are reflected again, and likewise the second images are reflected, forming a new set of images. Obviously the successive images are farther and farther away so that the image the farthest away would be the faintest in loudness. Optically, one stationed at A would see many images of S in all directions.

The effect of reverberation is to cause blurred speech and music, due to the overlapping of the successive syllables in speech. Up to a certain point this overlapping is apparently beneficial because it increases the loudness of sound, but beyond this optimum point overlapping of successive syllables is detrimental. Thus, there is a period of reverberation, depending on the size of the auditorium, which will give *optimum* results. Although reverberation greater than the optimum value is detrimental, it is tolerable if not excessive. Thus, there is a time of reverberation greater than the optimum period which will give *acceptable* results. In general, the reverberation time should never be much greater than two seconds.

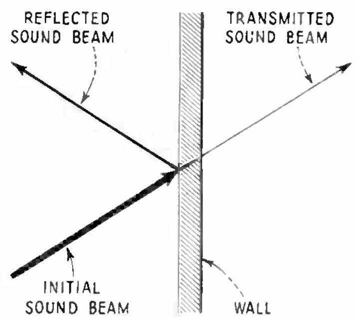


Figure 108—*Reflection, absorption and transmission of sound*

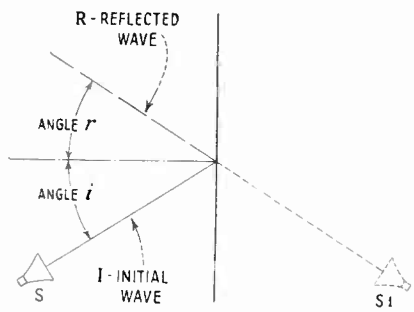


Figure 109—*Reflection of sound*

The audience in any theatre causes the time of reverberation to vary, for each auditor absorbs a large quantity of sound. It is therefore desirable to have optimum results obtained for the average size audience and acceptable results for the minimum size audience entertained in the auditorium.

The reverberation time of a room, which is the time required for a sound of given initial intensity to die away to the point where it is just barely audible, depends directly on the loudness of sound and the size of the room, and depends inversely on the absorption in the room. The standard reverberation time of a room is the reverberation time obtained when using an initial intensity of 1,000,000 times the intensity of the faintest sound which can be heard. This represents a sound volume of six times the loudness of a sound barely audible.

Increasing the size of a room increases the reverberation period due to the fewer number of reflections which occur in it during a given space of time, although the total number of reflections remains approximately the same.

159. Echo.—Whenever there is a time lag greater than one-twentieth of a second between two successive and similar sounds, echo becomes perceptible and annoying, particularly when the echo comes from a curved surface which concentrates as illustrated by the arrow penetrating the wall, part is reflected, and part is absorbed. The sound energy absorbed is in reality transformed into heat energy and, therefore, no longer exists as sound. The sum of the energies of the transmitted sound, absorbed sound, and reflected sound is equal to the energy of the initial sound beam.

As already pointed out in Chapter I the reflection of sound is in many ways analagous to the reflection of light and water waves, and therefore obeys the law of equal angle of incidence and reflection. Thus in Figure 109 angle "i" equals angle "r." Also by analogy to optics the reflected sound R appears to come from its image source S. The rebound of a billiard ball off the table cushion resembles the reflected ray of sound from a flat surface. In this case, the angle which the path of the ball makes with the cushion as it bounds away is of the same degree as the angle which the path of the ball made with the cushion as the ball approached it.

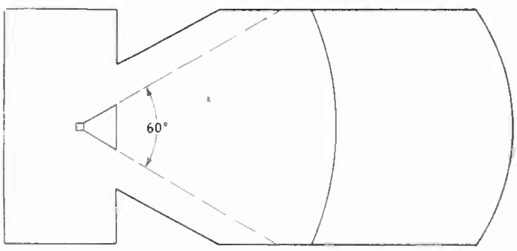


Figure 106—*Horizontal range of sound beam from loudspeaker*

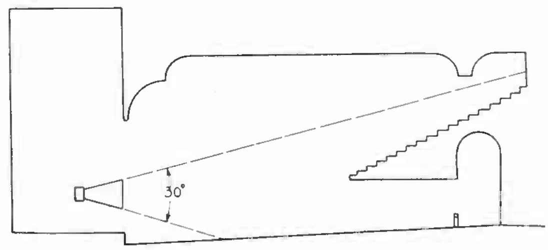


Figure 107—*Vertical range of sound beam from loudspeaker*

158. Reverberation.—The action of sound when confined in an enclosure is much more complex as compared to its action in free air. In free air, only the direct sound from the source can be heard. In a room, however, the sound one hears is composed of both the direct and the reflected waves. Consider the travel of a single ray of sound from the source S in Figure 110. As it proceeds as part of the expanding spherical sound wave, it first meets with a surface where it suffers partial reflection, absorption and transmission. The reflected portion now continues until it strikes a second surface, where it again suffers partial reflection, absorption and transmission. This process is repeated until the sound ray is completely dissipated. Likewise, all other portions of the spherical wave undergo this same process of multiple reflection. In an ordinary room with plaster walls and ceiling, due to these successive reflections the sound energy is rather quickly diffused throughout the entire room. In such a room the sound will suffer from 200 to 300 reflections before its energy is completely dissipated. If we recall that sound travels 1120 feet per second, it is readily seen that the duration of this prolonged "after-sound," called the reverberation time of the room, will be several seconds for the average theatre.

Probably we can obtain a better mental picture of reverberation by using optical analogy again. Let us imagine that we have a room with mirrored walls and both a source of sound and light at the point S as in Figure 111. If an the sound energy is propagated at a definite velocity, and in which the sound energy is detected by setting the ear-drum into vibration and hence producing the proper sensation in the brain. The velocity of sound in air is approximately 1120 feet per second at ordinary room temperatures.

For purposes of discussion, except where noted otherwise, we shall consider, as in Chapter I, that our sound source is a point source; that is, one from which the sound energy is emitted equally in all directions. We can consider this spherical wave as being made up of many sound rays, one traveling in each direction, and all coming from the same point, as shown in Figure 104. According to the law of diminishing intensity, the greater the distance the wave has traveled the less intense is the sound, and consequently of lesser sound loudness.

Figure 105 shows why the loudness of sound diminishes with distance. At A a certain amount of sound energy is concentrated in a fairly small area. As the sound waves move along to B the area of cross-section within which this sound

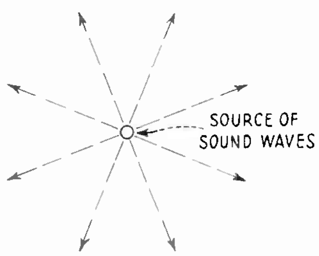


Figure 104 — Propagation of sound from a point source

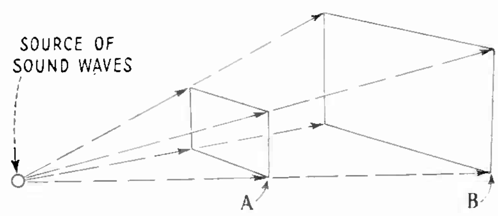


Figure 105—Dispersion of sound

energy is confined increases so that the same amount of sound energy is spread over a greater area, reducing the loudness of the sound.

Most of the loudspeakers actually used in theatres today are very directional and are not point sources, as pointed out in the previous chapter on loud speakers. For practical purposes the energy which they radiate may be considered as being confined within a 60° angle in the direction of the long axis of the baffle mouth (laterally) as shown in Figure 106, and within a 30° angle in the direction of the short axis of the baffle mouth as shown in Figure 107.

157. Some of the Properties of Sound Waves With Reference to Acoustics.—Sound waves display the properties of reflection, absorption, transmission, dispersion, and interference. We shall take up most of these properties in their application to auditoriums in what is to follow.

When a sound wave strikes the boundary between two different mediums, its energy is partially reflected, absorbed, and transmitted as shown by Figure 108. For the purpose of illustration the sound is shown as a concentrated beam striking a wall. The arrow points indicate the direction of travel. The lines representing the sound beam are shown of different width to give an idea of the variations of loudness. When the beam of sound waves strikes the wall, part of it is transmitted

CHAPTER XII

THEATRE ACOUSTICS

155. Introduction.—Throughout the previous chapters it has been pointed out that the aim of sound reproduction is to produce sound similar to the original music or speech as near as possible, that is, to obtain an exact likeness of the original sound. The conditions necessary to obtain good sound reproduction in an auditorium are:—that the sound should be of sufficient loudness in all parts of the auditorium, that the original quality of sound should be maintained, that the successive sounds in rapid speech and music should be clear and distinct, and that extraneous noises should be absent.

Obviously, to fulfill the conditions necessary for ideal sound reproduction requires that all forms of distortion introduced by the studio acoustics, recording equipment, sound film, reproducing equipment, and house acoustics be negligible. The importance of good auditorium acoustics has become fully recognized since the advent of talking motion pictures.

Our everyday dependence on sound has made the observation of the more usual acoustic defects in auditoriums the common experience of everyone. Each of us at some time or other has noticed an echo, a distinct repetition of sound, from a hillside or the wall of a distant building in the open, or, more often, from a high curved ceiling or a rear wall in a theatre. Likewise, everyone has experienced reverberation, a blurred prolongation of "after" sound, when talking or shouting in a hard tile walled swimming pool or in an empty hard plastered corridor or in a completely marbled lobby. Again, each has noticed the phenomena of resonance, the tendency of certain notes to be over-emphasized, in a powerfully resonant room, such as a small tiled bathroom or small marbled alcove.

It is the purpose of this chapter to discuss the more general acoustic phenomena in theatres, and give a brief picture of the general requirements of a theatre with ideal acoustics.

156. Review of the Nature of Sound.—Before discussing the action of sound in a room let us review the fundamentals of sound studied in the first chapter.

Sound is a form of wave motion, and as such has definite characteristics. Upon the *amplitude* of the wave motion or vibration depends the *loudness* of sound; upon the *frequency* of vibration (cycles) depends the *pitch* and *quality* of sound; and upon the relation existing between the direct and reflected waves depends the *intelligibility* of speech sounds, and the *clearness* of musical sounds.

Sound is a form of energy. We have learned that sound energy is produced by a body vibrating at audible frequencies feeding into a sound medium, through which gives the best illusion; that is, the apparent effect of speech is such that the actors in the picture actually seem to be speaking from the stage.

The vertical angles of the speakers which cover the orchestra seats are adjusted so that the line representing the upper limit of the 15 degree vertical angle strikes just above the last row of seats. If the theatre has a balcony which is not too close to the speakers, the orchestra and balcony may be covered with one pair of speakers in the same horizontal plane. In this case the vertical angle of the speakers is adjusted to give approximately equal intensity and intelligibility in both the orchestra and the balcony. When the balcony is too close to the speaker to be covered adequately in this manner, it is necessary to use separate speakers for orchestra and balcony. The speaker used to cover the orchestra is placed in the usual manner, below the center line of the screen. The balcony is covered by

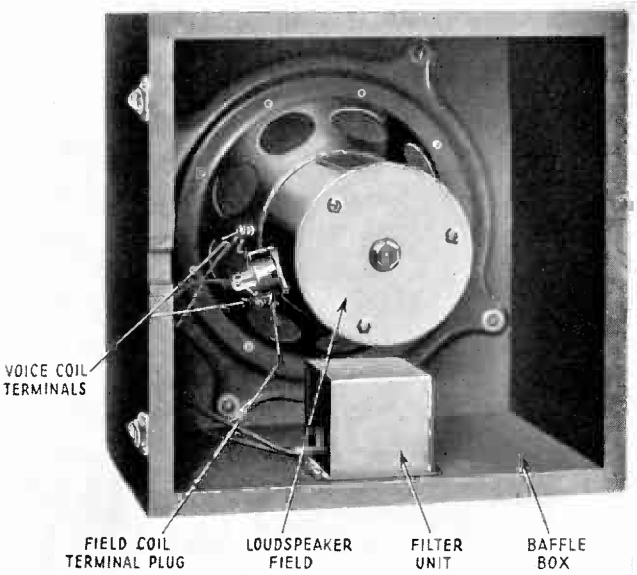


Figure 103—PL-22 loudspeaker unit in directional baffle

speakers placed just above the center of the screen, and adjusted vertically to properly cover the balcony without directing any sound into the orchestra. The number of speakers used depends upon the size of the balcony. Very high theatres which have a second balcony may require a third tier of speakers if the upper balcony is to be well covered. This is, however, an exceptional case.

The choice of location and number of loudspeakers to be used in a theatre depends upon so many variable factors that fixed rules for such choice cannot be laid down, but each theatre must be considered as an individual case and all variable factors must be considered separately and in combination.

For a further discussion of the problems involved in the location of loudspeakers, see Chapter XII.

These speakers are mounted in a rack directly behind the screen and as close to it as is possible without actually touching it. All parts of the rack surrounding the reproducer unit and the baffle itself are covered with sound absorbing material. This material is also used to cover the back of the screen, except where the speaker openings are located. This effectively deadens all sound which might escape back stage, reflect off hard walls and thus through the proscenium opening to the auditorium. This makes sure that the only outlet for the sound is through the portions of the porous screen adjacent to the mouths of the speakers.

Figure 103 shows the housing on the baffle in which the reproducer unit is mounted. The end of this box is removable to give access for servicing. A filter unit is placed here, and is connected across the voice coil. Its purpose is to eliminate

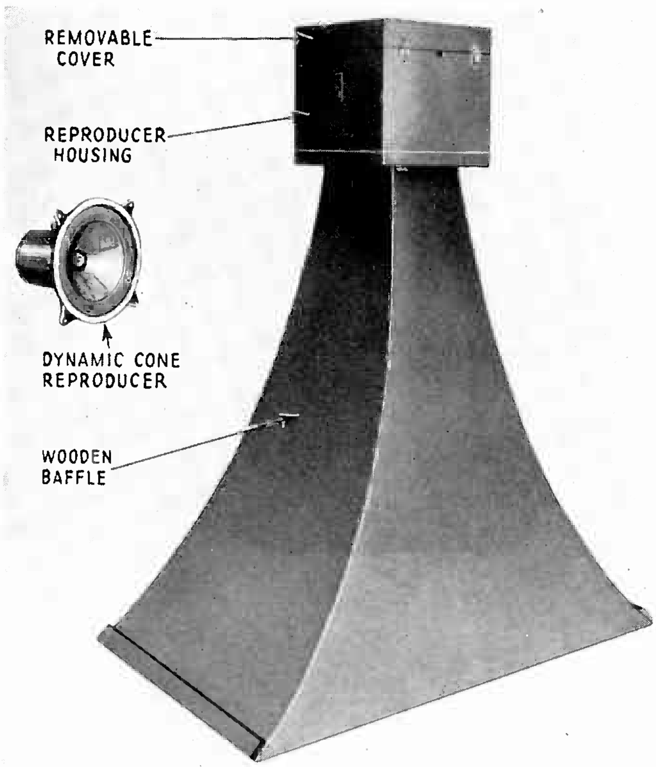


Figure 102—Six-foot directional baffle and reproducer unit used with it

undesirable frequencies introduced by needle scratch, etc. The Type PL-22 loudspeaker, used with the PG-13 equipments, is illustrated.

154. Location.—Anywhere from one to four speakers may be used in a theatre, and in some cases, more. The number and arrangement to be used in each particular case is worked out beforehand from the plans of the theatre in order to obtain the best distribution of sound. The speaker unit itself has an effective sound distribution over an area 30 degrees on each side of the speaker axis horizontally, and 15 degrees each side of the axis vertically. When one speaker is used it should be placed at the center, or slightly above the center, of the screen and close to it, as mentioned before. The location of the loudspeakers directly behind the screen

All monitors are mounted about six feet from the floor of the projection room and usually so they are best heard in the space between the projectors. The ideal location is on the end wall to the left of the projectionist when facing the front wall.

152. Phasing of Loudspeakers.—It has been mentioned that the coil moves in a certain direction when both the field current and voice coil current are in given directions. It can therefore be seen that when more than one stage speaker is used, they must be matched so that all field coils are polarized the same and all voice coils are "in phase." This means that their connections must be made so that at any instant the current in all the voice coils is in the same direction. If any field or voice coil connections were reversed, so that two speakers were not in phase, one cone would be moving in while the other moved out when reacting to one particular current impulse. This would produce interference at the line of intersection of the

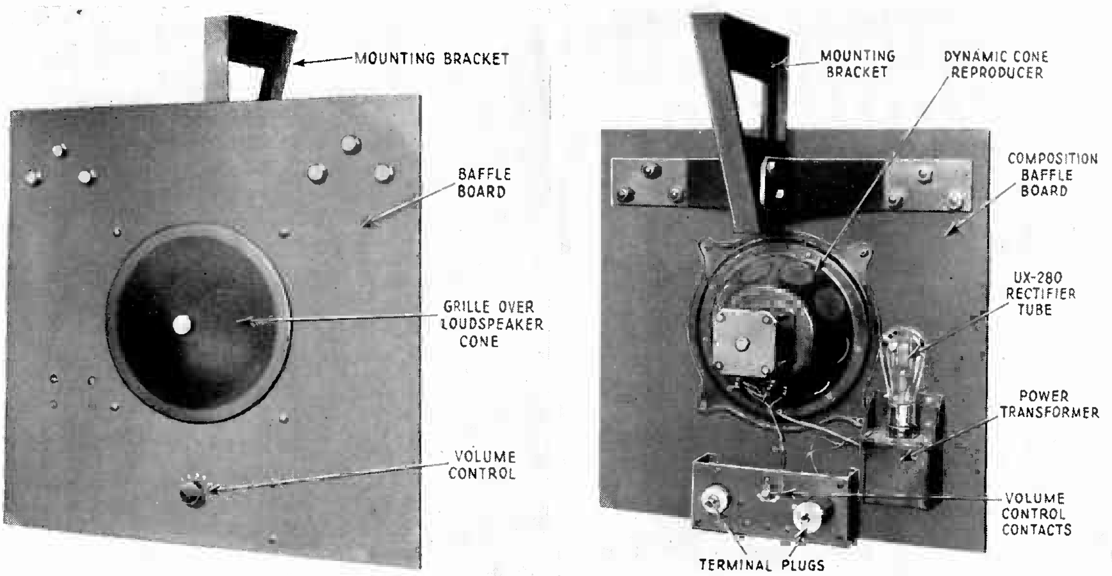


Figure 101—Type PL-7 projection room monitor loudspeaker using UX-280 rectifier tube

sound beams from the two speakers, and a "dead spot" would result. The speakers have been properly phased at the time of installation, and it is important that none of the connections are ever reversed.

(B) DIRECTIONAL BAFFLES

153. Construction.— All dynamic speakers, with the exception of projection booth monitors, are used in conjunction with a directional baffle, which is a large funnel-shaped wooden form. This unit is six feet long, constructed of soft pine one-quarter of an inch thick. The small end, where the dynamic speaker unit is fastened to it, is ten inches square, and this expands until the other end is about three by five feet. Figure 102 shows the type of construction and shape of this unit, as compared in size to the dynamic loudspeaker. Acoustic conditions in the average theatre are such that conditions are best met by the use of such a sound directing device.

150. Purpose of Monitor Loudspeakers.—A loudspeaker has been installed in each projection room for the purpose of affording the projectionist a means of following sound cues and to give some idea as to the continuity of the sound. It should be remembered, however, that due to the noise present in the projection room, no attempt can be made to judge quality or volume of stage reproduction by means of the monitor speaker. This should be left entirely to some one in the theatre auditorium and his signals to the projection room should be depended on in all cases.

151. Description of Monitor Loudspeakers.—Several types of dynamic monitor loudspeakers are in use. PG-1 to 8 equipments will be found to have one of two types. That illustrated in Figure 100 uses a Rectox unit mounted directly on the housing of the field coil. This coil is somewhat smaller than those used on other speakers but it is a 100 volt winding. This monitor may be used where a 110 volt

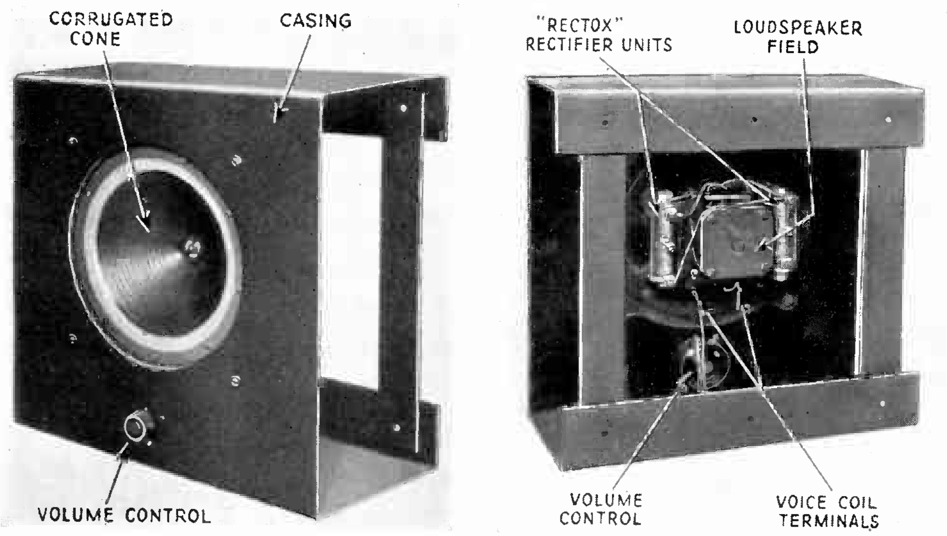


Figure 100—Projection room monitor loudspeaker using Rectox rectifier

AC supply is available. The AC is connected direct to the Rectox unit. The voice coil is connected to the amplifier through the monitor jack.

The other type of monitor (Type PL-7) used on these equipments is shown in Figure 101. This has a 100 volt field, which is supplied with direct current by means of an SPU (Type PK-6) using a UX-280 rectifier tube. Both of these monitors have a volume control consisting of a variable resistance in series with the voice coil. The monitor speakers (Type PL-10) for both the PG-10 and 13 equipments use a 12 volt field supplied in the PG-10 by the storage battery and in the PG-13 from the 12 volt generator. These units are slightly different in construction and appearance but in general are very similar to the type illustrated in Figure 101, except that no rectifier tube is used.

All monitors use a flat baffle board mounted as illustrated to separate the sound waves from the front and rear of the cone, and is essential for best reproduction. The baffle is made of an asbestos board composition in all types except the one illustrated in Figure 100, in which case the metal casing serves as a baffle.

representing the lines of force always flow from the same pole, but the direction of current in the voice coil changes constantly. Figure 98 (a) shows the current, and consequently the motion of the cone, in one direction, and (b) the other. This results in a rapid back and forth vibration of the voice coil, and the cone attached to it, in exact correspondence with the pulsations of the currents in the voice coil, which are the output of the amplifiers. The vibrations of the cone create sound waves which are a reproduction of the variations of electrical energy set up by the running of the disc or film recorded sound.

149. Stage Loudspeaker.—While all of the loudspeaker units used are of the dynamic type and vary but little from the construction shown in the diagram, Figure 97, there are slight differences of electrical and mechanical design.

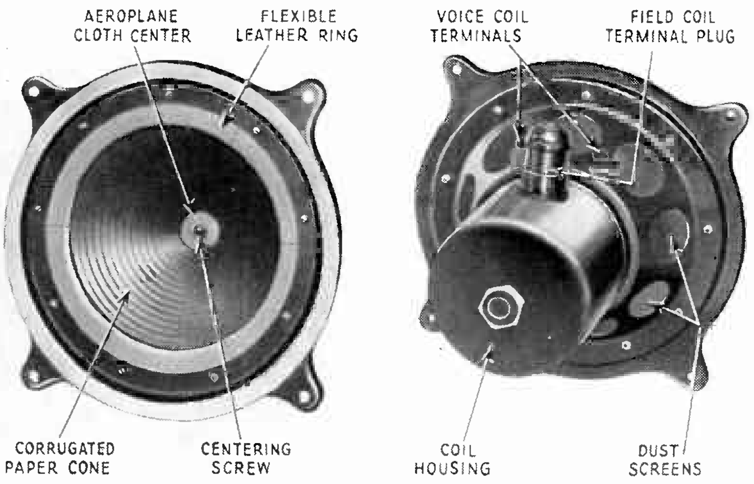


Figure 99—Type PL-11 dynamic loudspeaker

The stage loudspeaker unit used with the Types PG-1, 2, 3, 4, 6, 7, 8 and 10 Photophone equipments is the most widely used, and is illustrated in Figure 99 This receives its DC field coil supply from the Rectox rectifier unit when used with PG-3, 4, 6, 7, 8 and 10 equipments. This is a part of the power amplifier discussed in section 140. The field coil is nominally rated at 100 volts, although actually the voltage may be above or below that figure, depending on the source of current. The current used by this field coil is 0.1 ampere. In the PG-1 and 2 equipments the four-unit M-G set described in section 36 supplies field current to the loudspeakers.

The PG-13 equipment differs from all others in having a 12-volt field supply for the loudspeaker. This current is taken from the 12-volt generator, a part of its M-G set, each speaker field coil using 1 ampere. The speaker unit differs in construction and appearance but very little from the 100-volt field type just described.

free to move in one plane, along its axis, due to the flexibility of the aeroplane cloth and leather ring supporting the cone. This means that the voice coil may move in and out along the air gap.

The moving coil has been carefully centered in the air gap so that no part of it may touch either pole piece. This setting has been clamped by the centering screw. If the coil should touch either of the pole pieces at any time when the speaker is operating, the movement of the cone would be interrupted and distortion would result. Dirt in this recess would cause the same trouble. The speaker is protected with cloth screens to prevent dirt from entering, and these screens should not be removed. Front and rear views of this unit are shown in Figure 99.

The dynamic speaker used by RCA Photophone reproduces all frequencies in the audible range very faithfully. The tonal characteristics are extraordinarily

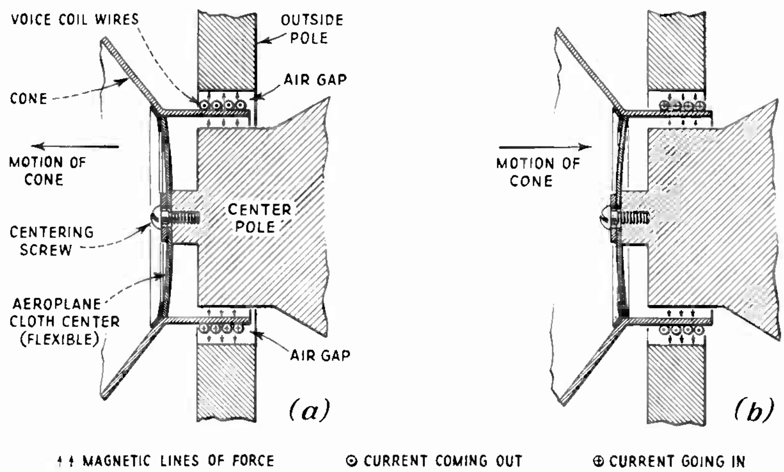


Figure 98—Operation of dynamic cone reproducer

natural. It is a superior mechanical achievement and a finely adjusted instrument, and while the construction is rugged and strong, it should be handled on the stage, where such handling is necessary, with as much care as possible.

148. Operation.— The dynamic loudspeaker operates on the same fundamental principles as those underlying the action of an electric motor. If a coil or winding carrying an electric current is placed in a magnetic field this coil has a tendency to move in a direction at right angles to lines of force in the field, the amount of movement being proportional to the number of lines of force and the amount of current flowing in the coil. The direction of movement depends upon the direction of flow of both the lines of force and the current in the coil. When alternating currents of various frequencies are sent into the voice coil of the dynamic reproducer the pulsations in one direction move the coil outward, and the pulsations in the other direction send the coil inward, since the lines of force from the magnet poles are always moving across the air gap in the same direction. This is true since the field is energized by direct current. Figure 98 shows how this action takes place. The arrows consist essentially of two main parts; an iron housing, or "pot," which is magnetized by a field winding, and a movable cone, on which is mounted a "voice coil." The magnetic field is produced by a powerful electro-magnet made up of a large coil of wire wound on an iron core and enclosed in the iron housing in such a way that the housing itself is a part of the electro-magnetic circuit. The purpose of this is to bring the two magnetic poles very close to each other. A study of Figure 97 will show how this is accomplished. The left end of the core is one pole, while the other pole is the left end of the iron housing surrounding the end of the core. Between them is located the voice coil, a sectional view of which is shown. By bringing the poles together in this manner the lines of force from one pole to the other, when the field coil is energized, are concentrated in a very small area.

