RADIO CONDENSERS, THEIR FUNCTION AND OPERATION

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SUCCESS AND HAPPINESS

I hope you have been reading and thinking about the short personal messages that appear on the inside of the front cover of the various lesson texts.

I would like to have you feel, as you read them before tackling a new lesson, that you are in my office with me, listening to a word of advice or cheer, prompted by my desire to be of real help to you. As I see it, my responsibility to you goes farther than to give you the very best Radio training I can—I want to help you get the most out of life—to attain a real happiness.

I hope you will realize that my many years of contact with thousands of ambitious men in all parts of the world, have taught me how to be a helpful friend to you. And in these "minute talks" I give you the benefit of what I have learned during my years of contact with N. R. I. men.

You, in common with all other N. R. I. men, desire Success. But behind your desire for Success is the desire for Happiness. You think that Success will bring Happiness. But such is not necessarily the case. I believe that you must train yourself for Happiness just as you must train yourself for Success.

Many a successful man today is not happy—just because he did not realize this important truth.

The first thing we must understand about Happiness is that it **comes from within!** External things—money, success, friends, do not make us happy or even satisfied with our lot. Happiness is a state of mind and unless we learn how to be happy within ourselves, we might have money, success, friends, everything we want, and still be unhappy.

So in some of these minute talks of mine, I am going to try to help you learn how to get the most happiness out of the Success there is in store for you.

J. E. SMITH

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Radio Condensers—Their Function and Operation

Capacity

The meaning of the word "capacity" as it is commonly used, is familiar to all of us. We talk about the capacity of a tank, the capacity of a freight car. In Radio we talk about the capacity of a *condenser*—that is, how much electricity or electrons a condenser can hold.

In Radio circuits, *condensers* play as important a part as the inductance coils, in fact, the two are nearly always used together. Condensers are of two main types—*fixed* and *variable*. Fixed condensers, used for by-passing Radio frequency currents, for blocking direct currents, as grid condensers, as coupling condensers, etc., have a constant capacity. The variable condensers used for tuning, balancing, controlling regeneration, etc., are arranged so that their capacity may be varied.

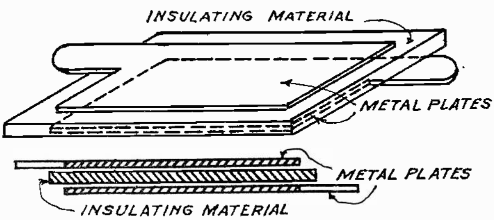


Fig. 1—Constructional Details of a Simple Condenser.

The constructional details of a simple fixed condenser are shown in Fig. 1. It consists essentially of two metallic parallel plates, generally made of tinfoil, copper or aluminum sheets separated by an *insulating* medium known as the *dielectric* of the condenser, which may be glass, mica, celluloid, oil, waxed paper or even air. Various types of commercial fixed condensers are shown in Fig. 2.

A typical variable condenser is shown in Fig. 3. This type of condenser consists of two sets of plates, one stationary (called the "stator") and the other rotating (called the "rotor"). The rotor plates interleaf between the fixed plates without touching them.

The capacity is varied by moving the rotor plates in and out of the stator plates.

When the rotor plates are completely out of mesh with the stator plates, the capacity of the condenser is least because the smallest areas of the plates are exposed to each other. It is greatest when the two sets of plates are completely intermeshed. For any positions between these, various intermediate capacities exist.

Condensers are by no means strange devices to most of us, and Figs. 1, 2, and 3 recall them to us. Condensers as capacities, "storerooms" for electricity is a new idea. What do we mean by storing electricity? We can store sugar in a barrel and gasoline in a tank. We realize these facts easily because we can actually see sugar, water and gasoline. In the same way we can store (charge) a condenser with electrons, actual little particles of electricity. Try to form a mental picture of these electrons, that really exist.

Fig. 2—Various Types of Fixed Condensers.

In any conductor millions of electrons are roaming around freely, held in the conductor by positive charges which prevent them, so to speak, from spilling out. Yet they can be withdrawn.

Figure 4 shows a water tank filled with water. Water is prevented from flowing out by a stop cock V. Should we open the valve V, the water will flow out. Place the palm of your hand under the valve and open it—a large force will push down on your hand. There is a force, a pressure, pushing the water out.

Take a large metallic ball; set it on an insulated stick and connect it to the ground through a wire W in which there is an electric valve S (a switch). (See Fig. 5.) In this case we open the switch S and electrons are stored in the ball. (How this is done will be explained shortly.) How can we prove that electricity is stored in it? Place little pieces of tissue paper on

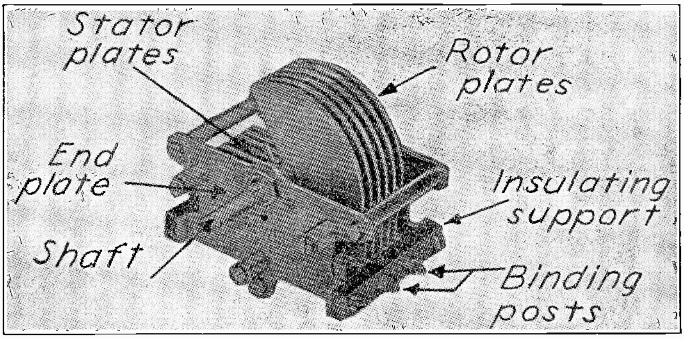


Fig. 3—Variable Condenser.

it and they will be shot off. Has it a pressure? Yes. Place a voltmeter across the open switch and a voltage (electrical pressure) will be indicated. Close the switch and the electrons will leak off to the ground.

In both cases, however, the stored material has been scattered so that it cannot be put to any good use.

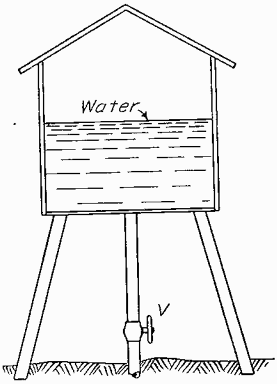


Fig. 4

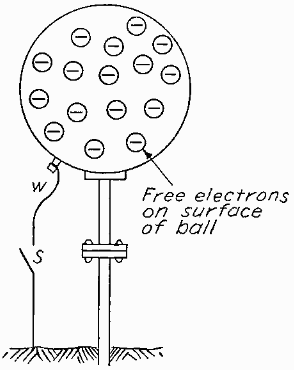


Fig. 5

Figure 6 (a) shows two water tanks connected together, the left-hand tank A is filled with water which is prevented from flowing into B by the valve V. Open the valve and a current of water will flow in the pipe and B will fill up until there is an equal amount of water in each tank.

Compare this with 6(b), two metal plates, close together, but insulated from each other by the open switch S. Note that plate A is charged, it has twice as many negative electrons as positive charges, while plate B has been robbed of half its electrons. Close the switch and the extra negative electrons will divide themselves equally between the two plates. In this rearrangement electrons flow through the conductor C from plate A to plate B. Don't forget that we said before that when electrons flow through a wire, we have a flow of current. The final conditions are shown in 6(c) and 6(d).

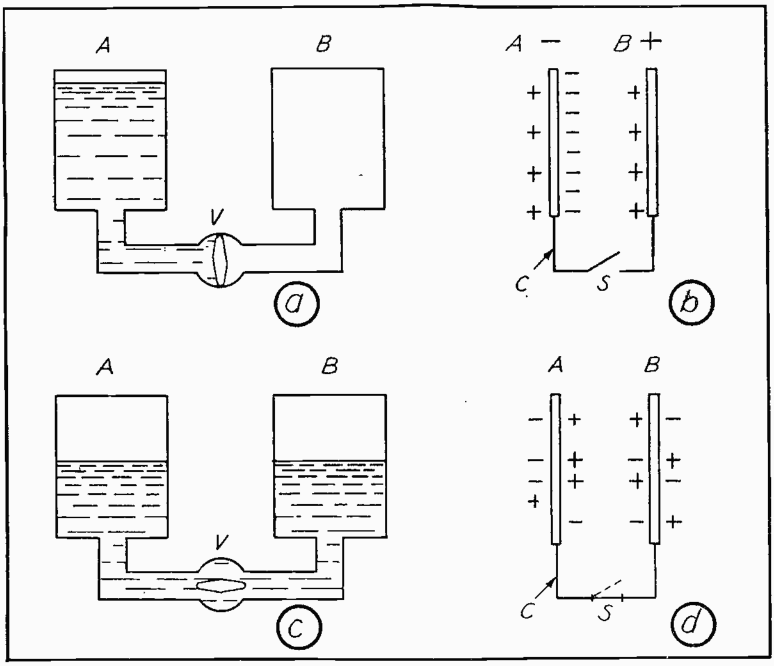


Fig. 6

ACTION OF A CONDENSER

Figure 7 will help us get an idea of how a condenser is charged with direct current. The upper electric circuit to the right of the diagram shows a battery connected to a condenser, but the circuit is incomplete because the switch is open. To the left is a tank connected to a rotary water pump and the tank is divided in the middle by a water-tight rubber diaphragm stretched across it. Obviously this divides the tank into two portions and as the pump is rotated in the counter clockwise direction, water is withdrawn from compartment "A" and forced into compartment "B." This is clearly brought out in the sketch below which really indicates that the diaphragm has been stretched, a force has been exerted on it. In a sense we can say that the tank has been charged, because if no more mechanical energy was applied to the pump, the diaphragm would force the water back through the pump causing it to rotate in the opposite direction, therefore, delivering power and leveling the water in compartment "A."

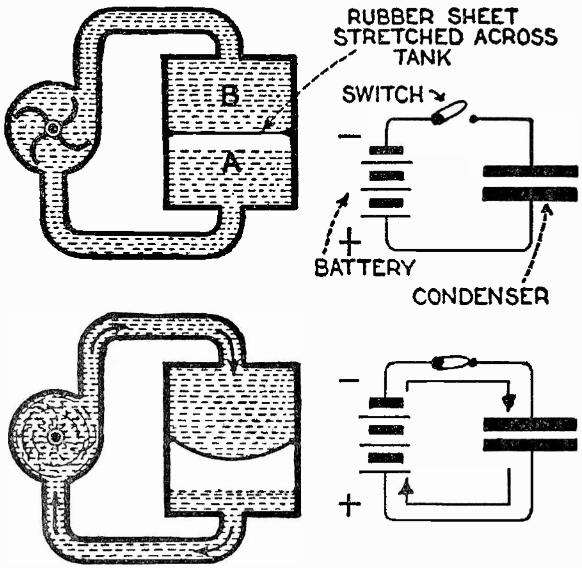


Fig. 7—Hydraulic Analogy Showing How a Condenser Is Charged With Direct Current

Let us see how close this is to the electrical condition in which we are vitally interested. But first let us review a few of the fundamental electrical concepts. We understand that a condenser consists of metal plates separated by insulating material, and both plates ordinarily have an equal amount of positive and negative charges and the positive, we must understand, cannot be separated from the metal plates. Then let us get a clear picture of what we mean by a battery and particularly, what we mean by saying that it develops an e.m.f. A source of e.m.f. is really nothing more than an electrical pump which has a positive and negative terminal. The positive terminal has the electrical property of drawing electrons to it. The negative side has the property of delivering electrons to a circuit. Therefore, in

Fig. 7 we have a battery with a positive terminal ready to draw electrons out of the lower plate of the condenser and a negative terminal from which electrons are forced into the upper plate. The lower right diagram of Fig. 7 shows this clearly. The lower plate of the condenser is robbed of electrons and these are returned through the wire to the upper plate. (This explains how the metal ball was charged in the previous discussion; an e.m.f. was connected between the ball and the switch, and the latter closed for a moment until the ball was charged to the limit of its capacity.)