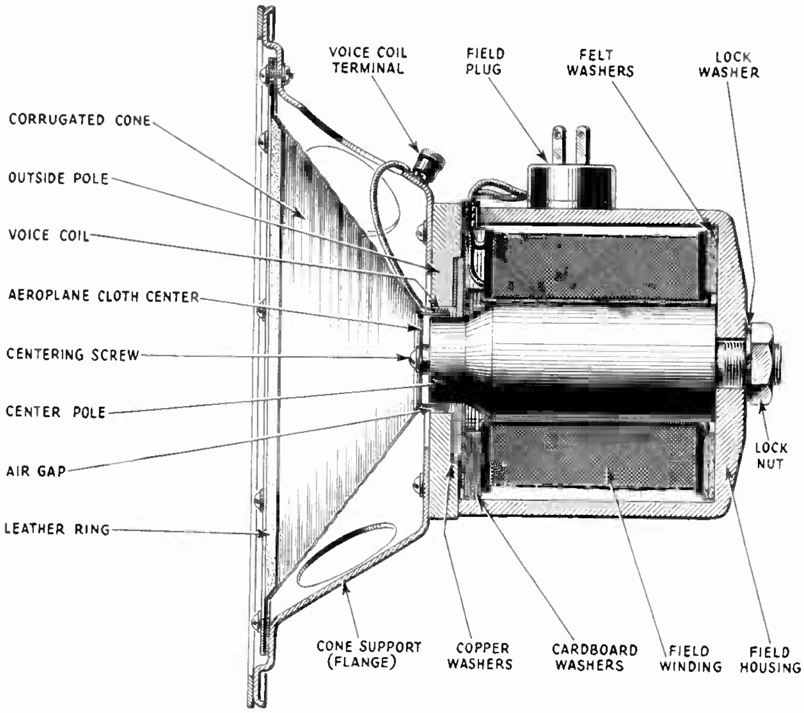


Figure 97—Construction of dynamic cone reproducer

The cone is about eight inches in diameter at its outside edge, or mouth, and is made of heavy paper impregnated with a moisture resisting compound. It is corrugated in concentric rings to improve the quality of reproduction. At the top, or apex, of the cone is placed a cylindrical fibre ring about an inch in diameter and one-quarter inch wide, cemented to the paper of the cone. On this is wound the "voice coil," a small coil of fine wire which is the end of the circuit carrying the amplifier output. This ring, with the coil on it, is centered in a position in the air gap between the two poles of the field. It is held in place by a screw passing through the center of a piece of "aeroplane cloth" stretched over the end of the fibre ring and at that end cemented to the cone. The monitor speaker, however, uses a thin piece of perforated fibre instead of aeroplane cloth. The outer edge of the cone is cemented to a very light, thin, flexible ring of leather, which in turn is secured to an iron ring flange rigidly supported on the field housing. When supported in this way the cone is

CHAPTER XI

LOUDSPEAKER EQUIPMENT

(A) LOUDSPEAKERS

146. General Requirements.—The last step in reproducing the recorded sound of a disc or film record on the Photophone reproducing equipments is by means of the loudspeaker. One or more of these units are mounted on the stage of the theatre, behind the picture screen, and are so located as to direct the sound produced by them through the screen to all parts of the theatre auditorium. Another loudspeaker, known as the monitor, is located in the projection room, and is operated whenever the equipment is being used, so that cues may be followed by the projectionist.

All Photophone reproducers use the same type of loudspeaker, both for stage units and for monitors in the projection rooms. Those on the stage are used in conjunction with a directional baffle, discussed later in this chapter.

A loudspeaker must be capable of setting up vibrations in the surrounding air which will range in frequency from about fifty cycles to six or seven thousand cycles per second if natural reproduction is to be obtained. The air can only be set into vibration if some solid object is moved in it, thus causing these movements to be transmitted to the air. Therefore, the function of a reproducer is to set a body which is in contact with the surrounding air into rapid vibration so that its vibrations correspond at all times to the frequency of the original sound, as reproduced electrically by the amplifier. Since it is impracticable to set a heavy object into vibration over the necessary wide range of frequencies, the vibrating element of the reproducer must be light in weight so that it follows faithfully all variations of the electrical impulses from the amplifier.

To produce the desired volume of sound, the vibrating mechanism must have a large surface, because the distance through which it moves is limited, and in addition, the driving mechanism for the reproducers must be capable of changing the electrical sound current into mechanical force without introducing an appreciable variation or distortion. That is, the driving force produced must be many times greater than the resisting forces tending to hold the movable parts in place.

The ideal mechanism for a faithful reproducer (loudspeaker) will consist of a very light weight piston which moves as a whole. The action of such a device is described in Chapter I. It is not practical to construct a mechanism as shown in Figure 1 which would be sufficiently light and stiff, but a cone shaped contrivance, as used in loudspeakers, answers the purpose admirably because it can be made both light and rigid.

147. Construction.— The RCA Photophone loudspeaker units are of the dynamic cone type, and are constructed to conform to the above general requirements. They

Power tubes and rectifier tubes become very hot when in operation and will burn the hand. Sudden cooling of the glass will cause strains and may crack it. Glass strain makes the glass extremely fragile and subject to breakage from a slight jar. Avoid placing hot tubes on a metallic or wet surface.

145. Dry Batteries.—The PG-3, 4, 6, 7, 8 and 10 equipments use dry batteries for plate ("B") supply of the voltage amplifiers. All equipments use dry batteries for the grid ("C") supply of the voltage amplifiers. The dry batteries need to be replaced periodically, their life depending mostly on time of actual use. This is usually taken care of by the RCA service man, but in some cases it may be necessary that the operator replace them. The plate supply requires "heavy duty" batteries, because the current drain is appreciable, and the use of small batteries is not economical. No current is drawn from the "C" batteries, so small sized batteries are satisfactory for this purpose. Their life when used in an amplifier is practically equal to their shelf life, but they should be replaced at least once a year, to avoid any possibility of noise being introduced into the reproduced sound from this source.

The condition of "B" batteries can most readily be told by the voltage. They should be replaced when the voltage has dropped 15 per cent of the original voltage. The voltage readings should be taken with the amplifier in operating condition with all the voltages on.

The polarizing voltage for the photo-cells is also supplied by dry batteries in all equipments except the Types PG-1, 2 and 13. Very little current is taken by the photocells, so that "light duty" dry "B" batteries are used for this purpose.

Old or poor grade dry batteries will cause a noise similar to static in radio. It is therefore advisable to use only good grade batteries and to replace them as soon as their voltage starts "dropping off." When the batteries get old, their voltage decreases rapidly, so that they may reach a condition which will cause noise in the loudspeakers during the running of a show if they are not replaced at the proper time.

special provision, in the form of metal covers for the tubes, is used to lessen this effect. These covers should be kept securely in place at all times.

Gassy tubes cannot always be detected by observation, but if a tube develops during operation a blue haze, both inside and outside of the plate, it is usually an indication of gas. Many good tubes will show a haze, which clears up in a few minutes, when first put into operation. If the gas condition is bad, arcing may occur between the grid and the plate when operating at high volume. This can be observed by looking down through the top of the tube. The effect of gas in a tube is to cause distortion and lessen the volume, and in bad cases noisy reproduction will be noticed.

Burned out filaments are easily detected by their failure to light. The effect of a burned out filament in a stage using two tubes, such as a push-pull stage, is to reduce the volume. If the tube is in a voltage amplifier stage it will only be necessary to increase the volume control setting to continue the operation, until such time as it is convenient to replace the tube. A burned out tube used in a stage employing only one tube will result in "no sound" and it must be replaced before the amplifier can be used.

Loose elements in vacuum tubes cause a grating or stuttering noise in the loud speakers. Although such defects may develop after the tube has been used for a considerable length of time, it usually shows up when the tube is first used or after a short time of operation. Tubes with defects of this kind can be readily located by tapping the top of the tube lightly, as the disturbance will be aggravated when the defective tube is tapped. Dirty socket contacts or dirty tube prongs will give the same indication, so that the condition of the socket and tube prongs should be checked before replacing a tube for this defect. The tube prongs may be cleaned with a fine sand paper. After sanding the prongs, any loose grains of sand should be removed by blowing, or by wiping the contacts with a clean piece of cloth.

The socket contacts may be cleaned by inserting a No. 6 machine screw into the socket holes. Care must be taken in scraping the contacts to avoid bending or breaking them. Caution—Do not clean the socket contacts with the voltage turned on.

Disarrangement of elements will not usually develop with the use of tubes, but may readily result from rough handling. Tubes should be handled carefully, especially when hot. A sharp blow may cause the electrodes to "short" (make electrical contact with each other). Disarrangement of elements may cause "no sound," low volume, noisy or distorted reproduction, depending on the nature of the disarrangement.

144. General Precautions in Replacing Tubes.—Do not replace tubes with the voltage on, because the removal of one tube may put excessive voltage on the other tubes of the amplifier, or the tubes may be damaged if the prongs were started into the wrong socket holes when replacing.

143. Replacement of Vacuum Tubes.—Vacuum tubes, like many other types of apparatus, do not have an indefinite life, but need to be replaced occasionally if the amplifier equipment is to give its best performance.

As a vacuum tube becomes old the emission of electrons becomes less until a condition is reached when the emission is so low that the tube will no longer give satisfactory results. The effect of "low emission," as this condition is called, is to cause a loss of volume and distortion of the reproduced sound. The distortion is most noticeable on low musical notes at high volume and the effect is indistinct reproduction.

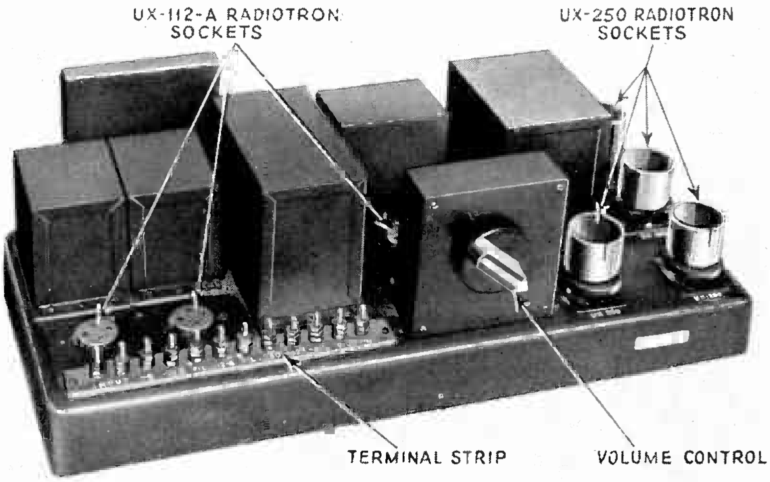


Figure 96—Type PA-41A amplifier unit used in the PG-13 equipments

The routine test of the tubes cannot be made by the projectionist as this requires a special test set and will be taken care of by the RCA service man, but in case of emergency the performance of the tubes may be checked by replacing them with tubes known to be in good condition.

Other types of defects (other than low emission) may develop with age or may be present after a short time of operation. Some of these are:—microphonic tubes, development of gas in the tube, burned out filaments, loose elements, and disarranged elements.

A microphonic tube is one that causes noises or howl in the speakers, due to mechanical vibration of the tube electrodes. All tubes are more or less microphonic, but some are worse than others. Certain stages of amplifiers are more susceptible to microphonic action than others and it is usually possible to arrange any set of tubes in an amplifier to eliminate a microphonic howl, but some tubes may be so highly susceptible to microphonic disturbance that they cannot be used any place in the amplifier and must be replaced. One stage of the voltage amplifiers used in the PG-3, 4, 6, 7, 8 and 10 equipments is so susceptible to this condition that tance coupled to a transformer which operates the next tube of the voltage amplifier, also a UX-112A. The output of this is impedance coupled to the transformer which actuates the grid of the third voltage amplifier tube (a UX-112A Radiotron). The output of the third UX-112A (output of voltage amplifier) is resistance coupled to a push-pull auto-transformer which operates four UX-250 Radiotrons in a parallel push-pull circuit. This is the power amplifier stage. The Type PA-41A amplifier is illustrated in Figure 96.

Volume control is provided by means of a control in the input circuit of the second UX-112A Radiotron.

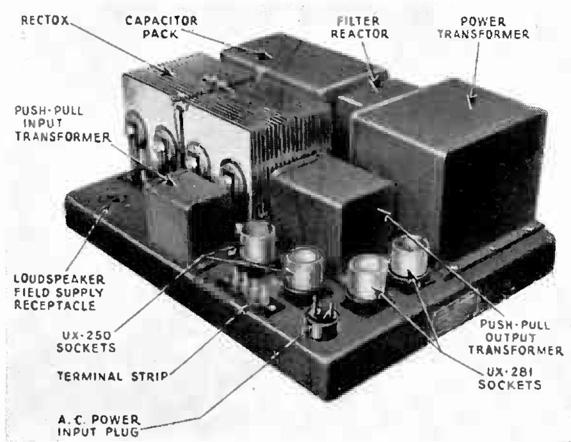


Figure 95—Type PK-1 power amplifier unit used in the PG-3, 4, 6, 7, 8 and 10 equipments

The filament and plate voltages for this amplifier (both voltage and power) are supplied from a motor-generator set. The three unit motor-generator set used with the Type PG-13 equipments is described in section 37. Grid voltages are obtained from small dry batteries ("C" batteries).

142. **Voltage and Power Amplifiers Used With Theatre Phonographs.**—The output of the pick-up of the theatre phonograph is connected, by means of a transformer, to a stage of push-pull amplification. The output of this stage is transformer coupled to a second stage of push-pull amplification. The output of the second stage is transformer coupled to the input of the power amplifier.

Both stages of the voltage amplifier (Type PA-11) use UX-226 Radiotrons, four of these tubes being used. The grid and plate voltages are supplied by a socket power unit (Type PK-4). This unit is similar to the rectifier described in section 134, except that it uses one UX-280 tube instead of two UX-281 tubes. A UX-280 tube has two plates and, therefore, is capable of full wave rectification, each plate being connected in the circuit as they would be if two tubes were used. The low voltage alternating current for lighting the filaments of the UX-226 Radiotrons is supplied by a low voltage winding on the rectifier power transformer. The power amplifier unit used is the Type PK-1 described in section 140.

140. **The Type PK-1 Power Amplifier Unit.**—This unit is used in the Types PG-3, 4, 6, 7, 8, and 10 equipments. The output of the voltage amplifier is transformer coupled to a pair of UX-250 power Radiotrons connected in a push-pull circuit, and the output of this amplifier is transformer coupled to the stage and monitor speakers.

All of the filament, plate, and grid voltages are supplied from a power supply unit which operates directly from a 110-volt 60-cycle supply, hence its designation of SPU, or socket power unit. In the power supply unit, two UX-281 Radiotrons are used to rectify the high alternating voltage from the power transformer. This rectified voltage supplies the high DC voltage for the plates and the lower DC

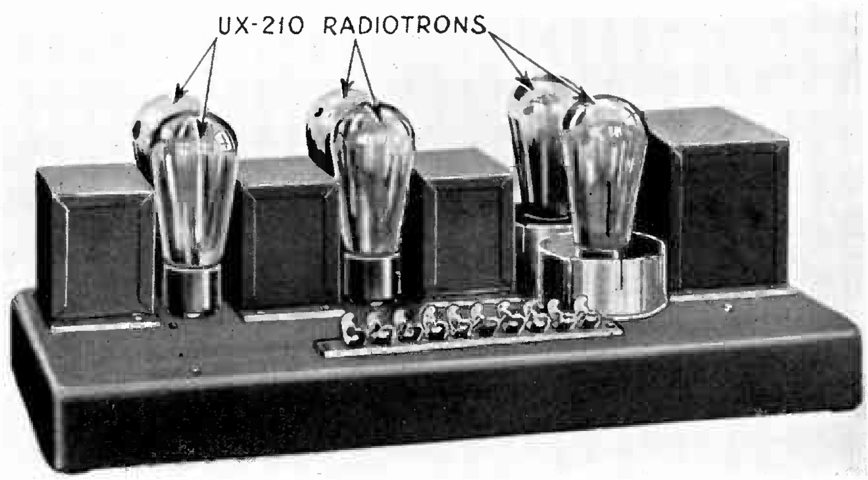


Figure 94—Type PA-12A voltage amplifier unit used in the PG-3, 4, 6, 7 and 8 equipments

voltage for the grids of the UX-250 Radiotrons. The power transformer also supplies low voltage AC for the filaments of the UX-250 and the UX-281 Radiotrons.

Incorporated in the same unit with the rectifier and amplifier is a Rectox rectifying unit which is used to supply the necessary DC power for the fields of the stage speakers. This amplifier unit, with its field power supply unit, is shown in Figure 95.

The PG-6 equipments utilize four power amplifier units of the type described above. The PG-3 and PG-7 each use two units, and the PG-4, PG-8 and PG-10 equipments use one power amplifier unit. Each power amplifier may be used to operate one, two, or four stage speakers.

141. **The Type PA-41A Amplifier Unit Used in the Type PG-13 Equipments.**—The voltage and power amplifiers of the PG-13 equipment are constructed as one unit. The voltage amplifier utilizes three UX-112A Radiotrons. The output of the projector circuits is coupled to the grid circuit of the first UX-112A of the voltage amplifier by means of an auto-transformer. The output of the first tube is resis-

to the power amplifier input transformer. In the PG-1 equipments the input to the power amplifier is connected to the grids of ten UV-845 Radiotrons in a parallel push-pull circuit. The power amplifier of the PG-2 is similar except that only four UV-845 Radiotrons are used.

These power amplifiers derive their filament, grid, and plate voltages from the four unit motor-generator set described in section 36.

138. **The Type PA-12A Voltage Amplifier Unit.**—This unit is used in the Types PG-3, 4, 6, 7 and 8 equipments. The output of the projector circuits is transformer

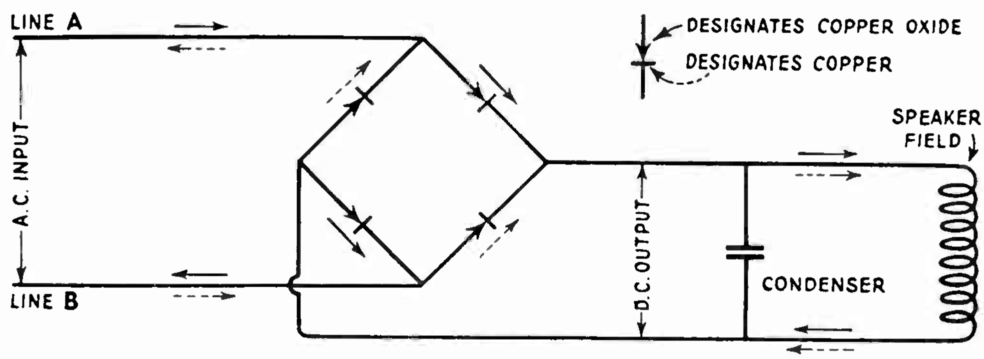


Figure 93—Schematic diagram showing the action of a Rectox unit.

coupled to the grids of two UX-210 Radiotrons connected in push-pull. The output of this stage is fed successively through two additional stages of transformer coupled push-pull amplification, each stage utilizing two UX-210 Radiotrons. Figure 94 shows the arrangement of the tubes. The two tubes on the right are in the input stage and are normally kept covered with metallic cans. The intermediate tubes and those on the left are respectively in the second and third stages of voltage amplification.

Volume control is effected by controlling the output of the second push-pull stage.

Filament current for the Radiotrons of this amplifier is supplied from Exide Type MVJ-13 storage batteries. See Chapter IV. The plate and grid voltages are supplied by standard "B" and "C" dry batteries.

139. **The Type PA-12B Voltage Amplifier Unit.**—This voltage amplifier unit, used in the PG-10 equipments, is similar in most respects to that described in the preceding section. It, also, utilizes three stages of transformer coupled push-pull amplification, but, in this case, the less powerful UX-112A Radiotrons are used, and the volume control is effected by controlling the input to the second push-pull stage.

The filament, grid and plate voltages are supplied in the same manner as described in the section above.

through the circuit when the AC "Line B" is positive and "Line A" is negative. In this way AC is fed into the unit, and DC is taken out of it.

The condenser across the DC output filters out the pulsations of the DC voltage. The speaker field winding, being highly inductive, aids in smoothing out the pulsations.

(B) RCA PHOTOPHONE AMPLIFIERS

136. Voltage Amplifiers Used in PG-1 and PG-2 Equipments.—In Types PG-1 and PG-2 equipments the output of the projector circuits (photo-cell or magnetic

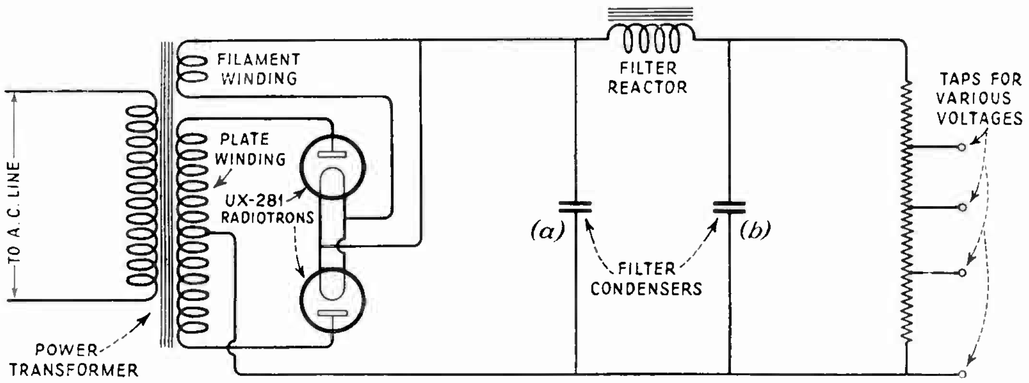


Figure 92—Schematic diagram of a typical vacuum tube rectifier circuit

pick-up) are transformer coupled to the grid of a UX-210 amplifier Radiotron. The plate circuit of this tube is transformer coupled to a UX-841 Radiotron, which has practically the same power capacity as the UX-210 but a much greater voltage amplifying ability. The characteristic of the tube which gives it its great voltage amplification also gives rise to another characteristic which renders it necessary to use either resistance or impedance coupling to the succeeding stage. In the voltage amplifier here described, the plate circuit of the UX-841 is resistance coupled into the grid circuit of another UX-210 Radiotron. The output of this tube is impedance coupled to the input transformer of the power amplifier.

Volume control is effected, in the case of the PG-1 voltage amplifier, by controlling the input to the UX-841 Radiotron. In the case of the PG-2 voltage amplifier, volume control is effected by controlling the input to the second UX-210 Radiotron. All plate and filament voltages are supplied from the four unit motor-generator set described in section 36. Small dry batteries provide the necessary grid voltage.

The amplifier panels are provided with meters for reading current through the various circuits and the voltages across them. The use of the meters will be taken up in a later chapter on the operation of the equipment.

137. Power Amplifiers Used in Type PG-1 and PG-2 Equipments.—As stated in the preceding section, the output of the voltage amplifier is impedance coupled plying current to the load when the rectified voltage is low. The purpose of the inductance is to smooth out the flow of current by preventing any rapid change of the current through it. A voltage divider resistor is sometimes used across the load. Its use permits the tapping off of various voltages for different purposes, but its presence is not required in the operation of the rectifier.

Another type of rectifier is used to supply DC power for the field of the loud speakers. This type of rectifier is called a "Rectox."

135. Rectox Rectifier.—The Rectox rectifier used on RCA Photophone equipments is shown in Figure 95. This rectifier is different from rectifiers previously

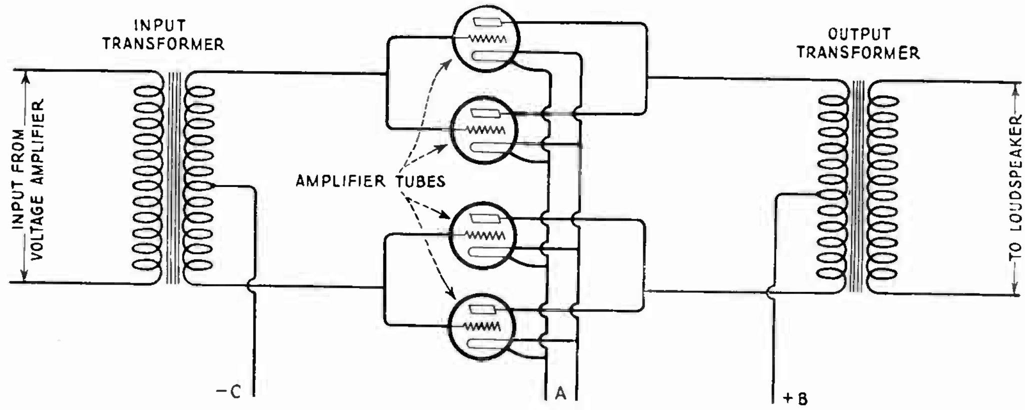


Figure 91—Schematic diagram showing a stage of push-pull parallel amplification

described in that no tubes are used. The Rectox unit consists of discs of copper coated on one side with copper oxide. Many such discs are clamped together with small lead discs or spacers between them, this spacer being located between the copper side of one disc and the copper oxide side of another. The purpose of the lead is to make a firm contact over the entire surface of each side of the disc. The softness of the lead allows it to "flow" slightly so that it makes contact with all points on the disc and prevents injury to the copper oxide coated surfaces. The large plates of metal shown in Figure 95 are for cooling, the large area which they expose to the air effectively dissipating the heat generated in the unit.

Four such units are connected together as shown in Figure 93. It depends for its operation on the fact that current will flow through such a "stack" of oxide coated copper discs in one direction only, that is, from the copper oxide to the copper. A study of the diagram shows just how this fact is utilized in changing AC to DC without the use of any moving parts or vacuum tubes. The arrows show the direction of the current through the circuit. When the AC voltage is in one direction the current flows through one half of the units, and when it is in the other direction the current flows through the other half. The full arrows show the direction of the current through the circuit when the AC "Line A" is positive and "Line B" is negative. The dotted arrows show the direction of the current but this is not always necessary as there are many instances where AC is satisfactory for this purpose.

The DC power for the plate and grid circuits of the tubes can be obtained from batteries, motor-generator sets, or rectifiers. All three of these sources are used in Photophone equipments, depending on the design of the equipments. Batteries used for plate supply are called "B" batteries. Batteries used to obtain a negative grid potential are called "C" batteries. Storage batteries are sometimes used to light the filaments of the tubes. These batteries are commonly called "A" batteries. See Figure 89.

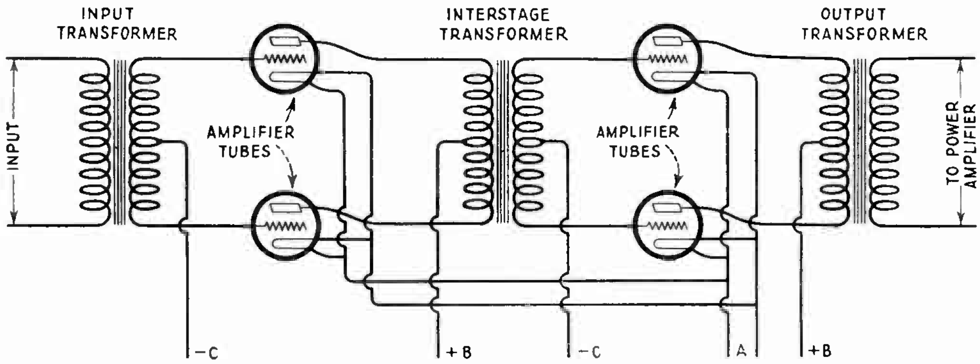


Figure 90—Schematic diagram showing two stages of push-pull amplification

As an outgrowth of the battery designations "A," "B" and "C," it is customary to call the source of DC power for the plate circuit of tubes, the "B" supply, and likewise the terms "A" and "C" supply are used to designate the voltage supply for filaments and grids respectively.

The various types of motor-generator sets used to supply power to operate the vacuum tube amplifiers are described in Chapter III.

134. Vacuum Tube Rectifiers.—Vacuum tube rectifiers used for "B" and "C" supply are often called SPU (Socket Power Units). These rectifiers are similar to the rectifiers described for battery chargers in Chapter V. Due to the high DC voltage required for the plate circuits of amplifiers, the Tungar bulbs are not suitable for "B" supply rectifiers. The UX-281 Radiotron described in Section 120 is used to rectify the AC to DC. Figure 92 is a schematic diagram of a typical vacuum tube rectifier using this type of tube. The power transformer shown in the diagram "steps-up" the line voltage to a fairly high value before it is rectified by the rectifying tubes. The rectifying action of these tubes is the same as that of the Tungars described in sections 56 and 57. The output of the rectifiers is a pulsating direct current, and is not satisfactory for plate or grid power supply and needs to be "filtered" (a process of removing the variations of voltage). The filtering is accomplished by using condensers and an inductance. The condensers serve as reservoirs for electricity, absorbing current when the voltage of the rectifier is high, and suprequirement to be met by all amplifier stages except that which supplies the speakers is that the voltage of the electrical pulsations must be "stepped up" sufficiently to operate the power amplifier tubes efficiently. The power amplifier tubes and their associated output circuits must be "heavy duty" in the sense that they must be capable of delivering sufficient power to operate the loud speakers connected to them at or near their maximum ability.

131. **Parallel Operation of Vacuum Tubes.**—Except in special cases, parallel operation of vacuum tubes is used only in stages of power amplification. It is used when one tube is not capable of supplying the necessary power for the operation of the loud speakers. Two tubes in parallel will deliver twice the power of one tube,

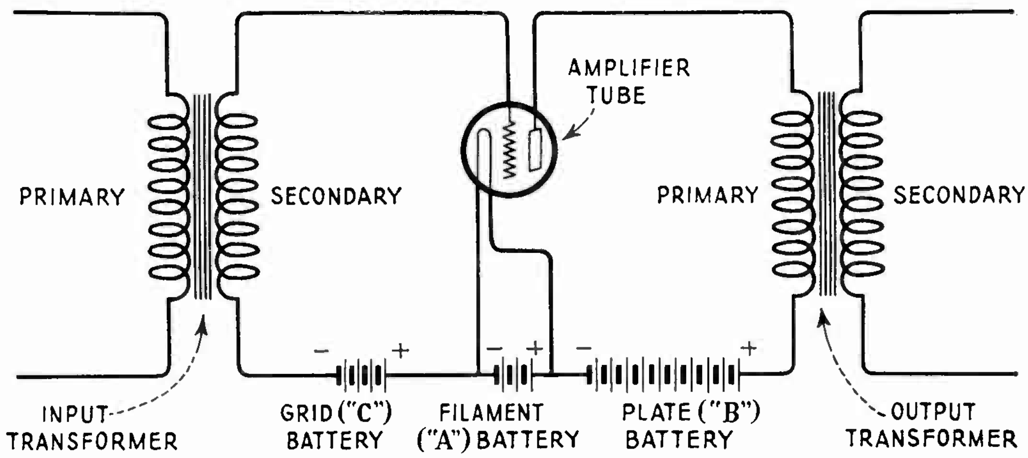


Figure 89—Transformer coupled amplifier circuit

and three tubes in parallel will deliver three times the power of one tube, etc. The grids of all tubes used in parallel are connected together, as are the plates.

132. **Push-Pull Amplification.**—Push-pull amplification requires two tubes of the same type in each stage. The grids of the tubes are not connected together, as is the case in parallel operation, but are connected to opposite ends of a mid-tapped transformer secondary. See Figure 90. The mid-tap is used as a common connection for making connection to the negative "bias" potential of the grids. As was stated before, the grid voltage varies due to the impressed alternating voltage, which causes the grid to be alternately more and less negative. In push-pull operation the grid of one tube is most negative when the grid of the other tube is least negative; therefore, as the plate current of one tube increases the plate current of the other tube decreases. To describe this action the word "push-pull" was coined. The action is similar to the operation of a hand-car, where one operator pushes on the cross bar as the other pulls, and vice-versa. A push-pull parallel stage is one in which two or more of push-pull circuits are used in parallel as shown in Figure 91.

133. **Power Supply for Vacuum Tube Amplifiers.**—Vacuum tubes require DC power for the plate and grid circuits. DC is also used for lighting the filaments,

This pulsating current as stated above is made of two components, one component being an alternating current.

The alternating component of the plate current induces a voltage in the secondary of the transformer due to transformer action. The voltage of the secondary is then impressed on the grid of the next tube.

Although transformer coupling, as in the case of impedance coupling, does not inherently permit equal amplification of all frequencies, practically, it accomplishes this within the limits required for natural reproduction of sound.

The advantage of transformer coupling is that it permits an increase of voltage between the vacuum tubes, because, as stated in section 19, a transformer can be

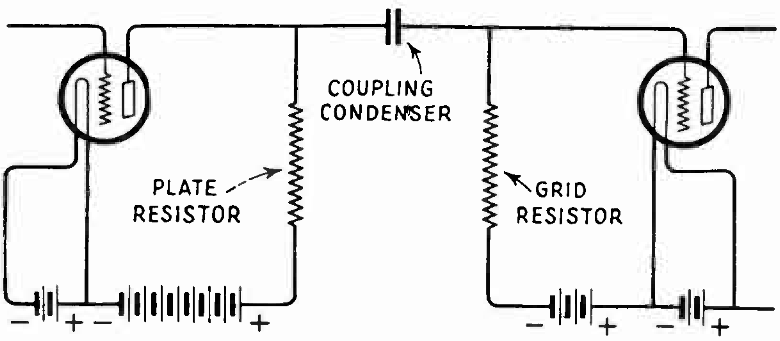


Figure 88—Resistance coupled amplifier circuit

wound to give a higher voltage on the secondary than that which is impressed on the primary. Therefore the amplification per stage can be greater than the amplification of the tube. Coupling transformers used in voltage amplifiers usually "step-up" the voltage three to four times.

129. Classification of Amplifier Circuits.—It is customary to think of the steps of amplification as "stages." Thus a stage of amplification consists of one or more vacuum tubes and associated circuits used in amplifying a voltage from one value to another. The beginning of one stage is usually considered to be the grid of one tube, and the end of the stage is at the grid of the next tube in the line of increasing voltage. Stages of amplification are classified according to type of circuit, such as "a stage of resistance coupling," "a stage of transformer coupling," etc., and according to the position of the stage in the amplifier such as "the input stage," "intermediate stage," and "output stage"; or in the classification of amplifier units according to another classification of circuits, such as "push-pull" stage, "stage of parallel operation," etc. The word "cascade" is used to describe the arrangement of stages in which each stage successively increases the voltage being amplified.

130. Voltage and Power Amplification. — In normal operation, practically no current flows in the grid circuit of a vacuum tube amplifier, therefore, the chief tube a pulsating direct current will flow in the plate circuit of the tube. This pulsating current can be considered as being made up of two distinct parts, one a steady direct current and the other an alternating current. The direct current part is known as the "DC component" and the alternating current part is known as the "AC component." The AC component is the part we are interested in because it represents the sound current and is the only part which is amplified in vacuum tubes. When the pulsating direct current flows in the resistor of the plate circuit of the first tube a pulsating voltage is produced across the resistor; this voltage like the current is made up of two parts or components. The AC component of the voltage causes alternating current to flow through the condenser

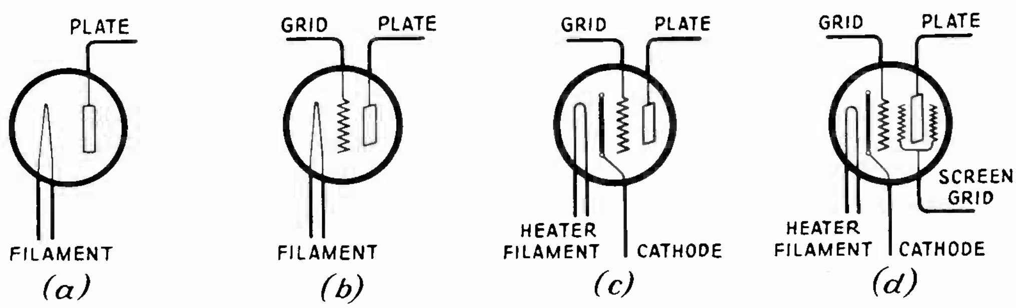


Figure 87—Symbolic diagrams of vacuum tubes

connecting the plate of the first tube to the grid of the second tube. This current flowing through the resistor in the grid circuit of the second tube produces an alternating voltage across it, which is impressed on the grid of the second tube.

The advantage of resistance coupling is that a wide range of frequencies can be amplified equally. The disadvantage is that a great deal of energy is used up in the resistor and a high direct voltage is required for the plate circuit. This type of coupling is particularly adaptable for use with tubes having a high amplification.

127. Impedance Coupled Amplifiers.—This type of coupling utilizes an inductive impedance instead of resistance in the plate circuit. Otherwise it is similar to resistance coupled circuits. Since the inductance offers a low resistance to direct current and a high impedance to alternating current, it will give an equal voltage amplification of the AC voltage while requiring a less DC voltage on the plate than is necessary in resistance coupled circuits. Its disadvantage is that equal amplification cannot be obtained over as wide a range of frequencies as is possible with resistance coupling.

128. Transformer Coupled Amplifiers.—Transformer coupling is the most common method of coupling vacuum tubes. Figure 89 shows a circuit using transformer coupling. The primary of a transformer is connected in the plate circuit between the plate and the plate voltage supply. If an alternating current is impressed on the grid of the tube, a pulsating current will flow in its plate circuit.

the heater type, and is different from the three electrode tube in that it has another grid called the screen grid, which very nearly surrounds the plate. The use of the screen grid permits a much greater amplification of an alternating voltage than is possible with a three electrode tube. In spite of its great amplification ability it has not come into general use as an audio frequency amplifier.

124. Vacuum Tube Symbols.—It is customary in circuit diagrams to use symbols to indicate tubes. Figure 87 shows four of the symbols ordinarily used to indicate the different types of tubes. The symbol for a rectifier tube of the UX-281

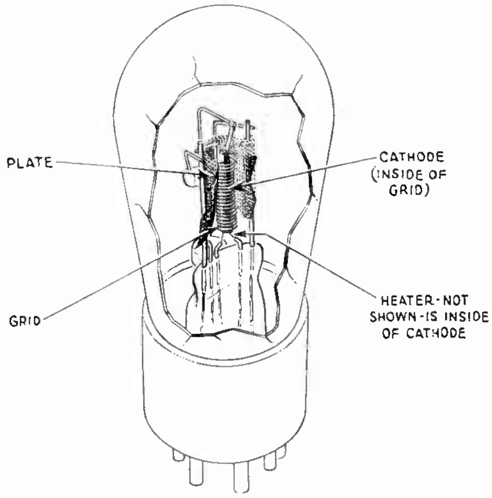


Figure 85—UY-227 Radiotron

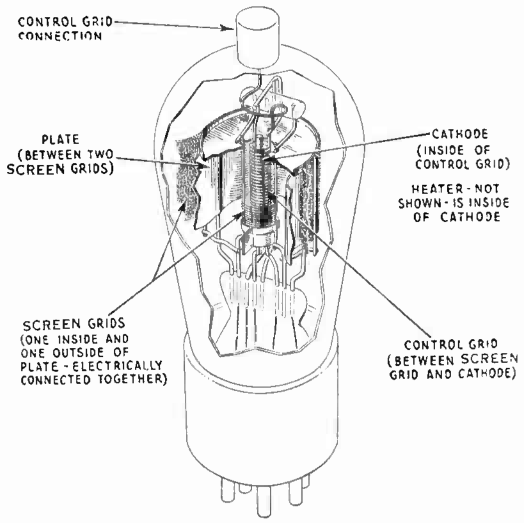


Figure 86—UY-224 Radiotron

type is shown in (a). The symbol for the ordinary type of three electrode tube, in which the filament emits electrons, is shown in (b). The symbol for the heater type three electrode tube is shown in (c), and (d) is used to indicate the heater type of four electrode (screen grid) tube. Other symbols are sometimes used, but except for slight variations, those shown here are the most common.

125. Vacuum Tube Amplifier Circuits. — Some means must be provided for coupling (making a connection between) vacuum tubes, if their amplifying property is to be utilized. There are three methods of coupling in general use, known as "resistance coupling," "impedance coupling," and "transformer coupling." These different methods are often used in combination so that a great variety of circuits are possible.

126. Resistance Coupling.—Figure 88 shows what is called a resistance coupled circuit. It consists of resistance in the plate circuit of the first tube and a resistor in the grid circuit of the second tube. The plate of the first tube is connected to the grid of the second tube by means of a condenser. The action of this circuit is as follows:—When an alternating voltage is impressed upon the grid of the first is used to heat the filament, and in special cases, when alternating current is used for the same purpose. But in audio frequency amplifiers where the sound currents are amplified many times after leaving the tube, an objectionable amount of hum would be produced in the loud speakers if this type of tube were used with its filament heated by an alternating current. There are two reasons for this. One is that the temperature of the filament (and therefore the electron emission) is not constant, but varies slightly with the current, which changes from zero to a maximum one hundred and twenty times per second (on sixty cycle systems). The other reason is that the alternating voltage across the filament introduces variations in the grid to filament voltage. Both of the above effects can be largely taken care of in the design of the tube and circuit in which it is used. The temperature changes are

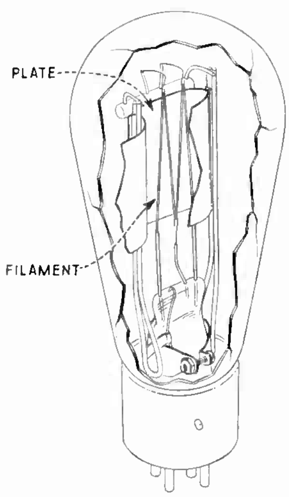


Figure 83—*UX*-281 *Radiotron*

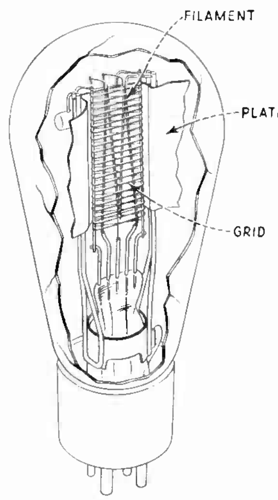


Figure 84—*UX*-250 *Radiotron*

reduced to a small value by making the filament large in cross-section, and most of the effect of the alternating filament voltage on the grid can be eliminated by connecting the grid circuit to the mid-tap of the filament transformer. However, these precautions are not sufficient in many cases and a tube of a different design is required. A type of tube, known as the heater type, fulfills the requirements adequately.

122. Heater Type Vacuum Tubes.—Figure 85 is an illustration of a UY-227 Radiotron, which is the most common of the heater type tubes. The cathode (emitting element) of these tubes is insulated from the filament or heating element. The cathode of this tube is maintained at a constant temperature and since it is insulated from the filament, it is not affected by the alternating voltage used to light the tube.

123. Screen Grid Vacuum Tubes.—Figure 86 is an illustration of the UY-224 Radiotron. This screen grid tube (sometimes called a four electrode tube) is of

When a three electrode tube is used as an amplifier, the grid is kept at a negative potential with respect to the filament. This negative grid potential is called the "grid bias" of the tube. If an alternating voltage is added to the steady negative potential of the grid, the relative negative potential between the grid and the filament will vary in accordance with the alternating voltage. The variations of the grid voltage will cause variations in the plate current. As the grid becomes more negative the plate current decreases and as the grid potential becomes less negative the plate current increases. If an electrical impedance, such as resistance, is placed in the plate circuit, between the plate and the battery, a voltage will be produced across it in proportion to the plate current. When an alternating current is impressed on the grid, a pulsating voltage will be produced across the resistor in the plate circuit. If the resistance in the plate circuit is sufficiently high, the pulsations of the voltage produced in the circuit, will be greater than the alternating voltage impressed on the grid. Therefore, three electrode vacuum tubes can be used to

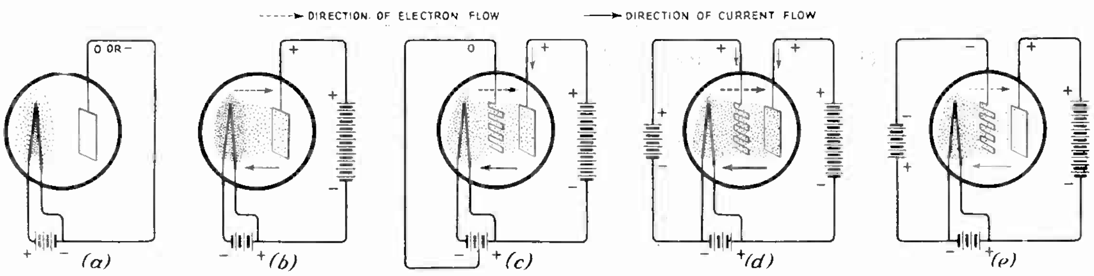


Figure 82—Electron action in vacuum tubes

amplify (increase) variations of voltage. Various types of tubes are used for various purposes. Tubes designed primarily to amplify alternating voltages, where the energy output is not important, are called "voltage amplifier tubes." Tubes designed primarily to give a large energy output are called "power amplifier tubes."

120. Description of the UX-281 Radiotron.—Figure 83 shows the construction of the UX-281 Radiotron, which is a two element tube and is made for use as a rectifier. The action of this type of rectifying tube is similar to that of the Tungar discussed in section 56, but the UX-281 tube is capable of rectifying higher voltages than the Tungar bulb and its output is more readily filtered to give a constant direct current.

121. Three Element Amplifier Tubes.—The UX-250 Radiotron is a three element amplifier tube of the power amplifier type. The construction of this tube is shown in Figure 84, and with the exception that it has another element, the grid, its construction is similar to that of the UX-281 Radiotron. Most of the small three element Radiotrons are similar in construction to the UX-250 Radiotron, the main difference being that of size. In this type of tube the electrons are emitted from the heated filament. Therefore the filament has two purposes, one is to generate heat and the other to emit electrons. This method is satisfactory when direct current

CHAPTER X

VACUUM TUBES AND VACUUM TUBE AMPLIFIERS

(A) VACUUM TUBES AND VACUUM TUBE CIRCUITS

119. **The Vacuum Tube As an Amplifier.**—The use of the vacuum tube as a rectifier was described in section 56. It will be remembered that the tubes discussed had but two elements, or electrodes, and that the current through the tube flowed in one direction only. The amplifier tube has three electrodes. The third electrode, called the grid, is used to control the flow of electrons through the tube. The action of this tube can best be described by going back to that which has already been discussed, namely, the emission of electrons from a heated conductor. In Figure 82 the direction of flow of the electrons is indicated by the arrows "dotted in," and the direction of current flow by the solidly drawn arrows. Figure 82(a) is an illustration of electrons thrown off by a heated filament. If no means is provided for drawing the emitted electrons away from the filament they will fall back as rapidly as they are emitted and the space surrounding the filament will be filled with a constant number of electrons. If a source of DC voltage is connected across the plate and filament, so that the plate is at a positive potential with respect to the filament, electrons would be attracted to the plate and a current would be set up as shown in (b) of Figure 82. The figure shows the current flowing from plate to filament in the tube, while the electrons flow from the filament to the plate. The reason for this was discussed in section 56. If either the temperature of the filament, or the potential on the plate was varied, the flow of current would vary, but it would always flow in the same direction. Variations of the electron flow can also be obtained by placing a third element, the grid, between plate and the filament. The grid is made of very fine wire suspended with relatively large distances between the successive turns as shown in Figures 84 and 85, and is mounted closer to the filament than to the plate. If the grid is connected to the filament battery at a point half way between the filament connections, as shown in (c) of Figure 82, so that the average difference of potential between the grid and filament is zero, no change in the plate current will be noticed. If the grid is connected at a positive potential with respect to the filament a much larger current would flow in the plate circuit, because the grid would aid the plate in drawing the electrons away from the filament. Since the grid is much closer to the filament than to the plate, its effect on the electron flow is relatively greater than that of the plate. Many of the electrons which are speeded up by the positive grid will pass between the grid wires and go to the plate as shown in Figure 82(d), but some of them will be collected by the grid and establish a current in the grid circuit. If the grid is kept at a negative potential with respect to the filament no current will flow in the grid circuit, and the plate current will be reduced due to action of the grid in forcing some of the electrons back to the filament, as shown in Figure 82(e).

The circuits affected by this relay are two in number. One set changes the sound output from one projector to the other, and on the PG-1, 2 and 10 equipments, does this by short circuiting the secondary of the projector which is not to be used, thus clearing the circuit on the projector from which the sound is to be used. The other circuit transfers the pilot lamp connections to indicate which projector is connected to the amplifier. The pilot lamps are located behind red bulls-eyes, on the front of the amplifier. In the case of the PG-13, however, the relay acts in a different manner, although the results are the same. The relay armature changes the traveling contact over and selects either one of the output circuits from the projectors, instead of shorting out the one not to be used. In this case the one not used merely has an open circuit.

The difference in operation between relay and potentiometer faders is the fact that fading by means of a relay gives an immediate change, as the relay operates instantaneously. Although a slow change is possible with the potentiometer type of fader, it is not usually desirable, and in fact is used very seldom. The fader arm is swung over rapidly, so that the effect is practically the same as with the relay type which operates instantaneously.

Should "cross-talk" or failure of sound suddenly develop when fading, it is usually due to a dirty relay contact. "Cross-talk" is characterized by the failure of either projector to "fade out" when the fader switch is thrown, with the result that both projectors are in the circuit. Clean the relay contacts by rubbing a card or paper up and down between the points. *Do not use emery or other abrasive.*

118. **Volume Controls.**—The volume controls used on Photophone equipment are of both the rheostat and potentiometer type of variable resistance, and are of the same construction as potentiometer faders described in section 115, and illustrated in Figure 79. Potentiometer connections are used on Types PG-1, 2, 10 and 13. These are used to vary the input to the grid circuit of the tubes controlled. Rheostat connections are used on Types PG-3, 4, 6, 7 and 8, and are in the plate circuit of the tubes controlled. The actual location of the volume controls on the apparatus is given in the table. On Types PG-6, 7 and 8, in which the volume controls are located on the amplifier, two controls are used, one for each of the two voltage amplifiers, and are located adjacent to each output fader.

Volume controls located on the input control panel (Types PG-3 and 4) are used without an output fader, the method of changing from one voltage amplifier to another, in the case of Type PG-3, being a switching arrangement consisting of a row of three tumbler switches. The Type PG-4 has but one voltage amplifier.

Volume controls, when mounted on the amplifier rack itself, are conveniently located three or four feet from the floor. In the case of the PG-13, the amplifier unit itself is mounted on the wall and is much smaller than any of the amplifiers used with other types of equipment. This means that the amplifier itself may be mounted in the position which would be occupied by the input control panel on types of equipment using them.

Output faders are similar in construction to volume controls, and are placed across the output of the voltage amplifier. They are used to give a smooth, noiseless change from one voltage amplifier to the other.

knob, with pointer, is mounted on the shaft after the plate has been placed. The moving contact arm, made of spring brass, is on the front of the Micarta plate, and, therefore, just inside the hole in the panel front. When the name plate is removed the contacts are exposed, which affords easy access for cleaning. The potentiometer faders are shown in Figures 74 and 79.

The potentiometer fader is in the "Off" position when the pointer is up. The extreme position to right or left is the point at which the fader should be when operating the equipment.

The volume controls for various types of equipments are constructed in the same manner, the difference being only in connections and location. The contacts

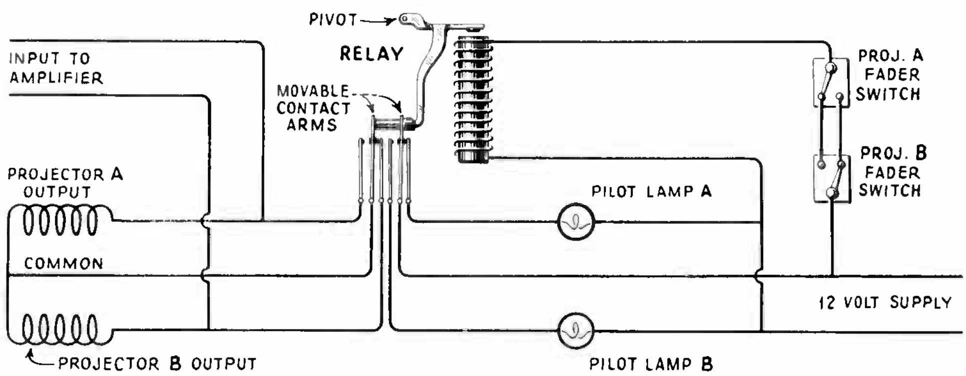


Figure 81—Connections of a relay fader—short-circuiting type

of all these units are cleaned by removing the knob and name plate, and applying a clean rag moistened with Carbona.

117. Construction and Operation of Relay Faders.—Types PG-1, 2, 10 and 13 do not use the above mentioned fading potentiometers, the sound change-over on these types being controlled by means of a relay. A relay is an electrical device by which circuits are controlled, or switched, by means of a control circuit actuating an electro-magnet. The circuit controlling the electro-magnet is entirely separate from the other circuits involved, the usual method of control being to close the operating circuit, which actuates the magnet. This magnet attracts an iron armature which mechanically makes or breaks one or more contacts. As applied to Photophone faders, this device consists of a straight electro-magnet operated by the twelve volt supply, from the storage batteries on PG-10 and from the low voltage generator on PG-1, 2 and 13 equipments. See Figure 81. This is controlled by two three-way switches, one mounted on each projector. The electro-magnet actuates an iron armature, which in turn moves two movable contacts. These are insulated from each other and from the armature by a small insulating block. These two movable contacts each normally make contact with one fixed contact arm, when the actuating circuit is open. When the magnet is energized by throwing either fader switch, the armature pushes the small insulating block, and the two movable contacts are moved over so as to make contact with two other fixed contacts.

for each projector. Types PG-3, 4, 6, 7 and 8 make use of a special type of potentiometer.

115. Connections of Potentiometer Fader.—When it is desired to vary the voltage of the input of an amplifier by means of a variable resistance so as to completely cut it off, or in this case, to completely "fade out" the sound, a potentiometer is better adapted than a rheostat. With connections made as shown in Figure 78, it is possible to change smoothly and rapidly from maximum output to zero. When the sliding contact arm is at the point of the potentiometer farthest from the one output connection a maximum voltage is obtained at the other output circuit. As this arm is moved towards the end of the potentiometer at which the other output connection is made, the voltage is reduced until it is finally brought to zero. At this point, the output circuit is short circuited due to the fact that the sliding arm of the contact is resting immediately above the other output connection.

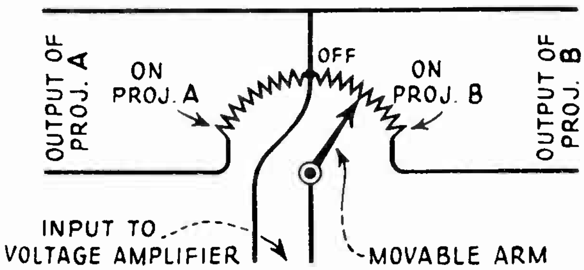


Figure 80—Connections of potentiometer fader

The fading potentiometer used on Photophone input control panels is, in effect, a double potentiometer, connected as illustrated in Figure 80. In other words, its effect is that of two potentiometers connected together, one being used to cut out the signals from one projector while the second picks up where the first left off, and increases the signals from the second projector as the movable arm moves through its travel. The output from the two projectors has a common connection made to the center of a group of resistor units. The other connections from the output of the two projectors are individually connected on opposite ends of this group of resistors. The input to the amplifier is taken off at the sliding contact and at the mid-connection of the potentiometer. Thus, when the resistor sliding contact is at the center of its swing, there will be no input to the amplifier, as the input circuit has been short-circuited. If it is on the extreme position to the right, the right-hand projector will be used and the other will be out of the circuit. When at the extreme left of the swing, it will cut out the right projector and the one on the left will be in the circuit.