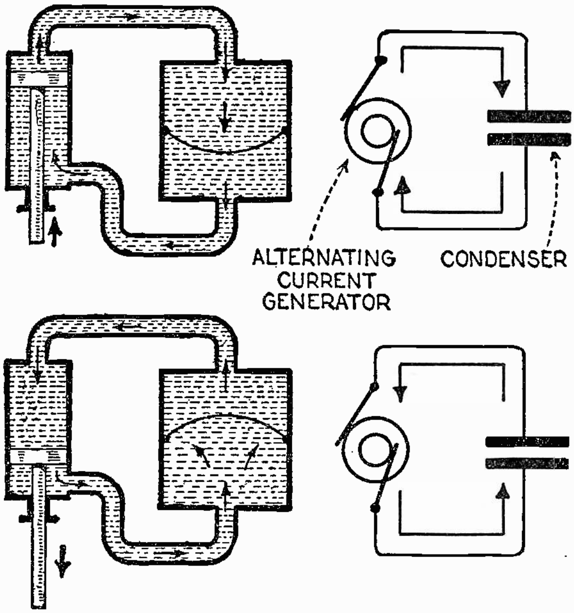


Fig. 8—Hydraulic Analogy Illustrating the Flow of Alternating Current Through a Condenser.

When the e.m.f. or battery is removed the electrical power stored in the condenser can be used, just as the charge in the water tank in Fig. 7 was used to turn the pump backwards.

If we increase the diameter and length of the tank, we can increase the amount of water it can store. This naturally increases the surface area of the tank. If a large amount of water is to be stored, we use a tank with a large surface area. Now the chief purpose of a condenser is to store electrical energy; therefore, we can see that the greater the surface area of the plates, the more electrical energy can be stored.

It is impracticable, for many reasons, to use condensers which have very large plates. To obtain a large capacity for Radio work, it is necessary to construct the condenser of several plates connected as shown in Fig. 3. This amounts to the same thing as having fewer plates with larger surface areas.

CHARGING A CONDENSER

Now, let us consider how a *simple condenser* can be charged using a 6 volt battery, switch (S) and a galvanometer (G) (an instrument which indicates the presence of very small electric currents) connected as shown in Fig. 9. When the plates of the condenser are connected by means of the metallic conductor to the battery, (or some other source of constant e.m.f) a certain difference of potential (one plate will be negatively charged and the other we say is positively charged) will be established between the two plates. When the switch "S" is

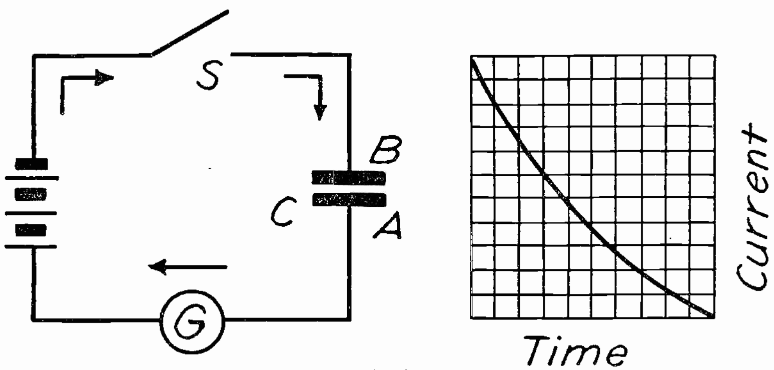


Fig. 9

closed, it will be found that a momentary current will flow, which will be indicated by the needle of the galvanometer "G," But this current will soon stop flowing even though the battery still has an e.m.f. of 6 volts. You must realize that 6 volts can only withdraw from one condenser plate a definite amount of electrons· When the negative side of the condenser is charged to a point where the difference of potential between it and the other plate is 6 volts, charging stops, that is, no current will flow from the battery.

This stopping of current shows that the condenser is fully charged and it has developed an electromotive force equal, but opposite to the applied e.m.f. In order that the difference of potential (an e.m.f.) exists between plates "A" and "B," the electrons in the circuit must have been redistributed; that is, a certain number of electrons was removed from the positive plate "A" and a like number deposited on the negative plate "B." The transfer of these electrons, from one plate of the condenser to the other plate, is effected through the metallic circuit in which the battery is connected. The battery acts as a pump, drawing the electrons off one plate of the condenser and forcing them onto the other plate.

During the time that this transfer of electrons is being effected, an electric current flows in the external circuit.

Thus, the plates of the condenser become *charged* with electricity of opposite polarities, the plate carrying the excess of electrons acquiring a *negative charge* while the one from which they are removed acquires a *positive charge*. Furthermore, a condition of electrostatic tension (force) is established in the dielectric between the positive and negative plates which acts in

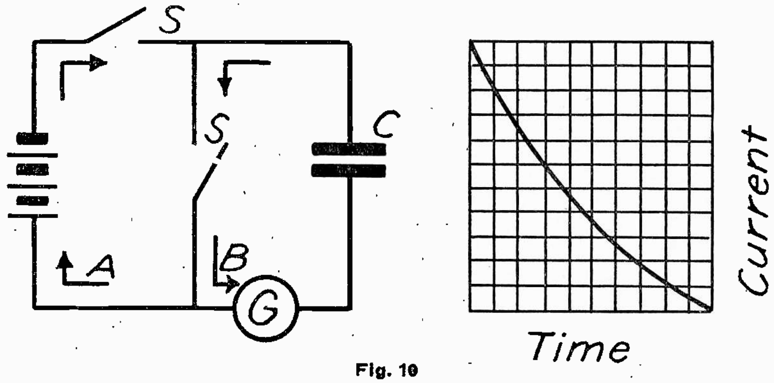


Fig. 10

opposition to the electromotive force of the battery. If the switch "S" is opened and a voltmeter applied to "A" and "B" it will be found that the condenser has an e.m.f. which is the result of the charging.

It is obvious then, that if the two charged plates of the condenser were suddenly connected together by a metallic conductor, across the dielectric, a flow of electrons would take place from the negative plate to the positive plate.

DISCHARGING A CONDENSER

In Fig. 10, we have connected to the previous circuit (Fig. 9) another switch "S-1." When switch "S" is closed and "S-1" is open, the plates of the condenser will receive a charge, the potential difference of which is the same as that of the battery. If switch "S" is then opened and "S-1" is closed, the galvanometer "G" will indicate a flow of current, but in the opposite direction showing that the condenser is discharging. In other words, the difference in distribution of electrons on the condenser plates is being equalized by means of a current flow from one plate to the other.

The negative plate, now instead of receiving electrons as it did when being charged, is losing electrons which explains why the electrons will flow in the opposite direction when discharging.

As was previously stated, the condenser when charged developed a back pressure in opposition to the electromotive force of the battery. At full charge it balances the applied e.m.f. and current flow stops. At the instant charging starts the amount of current is at maximum but it quickly tapers off to zero as shown by the graph in Fig. 9.

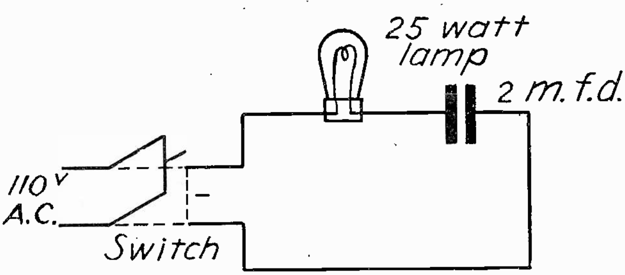


Fig. 11

Likewise when a condenser is discharged, the current flow is greatest at the instant of short-circuiting. This rapidly tapers off as shown by the graph in Fig. 10. Were it not for the resistance in the circuit, the condenser would discharge instantaneously. But because of this resistance, the current tapers off.

ALTERNATING CURRENT FLOW IN A CONDENSER CIRCUIT

The action of a condenser in an alternating current circuit is quite different from that of a direct current circuit.

This difference can be illustrated very easily by connecting a 2-mfd. capacity condenser in series with a 25-watt light bulb to a 110-volt alternating current house lighting circuit. (See Fig. 11.) With this arrangement you will find that the bulb will light, but with the same arrangement on a direct current circuit it would not light, because the electrons in a D.C. circuit are going in one direction and when the condenser is fully charged, it exerts a back e.m.f. which balances the applied e.m.f. and current flow stops.

There will, however, be a force urging the electrons to cross over from the negative plate to the positive plate but the insulation between the two sets of plates prevents them from going across, thus a condenser effectively blocks a *direct current* from flowing around the circuit after it is once charged.

When an *alternating current* is used the impressed e.m.f. continually rises in magnitude and changes in direction. The condenser is charged to the extent of the amplitude of one alternation. When the A.C. voltage reverses its direction, it charges the condenser in the opposite direction. Thus the plates of the condenser are alternately charged and discharged, when one is negative the other is positive and so on, following the alternations of the A.C. current.

This continual charging and discharging of the condenser by-passes or allows a continual flow of electrons back and forth through the light bulb and the connecting wires, even though we have practically an open circuit between the two sets of plates of the condenser.

The current that flows in such a circuit, as in Fig. 11, is an A.C. current. An important thing to remember is that when a condenser is being alternately charged and discharged by an A.C. e.m.f., the current that flows depends upon the strength of the e.m.f., the size of the capacity, and the frequency of the A.C. The greater the frequency the greater the movement of electrons, that is, the flow of current.

OSCILLATORY CIRCUITS

We have now had an introduction to the three important quantities used in Radio receivers and transmitters, namely, *resistance, inductance,* and *capacity.* In many cases you will have all three connected together in series and the condenser charged. What will happen?

In Fig. 12 we have a capacity "C" in series with an inductance "L" and a resistance "R." The resistance "R" represents the direct current resistance of the inductance. It is never possible to have an inductance without having it contain some direct current resistance, and in order to bring out some of the fundamental principles, this direct current resistance is shown separately. The battery "B" is connected to this circuit by means of two switches "S" and "S-1." When "S-1" is open and "S" is closed, the battery e.m.f. will find a path through the resistance "R," the inductance "L," to the condenser "C," and in so doing, the condenser "C" will gradually assume a charge until the potential difference between the two plates is equal to the potential of the battery. From our previous study, we have found that if a circuit is provided to discharge the condenser, it will gradually give off whatever charge it holds until its plates come to a state where no potential difference exists between the two.

When switch "S-1" is open and switch "S" is closed, the battery will gradually charge the condenser until it assumes a potential equal to that of the battery. Now by opening switch "S," the battery circuit is opened and the condenser remains in a charged position. Now let us close switch "S-1" so that a complete circuit is provided for the condenser to discharge. At the instant the switch "S-1" is closed, electrons rush out of one condenser plate in order to equalize the other. In proceeding through the circuit, the electrons passes through resistance "R" and inductance "L."

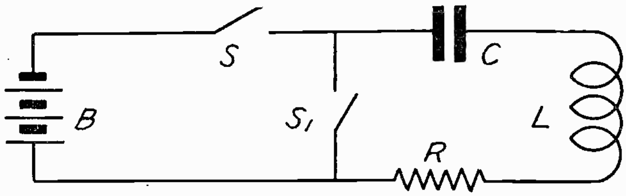


Fig. 12—Fundamental Oscillatory Circuit.

Naturally when current flows through the resistance power is lost, as we have already learned. This loss is equal to I^2R.* On the other hand, the current in flowing through the inductance builds up a magnetic field around it, storing within it electrical magnetic energy. The result is that although the condenser charge has been neutralized the condenser no longer has a difference of potential, some of the energy of the condenser is stored in the inductance.

As the inductance cannot hold its magnetic energy after the condenser has lost its e.m.f., it naturally gives up its energy, which collapses on the wires, inducing an e.m.f. in the coil and this e.m.f. charges the condenser again but in the opposite direction. Of course, this is accompanied by a flow of current and more energy is lost in the resistance, in the form of an I^2R loss.

Then the condenser discharges again in an attempt to equalize the electrons on the two plates and again energy is lost

*The amount of power dissipated as heat in circuit resistance is equal to the square of the current multiplied by resistance (IxIxR) and thus power is measured in watts.

in the resistance. But enough energy remains to create a magnetic field about the inductance. The polarity of which reverses when the direction of current reverses. This magnetic field is of opposite polarity but, nevertheless, energy is stored. When the condenser has given up all of its energy the inductance proceeds as before, its magnetic field collapses on it, and delivers an e.m.f., which charges the condenser in the original condition but much less than previously because of the I^2R losses.

The process continues and with every charge and discharge of the condenser, power is lost in the resistance and the quantity of electricity stored becomes less and less.