116. Construction of Potentiometer Faders.—The potentiometer fader consists of a Micarta plate about four inches square, on which are mounted a semi-circular row of brass button contacts. For each one of these contacts there is one small resistor unit. These individual resistance units are connected in series, one end of each being connected to the contact, and the other end to the adjacent unit. The plate is mounted on the rear side of the input panel, with a center shaft projecting through. The shaft is mounted so as to be centered on a three-inch round hole in the front panel. A name plate covers this hole, and the control

To increase the current (i.e., cut out resistance) on rheostats mounted on input control panels, turn the knob to the left, or counter-clockwise, and turn the knob to the right, or clockwise, to do the same thing on rheostats mounted on projectors. The direction is indicated on the rheostat mounting. Most of the rheostats on input control panels, and all of those mounted on projectors, have a "dead point," or can be turned to an open circuit position. This makes the rheostat serve the purpose of a switch as well.

The exciter lamps should be run at nearly their maximum rating. As has been pointed out in section 84, there are two types in use, the 5 ampere and the 7½ ampere. Although the exciter lamp current can be varied at will, the lamps should not be used as volume controls. The current values should be equalized, and the only exception to this is the necessary balancing of sound-on-film output

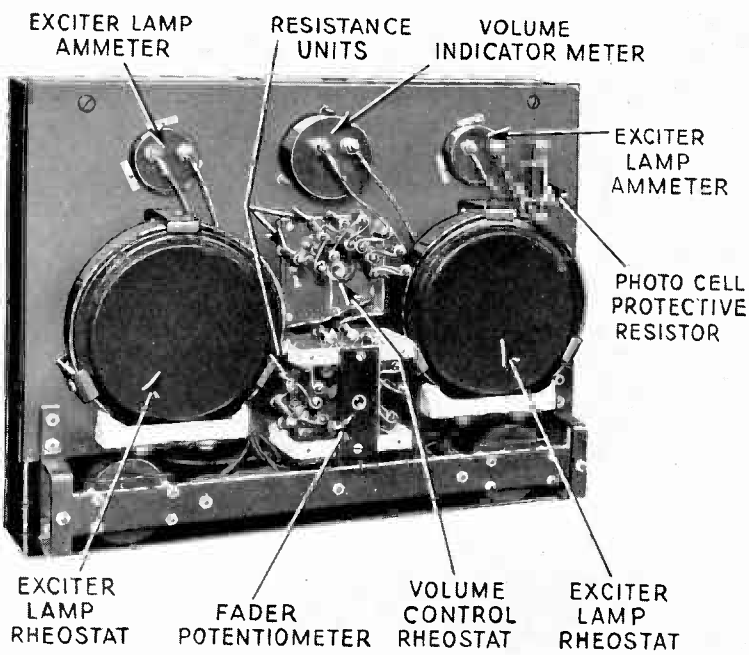


Figure 79—Rear view of Type PA-16A input control panel

in order to compensate for photo-electric cells of slightly different sensitivities. As it is impossible always to secure cells of exactly the same values, it is then very easy to decrease the exciter lamp current of the projector containing the more sensitive cell until the sound output is equal to that from the other projector. The adjustment necessary will be very slight. The current values which give equal output should then be remembered, and the same setting used every day. Both exciter lamps should always be turned on, except when running on disc.

114. Purpose of the Fader.—In order to change the sound output of the projectors from one to the other as each succeeding reel of film comes to an end, a change-over switching arrangement, known as a fader, is used. This change, in different types of Photophone equipment, is accomplished in two different ways. Types PG-1, 2, 10 and 13 use a relay actuated by either of two switches, one

Consider the application of the rheostat to the control of the exciter lamp. It is connected in series with the load, which in this case is the exciter lamp filament. That is, the connections are made to one end of the continuous length of resistance wire, and to the movable arm. Any change in setting of the rheostat knob makes a corresponding increase or decrease in the amount of resistance in series with the lamp. This causes an increase or decrease in the amount of current passing through the circuit, since increasing the resistance decreases the current, and vice-versa, when the line voltage remains the same. However, the voltage across the lamp itself is decreased when resistance is inserted, the resulting current in the circuit being indicated on the ammeter. Figures 77 and 78 show both rheostat and potentiometer connections of two similar circuits.

For very fine and smooth control of voltage over a wide range, a potentiometer is much better adapted than a rheostat. Potentiometers are similar in appearance

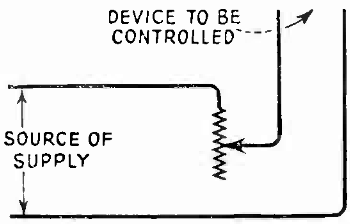


Figure 77—Rheostat connections

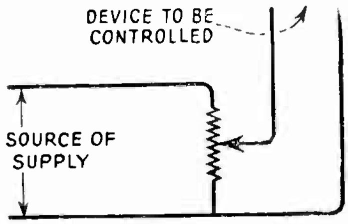


Figure 78—Potentiometer connections

and construction to rheostats, the difference being only in the connections. Section 14 mentioned the similarity in action between a potentiometer and a water pipe with valves tapping off water at different distances from the pump, or source of pressure. The potentiometers are made with resistance taps, so that their action, when connected in the circuit properly, as in Figure 78, is similar to the water system. With potentiometer connections it is possible to obtain any voltage from maximum to almost zero, because any "pressure" may be tapped off, while to obtain the same range of control with rheostat series connections, it would be necessary to use a much greater amount of resistance, thus making the device very bulky and cumbersome.

113. **Construction and Use of Exciter Lamp Rheostats.**—Three types of construction are employed on the various rheostats used on the controls under discussion, two of these being used for exciter lamp rheostats. Those mounted in input control panels (equipments in Classes II and III of the table) are made of resistance wire embedded in vitreous enamel, with tapped points consisting of brass button contacts projecting through the enamel in the form of a circle. This unit is made with the enamel baked on in a round pressed steel plate. A rotating contact arm, actuated by a handle, passes over the circular row of contact buttons. This entire unit is encased in a pressed steel housing, as shown in Figure 79.

The rheostat used for projector mounting (Class IV) consists of a short cylindrical form around which a length of resistance wire is wound. A rotating arm with a contact roller mounted on the end of it passes over this wire wound form, and is controlled by a handle, or knob. This whole unit, together with the ammeter, is mounted on the sound head.

Types PG-1 and 2 have all units—exciter lamp rheostats, ammeters and relays—mounted in the amplifier rack, the only control on the projector being the fader actuating switch.

One more switching device is used in connection with the above mentioned controls. This is the "Film-Disc" switch, illustrated in Figure 76, used on Types PG-1, 2, 3, 4, 6, 7 and 8. The function of this is merely to change one side of the output from the film or disc circuit, so that one or the other is always connected to the input of the amplifier. Since one side of the circuits from film and disc outputs is a common lead, only a single-pole switch is necessary. One such switch is provided for each projector. As mentioned before, this is mounted on the sound head on Types PG-10 and 13. All other equipments are provided with

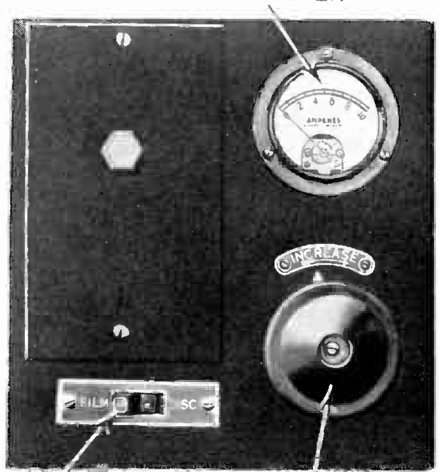


Figure 75—Photo-cell housing of sound heads used in PG-10 and 13 equipments

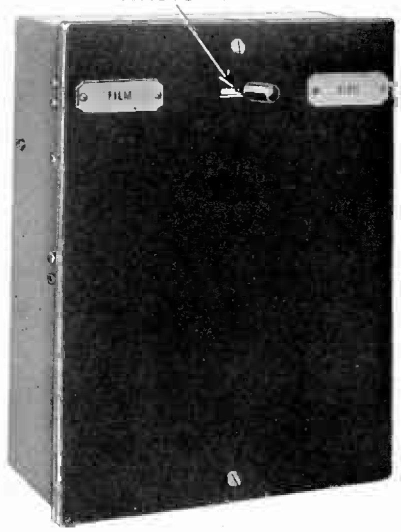


Figure 76—Film-Disc switch for wall mounting

a special switch box, which serves as a terminal box as well. It contains terminals for both sound head and turntable output circuits and necessary resistors and potentiometers for balancing film and disc output, so that each will be equal on the same projector. One form of this box is illustrated in the figure. This type is placed on the front wall of the projection room, near the operating side of the projector it controls. Another type is mounted on the sound head on top of the photo-cell housing. Both serve the same purpose and have similar types of switches. These are off in the center position. On Types PG-10 and 13 this switch is mounted in the photo-cell housing on the sound head, and is similar in purpose to the others, although different in appearance. It is a standard type of tumbler switch.

112. Rheostat and Potentiometer Connections.—Rheostats and potentiometers, as was mentioned in section 14, are nothing more than wires of relatively high resistance, much higher than those used ordinarily in electrical circuits, so made and connected in a circuit as to vary the amount of current passing through it.

These panels consist of an iron box 15 by 18 inches and 5 inches deep. This is mounted on the front wall of the projection room, between the projectors and about 4 feet from the floor. In it are mounted the following:—

(a) Two Exciter Lamp Rheostats and Ammeters, one for each projector.
(b) Potentiometer fader.
(c) Two five-prong input plug receptacles.
(d) Volume control. (On PG-3 and 4 equipments only.)
(e) Volume indicator milliammeter.

The two rheostats, labelled "Film Lamp-Projector A" and "Film Lamp-Projector B," control the current flowing through the exciter, or film, lamps. This current is indicated on the ammeter immediately above the rheostat knob.

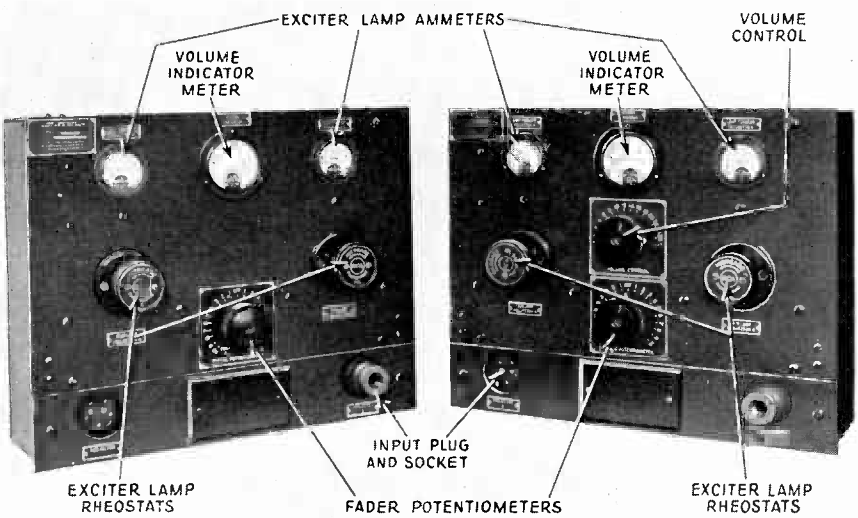


Figure 74—Input control panels
Left—Type PA-16B used in PG-6, 7 and 8 equipments
Right—Type PA-16A used in PG-3 and 4 equipments

The volume indicator is merely a delicate ammeter which moves back and forth as the sound input varies the amount of current flowing into the amplifier. This meter should never be allowed to read more than 0.85. This point is indicated on most equipments by a red line on the meter. It should never be necessary to run the equipment anywhere near that output.

The five-prong plugs which go into the receptacles on the input panel are removable. In this way it is made possible to use more than two projectors from the same input panel. In some cases where no more than two projectors will ever be used the input circuits have been wired permanently into the panel by means of conduit.

111. **Input Controls Mounted on Projectors.**—In types PG-10 and 13 equipments there is no input control panel as such, the various rheostats and meters being placed on other units of the equipment.

In Types PG-10 and 13 the exciter lamp rheostat and ammeter, as well as the "Film-Disc" switch, are mounted on the sound head as shown in Figure 75. The volume control is mounted on the amplifier and the fader is of the relay type. The relay is actuated by a switch, usually mounted on the projector under the lamp house or on the front wall of the booth.

CHAPTER IX

INPUT CONTROLS

109. **General Classification.**—Under this heading are included the various pieces of apparatus used for the purpose of controlling the circuits between projectors and amplifiers on Photophone equipments. These devices contain the necessary switches and controls for operating exciter lamps, for changing, or "fading," sound output from one projector to the other, and for controlling volume.

These controls come under three classifications; the control for the exciter lamp current, for the sound output circuits from projectors to amplifier, and for volume of output.

On some equipments all of these controls are grouped together in one unit, called the input control panel. On others the locations vary, so that the fader itself, for instance, may be in one place, and its actuating switch in another, so that even though the apparatus described in this chapter is closely related as to function, it is not unified as to location. However, since the subject of circuit controls is of prime importance during the running of the show, it is important that a complete description of the equipment used for this purpose, and its construction and operation, be grouped together and presented as in this chapter.

The following table shows just what devices are used, together with their location on different types of equipment:—

Type No. (New)	Type No. (Old)	Type of Fader	Location of			Class No.
			Fader Control	Volume Control	Exciter Lamp Rheostat	
PG 1 & 2	A&B (MG)	Relay	Projector	Amplifier	Amplifier	I
PG 3 & 4	C & D	Potentiometer	Input Control Panel	Input Control Panel	Input Control Panel	II
PG 6, 7, 8	B (SPU) C-1, D-1	Potentiometer	Input Control Panel	Amplifier	Input Control Panel	III
PG 10 & 13	F & G	Relay	Projector	Amplifier	Projector	IV

The Class numbers are used for reference purposes only. It will be seen that there are two quite different types of fader switches in use, whereas the other differences shown in the table are for the most part differences of location only. All these controls, with the exception of the relay type of fader, used on the PG-1, 2, 10 and 13, operate through the use of two special type of resistors, the rheostat and the potentiometer.

110. **Input Control Panels.**—A reference to the table will show that on PG-3 and 4 equipments all the controls mentioned are mounted on the input control panel. Types PG-6, 7 and 8 also use an input control panel, similar in all respects to the other, except that it has no volume control. Both types are illustrated in Figure 74. Figure 79 shows a rear view of one type.

properly inserted photo-cell will cause poor contact and will result in noisy reproduction. It may also cause a reduction in volume.

Keep the door of the photo-cell housing closed to exclude outside light. If outside light comes from an alternating current source, it may cause a very undesirable hum in the speaker.

Be sure that the door of the sound head is closed to exclude light. The reason for this is the same as above.

Always have an extra exciter lamp set up ready for an emergency on Types PS-14 and 16 sound heads, or have a complete set of good lamps set up and focused in the Types PS-1, 5, 6 and 8 sound heads.

Keep both exciter lamps lighted at all times during the show when running sound-on-film.

Be sure that the exciter lamps are properly adjusted vertically. Improperly adjusted exciter lamps will result in a decrease in volume and possible "fuzzy" sound reproduction.

Keep the light aperture in the sound gate clean, and be careful oil does not get into it. Oil in the light aperture may result in "fuzzy" sound from the speakers.

106. Oiling Points on the Motor Side of the Type PS-14 Sound Head (*Used with the Power's Projector with DC Motor Drive*).—No illustration is given. The method of oiling is essentially the same as that given for the sound head with Power's Projector with AC motor drive—the DC sound head being equipped with direct gear drive the same as the AC sound head. The DC motor bearings are packed in grease, and will be taken care of by the RCA Photophone representative.

107. Re-Winding Film and Painting Splices.—Particular care should be taken when handling sound film to keep it clean and prevent it from being scratched. When re-winding film see that the reels have no rough edges which might scratch the film. Line up the reels so as to prevent the film from rubbing against the sides of the reels. Scratched or dirty film will give poor sound reproduction.

When a break occurs in a sound film it should be patched in the usual manner, but the sound track requires special treatment. The sound track should be painted

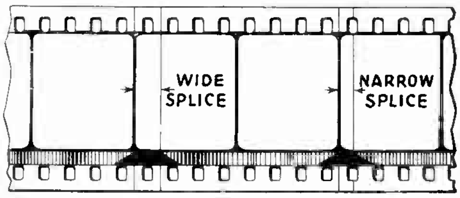


Figure 72—Methods of splicing variable density sound film

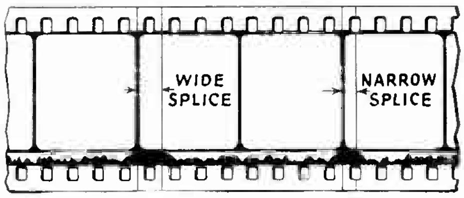


Figure 73—Methods of splicing variable area sound film

as shown in Figures 72 and 73. Paint a half moon over the sound track if the recording is variable area, and a blunt apex if the recording is variable density. Use Zapon concentrated Black Laquer No. 2002-2.

108. A Few Items to Remember when Using Sound-on-Film.—

See that the sound gate is closed while running the projector. An open sound gate will cause poor intelligibility of sound reproduction and may result in damage to the film.

Keep the film clean. Dirty sound film means a poor picture and poor sound.

Paint your film splices. Poor splices in sound film produce "plunks" in the loud speaker.

Keep the sound film clean. Emulsion and dirt on the sound gate will cause a "flutter" in the sound at the higher frequencies.

Keep the optical system clean. A dirty or oily lens in the optical system will produce "fuzzy" or "mushy" sound reproduction.

Do not permit dust and dirt to collect on the surfaces of the photo-cell or the lens ahead of it. Dirt on these surfaces will cause loss of volume.

See that the photo-cell is inserted all the way down in its socket. An im-

One in the shaft bearing of the impedance roller.

One in the shaft bearing of each sprocket.

Put one drop of a good grade of light machine oil in these holes twice every day. When oiling the pad rollers, the sound gate rollers and sound gate idler roller, dip the end of a tooth pick in a good grade of light machine oil, and apply the oil which adheres to the tooth pick to these oiling points once every day.

105. Oiling Points on the Motor Side of the Type PS-14 Sound Head (*Used with the Power's Projector With AC Motor Drive*).—The oiling points on the drive side

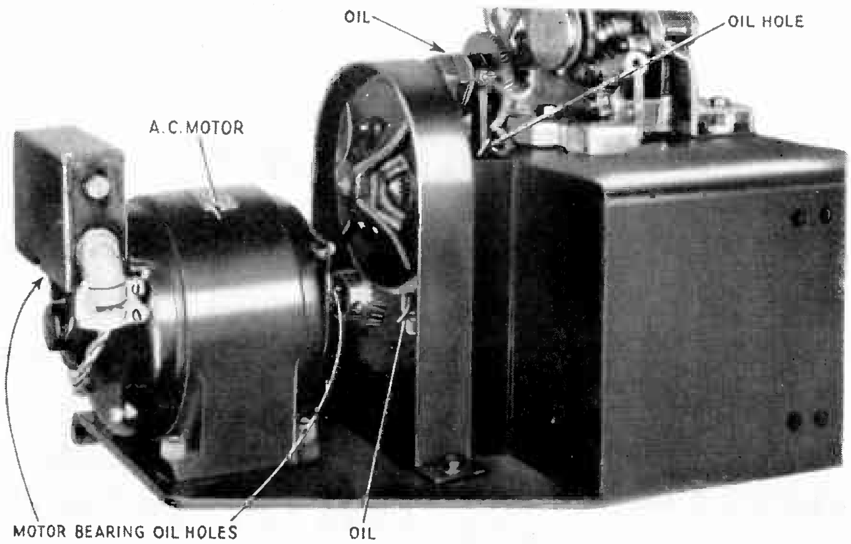


Figure 71—Oiling Points in drive side of Type PS-14 sound head (AC motor drive)

of the sound head as shown in Figure 71 are seven in number, and are located as follows:—

The oil hole in the bearing of the shaft gear assembly which drives the projection head.

One oil hole in the bearing of the main drive shaft of the sound head.

One oil hole in the bearing of the shaft which drives the turntable flexible drive shaft.

Two waste packed oil chambers on the motor (one at each end of the motor shaft).

Two oil holes, one on each end of the turntable flexible drive shaft (not shown).

Put one drop of a good grade of light machine oil in each of these holes twice every day. Keep the two waste packed oil chambers of the motor saturated with a good grade of light machine oil.

the chain guard removed. The oiling points on the drive side of the sound head are six in number and are situated as follows:——

Two oil pipes in the upper left-hand corner of the sound head near the photo-cell housing.

One oil cup on the projector and sound head main drive assembly.

The two holes in the turntable flexible drive shaft.

The projector and sound head drive chain.

Put one drop of a good grade of light machine oil in each oil pipe every two hours. Place a small quantity of cotton waste in the bottom of the oil cup and keep the packing saturated with a good grade of light machine oil. Keep the drive chain

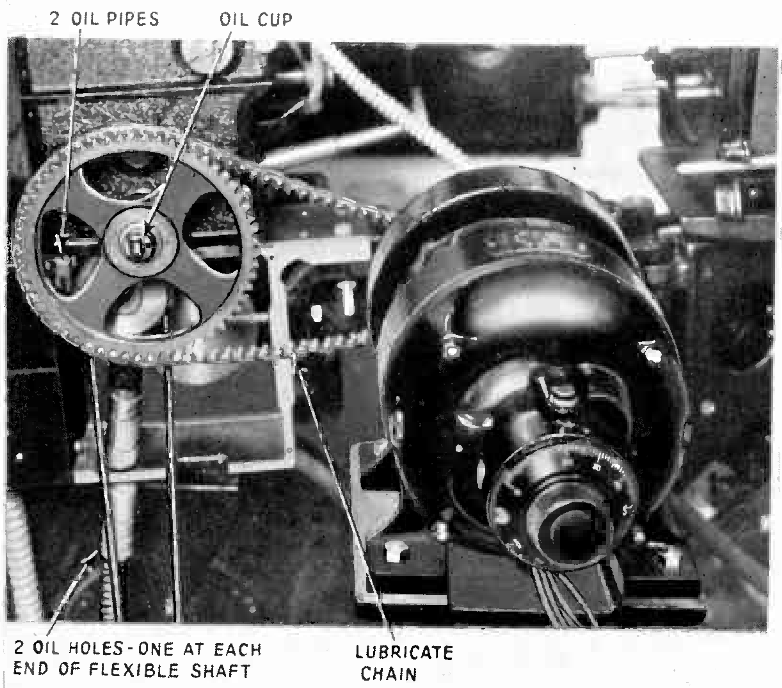


Figure 70—Oiling points in drive side of Type PS-16 sound head (DC motor drive)

clean and lubricate it as described in section 95. Apply about two drops of a good grade of light machine oil to the two holes in the flexible drive shaft twice every day. The DC motor bearings are packed in grease and will be taken care of by the RCA Photophone representative.

104. Oiling Points on the Film Side of the Type PS-14 Sound Head (*Used with the Power's Projector*).—All oiling points on the film side of the sound head are indicated by red circles, and are located as shown in Figure 68. These oiling points, aside from the oil holes in the pad rollers and the two rollers on the sound gate, are five in number and are situated as follows:——

One in the center plate of the sound head just above the sound gate.

One in the upper right-hand corner of the sound gate and drive assembly compartment adjacent to the sound gate.

One in the shaft bearing of the impedance roller.

One in the shaft bearing of each sprocket.

Put a good grade of light machine oil in each of these holes twice every day. When oiling the pad rollers and the sound gate rollers, dip the end of a tooth pick in a good grade of light machine oil and apply the oil which adheres to the tooth pick to these oiling points once each day.

102. **Oiling Points on the Motor Side of the Type PS-16 Sound Head** (*Used with the Simplex Projector and AC Motor Drive*).—The oiling points on the drive side of the sound head, as shown in Figure 69, are seven in number.

Two oil pipes in the upper left-hand corner of the sound head near the photocell housing.

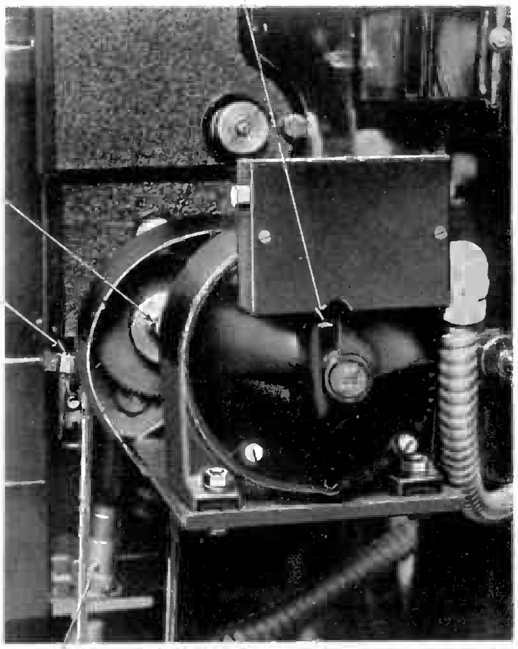


Figure 69—Oiling points in drive side of Type PS-16 sound head (AC motor drive)

One oil cup in the projector and sound head main drive assembly.

Two waste packed oil chambers on the motor (one at each end of the motor shaft).

Two oil holes, one on each end of the flexible drive shaft.

Put one drop of good grade of light machine oil in each oil pipe every two hours. Place a small quantity of cotton waste in the bottom of the oil cup and keep the packing saturated with a good grade of light machine oil. Keep the two waste packed oil chambers of the motor saturated with a good grade of light machine oil. Apply a good grade of light machine oil to the two oil holes in the flexible drive shaft twice every day.

103. **Oiling Points on the Motor Side of Type PS-16 Sound Head** (*Used with the Simplex Projector with DC Motor Drive*).—Figure 70 shows the equipment with

The drive motors used are described in sections 27 and 32.

100. Threading the PS-14 and PS-16 Sound Heads.— Figure 67 shows a PS-16 sound head properly threaded. After leaving the take-up sprocket of the projection head the film passes down through a slot in the frame into the sound head. From the slit it passes through the sound gate, under the idler roller at the bottom of the gate, then to the left over the impedance roller, and from the roller to the constant speed sprocket. There should be a two sprocket-hole loop between the projection

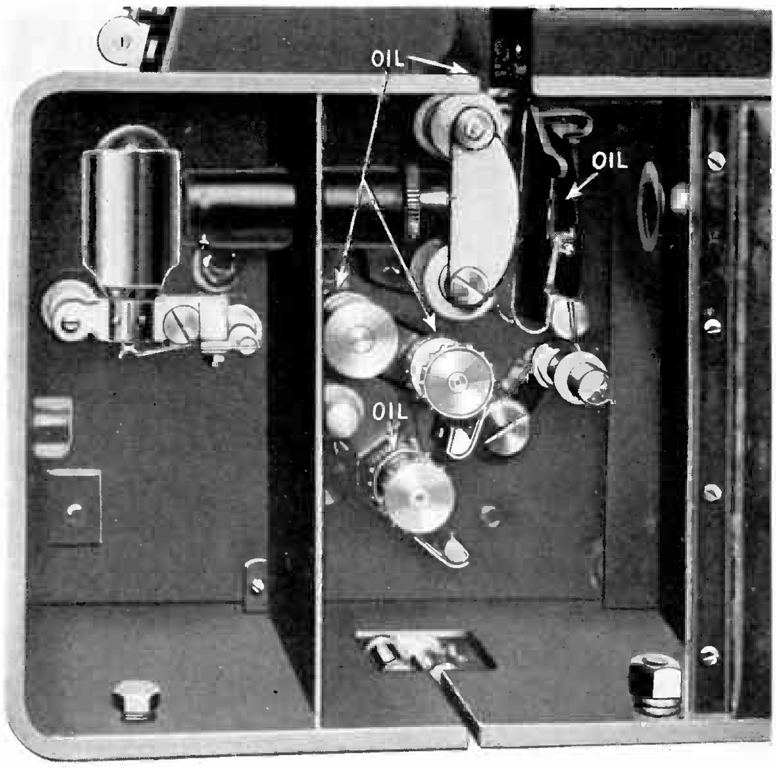


Figure 68—Film side of Type PS-14 sound head, showing oiling points and exciter lamp shield in place

head take-up sprocket and the sound gate. After leaving the constant speed sprocket the film passes to the left to the sound head take-up sprocket. There should be a four sprocket-hole loop between these two sprockets. From the take-up sprocket the film passes to the lower magazine. The purpose of the sound head take-up sprocket is to prevent any irregularity in the action of the take-up reel from being transmitted to the constant speed sprocket.

101. Oiling Points on the Film Side of the Type PS-16 Sound Head. (*Used with the Simplex Projector*).—The oiling points on the film side of this sound head are the same as those of the type PS-14 as shown in Figure 68 (with the exception of the hole in the center plate of the sound head above the sound gate), and are indicated by red circles. These oiling points, aside from the oil holes in the pad rollers and the two rollers on the sound gate, are four in number and are situated as follows:—

One in the upper right-hand corner of the sound gate and drive assembly compartment adjacent to the sound gate.

PS-16 is used on Simplex Projectors. Figure 65 shows the location of parts in both types. The mechanisms of these sound heads differ in many respects from those described above.

The sound gate, while similar in principle to the other gates, is considerably different in construction. This gate is shown in Figure 66. The movable part of the gate is pivoted and the tension springs, which are shaped like sled runners, are readily adjustable. These springs hold the film against the film guide plate.

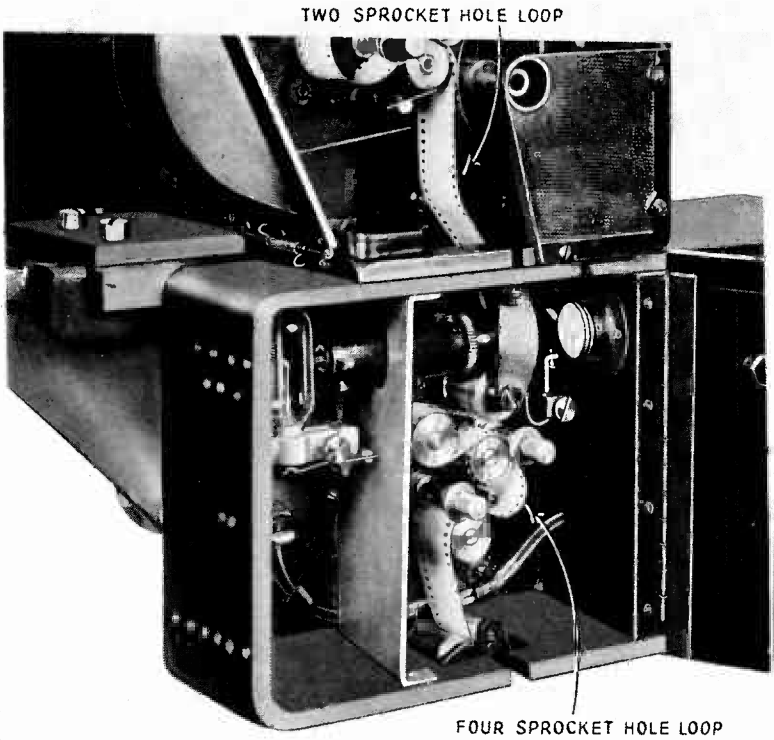


Figure 67—Film side of PS-16 sound head

The viscous damping device is not used in this type of sound head but a device known as an impedance roller is used instead. This consists of a flywheel attached to a roller about the size of a sprocket wheel. This device is driven by the film passing over it and is not connected to the drive mechanism in any other way. The film after leaving the sound gate passes over the roller to the constant speed sprocket. The inertia of the roller serves to take out "wows" or "ripples" by taking out any irregularities due to the motor drive and back lash of the gears, and causes the film to be pulled through the gate at an absolutely constant speed. The use of the impedance roller eliminates the necessity of a viscous damping device and makes for practically fool-proof operation.

The exciter lamp assembly differs from that used in the PS-1 sound head in that no turret is used. The lamp socket is mounted on a bracket, is guided into the proper place by long pins, and is held in place by friction so that the lamp and socket assembly can be removed and replaced quickly without affecting its adjustment. A spare socket is supplied with the equipment and a spare exciter lamp should be set up in the extra socket, focused, and set conveniently aside for emergency use.

The felt washer of the viscous damping device should be kept lubricated as described in section 92.

97. Types PS-5, PS-6, and PS-8 Sound Heads.—These sound heads are used with the Type PG-10 equipment. The PS-5 is used on Powers projectors, the PS-6 is used on Motiograph projectors, and the PS-8 is used on Simplex projectors. The film side of the PS-5 is shown in Figure 64. The film side of these sound heads are very similar to the PS-1 sound head. The main points of difference are as follows:—these sound heads have no illuminator in the optical system, and the sound gate is different in that the light aperture is large and will not clog. The adjustments described in sections 89, 90 and 92 for the PS-1 also hold for the PS-5, 6, and 8 sound heads.

98. Lubrication of the PS-5, PS-6, and PS-8 Sound Heads.—The lubrication of the film side of these sound heads is the same as the PS-1.

The lubrication of the drive side of the PS-8 is the same as described for the PS-1 sound head.

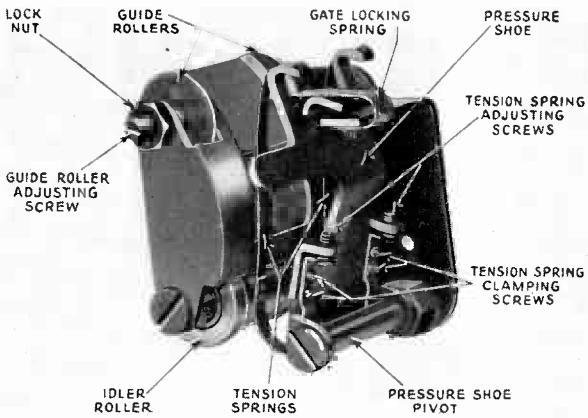


Figure 66—Sound gate used in Types PS-14 and 16 sound heads

The lubrication points of the drive side of the PS-6 sound head are as follows:—one oil hole and one self-closing oil cup on the shaft of the chain driven sprocket, one oil hole on the gear shaft directly below the chain driven sprocket wheel, one oil cup on the gear shaft below and to right of the chain driven sprocket, two oil holes, one near each end of the turntable flexible drive shaft. These points should be oiled once a day with a good grade of light machine oil.

The lubrication points of the drive side of the PS-5 sound head are as follows:—An oil cup on the gear shaft directly above the chain driven sprocket, two oil holes on the shaft of the chain driven sprocket, and two oil holes, one near each end of the flexible drive shaft. These points should be oiled once a day with a good grade of light machine oil.

The PS-5, PS-6, and PS-8 sound heads have a viscous damping device, the lubrication of which is described in section 92.

The chains should be lubricated once a week as described in section 95.

The oiling of the projector drive motors is described in section 31.

99. Types PS-14 and PS-16 Sound Heads.—The PS-14 and PS-16 sound heads are used with PG-13 equipments. The PS-14 is used on Powers projectors, and the turn when the film is passing through. It should just move when a patch passes through.

95. Chain Drive.—The PS-1 sound head is driven through a Morse silent chain. When the chain is in good operating condition it will run silently without slipping. Regular lubrication (at least once a week) with a heavy engine oil (such as Mobile B) or cup grease will help materially to keep the chain in good condition. Should it be necessary to remove the chain for any reason, make sure that it is replaced correctly. Be sure that the arrows stamped on the side of the links point in the direction the chain is to run. Do not use for lubrication any grease containing graphite or other solid matter.

96. Lubrication of the Type PS-1 Sound Head.—Figure 64 shows the oiling points on the operating side of the PS-1 sound head. Four oil ducts, fed by a trough located near the top of the sound gate, supply oil to the constant speed sprocket and

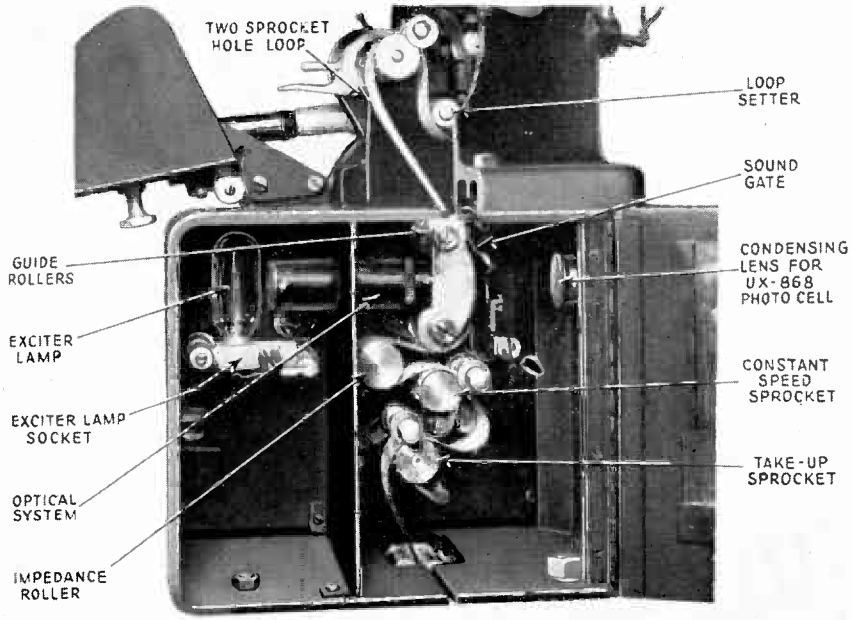


Figure 65—Film side of Type PS-14 sound head (Type PS-16 is similar)

take-up sprocket, and also oil two bearings of the sound head drive mechanism. The sound gate guide rollers and the sprocket pad rollers should be oiled once a day as follows:—Dip the end of a tooth pick in a good grade of light machine oil and apply the oil which adheres to the tooth pick to the bearings of the guide rollers, and to the oil holes in the pad rollers.

The drive side of the PS-1 sound head should be lubricated as follows:—The oil cup on the shaft of the chain drive sprocket wheel should be packed with cotton waste, and the waste should be kept saturated with a good grade of light machine oil. An oil pipe, terminating a little to the right of the sprocket wheel referred to above, should receive one drop of a good grade of light machine oil once for every two hours the machine is run. See Figure 63.

Different types of projector drive motors are used with this sound head, the lubrication of which was covered in Chapter III.

The drive chain should be lubricated once a week as described in section 95.

Do not permit the screw to turn as the lock nut is tightened. Make a final test when this is tight. If the damping device does not act in the manner described, notify your service man. Check each damping device twice weekly. The purpose of the lower take-up sprocket is to prevent the flutter that a poor take-up, or a bent take-up reel would introduce by jerking the film engaged on the constant speed drive sprocket.

The contact surface of the felt washer should be kept lubricated with Alemite grease. This is accomplished by keeping the grease cup shown in Figure 63 filled with this grease and giving the cup a half turn once for every three hours the projector is run. Do this while the machine is idle, then start it up and let it "turn over" a few minutes before threading up. Turning the grease cup while the projector is in motion may impart a "wow" for several seconds.

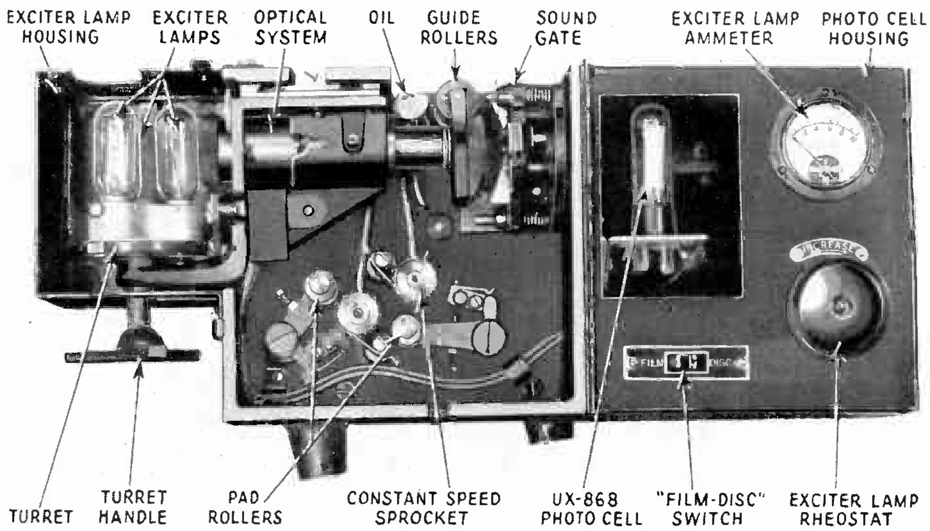


Figure 64—Film side of Type PS-8 sound head (Types PS-5 and 6 are similar)

93. **Threading the Type PS-1 Sound Head.**—The Type PS-1 sound heads are threaded as shown in Figure 60. After leaving the lower take-up sprocket of the projector head and passing into the sound head, the film passes between the sound gate guide rollers and then through the sound gate. The film then passes over the constant speed sprocket. The loop between the lower take-up in the projector head (through the gate) and the constant speed sprocket should be about two sprocket holes. After passing the constant speed sprocket the film passes from the right under the sprocket to the lower take-up sprocket. A loop of four sprocket holes should be left between the constant speed sprocket and the take-up sprocket. The film, after leaving the constant speed sprocket and passing under the take-up sprocket, goes direct to the lower magazine. After closing the sound gate take out any slack between the sound gate and the constant speed sprocket by drawing the film up through the gate.

94. **Adjustment of the Pad Rollers.**—The pad rollers on both sound head sprockets should be adjusted in the same manner as the pad rollers on the Simplex heads; that is, set up so that two thicknesses of film will just pass between the sprocket and the roller. Under no condition should the fibre roller of the constant speed sprocket

92. Viscous Damping Device Used in the PS-1 Sound Heads.—The sprocket which pulls the film through the sound gate is called the constant speed sprocket. It is driven through a viscous damping device similar to that described in Section 71 for turntable drive. The purpose of this device is the same as when it is used in the turntable drive mechanism; namely, to remove any unevenness of drive which might be imparted by the motor or due to gear back-lash.

The adjustment of the device is also similar to that described in Section 71 and consists of adjusting the pressure of a felt washer bearing against the flywheel. The location of the adjusting screw and lock nut on the drive side of the sound head is shown in Figure 63.

The damping adjustment is checked in the following manner:—Thread the projector in the usual manner. Start the machine and when it is up to speed, press the thumb against the constant speed sprocket. Use almost as much pressure as has

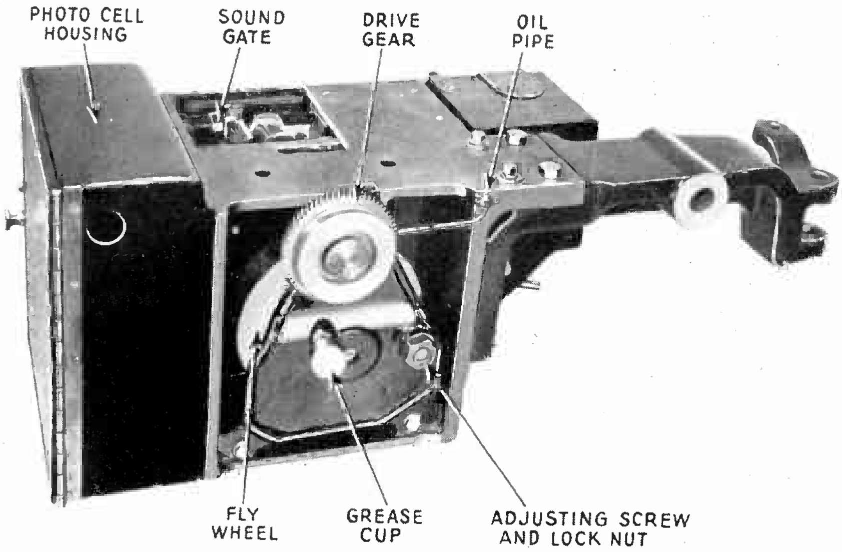


Figure 63—Drive side of Type PS-1 sound head (Types PS-5, 6 and 8 are similar)

to be exerted in opening the sound gate. When pressure is applied, the four sprocket hole loop between the constant speed sprocket and the lower take-up sprocket immediately becomes smaller. When the pressure is suddenly removed, the loop becomes larger and should oscillate several times, each succeeding oscillation becoming smaller until the loop resumes its original position and remains constant in size. If the damping mechanism is correctly adjusted the loop will make three distinct oscillations, regain its normal size and remain constant thereafter. If the loop does not oscillate three times, the adjustment is too tight, or if it oscillates more than three times the adjustment is too loose. Correct for either condition by loosening the lock-nut on the adjustment screw and turning the screw clockwise to tighten and counter-clockwise to loosen. This adjustment screw is on the drive side of the sound head. Give the screw only a small fraction of a turn at a time and check the adjustment as described. It may be necessary to repeat the operation two or three times before the correct adjustment is obtained. When correct, tighten the lock nut with a wrench.

The sound gate is very important and should be given constant attention. The optical system has been adjusted to bring the light beam to an extremely sharp focus at the point where the emulsion surface of the film is in contact with the film guide, or gate shoe as it is usually called. If dirt or emulsion is permitted to collect on the shoe, the film will be thrown out of its normal position; that is, brought out of the proper focal plane, and the effect on the sound reproduction is the same as that caused by throwing the optical system out of focus.

When the gate with the removable pressure plate is used take out the pressure plate after every reel and clean the gate thoroughly. Be sure to use soft materials only. Never use any metallic instrument such as a screw driver, knife blade, etc., as a scratched gate shoe will scratch film and scratched film produces poor sound. When replacing the pressure plate see that the lip of the plate starts into the recess of the stationary part and press the plate on. The catch will automatically lock in place and hold the pressure plate firmly. Care must be taken not to injure or bend the tension spring.

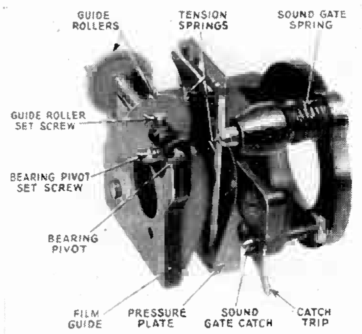


Figure 61—Original sound gate used in Type PS-1 sound head

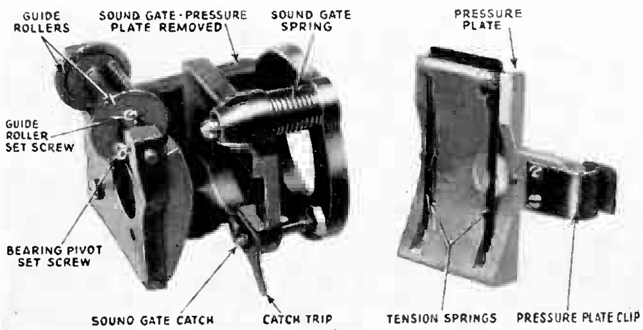


Figure 62—Improved sound gate used in PS-1, 5, 6 and 8 sound heads

The sound gate guide rollers must also be cleaned so that they will revolve freely. If it becomes necessary to remove the roller assembly, do not disturb the inside bearing pivot or loosen the collar which holds the outside roller in position. It will then be very easy to return the guide roller assembly to its original position.

When replacing the guide roller assembly adjust the front bearing pivot so there is no side play, while allowing the guide rollers to turn freely. This is important because the guide roller prevents the film from weaving, and holds it in such a position that the light beam will not be in contact with any part of the film other than the sound track. If the roller is replaced out of alignment, the beam may be in contact with either the sprocket holes or the picture frame lines. The effect of this will be a sound from the loud speakers like that of a motor-boat engine. The stationary part of the sound gate contains a small rectangular light aperture which allows the light from the optical system to reach the film. This light aperture should be kept clean and free from lint at all times. If dirt collects in the aperture, the amount of light reaching the film is reduced which results in low volume and "fuzzy" reproduction.

means of the knurled nut. Do not use a pair of pliers, as the exciter lamp base may become cracked. When the lamp is once properly focused it need not be touched again.

90. Optical System.—The optical system is a very delicate piece of mechanism and its adjustment should never be changed by the projectionist. It has been very accurately adjusted with the use of delicate instruments, and if it is moved even a few thousandths of an inch the quality and volume of reproduction will suffer. In the optical system used in type PS-1 sound heads a small vertical illuminator is furnished for the use of the RCA service man. The position of this illuminator is controlled by a slotted knob on the side of the lens barrel. (See Figure 60.) The slot should always be in a vertical position, as the amount of light reaching the photo-cell is greatly reduced if it is at any other angle. The optical system was designed to

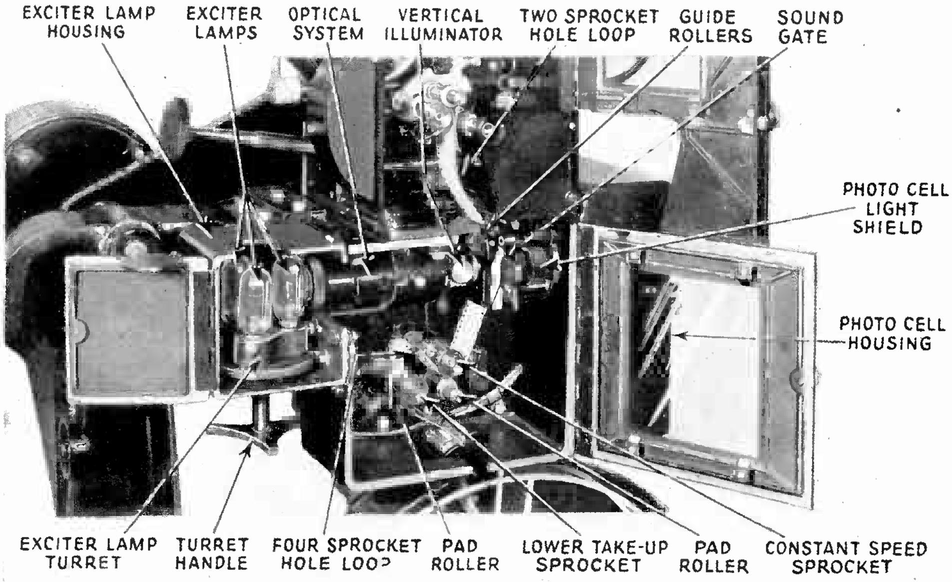


Figure 60—Operating side of Type PS-1 sound head

have the illuminator left in at all times, and it should not be removed as this allows dirt to enter the optical system. Pull out the light slit slide occasionally and blow out any dust that may have collected.

When the optical system is focused, a condition is reached whereby every frequency that it is possible to record will be reproduced. If this focus is changed the quality will be very poor; all frequencies in the upper range will be lost, and all other frequencies will be distorted.

91. Sound Gates Used in Type PS-1 Sound Heads.—Two types of gates are used in the type PS-1 sound heads. These are illustrated in Figures 61 and 62. There are two differences between them. The pressure plate is easily removable in the gate shown in Figure 62. Although the pressure plate may be removed from the gate shown in Figure 61 by removing a screw, it should not be removed by the projectionist. The other difference is in the size of the light aperture in the stationary section of the gate. The aperture of the gate shown in Figure 62 is the larger of the two.

electrons collected by the anode do not remain there, but flow off immediately in the form of an electric current through the external circuit and return to the cathode. Therefore, a varying amount of light falling on the cathode will cause a varying current in the external circuit. Two types of cells are used in RCA Photophone equipment. One is known as the UX-867 and the other as the UX-868.

86. **Description of the UX-867 Photo-Electric Cell.**—The UX-867 cell is illustrated in Figure 58, and consists of a glass bulb connected by a glass neck to a standard radio tube base. The inner surface of the bulb is coated with metallic silver except for a small window on one side. This silver coating is in turn coated with a thin layer of caesium (the active material). The purpose of the silver coating is to make a good electrical connection to the coating of caesium. An external connection to the silver coating is made by means of a short lead from the inner surface of the glass to a metal tip at the outside of the glass. There are two wires at the center of the bulb which are connected together in the base and connected to one prong. These wires form the anode of the cell. This cell is not used in many of the RCA Photophone equipments at present, the UX-868 cell being used almost exclusively.

87. **Description of the UX-868 Photo-Electric Cell.**—Figure 59 is an illustration of the UX-868 cell. It consists of a curved plate or cathode coated with caesium, and a wire anode mounted parallel to the long axis of the plate. This cell, in spite of its small size, is very sensitive and highly efficient, as photo-electric cells go. Its small size makes it admirably suited for use in sound on film reproducing equipment. The large output of these and the UX-867 tubes make it unnecessary to mount a vacuum tube amplifier close to the cell and eliminates the necessity of the unsatisfactory practice of mounting vacuum tubes on the projector.

(B) RCA PHOTOPHONE SOUND HEADS

88. **Description of the PS-1 Sound Heads.**—The Type PS-1 sound heads are used with PG-1, 2, 3, 4, 6, 7 and 8 equipments. The type PS-1 sound head consists of a housing containing an exciter lamp assembly; an optical system, for focusing the light on the film; a sound gate for guiding the film past the beam of light; a viscous damping device to insure an absolutely constant speed of the film; and a photo-cell and its transformer for translating the light variations into electrical variations. (See Figure 60.)

89. **Exciter Lamp Assembly of PS-1 Sound Heads.**—Three exciter lamps are mounted on a turret in this sound head. Only one of the lamps is used at a time, but any one of them can be lined up quickly in front of the optical system by merely rotating the turret by means of a handle provided for the purpose. The reason for having the three lamps is that, in case the one in use should burn out, a new lamp can be quickly rotated into place. These lamps should be adjusted for proper setting when they are mounted, to prevent delay when it becomes necessary to change lamps. The lamps are adjusted by raising or lowering them in their sockets. They should be adjusted to give a round circle of white light on a card placed between the sound gate and photo-cell housing. If the adjustment is not right the circle will not be complete. In such cases the lamp should be raised or lowered until a full circle of light is obtained. The lamp should then be clamped in place with the fingers by

be replaced when the coating reduces the efficiency of the lamp to a point where satisfactory results cannot be obtained when the lamp is drawing its rated current.

85. Photo-Electric Cells.—A photo-electric cell is a device which varies in electrical resistance in proportion to the amount of light falling upon it. Although there are various devices to which this description might apply, the photo-electric cell used in "talking movie" sound reproducers, as made by the leading manufacturers of such equipment, make use of the fact that when light falls upon the surface of a metal, electrons are emitted from its surface. Although all metals emit electrons when subjected to light, only a few of them are affected by ordinary or visible light. The active metal used in the cells furnished by the RCA Photophone is caesium. When

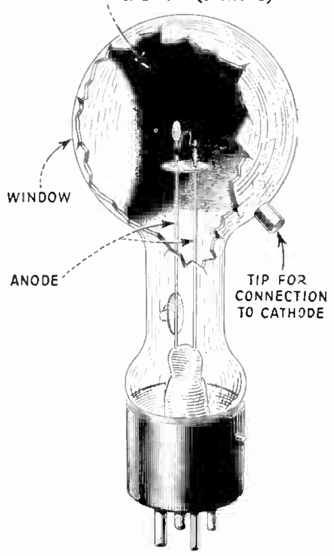


Figure 58—UX-867 Photocell

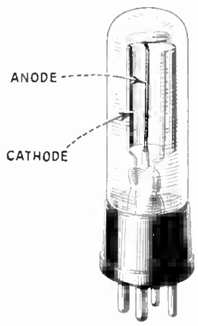


Figure 59—UX-868 Photocell

light falls upon this metal, electrons are emitted from its surface. The number of electrons emitted is directly proportional to the amount of light falling on the surface of the metal; that is, if a certain amount of light falls upon the surface of the metal, a definite number of electrons will be emitted, and if the amount of light falling on the surface is doubled, the number of electrons emitted will also be doubled. In order to make use of this fact some method of collecting the electrons is necessary. To obtain this end a plate coated with the active metal is placed within a vacuum tube and an electrical connection is made from it to the outside of the tube. Another conductor set in the proximity of the plate is also placed within the tube and has a lead brought out for electrical connection. The plate or metallic surface coated with the active metal is called the cathode, and the other conductor is called the anode. If the cathode is connected to the negative side and the anode is connected to the positive side of some source of DC potential (such as a battery), the anode will collect the electrons emitted from the cathode. Since the number of electrons emitted depends upon the amount of light falling on the cathode, the number of electrons collected by the anode will vary with the amount of light falling on the cathode. The

CHAPTER VIII

SOUND HEADS

(A) SOUND REPRODUCTION FROM FILM RECORDINGS

81. **General Discussion.**—We have seen that the aim, in all types of recording on film, is to create a photographic record in the form of a narrow sound track which would vary the amount of light through it (from a steady source of illumination) in proportion to the sound pressures on the diaphragm of the microphone.