You can get the idea a little better perhaps by looking at Fig. 13. This illustration shows a heavy weight hung on a spring in a normal position of rest O. Suppose we pull the weight down and let go. What happens? When we let go, the

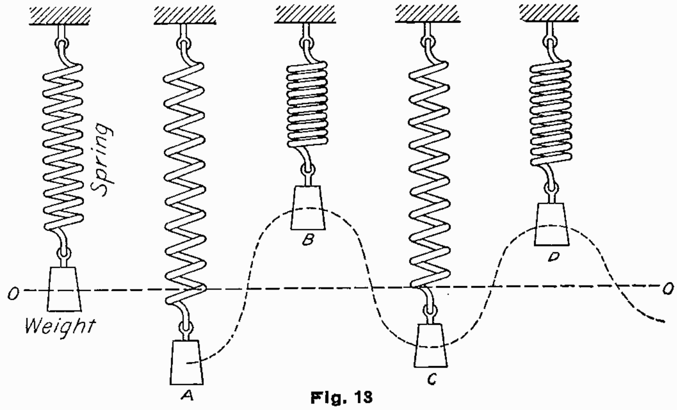
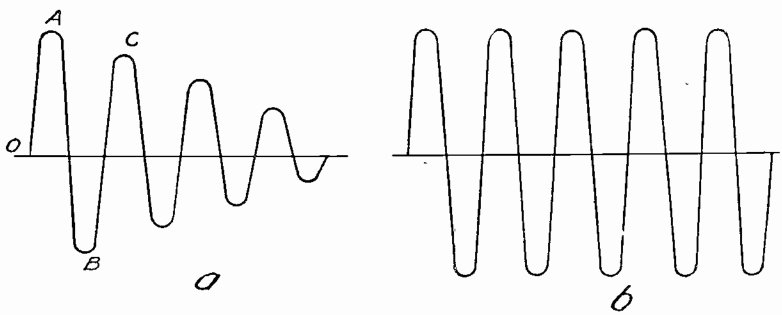


Fig. 13

weight is in the position A. The spring then pulls the weight upward until it reaches the point B, then the weight falls down again below the original position O to the position C. You will notice that position C is not as low as position A. The spring then pulls it upward again to the position D. The weight thus oscillates up and down with a decrease in its amplitude during each oscillation. Now let us consider in detail what goes on during this oscillation.

When we pulled the weight down we had to exert a certain force, and this produced a tension in the spring, due to our stretching it. Therefore, energy was put into the spring. Now, when we let go of the weight, the tension or energy in the spring pulls up the weight. In pulling up the weight, the spring gives up all of its energy, excepting a small part, to the weight. The energy which the weight does not receive is lost in friction with the air. The weight finally gets to the top of its journey and no longer moves upward. It is clear that since the spring no longer pulls the weight upward that it has lost all of its energy. Where has this energy gone? The answer is, all the energy that was not lost in friction has been given to the weight. It is clear that this must be so, for at that instant the weight begins to move downward. In moving down, the weight gradually returns its energy to the spring by stretching it, for soon the weight stops moving downward as the spring is stretched to its limit and then moves upward again, repeating the whole process of transferring energy from one place to another. But gradually the system oscillates with decreased amplitude until finally it comes to rest, after all the energy in the system has been used up in friction with the air.



Damped Wave Fig. 14 Undamped Wave

The coil and condenser act in a very similar manner, as we have seen. The energy in the spring may be likened to the charge (or voltage) of the condenser. The coil takes the part of the weight. The up and down motion of the spring and weight is like the to and fro motion of the electrons in the electric circuit.

If we were to place an oscilloscope, such as we have described before, into the circuit, Fig. 12, we could get a picture of the flow of current and it would appear exactly like Fig. 14(a). Such a variation of current is referred to as an oscillation, and in this particular case, as a *damped wave* oscillation because the oscillations die off rapidly. Of course, it is not really a wave. It is nothing more than a picture of current variations as they would appear if we watched them through the oscilloscope. You will learn later how rapid oscillations produce electromagnetic waves which we know are Radio waves. Although we refer to these as waves, to be absolutely correct we should talk about them as damped wave current oscillations, for they are really in current form.

If we were to remove the resistance "R" from the circuit in Fig. 12 (which, by the way, would be impossible, as we could not build a capacity "C" or inductance "L" without some resistance) we would find that no energy would be lost in the successive discharges of the condenser and we would have what is known as an undamped current oscillation, as shown in Fig. 14(b). More often we call this particular variation in current a continuous wave oscillation. Just how we can obtain an effect equivalent to removing R we shall learn later. No doubt, you have heard the word C. W. transmitter. It is the continuous wave transmitter that is used in all broadcasting stations and in all modern Radiotelegraph transmitters.

The damping quality or the dying away of a wave is governed by the amount of resistance in the oscillatory circuit. The greater the resistance included in the oscillatory circuit, the shorter the time will be before the current in the circuit ceases to flow. If the resistance in the circuit is low, the current tends to oscillate for a greater length of time.

MEASURES OF CAPACITY

The capacity of a condenser to store electrical energy depends on *four* things, (1) *the surface area or size of its plates,* (2) *the number of plates in the condenser,* (3) *the separation of the plates or thickness of the dielectric (insulation) between them,* and (4) *the substance used for the dielectric between the plates.*

It would seem that a very thin dielectric would give the best results. This is true as long as the material is not so thin that its dielectric strength will break down and a discharge take place through it.

This can best be explained by a comparison with some simple arrangement as that shown in Fig. 15. This consists of two small balloons, connected to a gas jet from which they are filled or charged, if you wish, with gas. The two balloons in this illustration are of the same size, but one is made of thick rubber and the other of thin rubber.

A constant pressure is forced through the valves in the pipe but you see that the thin balloon has expanded perhaps to twice the size of the thick rubber balloon, yet both have been fed by the same pressure. By "pressure" here is meant the tendency of the gas to force its way against the sides of the rubber and to expand it.

We might increase the pressure and both balloons would increase in size, but suddenly the thin balloon would break, whereas the thick rubber balloon could withstand even a greater pressure than that at which the thin balloon exploded. Of course, we might increase the pressure on this balloon until it also would break down. In other words, each balloon has a break-down pressure above which it will not resist the forces attempting to tear it apart. Naturally the safe pressure to which these balloons can be subjected to, will be somewhat less than the break-down pressure.

We may even try another experiment with balloons, in which case a small and a large balloon of the same thickness are employed. We would find that the volume of the large balloon

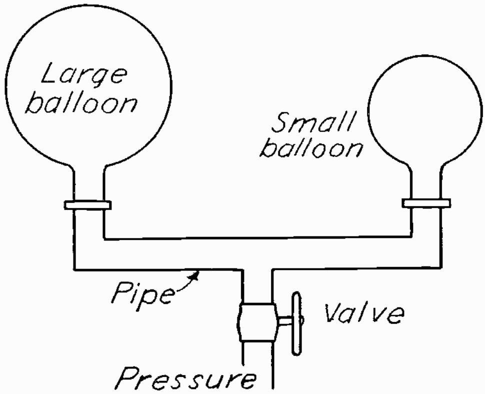


Fig. 15

would always be greater than that of the small one. But more than likely we would find that both balloons would break at the same pressure.

We have very similar conditions in Radio circuits. Two condensers may have metallic plates of equal surfaces but if one has a thicker dielectric than the other, the former would not store as much capacity as the one with a thin dielectric, and at the same time the condenser having a thin dielectric would not stand as high an electrical pressure (e.m.f.), as the condenser having the thick dielectric. It would not be as safe to operate the thin dielectric condenser on heavy voltages. Condensers are always rated at working voltages, which means a safe voltage which the condenser can stand continuously without danger of breaking down. The farther it is charged with a voltage above that value, the more unsafe it becomes and the more likelihood that it will break down, and become worthless. Likewise, if two condensers both have the same dielectric thickness but one has a greater surface area, this one would naturally have the greater capacity for storing electricity.

Electrically, if we apply a greater voltage we draw more electrons out of the one plate and put more into the other one. Naturally the electrons on one side of the plate tend to force their way through the dielectric, in order to get onto the other plate and if the difference in the number of electrons is great enough, they will actually break through the dielectric.

Let us sum up what we have learned. The *thinner the dielectric,* the greater the capacity because a given charge will create a larger electrostatic tension in the dielectric, therefore, the thicker the dielectric the less the capacity; also the greater the area of plates, the greater the capacity. Every condenser has a working voltage which is the highest voltage it is safe to apply to it. This should not be exceeded for safe operation. It should be remembered that a condenser, like every other electrical or Radio device, is designed to work at a certain safe voltage and this working voltage is less than the probable breakdown voltage.*

Thus we might have condensers rated at 300 volts, their safe working voltage. Their actual breakdown voltage may be 400, yet the manufacturer suggests that where voltages above 300 are to be handled, condensers of higher ratings should be used.

It is necessary to have a measure for the capacity of condensers. You already know that a coulomb is the *amount* of electricity that flows past a single point during one second of time in a conductor through which one ampere of current is flowing. When a condenser requires a charge of one coulomb to bring its plates to a potential difference of one volt, it is said to have a capacity of *one Farad.* But this unit is too large for ordinary purposes. The microfarad (one millionth of a farad) is the practical unit of capacity. Even smaller values of capacity are used in Radio circuits and these are expressed in milli-microfarads (thousandth of a microfarad) and in micro-microfarads (millionths of a microfarad). It is more common, however, to designate the capacities of condensers used in Radio circuits in decimal fractions of a microfarad. Thus, 250 micro-microfarads is commonly expressed as .000250 mfd (microfarad).

* The breakdown voltage of a condenser depends mostly upon the material used for the dielectric and the thickness of the dielectric, or separation between the plates.

A condenser of .001 mfd. requires a charge of one billionth of a coulomb to charge it to a potential of one volt. In other words, since a current of one ampere represents one coulomb per second, a current of one ampere would have to flow for only one billionth of a second to charge a perfect .001 mfd. condenser to a potential of one volt; or similarly, if a current of one milli-microampere flows for one second, it will charge the condenser to a potential of one volt.

TABLE NO. I

Number of Plates in Condenser	Maximum Capacity of Condenser in Microfarads
7	.00015
13	.00025
17	.00035
23	.00050
43	.001

Expressed in a formula, the relation between capacity (C), quantity (Q) and potential (E) is as follows:

$$C = \frac{Q}{E}; \qquad Q = CE; \qquad \text{or} \qquad E = \frac{Q}{C} \qquad (1)$$

Variable air condensers (having air dielectrics) used for tuning Radio circuits are often rated by the total number of their plates; that is, a condenser with six rotor plates and seven stator plates would be rated as a thirteen-plate condenser. Commercial types of variable air condensers are usually of the sizes given in Table No. 1, and their capacity is approximately as indicated.

TABLE NO. II

Material	Dielectric Constant
Air	1
Paper	1.5 to 3
Paraffin	2 to 3
Mineral Oil	2.5
Rubber	2 to 4
Mica	4 to 8
Glass	4 to 10
Castor Oil	4.7
Porcelain	5 to 7

Dielectric values of different substances with air taken as the reference standard.

It is a common expression among Radio men to say double O one, triple O five, triple O two five, meaning condensers of .001, .0005, .00025 of a microfarad.

DIELECTRIC CONSTANT

Reference has been made several times to the material used for the dielectric in condensers. Different materials influence the capacity of a condenser to a very marked extent. The dielectric constant of any material is equal to the ratio of the capacity of a condenser using the particular material as a dielectric, to the capacity of the same condenser using air as a dielectric. In other words, the dielectric constant of any insulator is the number of times its use as a dielectric will increase the capacity of the condenser over its capacity when air is used as a dielectric.* Table No. II gives the dielectric constants for various materials with air taken as the reference standard. Air has a numerical value of one and all other substances have so many times the dielectric value of air.

A wide variation is seen in the values given in Table No. II for the same substances, as there are different grades and kinds of the same materials which vary considerably in many of their physical properties.

From the previous pages and paragraphs it can be seen that the capacity of a condenser increases if we increase the area of the plates, if we substitute the material between the plates with a material having a greater dielectric constant and if we decrease the thickness of the dielectric. A condenser is made with the thinnest material possible so as to obtain as large a capacity as possible with minimum material. However the minimum thickness of the dielectric depends on the breakdown voltage of the material—often referred to as the dielectric strength of the material. The material having the highest dielectric constant does not necessarily have the greatest dielectric strength.

Condensers which you buy for service work usually have a working voltage stamped on its case, which is the highest voltage it is safe to apply to the condenser. You should never choose one which has a rating less than the voltage in the circuit in which it is to be used.

CAPACITIES IN PARALLEL AND IN SERIES

Not always do we use individual condensers but quite often condensers, like inductances and batteries, are connected in series

* For example, suppose a condenser using air separating its plates has a capacity of 100 micro-microfarads, this same condenser is then immersed in mineral oil. As the dielectric constant has increased 2.5 times, the capacity of the condenser will increase to 250 micro-microfarads.

or parallel and consequently, we are interested in the total capacity of the arrangement.

When condensers are connected in parallel we have a very simple formula, that is, their capacities are added together to get the total capacity (C). Thus,

$$\text{Total Capacity } C = C_1 + C_2 + C_3, \text{ etc.} \qquad (2)$$

For example, the total capacity of two 3-microfarad condensers connected in parallel would be $C = 3 + 3 = 6$ mfd.; three condensers having respectively 4, 4, 2 mfds. are connected in parallel. The total is

$$C = 4 + 4 + 2 = 10 \text{ mfd.}$$

The simplest case is where the condensers in parallel are of the same size and the rule is the total capacity equals the

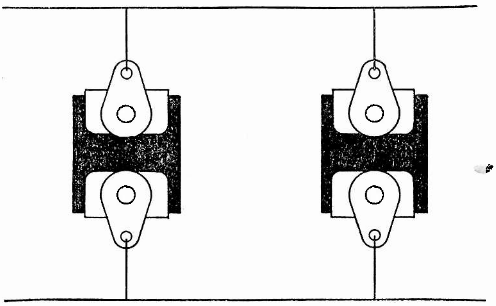


Fig. 16—Condensers Connected in Parallel.

number of condensers times the capacity of one condenser. That is,

$$C = N \times C_1 \qquad (3)$$

Should condensers be connected in series, the following formula is applied:

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \text{ etc.} \qquad (4)$$

For example, if three condensers of 5, 4 and 2 mfd. capacity were connected in series, the total capacity would be:

$$\frac{1}{C} = \frac{1}{5} + \frac{1}{4} + \frac{1}{2} = .2 + .25 + .5 = .95 \ \left(C = \frac{1}{.95} = 1.05 \text{ mfd.}\right)$$

Notice that the total capacity of a series arrangement is always less than the smallest capacity.

The simplest case is when all capacities are equal, in which case

$$C = \frac{\text{Capacity of one Condenser}}{\text{Number of Condensers}} \qquad (5)$$

Thus, if four 8 mfd. condensers are in series, the final capacity will be

$$\frac{8}{4} = 2 \text{ mfd.}$$

REVIEW

Resistors, coils and condensers may be connected in series or in parallel.

TABLE NO. III

Material	Connected in series	Connected in parallel
Resistors (resistance)	Increase	Decrease
Coils (inductance)	Increase	Decrease
Condensers (capacity)	Decrease	Increase

Table No. III shows us clearly what we have already learned, that is, what happens when they are connected in either way.

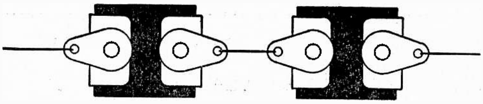


Fig. 17—Condensers Connected in Series.

CAPACITIVE REACTANCE

When direct current flows through a circuit it is opposed only by the resistance of the circuit; but when alternating current flows it is opposed by both the resistance and the A.C. opposition, called the reactance, of the capacities and the inductances in the circuit. In a previous lesson we studied inductive reactance and its effect in a circuit. Condensers offer *capacitive reactance* to A.C. current flow. But the effect of capacitive reactance is directly the reverse of the effect of inductive reactance.

You remember that inductance in an A.C. circuit caused the voltage to lead the current—they were out of phase. Capacitive reactance causes the current to lead the voltage or we can say the voltage lags behind the current. The voltage and current in a circuit with a coil in it is thrown out of phase because of the magnetic field which is set up about the coil and the prolongation of current flows due to the collapse of the field. The voltage and current in a circuit with a condenser in it is thrown out of phase by the *back* e.m.f· which opposes current flow. This back e.m.f. reduces the effect of the applied e.m.f., causing the current to rise to maximum value before the voltage reaches maximum value.

Reactance, as stated before, is the name given to the opposition to flow of alternating current when this opposition is *caused by the inductance of a coil, or by the capacity of a condenser.* Reactance is measured in *ohms.* The total opposition to the passage of an alternating current through a circuit is called *impedence.* Reactance is called the reactive component of the circuit impedance. Reactance caused by the capacity of a condenser is called *capacitive reactance.* Either kind of reactance may act to hinder or aid the flow of alternating current. *Inductive reactance, the reactance of a coil, increases with the increase of frequency and is often called positive reactance. Capacitive reactance, the reactance of a condenser, grows less with increase of frequency, and is often called negative reactance.* The values of inductive reactance may be preceded by the positive sign (+), while the value of capacitive reactance may be preceded by the negative sign (—). When the frequency is measured in kilocycles and the inductance in millihenries, the inductive reactance in ohms is as follows:

$$\text{Inductive reactance} = 6.28 \times \text{frequency} \times \text{inductance} \qquad (6)$$

The same formula holds true when the frequency is measured in cycles, and the inductance in henries.

The number 6.28 is the approximate value of 2π, the Greek letter which stands for the ratio of a circle circumference to its diameter. When the frequency is measured in cycles and the capacity in microfarads, the capacitive reactance in ohms is found by dividing 159,000 by the frequency in cycles times the capacity in microfarads.

$$\text{Capacitive Reactance} = \frac{159{,}000}{\text{Frequency} \times \text{Capacity}} \qquad (7)$$

159,000 is one million divided by 2π or 6.28.

If the inductive reactance which is considered as a positive quality just equals the capacitive reactance which is considered a negative quality, the two will balance each other and no effec-

tive reactance will be left in the circuit, provided they are in series. The only opposition then remaining to the flow of alternating current at the particular frequency being considered is the resistance, and the circuit is said to be in resonance with that frequency.

To a direct current, a condenser has extremely high resistance. In fact, to direct current, whose voltage is not great enough to break through the dielectric, the condenser offers an infinitely high resistance—it acts as a break in the circuit. A condenser does not offer this infinitely high resistance to alternating current, but offers only reactance. Here again, the reactance does not cause a loss of energy but stores it in the dielectric of the condenser in the form of an electric stress which will return energy to the circuit.

To an alternating current of given frequency, a large condenser has less reactance than a small one and the larger the capacity of the condenser, the less is its reactance at a given frequency.

In an alternating current circuit a condenser having definite capacity will have less reactance at a higher frequency than the same capacity at a lower frequency.

To bring this out more clearly, suppose we have a condenser of 1 mfd. capacity and we desire to determine its reactance when placed in a 60-cycle circuit.

$$\text{Capacity Reactance} = \frac{159{,}000}{60 \times 1} \quad \text{or}$$

approximately 2650 ohms, the reactance.

Now suppose that this 1 mfd. condenser was inserted in an alternating current circuit, the frequency of which was 3,000 cycles. Solving this formula, we find that the reactance at a frequency of 3,000 cycles is approximately 53 ohms.

$$\text{Capacity Reactance} = \frac{159{,}000}{3000 \times 1} \qquad \text{or 53 ohms.}$$

PHASE RELATION OF VOLTAGE AND CURRENT IN A.C. CIRCUITS

The phase difference between a voltage and a current in an alternating current circuit has been defined as the time difference between their amplitudes or difference in position of maximum voltage and current waves in a cycle. The voltage rises and falls, going through all values from maximum in one direction to maximum in the opposite direction.

The current resulting from the alternating voltage goes through corresponding changes. If the two are in phase, that is, if the phase difference between them is zero, the maximum value of the current occurs at the same time as the maximum value of the voltage. Also the two are zero at the same time. When there is a phase difference the current may reach a certain value either before or after the corresponding value of the voltage.

In other words there are *three* possible relations that may exist between the current and the voltage which causes the flow:

First, as explained in a previous lesson, the voltage and the current may be in phase with one another, that is to say, they may be acting in unison with each other.

This is well illustrated by Fig. 18. The e.m.f. or (voltage) is shown by the heavy curved line E while the current is represented by the light curved line I. Notice that the current and pressure reach a maximum value at 90 degrees and both decrease to zero at 180 degrees. The same changes occur when the pressure is exerted in the opposite direction and both continue to change in this manner for each cycle that takes place in the circuit.

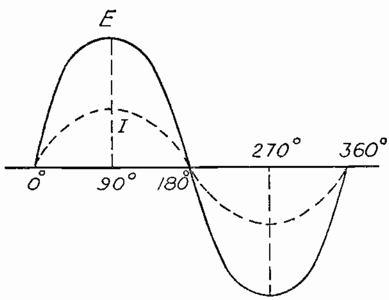


Fig. 18
E M F and Current in Phase

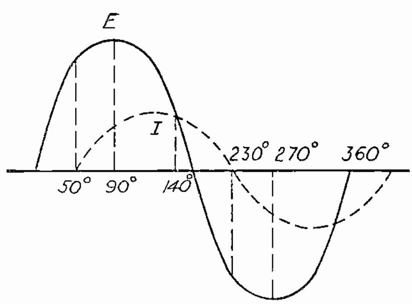


Fig. 19
E M F leading Current by an angle of 50°

The *second* possible relation is where the current lags behind the pressure. This is caused by the presence of inductance in a circuit. (Inductance is the property of an electric circuit which opposes a change in current.) This is illustrated by the curves shown in Fig. 19. Notice that the current is zero *after* the pressure has increased to a value of nearly three-fourths of its maximum value; that is to say, when the pressure is maximum the current has reached about one-half its maximum value and by the time the pressure begins to die down to about one-half its maximum value, the current has reached its maximum value.

Follow these two curves throughout the cycle and familiarize yourself with the relations existing between them in a circuit containing inductance.

If it were possible to have a circuit with pure inductance alone, with no resistance or capacity, the current would lag 90 degrees behind the pressure at all times. (See Fig. 20.) If you stop and think for a moment you will see that when the pressure is maximum the current would be zero and according to that we would have practically no power in the circuit.

The *third* possible relation is where the current leads the pressure. This is illustrated in Fig. 21. These curves are for a circuit containing capacity alone without resistance.

If it were possible to have a circuit with pure capacity alone, with no resistance or inductance, the angle of lead would be 90 degrees, just as the angle of lag in a purely inductive circuit was 90 degrees.

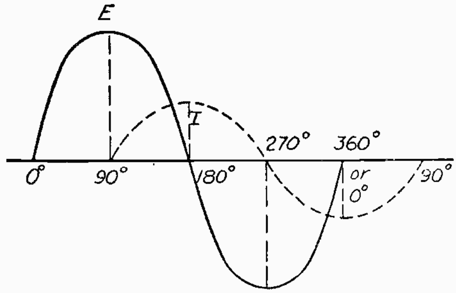


Fig. 20 E M F leading Current by 90°

A circuit, however, which contains capacity only is just as impossible as a circuit which contains inductance only.

There is always some resistance in any circuit. When we have resistance in addition to capacity in series, the current will lead the applied voltage by less than 90 degrees because the resistance has the tendency to bring the current and voltage in phase. Consequently useful power can be obtained from a circuit which includes capacity as was shown when the power in a capacitive A.C. circuit was used to light an electric bulb.

As previously mentioned, if there is an equal amount of inductive and capacitive reactance in a circuit the two will neutralize each other. Their effects are 180 degrees apart.

RESONANCE

You remember we stated in a previous paragraph that the flow of alternating current in a circuit is opposed by three things: The resistance, the inductive reactance and the capacitive reactance. The resistance is due to resistance of the various conductors in the circuit and to the resistance of the connections between them. The total resistance may be reduced by using good conductors of the proper size, but resistance cannot be completely eliminated from any circuit. The inductive reactance depends on the inductance in the circuit—the greater the inductance in the coils and other parts, the greater the resultant inductive reactance. The capacitive reactance depends on the capacity of the condensers and other parts in the circuit. The greater the capacity, the less the capacitive reactance.