Sound reproduction from film recordings requires that the variations of the amount of light transmitted through the photographic record (from a steady source of illumination) be accurately translated into sound. To accomplish this a thin beam of intense light, the width of which is equal to the width of the sound track, is focused on the sound track. The varying light which passes through the sound track affects a sensitive photo-electric cell so as to cause a varying electric current to pass through it. In the RCA Photophone system, this varying current is passed through a transformer primary. The voltage generated in the secondary of the transformer is amplified in the vacuum tube amplifier, the output of which is used to operate loud speakers.

82. **General Requirements for Good Reproduction from Film Recordings.**—The source of the light which shines through the film must be steady (that is, there must be no fluctuations in the amount of light). The beam of light must be as thin as the beam used in recording, and exactly as wide as the sound track. Stated as dimensions, the beam should not be more than 0.00075 of an inch thick and be exactly 0.070 of an inch wide.

The translating device (photo-electric cell) must be capable of accurately translating the light variations into electrical variations.

The speed of the film passing the light beam must be the same as the film speed of recording and *must be absolutely constant.* Variations in speed would cause variations of pitch which would be recognized as "wows."

The sound track of the film must be clean. A dirty sound track would cause extraneous variations of the transmitted light and produce a grating noise in the loud speakers.

83. **Reproduction from Variable Density and Variable Area Recordings.**—Although the sound tracks of the variable area and variable density recordings do not look alike, the variations of the light transmitted through them are the same. Therefore, reproducing equipment which is suitable for reproducing from one type of recording is equally capable of reproducing from the other. All producers of standard sound recordings on film use the same width of sound track, and use a light beam of approximately the same thickness.

84. **Exciter Lamps.**—Five ampere exciter lamps are used in most of the RCA Photophone equipments but 7½ ampere lamps are sometimes used. These lamps should be operated at a current slightly less than that for which they are rated. They should be kept clean. Any good grade of lens fluid is satisfactory for this purpose. As the lamp becomes old a dark coating inside the lamp materially decreases its efficiency. For this reason exciter lamps should not be used until burned out, but should

No special amplifier is provided, and this triple turntable may be used only with Photophone standard equipments.

79. Non-Synchronous Turntable Drive Motors.—The motors used to drive the non-synchronous turntables are similar, except in size, to the motors used in the induction type watt-hour meters. The action of the motor is similar to that described for the starting of the split-phase start induction motor used for projector drive (See Section 32), but the mechanical construction is entirely different. Instead of a squirrel-cage rotor a flat disc is used which rotates between two sets of poles. The pole pieces are so wound that when a single-phase alternating voltage is applied to the winding a moving magnetic field is created, which acts with the eddy currents set up in the disc by the transformer action to produce rotation. The speed of the motor is controlled by means of a brake, operated by a fly-weight governor. This device keeps the speed at a constant value. The speed can be adjusted by means of speed control knobs located at the side of each turntable. This speed should be adjusted to 78 r.p.m.

Normal operation of the motor will produce more heat than can be comfortably tolerated while touching any part of the coil units. This is mentioned in order that the operator will not misconstrue this heating effect to indicate a defect.

The turntable motors should be oiled about once a month with light machine oil. (*Do not use Three-in-One oil.*) The points to be oiled are the upper turntable bearing, the lower turntable bearing and both bearings of the governor. The worm and gear should be lubricated with a light grease. In addition to the regular lubrication, all bright metallic parts except the motor disc should be covered with a light film of oil to prevent rusting.

80. Speed Regulation of the Non-Synchronous Turntables.—The governor will maintain a constant speed of the motor within a range of sudden voltage changes of 20 volts, providing all the parts are correctly adjusted. Any adjustment made on the motor (including lubrication), will have a certain effect on the regulation of speed and the speed adjustment should be checked before the unit is again placed in service.

The speed may be checked as follows:

(a) Place a record on the turntable and insert a small piece of paper under the edge of the record to serve as an indicator.

(b) Play the record in the normal manner and count the number of revolutions made by the turntable for one minute. The speed should be 78 revolutions per minute.

(c) Turning the speed regulating knob clockwise allows the motor to run faster and turning the knob counterclockwise causes the motor to slow down. Adjust by trial until the speed is 78 revolutions per minute as determined from a full minute's count.

NOTE: The speed of the machine should be checked at least four or five times a year. Improper speed will cause distortion.

the "Short-Play" switch should be in the "Play" position for record reproduction. To transfer to radio reproduction the "Radio-Record" switch should be placed in the "Radio" position. By placing the "Short-Play" switch in the "Short" position, either the radio or record output may be monitored without sound reproduction from the speakers by plugging headphones into the monitoring jack.

Each turntable is equipped with an automatic stop for stopping the turntables at the end of the record, and a manually operated start-and-stop lever so that each turntable can be started or stopped separately. This phonograph does not have the pick-up lift knobs as in the phonograph described in section 76 but is otherwise similar to it except in the details noted above.

Fading from one turntable to the other is accomplished by throwing the fader switch toward the table from which sound is desired.

The Type PT-6, another non-synchronous twin turntable in a steel case, is sometimes used. This turntable is similar to that shown in Figure 56.

Neither the PT-1 nor the PT-6 are supplied with individual amplifiers or loud-

Figure 57—(Type PT-1) Non-synchronous twin turntable

speakers. They are used solely in conjunction with Photophone standard theatre equipments.

These turntables may be used only with Photophone standard theatre equipment, no individual amplifiers being provided.

78. **The Type PT-9 Non-Synchronous Triple Turntable.**—The Type PT-9 non-synchronous triple turntable is similar to the twin turntable described in section 77 with the addition of another turntable. The circuits are so arranged that the output of the additional turntable is connected in the circuit of the turntable which is "faded in." The purpose of the additional turntable is to provide background music or special effects such as areoplane or locomotive noises.

When the additional turntable is not in use its volume control should be in the "Off" position. The volume from the other two turntables is controlled by means of the fader potentiometer.

The selector switch just mentioned can be used for converting the equipment instantaneously to the special use of amplifying either a radio program or some other special program. For ordinary use, the selector switch is in the center or "Record" position.

Fading from one turntable to the other is accomplished by turning the fader potentiometer so that its indicator points toward the table from which sound is desired.

The speed regulators are for adjusting the records to operate at the proper speed, which is 78 revolutions per minute.

Pick-up lift knobs are provided for use when it is desirable to make quick change-over from one record to the other. The pick-ups are lifted from the record when the knob is pushed in. The pick-up can be set over the record in any desired position and lowered by pulling out on the lift knobs. This can be done with one hand, leaving the other free for operating the fader potentiometer.

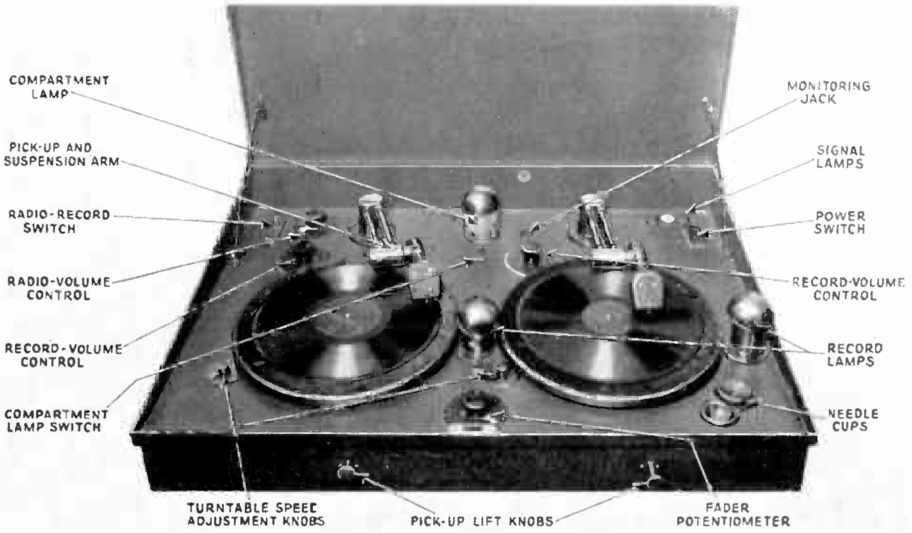


Figure 56—Theatre phonograph (Type PT-4)

The other type of theatre phonograph in a steel case containing a twin turntable (PT-5) is similar to that just described, the chief differences lying in the construction of the cabinet.

Both of these types are equipped with amplifiers, as described in section 142, and, together with loudspeaker units, are known as the PG-17 and PG-18 equipments respectively.

77. Type PT-1 Non-Synchronous Twin Turntables.—The Type PT-1 has a wooden case and is shown in Figure 57. It consists of two electric turntables of 78 r.p.m., one fader switch, one "Radio-Record" switch, one "Short-Play" switch and a record light. The top is on hinges and may be removed when desired. At the rear is a binding post panel providing connections for the record output and radio input. The "Radio-Record" switch should be in the "Record" position and

75. Non-Synchronous Turntables.—The purpose of the non-synchronous turntable is to provide music in the absence of an orchestra, or during the showing of pictures for which no special sound accompaniment is provided. It also provides a method for playing overtures and exits. RCA Photophone has five types, four in steel cases. Three contain two 78 r.p.m. turntables and the other contains three turntables of the same speed. The phonograph with a wooden case contains two 78 r.p.m. turntables.

76. Types PT-4 and PT-5 Theatre Phonographs.—The Type PT-4 is built into a steel case and is equipped with two turntables. See Figure 56. Both turntables turn whenever the power switch is on, but either table can be easily stopped by simply pressing a finger against it until it comes to rest. This can be done without damage to the mechanism as each turntable is driven by a separate electric motor. If a turntable has been stopped to change a record, it will automatically start again so long as the switch is left on.

Figure 55—Placing a pick-up in the starting position for synchronous reproduction

The pick-up lamps are used for illumination only. They are neither signal nor pilot lights except in so far as they are always burning when the power switch is turned on. The compartment lamp, likewise, is for illumination only. It operates from the switch directly in front of the lamp and it lights only when the power switch is on. The three signal lamps in the right-hand corner are controlled from the rear of the theatre. Signals may be arranged with someone stationed in the theatre at the signal lamp controls, for the proper monitoring of the volume.

To the right of the compartment lamp is a socket for inserting the plug of a monitoring speaker.

The two volume control knobs, control the volume of their respective pick-ups. The radio volume control would be used only if the amplifying equipment were used to amplify a radio program received upon an individual radio set. If it is desired to use the equipment for this purpose, connect the two output wires from the receiving set to the terminals marked "Radio" on the rear panel, and set the selector switch on the "Radio" position.

The whole mechanism runs in oil, the proper level of which is about one-eighth inch below the top of the oil cup. The turntables that do not have oil cups may have the oil level checked by removing the turntable. The oil level should be such that one-half of the worm gear is immersed in oil. The oil must never be allowed to drop below this position. Quaker State Medium oil is recommended for lubricating this turntable.

The turntable is driven through a flexible steel shaft which should receive oil regularly twice a day through the two oil holes—one at each end of the shaft.

74. **Operation of Synchronous Disc Equipment.**—The operation of sound-on-disc in synchronism with the picture requires that disc and film both start at definite reference points. One frame of the film is always marked to indicate the starting point. Thread the projector, placing the marked frame in the light aperture.

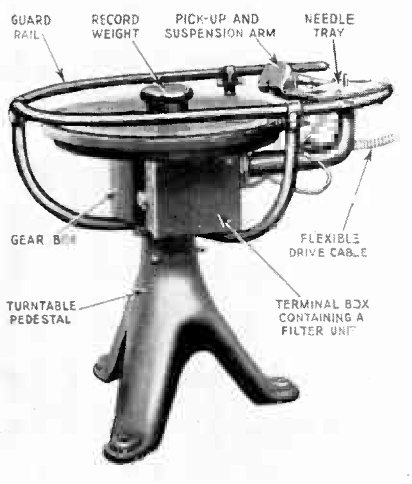


Figure 53—Type PT-10 synchronous turntable (for PG-13 equipment)

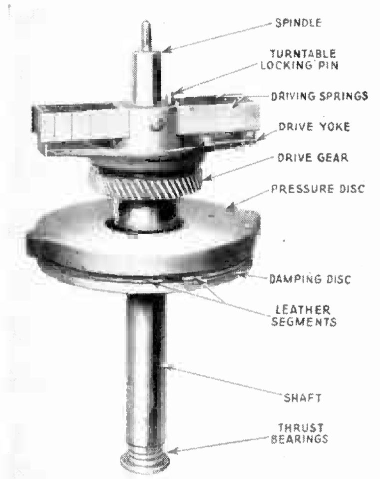


Figure 54—Viscous damping device of PT-10 synchronous turntable

After the film has been threaded as indicated, place the record on the turntable. *Use both hands when placing or removing the record,* as the hole in the record fits the turntable spindle snugly, and the record is liable to bind if it is not level when placed over the spindle. This binding may cause the record to become broken in an attempt to free it. After the record is placed on the turntable, lift the pick-up with the right hand, and hold it a little above the record near the inside record groove. With the left hand rotate the record (*do not move the turntable*), until the pick-up is just over the starting point of the record. This point is indicated by a radial line, or groove, which terminates at the starting point of the spiral groove, as shown in Figure 55. Set the pick-up needle into the groove at this point, and test its setting by applying a slight pressure sidewise in each direction to make sure the needle is in the groove. When this is done, the projector is ready to start in so far as the proper synchronizing of the disc and film is concerned. Turn the projector until the turntable has rotated one-half turn to see that the needle tracks properly.

A large grease cup on the turntable mechanism supplies lubricant between the felt damping washer and fly-wheel. This grease cup should be filled with Alemite grease and should be given one-half turn every three hours. Do this while the machine is at a standstill, after which the projector should be run for a minute before threading up to "run in" the grease. The location of the grease cup is shown in Figure 52.

Never turn up the grease cup while sound is being run from the machine as a very bad "wow" is certain to result.

The gear box on the motor bracket is filled with grease which will be changed about once a year by the RCA service man and should require no other attention.

72. **The Type PT-7 Turntable.**—This type of turntable is illustrated in Figure 52. It is mounted on a three-legged base instead of a round pedestal used with the standard turntable. The interior mechanism is identical to that previously described. Its care and adjustment is also the same. The type PT-7 turntable is used only in PG-10 equipments.

Figure 52—Type PT-7 synchronous turntable (Used in PG-10 equipments)

73. **The Type PT-10 Turntable.**—This turntable is used in the PG-13 equipments and is of entirely different construction from either of the previously described types (See Figure 53). The adjustable viscous damping device has been eliminated, as well as the use of Alemite grease. This turntable mechanism is illustrated in Figure 54. The vertical shaft carries the turntable. A gear, which is assembled with a yoke, is free to move on the shaft, but is connected to the shaft by means of two springs which transmit the motion from the gear to the shaft. These springs take out any jerking motion which may be present in the gear. A friction device for introducing a constant drag on the mechanism to prevent oscillation due to gear back lash is included, and consists of a damping disc with four leather segments fastened to it, assembled on the shaft and rotating with it. A heavy iron plate, held stationary, rests on the leather segments to produce the desired amount of friction. The turntable, which is one and three-quarters inches thick and two and one half times heavier than those described previously, acts as a fly-wheel.

A double chain sprocket is mounted on the motor shaft, one sprocket being chained to the projector head, and the other being chained to a standard gear box on the motor bracket. From this gear box the power is applied to the turntable mechanism through a flexible hose coupling. This turntable is somewhat similar in appearance to that shown in Figure 52. See the Frontispiece also.

In order to avoid "wows" caused by sudden small variations in the speed of the driving motor, a viscous damping device is incorporated in the turntable mechanism. Figure 51 is a drawing of the damping device which operates in the following manner:—A large fly-wheel is on the drive shaft of the worm gear which drives the shaft the turntable rests on. This fly-wheel is driven through a pair of helical springs mounted in a recess in the fly-wheel. Stop pins are provided so that the springs can wind or unwind only a certain amount.

A felt washer bears against one side of the fly-wheel and introduces friction, or drag, and prevents any back-lash in the gears, which might be caused by slight changes of motor speed, from causing a "wow." The pressure of the felt washer

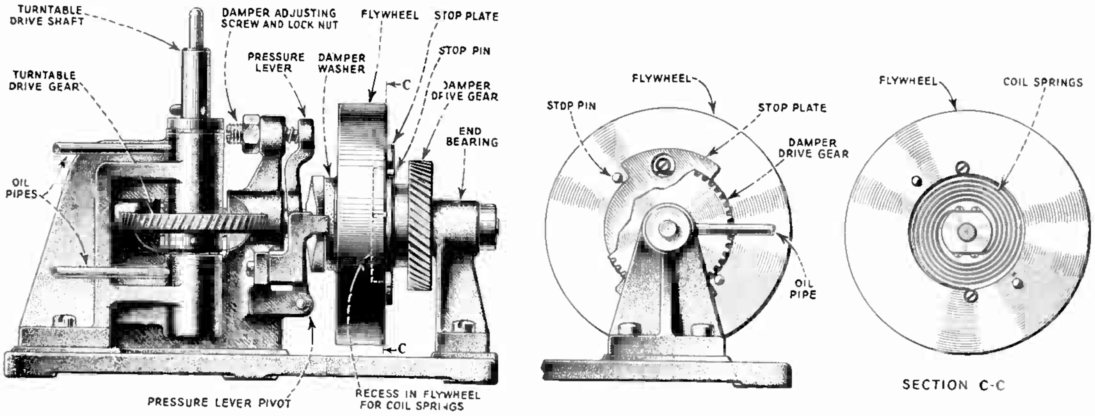


Figure 51—*Synchronous turntable viscous damping device*

against the fly-wheel can be adjusted by means of an adjusting screw, which is locked into position by means of a lock nut. The pressure on the washer should be adjusted to the lowest value that will just prevent "wows."

Before making the adjustment, see that the turntable has been properly oiled and greased as described later and run the projector for a minute. Remove the turntable by lifting it off. Loosen the adjusting screw locknut and adjust the screw so that there is just a very slight pressure of the washer against the fly-wheel. Replace the turntable and select a disc with slow music containing sustained high notes, such as a violin solo, and run the sound and film and listen for "wows." If "wows" are heard, stop the machine, increase the pressure slightly, and listen for "wows" again as outlined above. Continue increasing the pressure by small amounts until no "wows" are heard and then secure the adjusting screw in place by tightening the lock nut.

Keep the parts clean and see that the bearings receive sufficient oil. It is advisable to pack wool waste in the oil cups, and keep it saturated with good grade of machine oil.

70. Phonograph Pick-Up.—The magnetic pick-up used with RCA Photophone equipment is of the low impedance type. It consists of a permanent magnet, a soft iron armature, and a small coil of fine wire. The soft iron core which carries the needle is pivoted in rubber, and its upper end is held in place by a small rubber damping block. The needle and armature assembly can move slightly about the armature pivot, and with sufficient ease to prevent undue wear on the record. The armature swings back and forth as the needle follows the groove of the record, and the magnetic lines of force which pass through the armature change both in number and direction. Since a coil is wound around the armature, an alternating voltage will be generated in it. Figure 50 illustrates this action. When the armature is in the position shown in (*a*) of the figure, the lines of force will flow down through the armature. When it is in the position shown in (*b*) there are no lines of force through the armature, and when it is in the position shown in (*c*) the lines of force will flow up through the armature. Thus the magnetic pick-up is a small AC generator. The voltage generated alternates in exact correspondence with the sound

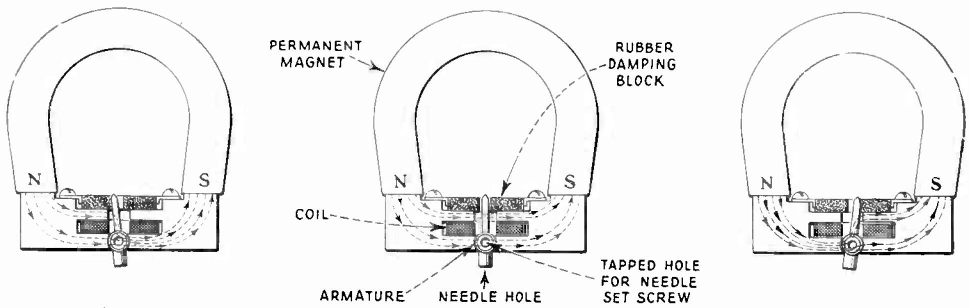


Figure 50—Operation of the magnetic pickup

track on the record. The voltage generated by the pick-up is very low and must be amplified many times before it can be used to operate the loud speakers.

The tone-arm pivot rests on a ball-bearing inside of a brass bushing in the tone-arm bracket. If the ball-bearing is lost the tone arm may bind, causing the pick-up needle to jump the record grooves and throwing the sound out of synchronism. Therefore, avoid removing the brass bushing. A drop of oil should be applied to the tone-arm pivot about once a month.

Felt washers and sponge-rubber cushions are used at the tone-arm horizontal pivot to prevent mechanical vibrations in the turntable from affecting the sound produced by the pick-up.

If these sponge rubber cushions become shoved to one side so that the metal pivot of the tone-arm touches the metal casing, a very bad hum will be produced and can be heard from the loud speakers. To correct this, remove the tone-arm from the horizontal pivot and rearrange the sponge rubber so that the pivot is completely surrounded.

71. The Type PT-2 Synchronous Turntable.—This type of turntable is used with Types PG-1, 2, 3, 4, 6, 7 and 8 equipments. The same motor which drives the projector and sound head mechanisms is also used to drive the synchronous turntable.

CHAPTER VII
TURNTABLES

69. General Requirements.—The aim in any type of sound reproduction is that the reproduced sound be as nearly like the original sound as it is possible to make it. The discs, when properly made, carry a nearly perfect record of the sound, but this is not enough for good sound reproduction because no matter how nearly perfect the record, it would not give satisfactory reproduction unless it was used with suitable reproducing equipment properly operated.

The frequencies of the reproduced sounds should coincide with the frequency of the original sound (or there will be a change of pitch). This condition can be obtained by running the disc record during reproduction at exactly the same speed as the wax disc was run when the sound was recorded. For synchronous records this speed is thirty-three and one-third revolutions per minute. For non-synchronous records the proper speed is seventy-eight revolutions per minute.

This is accomplished by making the speed of the reproducer turntable correspond with the speed of the recorder. For synchronous disc reproduction this is taken care of in the design of the projector, and constant speed motors are used for projector drive. When DC motors are used for projector drive the speed must be adjusted by the operator as outlined in section 27. The speed of the non-synchronous turntables must also be adjusted by the operator. The method of doing this is described in section 79.

A second consideration is that the record must be rotated at an absolutely constant speed as even slight variations in speed will result in "wows." To prevent any such slight variations of speed a mechanical "filtering" device is incorporated in the synchronous turntable drive.

For synchronous reproduction of sound the record and picture must coincide at all times. Since the turntable mechanism is mechanically geared to the sprocket which pulls the film through the machine, the proper relation of speed between film and disc is maintained at all times. Barring mishaps, such as the needle jumping the groove, or breaking of the film, the sound and picture will remain synchronized throughout the run, if properly started.

The device for translating the sound record of the disc into sound itself must be capable of doing so without introducing distortion. The operator's responsibility in regard to this lies mostly in seeing to it that the record is clean and that a good needle is used in the pick-up. As stated in section 63, the record is purposely made abrasive, so as to wear the needle quickly to a good fit. The needle continues to wear after a good fit is secured, therefore, a new needle should be used every time a record is changed. Only a good grade of needles should be used.

68. Synchronizing Sound on Film.—The sound film is usually run on an entirely separate machine from the camera for practical reasons, and the two films must be so synchronized that when they are printed together they will be in synchronism throughout the length of the film. This is accomplished by running the camera and the recorder at exactly the same speed. They are both driven by synchronous motors connected to the same power supply, and this keeps them always in synchronism. Some kind of marking is required so that the picture and sound track can be lined up for printing. This is sometimes taken care of by marking the film by means of a small marker lamp which shines on the film outside of the sprocket holes. Since the sound gate of the projector is 19 frames from the picture in the light aperture it is necessary to displace the sound track by 19 frames when they are printed together. The advantage of sound-on-film is that the sound will always be in synchronism with the picture if the projector is properly threaded. The breaking of the film does not interfere with the synchronous action, so that a blank patch is not necessary.

the galvanometer. The light stop between the lens and the mirror is for the purpose of cutting off the fringe of distorted light so as to give a clear cut beam of light. The galvanometer window is tilted at a slight angle to keep the light reflected from its surface from entering the optical system. The reflected light from the mirror passes through the cylindrical lens, which condenses the light in one direction only. It then passes through a spherical condensing lens which reduces the beam size still more. The beam from this lens is focused on the slit in the aperture plate (this slit is 0.003 of an inch wide). The light which passes through the aperture plate slit is focussed on the film through a microscope objective lens system. This objective reduces the size of the beam by a 4 to 1 ratio in both directions so that the resultant beam on the film is 0.070 of an inch long by 0.00075 of an inch wide.