When we speak of adjusting the capacity and inductance to resonance, we refer to resonance at a certain frequency. When the inductive and capacitive reactances are equal and their effects are neutralized at any certain frequency the circuit is said to be in a state of *resonance* with that frequency or simply in *resonance*. In a simple circuit containing inductance and capacity in series, at any given frequency, there are certain values of

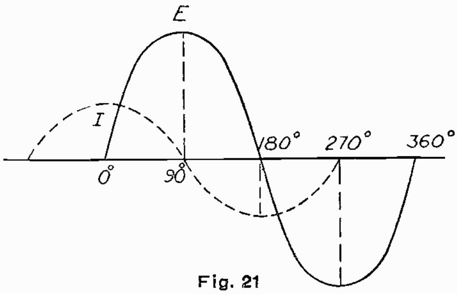


Fig. 21
E M F lagging Current by 90°

capacity and inductance which cause resonance at this frequency, but at no other frequency. If the frequency in the alternating current circuit should change, it would be necessary to make a different adjustment of either inductance or capacity in order that the resonant condition might again be obtained at the new frequency. This is why we must readjust dials for different stations. When the capacity and inductance are adjusted to balance each other at one certain frequency the maximum possible current at this frequency will then flow through the circuit, although currents of other frequencies still will be opposed by the reactances.

If the frequency is lowered, either the inductance, the capacity, or both, must be increased to maintain resonance. If the frequency is increased, then the capacity, the inductance, or both, must be decreased to maintain resonance. In other words, the greater the frequency the less must be the capacity and inductance, and the lower the frequency, the greater must be the capacity and inductance.

This is the principle of tuning a Radio receiving set to incoming signals, when we adjust the capacity of the variable condenser or vary the number of turns of wire on the tuning coil, or do both to make the reactance zero, or as near zero as possible.

In other words, when we tune a circuit like the ones we have in Radio receivers, we adjust the reactances so that their sum is zero. Generally, we do not vary the inductance (of the coil) but only adjust the capacity. That is why we always use variable condensers for tuning. Suppose we are trying to receive a signal which has a certain frequency; then, when the current due to the signal flows through the tuned circuit, the coil has a certain reactance to it, and the condenser likewise has a certain reactance to it. In general, this reactance will be enormous, perhaps thousands of ohms, but as we turn the variable condenser dial, we change the capacity of the condenser; we are at the same time changing its reactance to the incoming signal. Soon we find a position on the variable condenser dial at which we begin to hear the signals. This means that we have so adjusted the reactance of the condenser that when summed up with the reactance of the coil, the net reactance is no longer very great. In reducing the net reactance, we permit a much greater current to flow in the tuned circuit and on account of this greater current we are now able to hear the signals. Before, when the reactance was very high, there was most likely a very small current flowing in the tuned circuit, but this current was so small that we could not hear the signals properly.

Now, finally, as we continue to turn the variable condenser dial, we get to a position where the strength of the signals is greatest. This is the condition of resonance, as we call it; the circuits are now tuned to the same frequency as the frequency of the incoming signals. If we turn the condenser dial still farther, the signals will get weaker, indicating that the circuits are no longer in resonance.

It is clear, then, that there is one certain adjustment of the circuits when receiving signals of a certain frequency, which will result in the loudest signals. This is the condition of resonance as we have said, and is obtained when we make the net reactance of the circuit zero. We do this by making the inductive reactance at the coil, exactly equal to the capacitive reactance of the condenser, and since we have opposite algebraic signs (that is, one is plus and the other is minus), they sum up to zero. So now, in order to have resonance, we must have this:

Inductive reactance minus capacitive reactance equals zero. This is the same thing as saying that—

Inductive reactance equals the capacitive reactance.

This is the most important thing that we have to learn in connection with tuning and tuned circuits. This relation gives you the principle of resonance, and if you get to understand it clearly, you will have little or no trouble in much of your study of Radio. You must first get into your mind the idea of what reactance is; after that, the idea of resonance comes easily enough.

TYPES AND NAMES OF RADIO CONDENSERS

All condensers function in the same way. The names applied to them indicate merely the particular uses to which they are put. For example, in Radio circuits, we have condensers which we call "fixed," "by-pass," "buffer," "tuning," "filter," "ganged." Then there are condensers such as "straight line" condensers, named from the peculiar manner in which they function.

Fixed condensers are used for "by-pass," "filter," "buffer" and other purposes, the difference between them being only a difference in size and in the voltage they are built to stand without breaking down.

For power pack work and in eliminators and filters connected to the lighting circuit, the important thing is the voltage breakdown test.

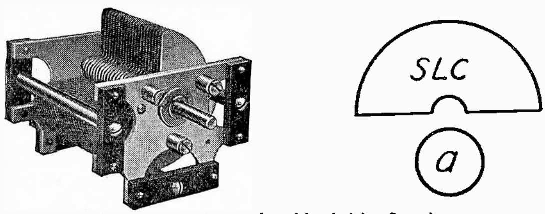
In Radio circuits, by-pass condensers have no great voltage strain on them because there is little voltage drop between the two ends of the coil which the condenser by-passes. The purpose of these condensers is to allow a path around the coil for Radio frequency currents which would be choked out by the coil.

There are three types of variable tuning condensers, the *straight line capacity*, the *straight line wave* and the *straight line frequency.*

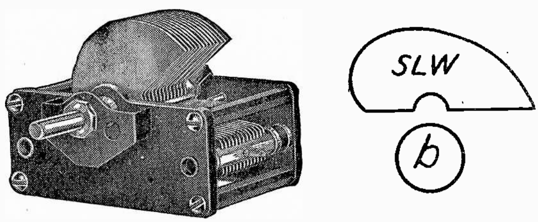
The straight line capacity variable condenser having semicircular plates gives a comparatively uniform increase in capacity as the rotor plates are turned and intermeshed with the stator plates. A condenser of this type when used for tuning purposes with a fixed coil in a Radio receiver will not give a uniform increase in wavelength as the dial is turned from zero to maximum. If a graph is plotted with dial settings against capacity, it is a straight line.

Therefore, since Broadcasting Stations are separated in frequency by 10 kilocycles, it will take only a very small motion of the condenser dial to cover 10 kilocycles and go from one station to the next, at the lower end of the scale (high frequencies) which will crowd the stations together on the dial at the low wavelengths.

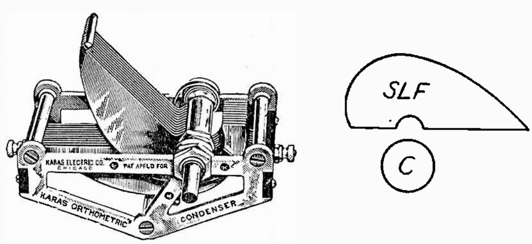
The straight line wave condenser is made by shaping the plates of the condenser so that the variation of the dial is proportional to the wavelength of the tuned circuit, that is, it does not give a uniform increase in capacity when varied, but does give a uniform increase in wavelength.



Straight Line Capacity Variable Condenser.



Straight Line Wavelength Variable Condenser.



Straight Line Frequency Variable Condenser.

Fig. 22

From the paragraphs above, it can be seen that SLC and SLW condensers are at a disadvantage when used for tuning circuits of broadcast receivers. However, they are useful in laboratory work, where equal increases of capacity or wavelength are desired.

Straight line frequency condensers are manufactured with plates shaped as shown in Fig. 22(c) which makes the rotation of dial proportional to the frequency of the tuned circuit. With this type of condenser, stations separated by 10 kilocycles in frequency come in at equally separated points on the dial.

There are some variable condensers, as for instance, the "centraline," "midline," etc., which have irregular shaped plates which permit approximately SLF tuning at the low end of the dial, SLW tuning at the center region, and SLC tuning at the upper wavelengths.

In modern Radio receiving sets, three or four Radio frequency circuits are tuned by a single control. This means that three or four variable condensers must be grouped (ganged) together on the same shaft and the assembly is called a "ganged" condenser.

TEST QUESTIONS

Be sure to number your Answer Sheet 7 FR-1.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and the best possible lesson service.

1. What will be the position of the rotor plates of a variable condenser, with respect to the stator plates, for least capacity?
2. What type of house current lighting supply would cause a lamp in series with a condenser to light?
3. What effect will resistance in an oscillatory circuit have on oscillation?
4. Which of the following capacity values is the smallest: 1 microfarad, 250 milli-microfarads, 250 micro-microfarads?
5. What effect will increasing the thickness of a dielectric have on the capacity of a condenser?
6. Variable condensers are often placed in liquids. Which liquid will result in the greatest capacity: Mineral oil (dielectric constant = 2.5), or castor oil (dielectric constant = 4.7)? (See * footnote, page 18.)
7. What is meant by the working voltage of a condenser?
8. What is the total capacity of two 2-microfarad condensers connected in parallel? (See formula (2) page 19.)
9. When we have resistance in addition to capacity in series, in an A.C. circuit, what is the phase relation between the current and voltage?
10. What word do we use to indicate that the inductive reactance and the capacitive reactance in a circuit are equal and their effects are neutralized at any certain frequency?

HOW A VACUUM TUBE WORKS
TYPES OF TUBES IN USE

8 FR-2

PIONEER HOME STUDY RADIO SCHOOL

NRI

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

YOU HAVE AN AIM IN LIFE

When you enrolled as a Student Member of N. R. I., you took the first step on the Road to Success and Happiness.

But while you may have to wait awhile before you begin to see Success coming to you, you need not wait for Happiness.

You have set yourself a Goal—you have an aim in life—you are looking forward to the sort of work you like, the sort of income you want, the respect and admiration of your friends, etc.

Right now you should be very happy in anticipation of these things and in working toward your Goal.

Realizing that you have every reason to be happy in your work right now, you will have an enthusiastic attitude toward your work. The study of your lessons will not be a burdensome task but a real pleasure. The difficulties you may encounter will only make you more determined to succeed.

Keep your Goal in mind. Never forget it for a moment. Of course you will have your moments of discouragement—we all have. But if you make a thorough search for the cause of your discouragement, you will most likely find that you have eaten something that did not agree with you—and realizing this, you will put your lessons aside for the time being and tackle them the next day with renewed vigor and a renewed determination to succeed.

When things look black say to yourself, "I have a Goal to reach and I'm going to reach it." Then think how unhappy you would be if you did not have this Goal. I am sure you will agree with me that there is nothing as pathetic as a rudderless ship or a man without an aim in life.

So here's to Success and Happiness—your Goal!

J. E. SMITH

NATIONAL RADIO INSTITUTE

WASHINGTON, D.C.

Revised 1932, 1933, 1935
1936 Edition

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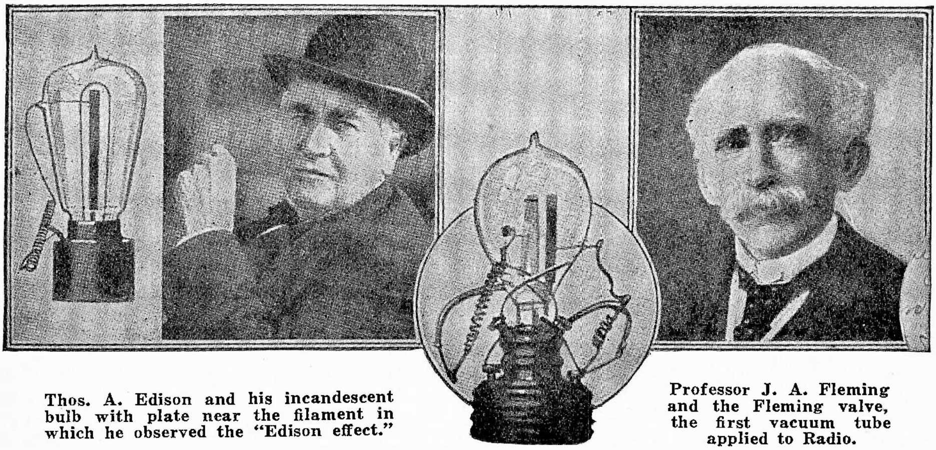
How A Vacuum Tube Works
Types of Tubes In Use

THE 2-ELEMENT VACUUM TUBE

You are well aware of the importance of the vacuum tube in Radio—you know that Radio as it is today was made possible by the rapid development of vacuum tubes in recent years. By means of vacuum tubes it is possible to amplify weak Radio frequency signals picked up by the aerial, it is possible to separate the audio frequency signals from the Radio frequency signals so they will operate some sound reproducing device such as earphones or a loudspeaker—and it is possible to amplify the audio frequency signals so that even distant stations can be heard through the loudspeaker.



Thos. A. Edison and his incandescent bulb with plate near the filament in which he observed the "Edison effect."

Professor J. A. Fleming and the Fleming valve, the first vacuum tube applied to Radio.

Fig. 1

In the process of development, the detector tube came first—that is, the tube which is used to separate the audio frequency current from the Radio frequency current. Before vacuum tubes were known, a crystal of some sort, galena, silicon or carborundum, was used to detect a radio signal—that is, to separate from it the audio frequency current. In effect, the crystal acted as a one-way valve, allowing current to pass through only in one direction so that the high frequency alternating current which carried the Radio signals would appear as a varying, pulsating direct current after passing through the crystal. Of course, a crystal cannot amplify, and in the days before vacuum tubes, headphones were used as loudspeakers were unheard of.

While a good crystal could be remarkably sensitive, it often required considerable patience to find the most sensitive spot on it, and considerable adjustment of the "cat whisker"* was necessary before any kind of reception was obtained. Then along came the first vacuum tube, to take the place of the crystal valve. This first vacuum tube used as a detector was not appreciably more sensitive than a good crystal, but it was very stable—there was very little to get out of adjustment.

From this we get our first concept of vacuum tubes—as being one-way valves. It is because of this that vacuum tubes are still known as valves in many foreign countries.

Now it is very easy to say "then along came the vacuum tube," but we, as students, cannot disregard the years of research that preceded the appearance of the first practical Radio tube. And tracing back, we must start with experiments which that greatest of all American inventors, Edison, performed with his then recently invented incandescent lamp in the year 1883. Having invented the simple device, which as we know now was destined, we might say, to turn night into day, he was not content, but set out to learn what went on inside the light bulb. In one of his experiments he inserted a small metal plate in the bulb along with the filament. Then he ran a lead wire from this plate to one of the filament wires and placing a galvanometer in the connecting wire he discovered that there was current flowing through it, when there was current flowing through the filament.

Being also a scientist, he sat down to figure this out. Of course, there was no direct electrical connection between the filament and the plate inside the bulb, therefore, in some unexplained way, current must be leaking across the space between the filament and the plate. Electrons were practically unknown in those days—in fact, from this simple experiment were to come those future experiments which proved the electron theory correct. So Mr. Edison decided to call his discovery a peculiar effect, and as he found no special use for it, he let it go at that. Now this effect which was to prove of so great value in the development of Radio, is known as the Edison effect.

From our knowledge of the electron theory, we can explain this without any trouble. When metal is heated the movement

*A fine wire resting lightly on crystal, so called on account of its appearance.

of free electrons becomes much greater. Each electron swings out in wider orbs—if the metal is hot enough those on the surface may swing clean out of the metal—out into space. Since they have no place to go, they return to the metal, bouncing off and on as it were. But if our heated metal is in a vacuum, as is the filament of a vacuum tube, and if there is a cold piece of metal, a wire or a plate in the tube, these electrons thrown off the heated filament will cross over to the cold plate. Then if the plate is connected by an external wire to the filament as in Fig. 2, many electrons will be thrown off the filament onto the plate, and these will move through the circuit and we have a flow of current*—a current such as first started Edison pondering on the matter when he noticed the deflection of his galvanometer needle, connected as previously described.

Before going on let us perform a simple little experiment, in our minds of course. Using practically the same set-up Edison

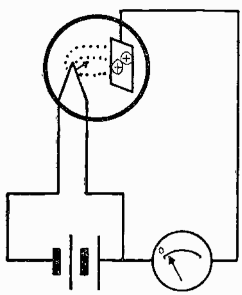


Fig. 2—Illustrating the electron emission from a heated filament to plate of vacuum tube.

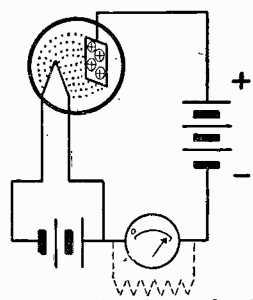


Fig. 3—Illustrating the result of electron emission when a positive charge is placed on the plate.

used, a bulb with a filament and a plate, and the plate connected externally to the filament with a sensitive meter in the external circuit which we can call the plate circuit, let us get another battery and put it in the plate circuit, the positive pole of the battery connected to the plate and the negative to the filament as in Fig. 3. Unless we use a resistor across the meter to pre-

* We should stop here to clearly fix in our minds the difference between electron and current flow. You already know that electrons are said to flow in the opposite direction to the current. Although this may be confusing at the start, you should remember this fact. Early in the development of the electrical science, current flow was considered in all circuit problems and rules were thus given to us. Therefore, in thinking of electrical circuits, consider current flow. However, when studying the internal action of vacuum tubes, it is quite simple to think of electron flow. Here we have the first example of electrons flowing from the filament to plate, but when considering current, you will have to think of current flowing from the positive terminal of the plate battery to the plate to the filament. You may consider electron flow and current flow as the same thing, but when you actually trace them in a circuit, you must consider the exact directions.

vent all the current from flowing through the meter, it may possibly burn out—because so much more current is flowing now than flowed without the battery in the circuit.

What conclusion can we draw from this? We made the plate positive by connecting the positive terminal of the battery to it—and because the electrons are negative in charge they will be drawn to the plate as they are thrown off the filament. These electrons return through the external plate battery circuit to the filament, thus completing the circuit. Consequently a comparatively large plate current will flow and from this we can deduce that the more positive the plate is with respect to the filament, the greater the amount of plate current.

Then, keeping the same hook-up, let us switch the polarity of the battery, connecting the negative pole of the battery to the

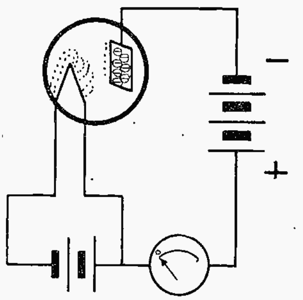


Fig. 4—Illustrating the result of electron emission when a negative charge is placed on the plate.

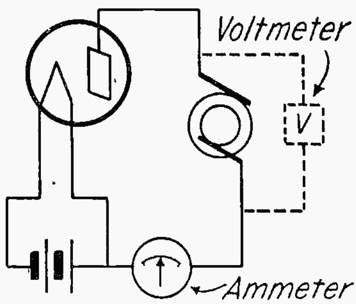


Fig. 5

plate as in Fig. 4. What about the galvanometer*? Its needle doesn't deflect at all—there is no passage of electrons from the filament to the plate. Why? As you well know, like charges repel each other. If the plate is negative there is an accumulation of electrons on the plate which repels any electrons thrown off the heated filament.

Now suppose we substitute an A.C. generator for the B battery in the plate circuit as in Fig. 5. We heat the filament by means of a battery as before, and use a galvanometer to measure the current flow. Let us say we can run the generator at a very low speed so that the frequency of the generated voltage will be only 2 or 3 cycles per second and therefore we will be able to watch the variations in meter readings. Figure 6 (a) shows the curve of the generated voltage—and from this you see that a generator first charges the plate positive, then nega-

*A Galvanometer is a sensitive ammeter.

tive, then the next cycle starts and the plate is charged positively and negative alternately. If we placed a voltmeter across the A.C. Generator, we would observe that the needle deflected first in the positive direction and then in the negative direction.

Now if we transfer our attention to the galvanometer, we notice that when the generator is placing a positive charge on the plate, current will flow through the circuit. But the instant the generator produces a negative voltage the galvanometer

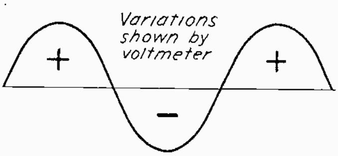


Fig. 6(a)

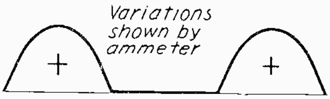


Fig. 6(b)

needle returns to zero and stays there until the generator again produces a voltage in the positive direction. Figure 6(b) shows the plate current curve. What actually happens is that only the positive voltages applied to the plate are able to cause a current flow through the plate circuit of this simple vacuum tube —when the generated voltages are in a negative direction, no current will flow because, as we have explained, our tube is a one-way valve.

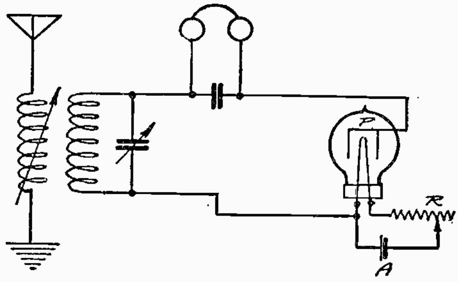


Fig. 7—Receiving circuit using a Fleming valve as a rectifier.

Coming back to Mr. Edison, after he had, as he thought, exhausted the possibilities of this experiment, he laid it on the shelf and went on to what he considered more important things. Thus it remained for Dr. J. A. Fleming to find a practical use for this Edison effect. It was in 1904 he tried a simple 2-element bulb in a Radio circuit and found that it made an excellent detector. These vacuum tubes, for such they were, were called Fleming valves—valves because they allowed current to flow in only one direction, and Fleming, from the name of the man who made the adaptation to Radio.

Figure 7 shows a simple Radio circuit using the Fleming valve in place of a crystal detector. Here the antenna, the transformer coils and the variable condenser take the place of the generator in our previous experiment. The galvanometer is replaced by the earphones. The Radio wave picked up by the aerial appears across the condenser as an A.C. voltage. This voltage is fed to the tube, but only one-half of it gets through—because the tube is a one-way valve. Figures 8(a) to 8(d) show graphically just what takes place. Figure 8(a) shows the Radio frequency current produced in the transmitter. Figure 8(b) represents the voice frequency from the microphone at the transmitting station. Figure 8(c) shows the two combined in the transmitter. The current in the antenna system of the receiver is in exactly the same form. After passing through the detector tube it is in the form shown in Fig. 8(d). the lower half is cut off. The phones which replace the galvanometer cannot follow the rapid vibrations of the high frequency current, but they can follow the up and down variations shown by the heavy line. It is this variation that is an exact replica of the original sound signal. The diaphragms of the phones vibrate, following these variations and so produce a sound like the original sound.

This short discussion of detection is meant to serve only as an introduction to the subject. Later on in the course you will be given an entire lesson on vacuum tube detectors and the principles of detection. But it has served to illustrate two important functions of vacuum tubes in Radio receivers—as rectifiers and as detectors.

Here it will be well to consider the filament and plate from the standpoint of construction and mechanical features. As even the most modern tube has a filament and a plate, we can learn a great deal about modern vacuum tubes from a study of these two elements in a simple tube.

It has been stated that when the filament is heated—and it must be hot enough so that it glows—electrons will be emitted, that is, shot off from it. But not all metals lose their electrons with the same ease—therefore some metals are to be preferred to others for use as filaments. The first filaments were made of carbon. Later tungsten was used as it provided better filament emission than carbon. But today where tungsten is used as the basic material for vacuum tube filaments, it is treated to increase filament emission.

There are two types of electron emitting filaments in common use today—the oxide coated tungsten filament and the thoriated tungsten filament. In making oxide coated filaments, the pure tungsten is dipped in a solution of hot paraffin and barium, strontium or caesium oxide. The filament is allowed to dry and when the paraffin has hardened it is baked. This coating process is gone through a number of times until the tungsten carries a coating of thick black oxide.