When the mirror is at rest, only one-half of the sound track is exposed. The other half of the light beam is cut off by a screen. When the mirror is moved to

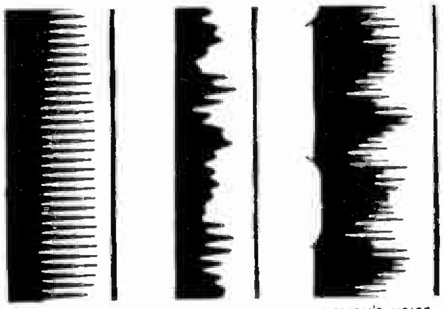


Figure 49—Variable area sound recording

its extreme position in one direction, the light beam is shifted off of the screen so that the beam covers the entire sound track. When moved in the other direction to its extreme position, the beam moves over so that it is cut off entirely by the screen and strikes no part of the sound track. When referring to the extreme position which the mirror moves it is not meant that this extreme is the maximum movement which can be obtained by the mirror, but only the maximum position to which it should ever move when recording. When the film moves through the recorder it is exposed to this fine line of light which varies in length as the mirror vibrates in response to the sound currents flowing through the loop supporting it. When the film is developed the part of the film which was exposed to the light beam will be opaque while the remainder of the sound track will be transparent. See Figure 49. The juncture of the opaque and transparent parts of the sound track form a wavy line which is practically an exact representation of the sound pressures of the original sound waves. When this sound track moves through the sound head of the projector the amount of light passing through the film will vary with the width of the transparent part of the track. This varying amount of light produces a varying current through a photo-electric cell. The effect of this current is amplified in a vacuum tube amplifier and the amplified variations are sent to the loud speakers which reproduce the sound.

are connected to binding posts 0.01 of an inch apart. A very tiny glass mirror is cemented across the loop half-way between the two ivory bridges. The entire mechanism is immersed in oil to dampen the movement. The assembly is placed between the poles of a permanent magnet in such a way that the wires lie across the plane of the magnetic lines of force as shown in Figure 48. When a current flows through the loop a turning force is created in the same manner as described in the discussion of motors in section 21. When the current through the loop is in one direction the loop twists one way, and if the current flows in the other direction the loop twists the other way. Sound currents are alternating currents, the frequency of which vary over a wide range. Since the sound currents are alternating currents of the same frequency as the sound, and of a magnitude proportional to the loudness of the sound, they will vibrate the mirror at the frequency and in proportion to the magnitude of the sound waves recorded. A beam of light from an

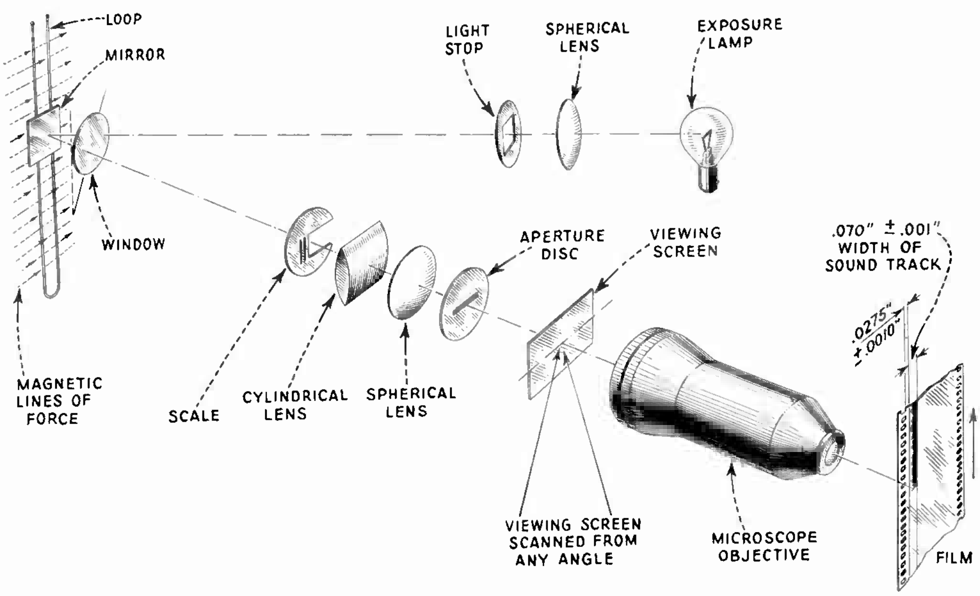


Figure 48—Schematic diagram of Photophone sound film recorder

incandescent lamp is focussed on the mirror. The vibration of the mirror sends the light across the exposed moving film through a suitable optical system containing lenses and a narrow slit. The mirror needs to move only a little to sweep the light beam comparatively large distances at the film. This beam, therefore, acts as a high ratio lever multiplying the effect of the moving mirror many times. This can be illustrated, and often has been by mischievious school boys, by placing a small mirror in a beam of light. A very small movement of the mirror changes the position of the reflected beam on a nearby surface through considerable space, making it difficult for the mischief maker to focus the beam on the eye of the person whom he wishes to annoy.

Figure 48 shows a schematic diagram of the galvanometer and optical system. The light from the lamp is focused through a condensing lens onto the mirror of blank film to replace parts of the film which were torn results in disagreeable breaks in the picture.

The methods of recording on disc are practically the same for all producers and they differ only in details.

65. Variable Density Recording on Film.—There are two different methods of variable density recording. One method, used by Fox Movietone, utilizes a variable intensity light called an "Aeolight." This light varies in intensity with the amplified sound currents and shines through a narrow slit onto the moving film, which is kept running at a constant speed of 90 feet per minute. A quartz block is coated with silver to make it opaque, and the slit is engraved in the metal to the desired size. The width of the slit is about 0.0008 of an inch. When the film is developed after being exposed to the variable intensity light, the sound tract will be made up of lines of varying density extending across the sound track as shown in Figure 47. If the frequency of the recorded sound is low, the width of the bands will be comparatively large, but, if the frequency is high, the bands of light and dark will be very close together and may be hardly distinguishable. The variation of density between successive dark and light bands determines the amplitude of the recorded sound.

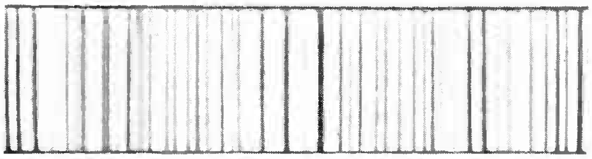


Figure 47—Variable density sound recording

The other method of making variable density film recordings is by the use of a light valve. This method is used in the Western Electric system. The light valve in this case varies the amount of light by the opening and closing of a slit. This slit is the space between two taut sides of a loop of wire suspended in a magnetic field. As the sound current passes through the loop, the loop opens and closes passing varying amounts of light through it. This light is then focussed with lenses on the moving film so as to form lines of varying density when the film is developed.

67. Variable Area Recording on Film.—The RCA Photophone employs the variable area method of recording on film. In this system the intensity of the light is kept at a constant value, but the area of the sensitized film which is effected by the light is varied. The system consists essentially of a source of light, a mirror which is vibrated by the amplified sound currents, and a suitable optical system for concentrating the light into a very fine beam.

The vibrator is a very sensitive galvanometer so constructed that the mirror follows faithfully all changes of sound currents over a very wide range of frequencies. It consists of a loop of flat wire 0.0005 inches thick and 0.005 inches wide, stretched over two ivory bridges, each similar to a violin bridge except in size, mounted 7/16 of an inch apart. This loop is put under tension by means of a spring attached to a tiny pulley at the closed end of the loop. The two ends of the loop potential of 180 volts DC is impressed across the plates, and a resistor of 20 to 50 million ohms resistance is in series with one of the leads. As the diaphragm is moved in and out by the action of the sound waves, the alternating current set up flows through the resistor and produces an alternating voltage across it. This alternating voltage is impressed on the grid of the first tube of a vacuum tube amplifier. The amplified signals are then used to operate the recording device.

63. Disc Recording.—In disc recording the output of the amplifier actuates a vibrating armature which has attached to it a sapphire stylus (cutting point). This stylus is placed on the surface of a rotating plate and cuts a wavy groove in its surface. This plate, while usually referred to as a wax plate, is in reality made of an insoluble soap. The plate is rotated at an absolutely constant speed of thirty-three and one-third revolutions per minute.

Any number of duplicates can be made from this wax record in the following manner:—The wax is coated with a fine powder of conducting material. It is then electroplated so as to give a metallic negative record called a "master." This master is again electro-plated after the surface has been suitably treated to permit an easy removal of the resultant positive plate. This positive is commonly called an "original." From the positive another negative is made, a metal mold called a "stamper." From it duplicate "originals" can be plated to make duplicate stampers. These successive plating processes involve no measurable injury to the quality of the record. By the custom of making a number of duplicates, the master is protected from accidents and wear to which it would be subject if used to make the finished record.

The stampers are used to press the final product, and as many as a thousand records can be made with one stamper. The material from which the records are made is called "record stock." This material must have a hard surface to resist wear, and must contain enough abrasive (wear producing material) to grind the needle quickly to a good fit. At the beginning of a run of a new needle the pressure on the record is very great because of the small area of the needle point. However, after a minute's wear the needle pressure is reduced to 50,000 pounds per square inch.

64. Synchronizing Sound on Disc.—When the wax record is made, the wax disc is rotated at a uniform speed of thirty-three and one-third r.p.m. and is driven by a synchronous motor. The camera is driven so as to have a film speed of ninety feet per minute by another synchronous motor operating from the same power supply as the motor which drives the wax disc. The recording disc and the camera are started at the same time, and after they get up to speed they are operated simultaneously. Since they are both driven by synchronous motors they will always have the same relative speed. Therefore, the sound and picture will always be in synchronism when reproduced if the film and disc are both started at the proper "start" position, unless there is a mishap such as the needle of the pick-up jumping the groove, or the film breaking and not being properly patched. Should the film break, it is necessary to have the same number of frames in the patched film as it had originally, if the sound and picture are to remain in synchronism. The addition of

61. Fundamentals of "Talking Movie" Sound Recording.—No matter which method of recording is used there are certain fundamental rules which must be followed if satisfactory results are to be obtained.

The record must be as nearly an exact representation of the original sound waves as it is possible to make. All the frequencies of the original sound should be present and in the same proportions as in the original sound; that is, there should be no discrimination against some frequencies as compared to others within the band of frequencies necessary for natural reproduction. Of still more importance is the necessity of preventing the addition to the record of frequencies not in the original sound.

The sound must be so recorded that its reproduction corresponds to the picture at all times; that is, the sound must be recorded so that when it is reproduced the sounds corresponding to the action of the picture occur at the same time that the action causing the sound is shown on the screen. The process involved in doing this is called "synchronizing."

62. Picking Up the Sound Energy and Converting It to Electrical Energy.—The first step of recording, the "picking up" of the sound energy and converting it into electrical energy is essentially the same in all modern recording systems. This is done by means of a sensitive microphone. The RCA Photophone, the Western Electric and Fox Movietone all use a condenser microphone similar to those used in radio broadcasting. The RCA Photophone microphone consists of two metal plates separated 0.0015 of an inch by an insulating material. One of the plates is made of duralumin rolled to a thickness of about 0.0015 inches and stretched to a very high tension on a frame. These two plates and the insulation between them form a simple condenser.

A condenser consists of two plates, or two groups of plates, separated by an insulating material. If an electrical potential (voltage) is applied between the plates they will become charged. When the plates are charged or discharged, the charge flows into or out of the condenser. This flow of a charge, as stated in section 13, is an electric current. If the capacity (ability to hold a charge) of a condenser is changed while a DC voltage is applied to the plates, the amount of charge which the condenser will hold will change in accordance to the change of capacity, and a current will flow in the leads connecting the source of the DC voltage and the plates of the condenser. The capacity of the condenser can be changed by changing the distance between the plates. Therefore if one plate is vibrated, an alternating current will flow in the leads because as the distance between the plates decreases a current will flow into the condenser, and when the distance between the plates is increasing a current will flow out of the condenser. If a resistor is placed in one of the leads connecting the source of DC to the condenser, an alternating current will be produced across the resistor due to the current flowing through it.

When a condenser microphone such as described above is acted upon by sound waves the diaphragm moves in and out at the frequency of the sound waves. A

CHAPTER VI

RECORDING

59. Historical.—Just when sound was first recorded is not known, but it seems that the Chinese, who were first to devise means of printing, making gun powder and many of the other things which we call modern inventions, were the first to record sound about 4000 B.C. Practically nothing is known of the method they used as they did not keep a record of the details of the device. The story is that a Chinese prince, wishing to communicate with a friend in some distant province without making the journey himself, would speak into a teak-wood box while turning a crank in the side of it. A courier would then carry the box to the prince's friend, who would, upon turning the crank, hear the reproduced sound message from the prince as it issued forth from a hole in the box. It is characteristic of that gifted race that no effort was made to exploit their discoveries, and it was not until after 6000 years, when Edison rediscovered a method of recording sound, that it came into general use. Edison discovered that indentations on a piece of lead foil could be used to actuate a diaphragm and produce sound. With characteristic resourcefulness, Edison set about developing this discovery, and in a short time produced a commercial machine which now goes by the name of "Phonograph."

Until recently the original sound energy of the source was used to actuate the stylus (cutting point) in making records. This required considerable sound energy, so that records could only be made in a special studio, and even with favorable conditions it was not possible to produce records which gave both faithful reproduction and ample volume. The records produced by this method were, therefore, a compromise between faithful reproduction and volume. The present method used by all up to date record producers employs electricity. The sound energy is first converted into electrical energy, amplified in vacuum tube amplifiers, and the electrical energy is then used to actuate the mechanism which cuts the impression on the record. With this method no sacrifice in faithfulness is necessary to obtain the desired volume, with the result that extremely faithful reproductions are now possible from disc.

60. Methods of Recording Sound.—At present there are two basic methods of sound recording. One method is that of cutting a groove in a wax disc and the other is a photographic impression on film. The methods of recording on wax discs by different producers are very similar although there are slight differences in the apparatus used. There are two fundamentally different kinds of recording on film. One is called the variable area recording used by Photophone; the other is called variable density, and is used by Western Electric, Movietone, and others.

desired charging rate. The regulators should be adjusted so that the readings on both ammeters are approximately equal. The charging current is the sum of the two ammeter readings. The ammeters should not read above 6 amperes each, for normal operation. They will operate satisfactorily at 7 amperes, but this higher charging rate will considerably shorten the life of the bulbs.

In case the bulbs do not light when the AC line switch is closed and the snap-switch on the charger is in the "On" position, look for blown fuses in the AC line circuit. If the fuses are O.K. and there is AC power available at the panel, the trouble may be due to dirty contacts in the bulb sockets or they may be loose in their sockets. The socket contacts should be kept clean and the bulbs should be kept securely screwed into their sockets at all times. If this is not done the solder may melt out of the center socket-contact and cause trouble.

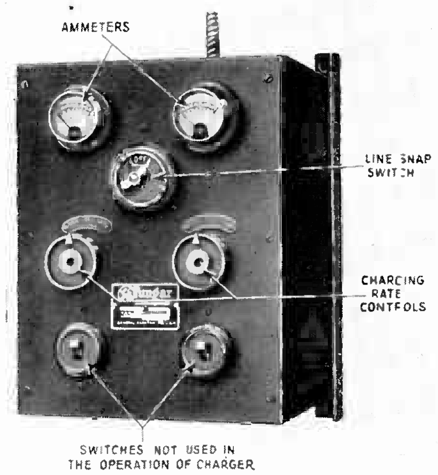


Figure 45—G. E. Tungar charger

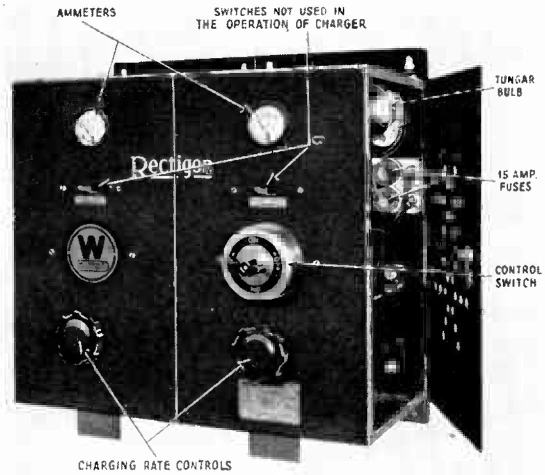


Figure 46—Westinghouse Rectigon charger

If the bulbs light but the ammeters do not show current with all switches in their proper positions for charging, check the fuses in the Tungar unit. These are accessible by opening the left-hand side door.

Use only 15 ampere fuses when making a replacement.

If the regulating switches are hard to turn, it is a good plan to lubricate the contacts and switch rider with a small amount of vaseline. This will also prevent the switch contacts from corroding.

The operation of the Tungar shown in Figure 45 is the same as the one just described. The panel of this Tungar has two extra snap-switches, which are not used in the operation of the charger.

The Rectigon charger shown in Figure 46 is similar to the Tungar just described except in the arrangement of the equipment. It also has two switches not used in the operation of the panel. One position of each of these switches is marked for "1 to 8 Batteries". *They should always be kept in this position.*

A spare Tungar bulb should always be kept on hand, and should be tested for at least one complete charge before being placed in reserve.

responding to a higher line voltage. This lead should never be connected to a tap of a lower rating than the line voltage, that is, the charging rate should not be increased by changing the tap connection to one which is below the line voltage.

Since the charging rates of these rectifiers are fixed to two values, 12 amperes and 24 amperes, depending upon whether one or both rectifiers are used at a time, the time required for charging is pretty well fixed for a particular condition of discharge. A charging rate of 24 amperes should not be used when the battery is gassing freely. A charging rate of 24 amperes should be used only when there is some one present who can periodically check the condition of the battery. The battery should not be charged at this high rate for long periods of time or overnight, as over-charging (particularly at a high rate) quickly ruins the plates. The 12

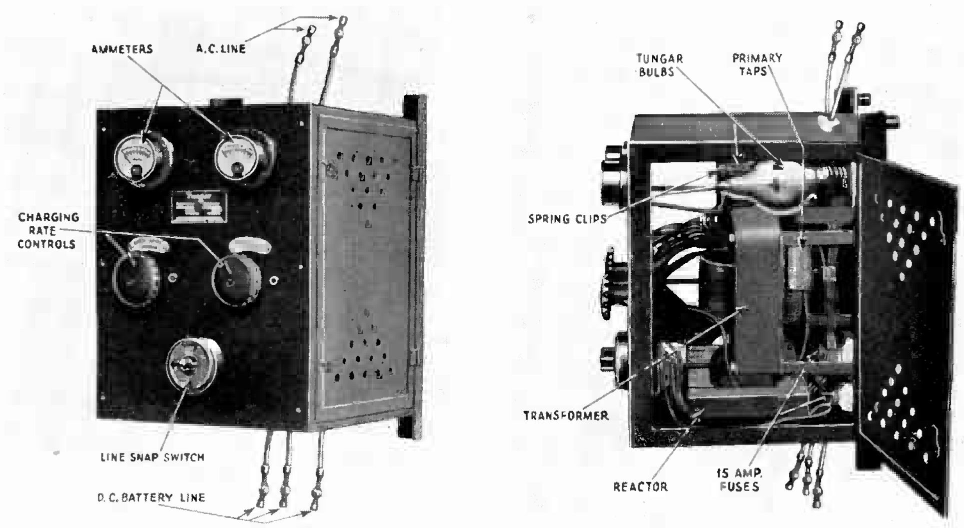


Figure 44—G. E. Tungar charger

ampere rate should always be used when there is sufficient time to charge the battery at this rate. To determine the time required for charging the battery use the table in section 50.

If the bulbs fail to light when the AC line switch is "On," look for blown fuses in the AC line circuit. If these fuses prove to be O.K. and there is alternating current available at the charger, turn "Off" the line switch, remove the bulbs, and clean the socket and bulb contacts. Return the bulbs to their sockets and screw them in securely. Make sure that the clip that fastens to the top connection of the bulb makes good contact. If the bulbs still fail to light, try one that is known to be O.K.

The Tungar charger shown in Figure 44 has separate controls and an ammeter for each bulb. To operate, see that both the regulator knobs are turned to the "Off" position by turning them to their extreme counter-clockwise position. See that the snap-switch on the charger is in the "Off" position. Connect the battery to be charged by means of the four-pole change-over switch. Turn the snap-switch on the charger panel to the "On" position and turn the regulator handles to give the

The rectifying action is as follows:—The ends of the secondary of the transformer are alternately positive and negative with respect to the center tap. When one end is positive with respect to the center tap, the other end is negative with respect to the center tap. Therefore during each half cycle of alternating voltage, the plate of one or the other of the Tungar bulbs is positive with respect to the filament, and a current will flow during each half cycle first through one tube and then through the other.

The current always flows out of the center tap of the transformer secondary into the positive side of the storage battery, through the battery, through the ammeter, and then through one or the other of the Tungar bulbs. This current is not the steady direct current which can be obtained from a battery, but a pulsating current which flows always in the same direction. It is satisfactory for charging storage batteries but is not suitable for use where a steady direct current is required.

The Rectigon and the other Tungar chargers are similar in principle to the one just described but differ considerably in their construction. These chargers are made up of two half-wave chargers connected together electrically so as to make

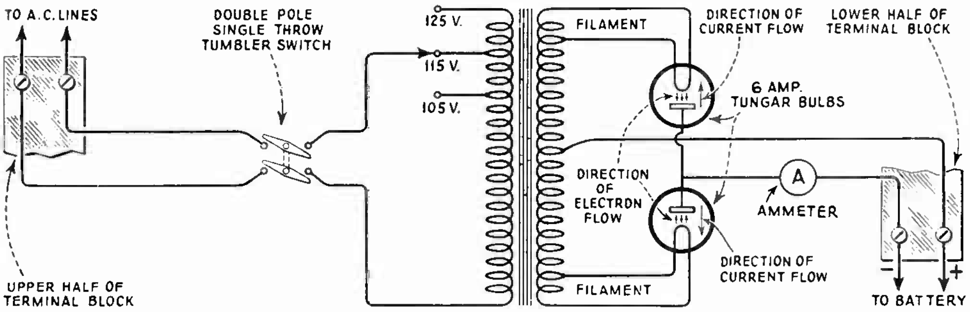


Figure 43—*Wiring diagram of G. E. Tungar charger illustrated in Figure* 42

a full-wave rectifier. They have two transformers, two ammeters and two current control, tap switches. The secondaries of the transformers are tapped for various voltages so that the charging rate can be varied by means of the tap-switches.

58. Method of Operation of Chargers.—To operate the Tungar charger shown in Figure 42, connect the charger to the battery to be charged by means of the four-pole battery switch. Turn the Tungar snap-switch "On". The ammeter should show a charging rate of about 12 amperes. Two of these units are always included in an installation, and when operated in parallel give a charging rate of 24 amperes.

The primaries of the transformers are tapped for primary voltages of 105, 115, and 125, and the line lead to these taps from the tumbler switch should be connected to the tap corresponding to the line voltage. If the line voltage is between 100 and 110 volts it should be connected on the 105 volt tap. If the voltage is between 110 volts and 120 volts it should be connected to the 115 volt tap, and if the voltage is between 120 volts and 130 volts it should be connected on the 125 volt tap. If the line voltage is low and the charging rate too high, the lead may be connected to a tap corvacuum tubes containing a heated filament and a plate is that the current flows in only one direction between the plate and the filament.

If one tube such as described above (see Figure 41) is connected to change an alternating current to direct current, the circuit is known as a half-wave rectifier because direct current flows during one-half of the cycle. During the other half-cycle (when the plate of the tube is negative) no current will flow. When two rectifier tubes are used with the proper circuit it is possible to cause direct current to flow in the load circuit for the entire cycle. Such an arrangement is known as a full-wave rectifier.

57. Description of Operation of Tungar and Rectigon Chargers.—The Tungar and Rectigon battery chargers are alike in principle. Figure 42 is a picture of a Tungar which is simple in construction and operation, and will be described in

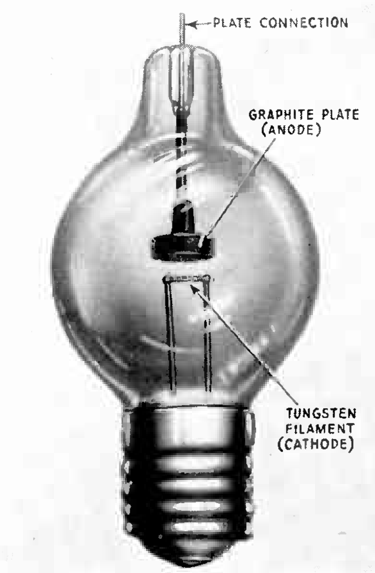


Figure 41—Tungar bulb

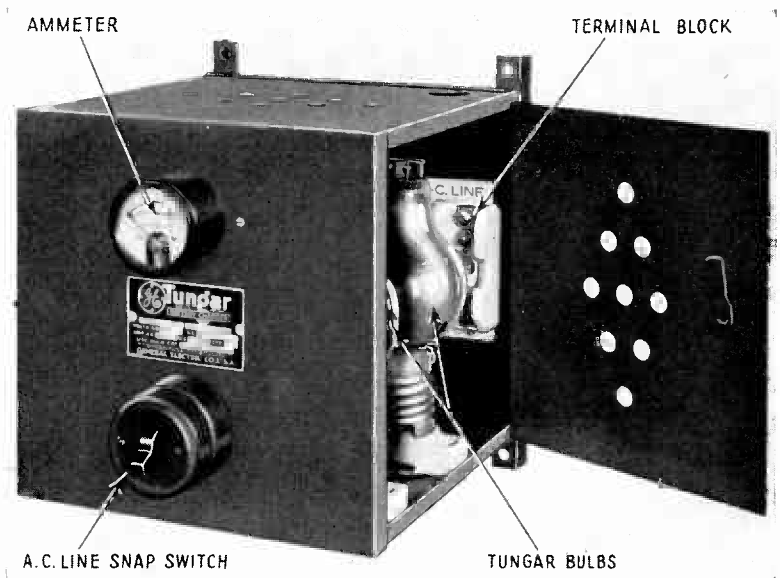


Figure 42—G. E. Tungar charger

detail. Figure 43 is a schematic circuit diagram of this Tungar. The device consists of a transformer, two Tungar bulbs, an ammeter, and a line switch all mounted in a sheet-iron case.

Referring to Figure 43, it will be noticed that an alternating current will flow in the primary of the transformer when the line switch is closed. A voltage will be generated in the secondary winding by transformer action. The secondary winding is tapped a few turns from each end to provide a voltage for lighting the filaments of the Tungar bulbs. These filaments are lighted in the same manner as an ordinary electric light except that it uses a very low voltage. (Two and one-half volts are used for lighting the Tungar filament.) The purpose of lighting the filament is to cause it to emit a large number of electrons. The secondary of the transformer is also tapped at its mid-point, and a connection is made from this tap to the positive side of the storage battery being charged. The plates of the two Tungar bulbs are wired together, and are connected, through the ammeter, to the negative side of the storage battery.

is a Rectigon charger and the other three are Tungar chargers. Two of the Tungar chargers are very similar to the Rectigon charger, but one Tungar charger is more simple in design and operation than the others.

The rectifiers utilize the property of a vacuum tube (which permits electrical current through it in but one direction) to change alternating current to direct current suitable for battery charging. Before going into the description of the Tungar or Rectigon battery chargers used with Photophone equipment it is better to understand something about the action of the rectifier tubes used in them. This knowledge is particularly important in order to understand the operation of vacuum tubes in the amplifiers which will be described in a later chapter.

While experimenting with incandescent lamps, Edison discovered in 1876, what has since been known as the "Edison effect." He found that, when a source of AC was so connected as to place an alternating voltage between the heated filament of a lamp and a metal plate within the bulb separated from (not touching) the filament, a current would flow from the plate to the filament but not from the filament to the plate.

This effect was subsequently explained as follows:—When any substance is heated to incandescence in a vacuum, it throws off into the space surrounding it vast quantities of invisibly small particles of negative electricity. These particles of negative electricity, as stated in Chapter II, are called electrons. Some substances throw off, or emit, electrons much more readily than others, and the hotter the substance the greater is the number of electrons emitted. The reason for this is that all matter is largely composed of these particles of negative electricity, which are always in rapid and violent motion. The increase of temperature increases the speed and violence of their motion. There is always an attractive force between these electrons and the substance, but when they attain a high speed some of them overcome the attractive force and leave the surface of the substance, only to return again unless some outside force carries them away. If a plate is placed within the tube and kept at a positive potential (voltage) with respect to the heated substance, some of the electrons will be attracted to it and a current will be established. But if the plate is negative with respect to the heated substance, the electrons will be forced back into the surface from which they were emitted and no current will flow. Therefore the tube acts as an electric valve, permitting current to flow in one direction but not in the other.

It will be noticed that in the above discussion it was stated that the electrons flow from a negative, heated substance to a positive plate. This direction of flow is contrary to the usual conception of the direction of flow of electricity, which is considered to be from positive to negative. The reason for this is that before the discovery of electrons, experimenters decided to consider that current flowed from positive to negative as a sort of arbitrary rule. This rule has continued in use even though later experiments seemed to prove the contrary to be true. Therefore, current is always considered to flow from positive to negative, although the electrons actually travel in the opposite direction. The important thing to remember about

55. Method of Operation of the Battery Charging M-G Set.—Before starting the set see that the battery control switch (see Figure 39) is in the "Off" position. Close the four-pole battery change-over switch so as to connect the battery to be charged to the generator. When a DC M-G set is used, close the line switch at the motor starting box. In case an AC to DC M-G set is used, turn the motor snap-switch "On." (This switch is at the lower left-hand side of the charger panel.) The M-G set will automatically come up to speed. Adjust the generator voltage to about eighteen volts by means of the generator field rheostat and turn the battery control switch "On." The ammeter should then show charging current. If it does not, increase the voltage a little so as to close the reverse current relay, and adjust the charging current to the desired value.