In the construction of a thoriated filament, thorium oxide is mixed directly with the tungsten before it is drawn into thin wire form. As part of the manufacturing process, a very high

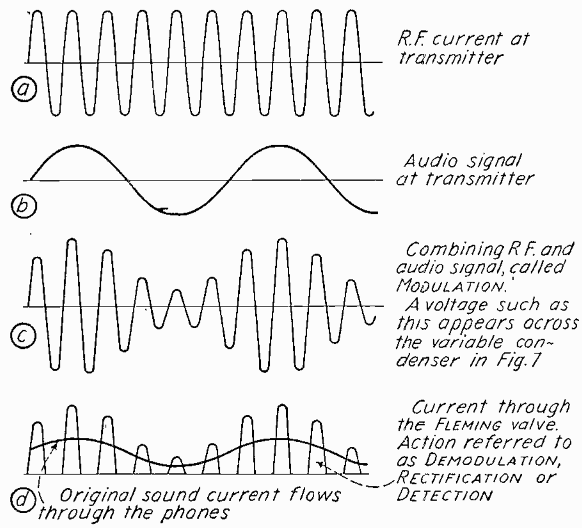


Fig. 8

voltage is applied to the filament which forces a certain amount of thorium oxide to the surface of the wire where it is reduced by the heat to a very thin coating of metallic thorium—only one atom thick. When the tube is in use and the filament heated, électrons from the thorium atoms evaporate very readily. As the thorium surface evaporates, the heat drives more of the thorium oxide to the surface as thorium to take the place of that which has been used up.

It is important to know that the only function of a battery in the filament circuits shown—what is now called the "A" battery—is to supply heating current for the filament. If it were practicable, the filament might just as well be heated in some other manner—as for instance, by a direct flame. This is brought out very clearly in modern heater type tubes. In these tubes the sole purpose of the filament is to heat another electron emitting element, called the cathode. For this reason the filament is called the heater. The filament in this case is a resistance wire turned back on itself, the electron emitting element being a specially treated tube which fits over the filament. Heat is supplied to the thin oxide covered metal tube (the cathode) causing the cathode to throw off electrons.

The plate is a sheet of molybdenum or nickel, sometimes in tubular form, completely surrounding the filament but more frequently two flat sheets shaped to surround the cathode and then clamped together. Molybdenum or nickel is used because these can withstand considerable heat without melting—the same reason why tungsten is used as the filament material in our present day incandescent lights. In some tubes the plate is cylindrical in form and is either sheet metal or wire mesh.

Is there anything else in our simple 2-element tube that we must study? Yes there is—there is space—the space surrounding the elements and the space between the plate and filament. We know this space is filled with "nothingness" because all the air has been pumped out—in other words there is a vacuum in the tube. We know that there is a vacuum in the ordinary light bulb—if air were present the filament would deteriorate rapidly due to the filament combining with oxygen in the air—this chemical action is called oxidation. A vacuum is necessary in a Radio tube for this reason and to help electron emission.

We have spoken of the electrons evaporating from the filament when it is made hot. We use the word evaporated advisedly for this action can be very well compared to the evaporation of water. All evaporation takes place at the surface—if we set a bucket of water in the sun the water will evaporate from the surface rapidly. Light and heat give the atoms and molecules on the surface greater energy, enough energy to overcome the force which is holding them to the surface. Consequently, they fly up and away. If we were to lay a film of oil on the surface of the water, evaporation would be retarded. If we were to mix alcohol with the water, evaporation would be accelerated.

If air were allowed to remain in the tube, the effect would be the same as putting a layer of oil on the surface of water—evaporation would be greatly retarded. Of course, you realize that air as we know it is composed of various kinds of gases—it isn't pure "nothingness." If we remove all the air from a tube, making it a vacuum tube, we remove that which would tend to keep the electrons from evaporating from the filament.

By coating the filament with a special oxide or by mixing thorium oxide with the tungsten of the filament, we do essentially the same thing as when we mix alcohol with water and electrons will be emitted from the filament with much greater ease than if it were pure tungsten.

From all this we can see that two things which vitally affect electron emission are: The material of which the filament is made and the degree of vacuum in the tube. There is a third which has probably suggested itself to you already—the degree to which the filament is heated. Very naturally, the hotter the

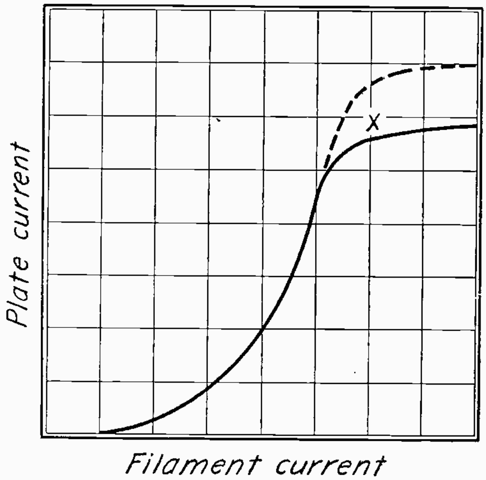


Fig. 9

filament is made the more electrons will be liberated from it, up to a certain point. If we were to use the hook-up shown in Fig. 3 and plot the meter readings as we slowly increased the filament current, we would obtain a curve as shown in Fig. 9. We would find that as we made the filament hotter, the plate current would go up—but we would find also that if we increased the filament current above a certain point, the plate current would no longer increase but would remain the same. This is shown in the graph at point X—the *saturation* point.

To understand why there should be a saturation point, we shall have to know something about the forces at work in a vacuum tube. We have already spoken about some of these—

the attracting force of the plate; the force that is given to the electrons on the surface of the filament by the heat applied to it; and we have mentioned that there is a force which tends to keep the electrons from evaporating but this force is greatly decreased when we remove all the air from the tube.

There is another force at work in the tube—the space charge. Figure 9(a) will help to make this clear. Look at A. Because the rheostat is set to full value, the filament gets practically no current and it will be cold. Therefore the plate ammeter reads zero as there is no movement of electrons from the filament to the plate. In B the rheostat arm is moved to allow a small amount of current to flow through the filament. The small amount of current warms the filament and a few electrons are

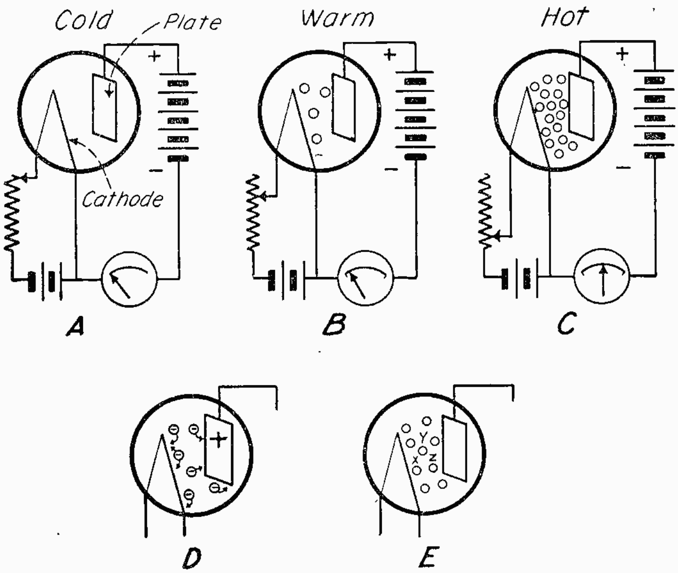


Fig. 9(a)

emitted from it. In C we have advanced the rheostat arm to allow enough current to flow to make the filament hot. Now many electrons fly off the filament onto the plate and the ammeter shows that considerable plate current is flowing.

When the space between the filament and the plate is filled with moving electrons, the phenomenon of "space charge" appears. We must remember that each electron is negatively charged. When an electron leaves the filament, it leaves a positive charge on the emitter.* Thus if it is not shot off from the

* This does not mean that the emitter assumes a positive potential. It still is at a negative potential with respect to the plate.

emitter with considerable force, it will tend to return to the filament. Then, too, all the electrons in space react on each other. Those near the plate, of course, are drawn to the plate. Those half-way between the plate and filament, however, are repelled to some extent by the electrons between them and the plate. This is shown in Fig. D and is called the effect of space charge. The result of the space charge is to reduce the number of electrons which actually reach the plate from the filament.

Figure E will make this even more clear. The electrons near point Z are attracted immediately to the plate. Those near point Y also are under the influence of the plate attraction, but these feel the effects of the electrons in front of them and behind them. It is a question which of the forces will be the greater. The electrons near point X which is nearer the filament, are acted upon by the forces which tend to pull them toward the filament. These feel the effect of the whole space charge. Therefore many of them will be driven back onto the filament.

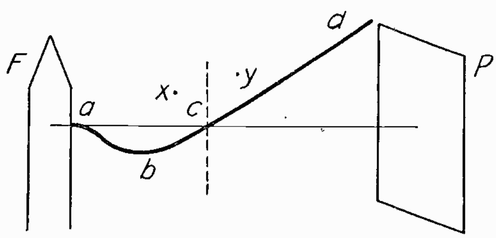


Fig. 10

Keeping this in mind let us look at Fig. 9 (a) again. Notice that when the filament is cold, there is no plate current. As the temperature is increased, the filament throws off electrons which are attracted to the plate. As the temperature is increased, the space between the filament and the plate repels a great number of electrons which return to the filament. If we attempt to increase the emission any more, even though more electrons are emitted they will not be attracted to the plate but will remain in the space, repelling further emission.

What takes place within a two-element vacuum tube may be explained graphically from Fig. 10. Let's say that the filament F is operating at normal temperature and the plate is made positive by connecting the positive terminal of the battery to P and the negative terminal to F as shown in Fig. 9 (a) C. If it were possible to place within the vacuum tube between F and P a movable metal screen which would allow all electrons to pass through it and we were to connect between this screen and the filament a voltmeter, we would find that as we move the screen from F to P the voltmeter would read various voltages. The solid curve of this figure shows what voltages would be read.

The a-b-c portion of the curve represents the position between F and P where the voltage would be indicated as negative. Any electron shot off from F into this space will find itself repelled to the filament or would remain in this space. For example, if an electron is emitted from the filament with sufficient energy to carry it to point X, the chances are it will be driven back by the negative space charge. If this same electron had force enough to get to point Y, it would travel on to the plate for, as you will note from this curve, at any position between c and d (the plate) the potential is positive and will therefore attract the electron (which is negative) to the plate.

Vacuum tubes are always operated with a filament current which will not change the plate current to a large degree with small changes in the filament current. This corresponds to point X on the plate current-filament current saturation curve shown in Fig. 9. At this point the space charge has an appreciable effect on current flow through the tube. A certain amount of voltage is used up in overcoming the effect of the space charge. Thus we can consider the space charge equivalent to an additional resistance in the plate circuit of the tube.

So far we have been considering increases in filament current only, with a fixed or constant voltage applied to the plate. Of course, if we increased the voltage supplied to the plate, we also increase the attracting force of the plate with the result that the space charge will be overcome to a greater extent and more current will flow in the plate circuit. The dotted line in Fig. 9 shows what would happen if we used a higher plate voltage than the voltage used when the original curve was taken. Note the new saturation point.

Now we can plot a plate voltage-plate current curve, keeping the filament current constant. As we increase the plate voltage, the plate current gradually rises—slowly at first, then faster until it reaches a saturation point. Our curve would look like the one shown in Fig. 11. Here saturation represents a condition where all the electrons emitted have been attracted by the plate and we can say that point X represents maximum filament emission for that particular filament temperature.

THE EFFECT OF GAS IN A TUBE

We have been assuming that the plate and filament were in a perfect vacuum. And yet it is almost impossible to obtain a perfect vacuum. Let us see what will be the effect of a few air particles left in a tube.

Air, as you know, is composed of various gases, chiefly nitrogen and oxygen. Therefore, if we have a few particles of air in our "vacuum" tube we have oxygen and nitrogen atoms. When high speed electrons moving from the filament to the plate hit up against an atom, they might strike with such force that they dislodge free electrons included in the make-up of atoms. The dislodged electrons join the general rush and

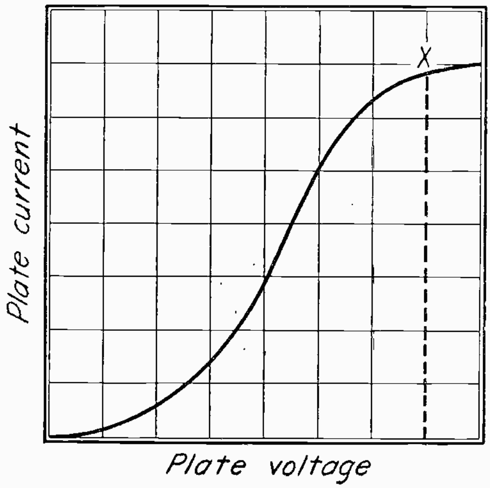


Fig. 11

move on to the plate. The positively charged atom, an ion, is repelled by the plate and attracted by the filament, so that it flies to the filament with great force. Thus we have additional movement—additional electrons moving toward the plate and the ions moving toward the filament. This naturally results in an increased current flow.