If the motor fails to start when the motor switch is closed look for blown fuses in the motor line circuit.

If the ammeter cannot be made to show charging current by manipulation of the generator field rheostat, look for blown fuses in the battery line. These fuses are located in the four-pole change-over switch box. If these fuses are all O.K.

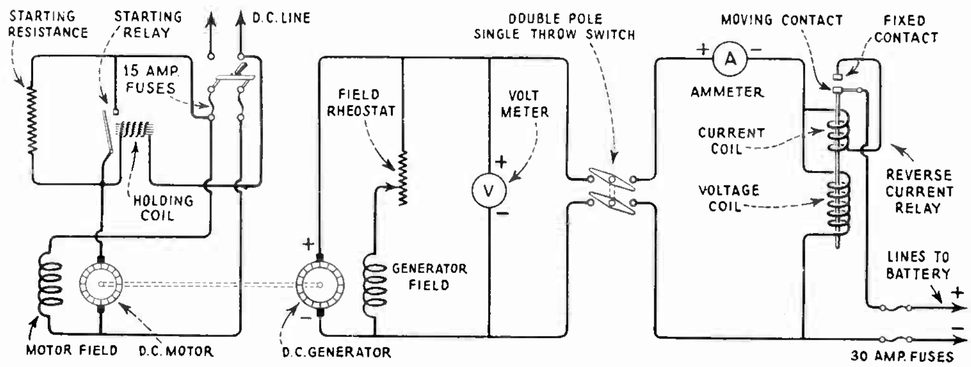


Figure 40—Wiring diagram of DC M-G charging unit

check the generator fuses, which are located at the rear of the M-G set control panel, just under the top of the right-hand side of the perforated cover. The cover can be removed by removing the three nuts at the end of the tie rods which hold the cover in place. After removing the nuts the cover can be lifted off. Do not remove or replace the cover unless all of the power to the set is off, including the connection to the battery. (The motor line switch and the four-pole battery change-over switch should be open.)

In case the reverse current relay sticks, and it is necessary to use a higher voltage than 20 volts to close the contacts of the reverse current relay, call this fact to the attention of the RCA service man at the first opportunity.

Both motor and generator have an oil hole in each end of their housing. Each oil hole is waste-packed and should be oiled about once a week. Several drops of a good grade of medium oil will be sufficient.

56. Tungar and Rectigon Chargers.—In place of the AC to DC motor-generator set previously described, any one of four types of vacuum tube rectifiers are frequently used for battery charging in Photophone equipment. One of the four types switch at the bottom of the panel is turned "On," and then only if the generator voltage is high enough to close the reverse-current relay. The action of this relay is as follows:—When the snap switch is closed the voltage coil is energized, and, if the voltage is high enough, the relay switch will close, connecting the generator to the storage battery. As long as the current is in a direction so as to charge the battery, the current coil of the relay will aid the voltage coil in holding the contacts closed. If the voltage of the generator dropped so as to allow current to flow from the battery to the generator, the current coil would "buck" the voltage coil,

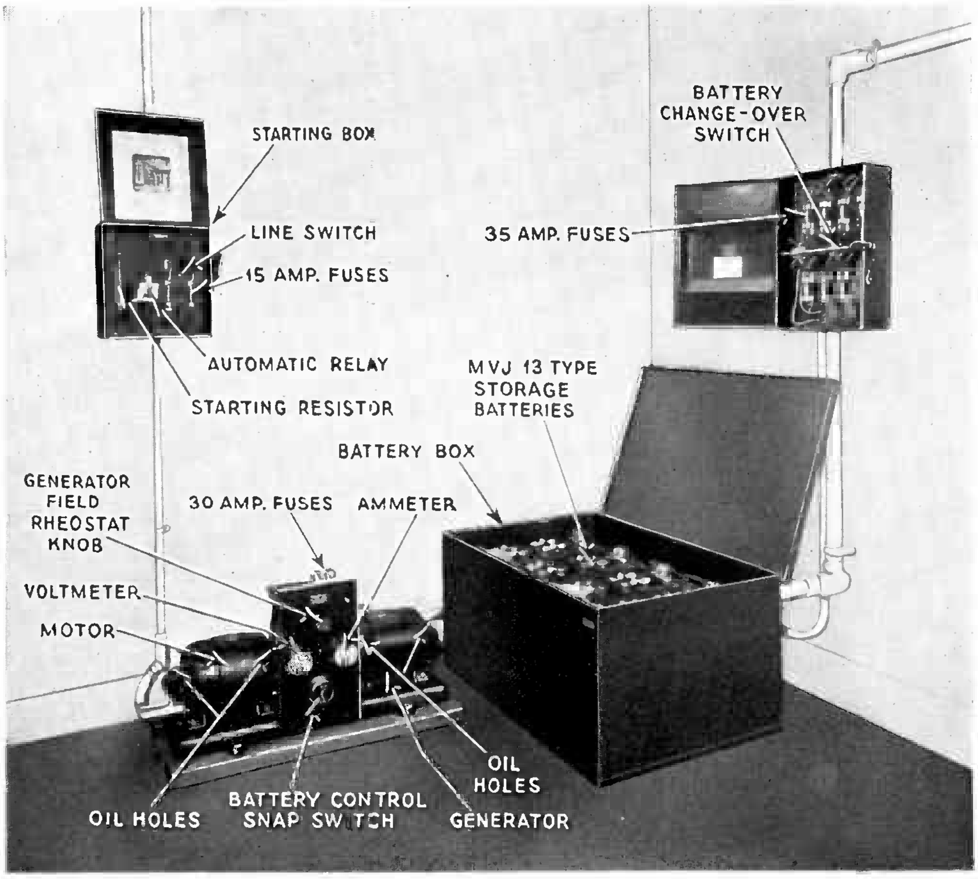


Figure 39—Battery installation for SPU equipments with DC M-G charger

causing the contacts of the reverse current relay to open, and prevent the battery from becoming discharged by running the generator as a motor. There are two fuses of thirty amperes capacity in the battery lines to protect the equipment and battery in case of a short circuit, or an excessively high charging rate.

When an AC motor is used the starting box is omitted, and an additional snap-switch is provided on the panel of the motor-generator set for starting the motor. The AC motor used is a single-phase motor of the repulsion starting type described in Chapter III (section 31), except that the motor used in battery charging sets is larger in size than the projector motor.

CHAPTER V.

BATTERY CHARGERS

52. Types of Battery Chargers.—The battery charging equipment furnished with RCA Photophone equipment can be divided into two general groups:

1. Motor-Generator sets
2. Vacuum tube rectifiers.

The motor-generator sets are used chiefly in DC installations while the vacuum tube rectifiers are used in AC installations, but in some cases a motor-generator battery charger may be used in an AC installation.

53. Motor-Generator Sets.—The battery charging generator is supplied with either an AC or DC driving motor, depending upon the power supply available at the place of installation.

The motor-generator set consists of a motor, either AC or DC, an eighteen volt DC generator and a control panel. When a DC motor is used, a starting box is also provided.

Figure 39 shows a motor-generator set with a DC motor, starting box, batteries, and the "four-pole double-throw" battery change-over switch. The starting box is usually mounted on the wall near the M-G set, and the battery change-over switch is usually mounted near the battery box. Figure 40 shows the schematic circuit diagram of the motor starting box and M-G set. This starting box is the same as that used with the ½ kv-a. DC to AC M-G set described in section 34 (see Figure 27).

54. Description of Operation of DC Motor-Generator Charger.—The motor is started by closing the line switch. This puts the full line voltage across the motor field, and across the armature in series with a resistor. There is a short-circuiting switch across the starting resistor which closes when the motor is near full speed. The short-circuiting switch is actuated by an electro-magnet. The coil of the magnet is connected across the armature of the motor. When the line switch is closed and the motor is at rest, there is no voltage generated in the motor to oppose the line voltage. A very large current would flow through the motor if it were not for the resistor in series with the armature. This resistor limits the current to a safe starting value. As the motor builds up in speed, the generated voltage of the motor increases, and soon reaches a value sufficient to close the magnetic switch, which short-circuits the resistor, thereby connecting the armature directly across the line.

Figure 40 also shows the schematic circuit diagram of the generator circuit. When the M-G set is up to speed the voltmeter on the panel will show the voltage generated by the generator, but no current will flow to the battery until the snap gravity, place it on open circuit; if below 1.195, reset the charging rate to correspond to the specific gravity and the length of the show in hours (use the table on page 57) so that it will be fully charged by the end of the show, when it should be placed on open circuit.

In installations where the charging rate is fixed, the number of hours required to charge the battery can be determined from the table.

Example:—If the specific gravity at the end of the show is 1.170 and the charging rate is 14 amperes find in the left hand column "14 Amps" and run across to the right to "1.170." This is the "10 Hrs." column. The battery should therefore receive 10 hours charge (not more) before the next discharge. This 10 hour charge can be given while the other battery is being used to run the show, or between shows, as most convenient.

Keep lighted cigars and cigarettes and all flames away from the battery. (The gas given off is explosive.)

Keep the battery connections tight.

Loose battery connectors will cause noisy reproduction similar to static in a radio receiver. If the battery connections are loose enough to arc, they are liable to ignite the explosive gas given off by the battery.

51. Care of Type XCR-19 Storage Batteries.—This type of battery is known as the high gravity type. It is used on RCA Photophone equipments PG-1, and PG-2. (See Section 36.) The purpose of the battery is to remove the "ripples" from the generator voltage. Batteries used in this manner are said to be "floating", and require special care.

Keep the outside of the batteries clean and dry.

Keep the separators always covered with electrolyte. (Do this regularly by adding only approved water (distilled if necessary). Keep the solution about one-quarter of an inch above the plates.

Use a hydrometer to determine the state of charge of the battery. (The specific gravity of one cell ("pilot cell") can be used to indicate the state of charge of the battery. The specific gravity when fully charged is between 1.270 and 1.285 and when discharged it is 1.150.

Maintain the voltage across these batteries at thirteen volts while the equipment is in use. This will cause the battery to remain fully charged. However if the specific gravity falls below 1.230 increase the voltage to such a point (slightly above thirteen volts) as will cause the battery to remain fully charged. If the electrolyte level in the battery drops at a greater rate than about one quarter of an inch every two weeks and the battery remains fully charged, the voltage being maintained is too high, and should be reduced slightly. When reducing the voltage see that there is no discharge and measure the specific gravity often.

If it is necessary to charge the battery do not exceed 9 amperes.

Keep lighted cigars, cigarettes, and all flames away from the battery. The gas is explosive.

Keep the battery connections tight.

At least once every six months the battery should be given an equalizing charge. See section 48.

Keep the batteries as fully charged as possible, but with the minimum of overcharge, and they will give better service and have longer life. Never permit the battery to remain in a discharged condition for any length of time.

The charging rate should not exceed 21 amperes. The rate to be used depends on:—

(a) The capacity of the charging equipment. (The rated current output, in amperes, of the charging equipment must not be exceeded.)

(b) The state of charge (Determined by the specific gravity).

(c) The time available for charging.

In installations where the charging rate can be varied:—

(a) At the end of the day's show read the specific gravity of the batteries just used.

(b) Charge at the rate shown in the following table corresponding to this specific gravity and the hours available before the next show.

CHARGING RATE	LENGTH OF CHARGE							
	6 Hrs.	8 Hrs.	10 Hrs.	12 Hrs.	14 Hrs.	16 Hrs.	18 Hrs.	20 Hrs.
4 amps	.....	.....	.....	.....	1.195	1.195	1.195	1.190
5 "	.....	.....	.....	1.195	1.195	1.190	1.190	1.185
6 "	.....	.....	1.195	1.195	1.190	1.185	1.180	1.175
7 "	.....	1.195	1.195	1.190	1.185	1.180	1.175	1.170
8 "	.....	1.195	1.190	1.185	1.180	1.175	1.170	1.160
9 "	.....	1.195	1.190	1.180	1.175	1.170	1.160	1.155
10 "	1.195	1.190	1.185	1.175	1.170	1.160	1.155	1.145
11 "	1.195	1.190	1.180	1.170	1.165	1.155	1.145	1.140
12 "	1.195	1.185	1.175	1.170	1.160	1.150	1.140	1.130
13 "	1.190	1.185	1.175	1.165	1.155	1.145	1.135	1.125
14 "	1.190	1.180	1.170	1.160	1.150	1.135	1.125	.....
15 "	1.190	1.175	1.165	1.155	1.140	1.130	.....	.....
16 "	1.185	1.175	1.160	1.150	1.135	1.125	.....	.....
17 "	1.185	1.170	1.160	1.145	1.130	.....	.....	.....
18 "	1.180	1.170	1.155	1.140	1.125	.....	.....	.....
19 "	1.180	1.165	1.150	1.135	.....	.....	.....	.....
20 "	1.175	1.160	1.145	1.130	.....	.....	.....	.....
21 "	1.175	1.160	1.140	1.125	.....	.....	.....	.....
22 "	1.170	1.155	1.130	.....	.....	.....	.....	.....
23 "	1.165	1.150	1.125	.....	.....	.....	.....	.....
24 "	1.165	1.150	1.125	.....	.....	.....	.....	.....

Example:—If the specific gravity is 1.150, and there are 16 hours before the next show. Find in the column headed "16 Hrs." the value 1.150. About half way down and at the left of the same row with 1.150 will be found the charging rate, 12 amperes, which is to be used.

At the beginning of each show check the specific gravity of both batteries. They should both be above 1.195 unless the preceding show has been unusually long. For the coming show use the battery which was idle the day before. If the other battery (the one on charge) reads above 1.195 in specific

The following rules should be borne in mind by those responsible for the charging of batteries:—

(a) Always charge a storage battery at the lowest rate possible consistent with the time available for charging.

(b) The charging rate can be comparatively high when the battery is in a discharged condition.

(c) The charging rate should be low when the battery is almost fully charged. (Reduce the charging rate when the cells begin to gas freely.)

(d) Never allow storage batteries to get hot (heat is generated in the battery when it is being charged. The nearer the battery is to the fully charged condition, the more heat is generated for a given charging current.)

(C) CARE OF STORAGE BATTERIES USED WITH RCA PHOTOPHONE EQUIPMENT

Two different types of storage batteries are used with Photophone equipment, and the methods of using them are different. Therefore the methods of properly taking care of them differ. The method of caring for these batteries is given separately below.

50. Care of Type MVJ-13 Storage Batteries.—The Type MVJ-13 storage batteries are used on all Photophone equipments where storage batteries are required, with the exception of the PG-1 and PG-2 equipments. The Type MVJ-13 batteries are of the low gravity type and are "manually cycled," *i.e.*, their charging has to be taken care of by the operator.

Keep the outside of the batteries clean and dry.

Keep the separators always covered with electrolyte. Do this regularly by adding only approved water (distilled if necessary). Keep the level of the electrolyte one-quarter of an inch above the top of the plates. *Never add acid, or anything else than pure water to the battery.*

Use a hydrometer to determine the state of charge of the battery.

The specific gravity of battery electrolyte can be determined by taking the specific gravity reading of one cell, called the "pilot cell." See section 46.

Never discharge an MVJ-13 battery below 1.150 specific gravity, except in an emergency. The specific gravity when fully charged is between 1.200 and 1.220. Do not attempt to bring the hydrometer reading above 1.220 or the battery may be ruined. In some cells the gravity may not go above 1.200. It is commercially impracticable to have the gravity of all cells exactly 1.220 when fully charged, and there is, therefore, a commercial tolerance of 1.200 to 1.220. Determine the "fully charged" specific gravity of the pilot cell by slightly over-charging it (until the specific gravity reading does not change for an hour), and use this figure to determine the state of charge in all future chargings.

charge of the entire battery. When two batteries are connected in series as used in Photophone equipment, the condition of both batteries can be determined from one cell. Select one cell for this purpose and always use it when taking readings.

It is practically impossible to take readings from a cell continuously without losing some of the electrolyte. Therefore, about once every three months select a new pilot cell. In this way the amount of electrolyte lost from all cells will be about equal.

When selecting a new cell for use as a pilot cell, charge the battery until the cell shows no further increase in specific gravity for a period of one hour (take half-hourly readings) and use this value as the "fully charged" indication for all future specific gravity readings taken on that cell.

47. Condition of Charge of the Batteries as Indicated by the Hydrometer Readings.—The specific gravity of the electrolyte of a fully charged battery is high, and becomes lower as the battery is discharged. If the charging current is continued after the battery has been fully charged, the specific gravity will not increase. The cell will gas freely because the only transformation which will take place in the cell, is the transformation of water into its component gases, namely, hydrogen and oxygen. A battery should never be fully discharged, that is, it should never be discharged until it will no longer deliver current or the battery will be harmed. In case of an emergency when it is necessary to continue the discharge of the battery below the limit set for routine operation, it should be recharged immediately. *A battery left in a discharged condition deteriorates rapidly.*

48. Equalizing Charge.—Storage batteries should be periodically given what is called an "equalizing charge." An equalizing charge is a continuation of the regular charge (but at a lower rate) until the cells gas freely, and until half-hourly readings of the specific gravity of the pilot cell shows no further increase over a period of one hour.

49. Factors Affecting the Charging Rate.—A battery may be charged at a fairly high rate when it is in a discharged condition without detrimental effects, but when a battery is almost fully charged a low rate of charge is desirable.

The battery should not get hot when charged. The temperature of the battery increases when it is being charged, but it should never be allowed to exceed 115 degrees Fahrenheit. (This temperature is just a little above that which is termed "luke-warm.") Feeling the outside of the battery does not give a good indication as to the temperature of the battery, because it requires considerable time before the outside of the case is heated by the electrolyte.

When a battery is almost fully charged it will gas strongly. This gassing is very similar to boiling, and causes the chemicals of the plates to loosen and drop off. This loosened matter settles to the bottom of the battery in the sediment space provided. If the rate of charging is reduced the gassing is reduced, with the result that only a very little of the chemicals are lost as compared with what would be lost if the batteries were charged at a high rate.

it sinks until the weight of the liquid displaced is exactly equal to the weight of the body. If the liquid is dense (has a high specific gravity), the body will not sink as far as it would in a liquid of lower specific gravity. An example of this is shown when a piece of wood is floated in water. The wood will sink to an appreciable depth in water, but the depth to which it would sink in mercury (quicksilver) is hardly noticeable. In fact, mercury will give a greater buoyancy to iron than water will give to ordinary wood. Therefore the depth to which a body sinks in a liquid is an indication of the specific gravity of the liquid. Such a body, calibrated to read the specific gravity of a liquid, is called a hydrometer.

Figure 38 is a drawing of a syringe hydrometer of the type used to measure the specific gravity of the storage battery electrolyte. It consists of a glass float (hydrometer) in a glass barrel. At the top of the barrel is a rubber bulb and at the bottom a rubber nozzle. The float consists of a small glass tube sealed at both ends to prevent the liquid from entering it. In the lower end of the tube are lead shot-weights, held in place by sealing wax, to weight that end of the float down so that it will float in an upright position. The upper part of the tube is a thin neck graduated in lines which are numbered to indicate the specific gravity of the liquid tested. Because the neck of the tube is of small diameter it is necessary for the tube to sink, or rise, considerably for each slight change of specific gravity of the liquid tested.

45. Using a Syringe Hydrometer to Determine the Specific Gravity of Battery Electrolyte.—When using a syringe hydrometer to determine the specific gravity of the electrolyte of a storage battery, first insert the nozzle of the syringe into the cell and squeeze the bulb, and then slowly release the bulb to draw up just enough electrolyte from the cell to freely float the hydrometer. Be sure that no large air bubbles cling to the sides of the hydrometer, and that it does not stick to the glass barrel. Shake the instrument a little to make sure that the glass float is entirely released when the reading is taken. The reading on the stem of the hydrometer at the surface of the liquid is the specific gravity of the electrolyte. Return the electrolyte to the cell from which it was taken, making sure that all the electrolyte is out of the syringe before removing it from the cell. It is a good plan to keep the nozzle of the syringe in the cell when a specific gravity reading is being taken, because electrolyte is almost sure to drip out and some of it will be lost. Besides, the electrolyte dropped on the top of the battery or other objects will cause corrosion unless cleaned off promptly.

Never measure the specific gravity of a cell immediately after adding water. Such a reading would not give the specific gravity of the electrolyte in the cell because the acid at the top of the cell would be diluted. After adding water, charge the battery until it gases freely before taking the next specific gravity reading.

A cheap hydrometer may be in error by as much as 30 points and should not be used.

46. Pilot Cell.—It is not necessary to take specific gravity readings of all the cells of a battery. The reading of one cell will give an indication of the state of

The importance of keeping storage batteries clean can not be overstressed. Aside from the unsightliness of a dirty battery, the accumulation of dirt, moisture and acid on the battery shortens the life of the battery by producing a leakage path for the current between terminals. This leakage current would not be the same for all the cells, with the result that it would be difficult to keep all the cells at the same condition of charge. Therefore some of the cells would have to be overcharged to fully charge the entire battery. Corrosion of the terminals would spoil the electrical connections, and might cause disturbing noises in the reproduction of sound.

42. **Adding Water to Batteries.**—Water must be added to each cell regularly, and the electrolyte should never be allowed to get below the top of the separators. They should never be filled higher than just below the bottom of the filling tubes, because there should always be room above the liquid for the gases to escape freely. The electrolyte expands when heated and its level rises. If the cells are filled too high, some of the electrolyte will be lost when the batteries gas, as they always do when being charged or discharged. Therefore, the best practice is to keep the electrolyte level about one-quarter of an inch above the plates by frequent fillings and thereby avoid all possibility of losing electrolyte. The frequency with which water should be added depends on how much the batteries are used. When used continuously they should be inspected daily. The water should be added just before charging, as this causes the water to mix thoroughly with the electrolyte.

Use pure distilled or other approved water only. Ordinary water often contains minerals and other impurities harmful to the batteries. When in doubt about the quality of other water, use distilled water.

Water used for filling storage batteries should not be stored in any metallic vessel (lead excepted). Glass, earthenware, rubber, lead or wooden receptacles that have never been used for any other purpose are satisfactory. If water is drawn from a tap, it should be allowed to run a few minutes before using it.

Never add acid under any circumstances. The acid is not "used up" by the chemical reaction in the battery and never needs replenishment.

43. **Checking the Condition of Charge of Storage Batteries.**—The most reliable means of checking the condition of charge of a storage battery is that of measuring the specific gravity of the electrolyte. The specific gravity of any substance is the ratio of weight of a given volume of the substance to the weight of an equal volume of water. The specific gravity of pure sulphuric acid is about 1.83; that is, a quart of pure sulphuric acid weighs 1.83 times as much as a quart of water. If water and sulphuric acid are mixed together, the specific gravity of the solution will be something between 1 and 1.83 depending on the percentage of acid in the solution. The percentage of acid in the solution can therefore be determined by measuring the specific gravity of the solution.

44. **Hydrometer As a Means of Measuring Specific Gravity.**—A hydrometer is a convenient instrument for measuring the specific gravity of a liquid. The principle upon which the hydrometer is based is as follows:—If a body is floated in a liquid

Hydrogen burns with explosive force in an atmosphere of air or oxygen. For this reason flames and sparks should be kept away from storage batteries at all times.

(B) CARE OF BATTERIES—GENERAL

A storage battery can be charged and discharged for an indefinite period if properly taken care of.

41. Cleanliness.—The batteries should be kept clean and dry. If electrolyte is spilled or if any parts are damp with acid, apply a solution of baking soda or ammonia, then rinse well with water and dry the battery. *The cleaning solution should not be allowed to get into the cells.* A suitable solution of baking soda can be

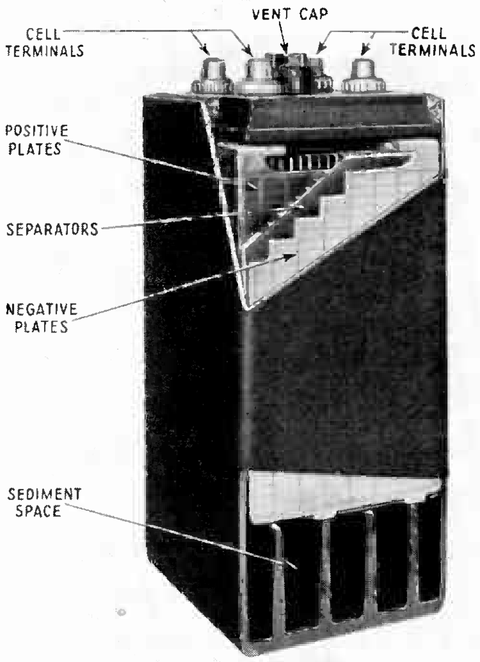


Figure 37—Sectional view of Type MVJ-13 storage cell

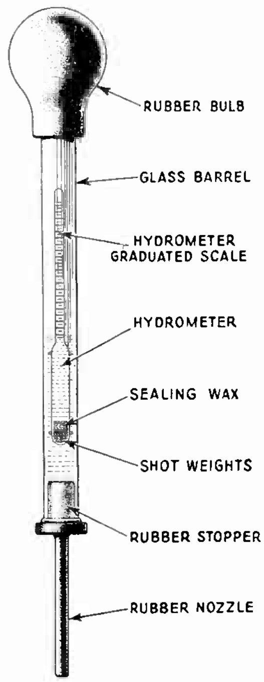


Figure 38—Hydrometer

made up by dissolving a pound of ordinary baking soda in a gallon of water. Ordinary household ammonia is equally satisfactory so far as neutralizing the acid is concerned, but its strong odor is often found to be objectionable.

Sulphuric acid is very corrosive in its action and will ruin clothing if allowed to remain for even a short time. It should be neutralized immediately when spilled so as to prevent corrosion. If the terminals of the battery are corroded they should be scraped clean, washed with a soda or ammonia solution and rinsed thoroughly. After they have dried, a thin layer of vaseline should be applied to prevent further corrosion. Vaseline can be applied easily, by means of a small paint brush, if it is heated to make it a liquid. *There will be no corrosion unless electrolyte is spilled and allowed to remain unneutralized.*

CHAPTER IV

STORAGE BATTERIES

(A) GENERAL DISCUSSION

38. **Types of Batteries Used.**—The storage batteries furnished with RCA Photophone equipment are of two types, the low gravity and the high gravity. The low gravity type is used to supply the necessary low voltage direct current for lighting the exciter lamps, Radiotrons, etc. The high gravity type is used when the battery is "floated" or connected permanently across a low voltage generator. The purpose of the "floated" battery is to filter out the "commutator ripple" of the low voltage generator which supplies the current for lighting the exciter lamps, Radiotrons, etc.

39. **Description.** Each battery is composed of three sections, or cells. Each cell contains two groups of plates, positive and negative, immersed in a sulphuric acid solution, called the electrolyte. The positive plates of a fully charged battery are lead peroxide and are reddish brown in color. The negative plates are of spongy lead and are grey in color. A porous non-conducting material is used to separate the positive and negative plates. Figure 37 shows an Exide storage battery with part of the side cut away to show plates, separators, and sediment space.

40. **Chemical Action of Charging and Discharging the Battery.**—When the battery is discharged, *i.e.*, when current is drawn from it, two things occur. The acid acts on the negative plates to form lead sulphate and hydrogen, and on the positive plates to form lead sulphate, water, and oxygen. Since sulphuric acid combines with the elements of the plates to form a deposit on the plates, the acid solution becomes weaker as the battery is discharged.

After a certain period of use, the chemical action taking place in the battery will exhaust it, and the battery must be recharged. To do this, a direct current from a generator or other source is passed through the battery in the direction opposite to that in which the current flows when the battery is discharged, and the chemical action is reversed. Lead sulphate and water combine to form lead, sulphuric acid, and oxygen at the negative plates; and lead sulphate and water combine to form lead peroxide, hydrogen, and sulphuric acid at the positive plates.

Since sulphuric acid is formed, the acid solution becomes stronger as the battery is charged.

The hydrogen and oxygen formed are gases, which escape through the vent caps of the battery. If these two gases are combined, by burning, they form water. Therefore, water is "used up" both when the battery is charged and when it is discharged, and needs to be replaced periodically to keep the acid solution above the plates.