In most Radio tubes, ionization is very undesirable as the increased current flow will upset the characteristics of the tube and the heavy ions striking the filament with tremendous force tend to break down the filament.

However, in some vacuum tubes for special purposes a particular kind of gas is used which ionizes readily and which does not tend to prevent electrons from leaving the filament to the same extent that air would. In these tubes ionization is desirable—in fact, it is made use of. Figure 12 shows the plate voltage-plate current characteristics of a gas-filled tube as compared with the same characteristics of an ordinary vacuum tube. Notice that the saturation point is much higher for the gas-filled tube than for the vacuum tube.

Gas content tubes are called soft tubes in the Radio industry. Hard tubes are those from which all possible air is exhausted, that is, tubes which have as perfect a vacuum as it is possible to obtain.

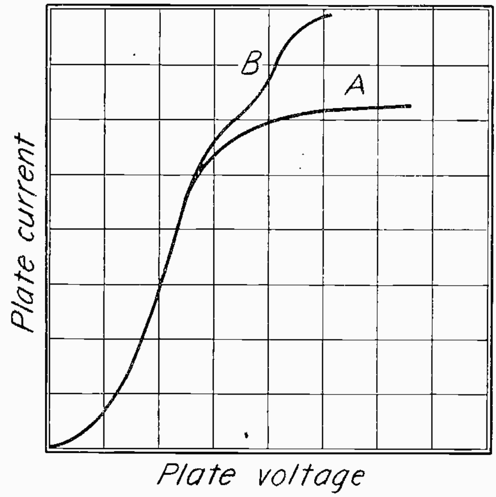


Fig. 12

THE 3-ELEMENT TUBE

Until 1906, the vacuum tube, that is, the Fleming valve, was used for Radio purposes only as a detector, taking the place of the crystal detector. But in 1906 Dr. Lee DeForest made the famous discovery that was to revolutionize the Radio industry. He discovered that by placing a third element in the tube in a certain manner, it was possible to make the tube act as an amplifier as well as a very sensitive detector. This third element as you probably know is the grid, which consists of a coiled or crimped fine wire placed directly in the path of the stream of electrons from the filament to the plate but much closer to the filament than to the plate. Since the grid is open in construction it does not to a great extent obstruct the normal electron flow from filament to plate.

Now let's see what effect this grid will have in the tube when we place a negative or a positive charge on it. Suppose, in Fig. 10, that we place a grid, at point b, a distance of a-b from the filament. We connect the grid to the filament through an external circuit and in this external circuit we connect a "C" battery with its negative pole connected to the grid. This connection of course puts a negative charge on the grid. Can you figure what will be the effect on the plate current? Easy enough, isn't it? The negative charge of the grid will add to the space charge, making it still more difficult for electrons to move from the filament to the plate, decreasing the plate current. Now suppose we reverse the "C" battery in the grid circuit, making the grid positive. If a negative charge increases the space charge, a positive charge on the grid will decrease the space charge be-

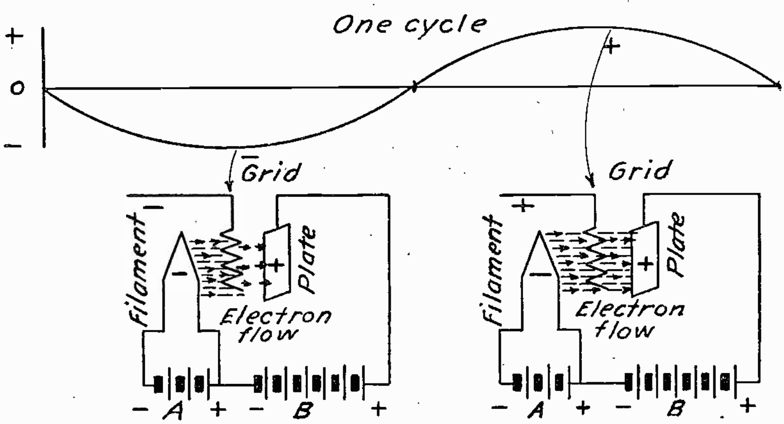


Fig. 13—Illustrating the effect on the electron flow in a vacuum tube when a negative and positive potential is placed on grid.

cause when the grid has a positive charge it acts as a miniature plate and draw electrons from the filament. The effect of this is that the electrons from the filament are helped by the grid at their most difficult part of their journey—once they get as far as the grid, the plate attraction begins to make itself felt and many electrons will fly right past the grid onto the plate, increasing the plate current.

If we had an arrangement whereby we could gradually change the polarity of the "C" (grid) battery at will so that at one instant the grid was positively charged and the next instant negatively charged, we could in effect impress an alternating current on the D.C. plate current. And no matter how rapidly we changed the polarity of the "C" battery, each time the grid was negative, the plate current would be reduced and each time the grid was positive, the plate current would be increased—assuming of course that we keep the A voltage and B voltage constant. This is shown schematically in Fig. 13.

From this you can see that the grid provides a very sensitive method of controlling plate current. More than that—as the grid voltage alternates, the plate current will become greater and smaller alternately, but still always flows in the same direction. Thus the plate current is largely made up of pulsating direct current, or as we sometimes say, direct current with alternating current superimposed upon it which explains why you sometimes hear of "the alternating component of plate current."

The grid is often compared to a trap. When closed, that is, when it is negative, electrons find it more difficult to get to the plate. When the trap is open, that is when the grid is positive, electrons move from the filament to the plate with great ease—with more ease in fact than if the grid were not there, for as previously stated, the positive grid actually helps the electrons over the worst part of their journey. One fact to remember about grid action is that the grid supplies no new electrons—none of the grid energy appears in the plate current. The grid is purely a control device and the beauty of it is that just a small change in grid voltage will result in a comparatively large change in plate current. This is due to the position and construction of the grid—much closer to the filament than to the plate. It is this and the control action of the grid that makes it possible for a tube to act as an amplifier whether in audio or radio frequency stages. This 3-element tube or triode as it is usually called, makes a very efficient and sensitive detector when operated in a special manner as we shall learn soon.

TUBES IN USE

Now that we see the importance of the grid in a vacuum tube, we are in a position to learn more about modern vacuum tubes. Not so many years ago the number of tubes in use for receiving purposes could be counted on one hand; today, the number in constant use makes us refer to tube tables issued by tube makers. But the important fact about these tubes is that they may be classified in a simple manner. We have considered the two element rectifier-detector tube. This tube has two electrodes, the filament and plate, and for this reason is generally considered in the class of diodes (meaning two electrodes). The introduction of the grid has given us a three electrode tube and these are classified as triodes. Vast improvements have been made in the operation of tubes by the use of two and three grids in the same tube structure. Laboratories have experimented with four, five, and six grids, but their use has not yet shown enough value to be made commercially available. Regardless of the number of grids, one of them is the control (trap acting) grid, while the others are merely auxiliary (helping) electrodes which improve the performance of the tubes. Tubes having two grids are called tetrodes (meaning four electrodes), often referred to as screen grid and variable mu tubes. Tubes having three grids are called pentodes (meaning five electrodes), and they are often classified as R.F. or A.F. pentodes, depending on whether they have been specifically designed to be used in the R.F. or A.F. sections of a receiver.

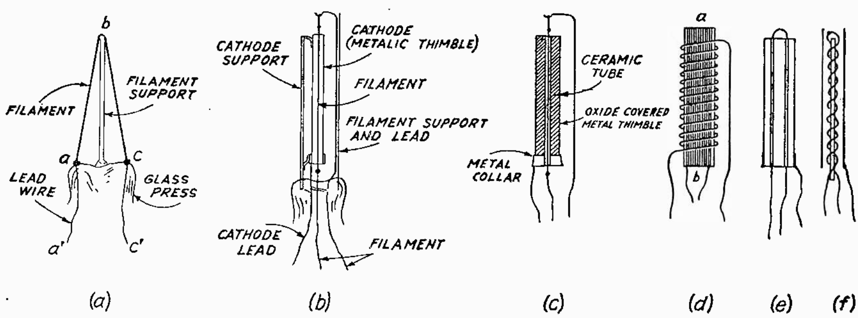


Fig. 14

Every one of these tubes must have a source of electrons, which we know is obtained by heating some electron emitting material. The materials used is still a subject requiring much research on the part of tube manufacturers, and from our point is of little importance. But we are interested in how they are heated as this factor controls the difference between battery, A.C., D.C. power, and automobile receivers. Briefly, a tube may be a filament or heater type tube. Where is the difference?

Figure 14(a) shows the simple filament type electron emitter. Current is made to flow from a′ through abcc′. The filament abc is a resistance wire which heats up with the flowing of current, and either the filament itself or the metal oxide covering the filament under the action of the heat throws off electrons. The filament must be rigidly supported and special lead wires aa′ and cc′ must be used in passing through the glass seal, shown as the press if no air is to leak through the seal. The lead wire should be a metal such as platinum, or usually nickel alloy, which expands and contracts under the influence of heat to a degree identical to the glass stem. The method of support and the shape of the filament may vary. The filament may be a narrow or wide inverted V or it may be an inverted W (see Fig. 22).

Filament type emitters are made for either A.C. or D.C. operation, that is, either an A.C. voltage or a D.C. voltage is applied to the filament. If we were to break open an A.C. and D.C. filament type tube, we would find that the A.C. type employed a very thick filament wire while the D. C. type used a thin
4 filament wire. If you were to use a D.C. type filament tube in an A.C. circuit, you would find that a hum would emanate from

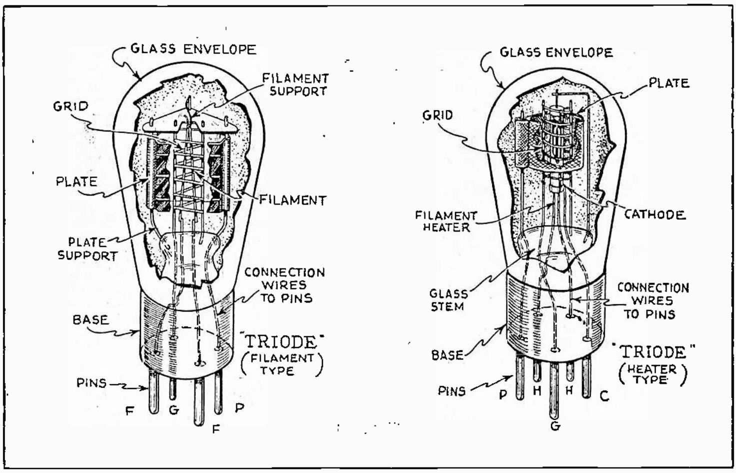


Fig. 15 Courtesy Radiocraft

the loudspeaker. The reason for the hum is apparent—alternating current rises to a maximum in one direction, reduces to zero, then rises to a maximum in the opposite direction. Of course, as the current rises the filament emission will rise too, and as the current falls so will filament emission. If the emission varies, the plate current will vary also. If our source of supply is 60 cycle A.C., we get what is called a 60 cycle hum in the phones or speaker. Now by making the filament wire thick, it will not lose its heat in the short time of a half cycle like a thin filament
9 wire will, and the difference in plate current will not be noticeable. Of course, A.C. type tubes may be used on D.C. power.

The second method of obtaining electron emission is to coat a metal thimble with a special metal oxide and indirectly heat the thimble. This is shown in Fig. 14(b). Note that a single straight filament runs centrally through a long metal cylinder which is coated with the metal oxide. The filament in this case has the only purpose of heating the electron emitter which is called the cathode* (memorize the word cathode). Therefore, the filament has two separate lead wires which in practically every case has no connection with the cathode or any of the grids or plates. A single lead wire connects to the cathode. The method of support shown is imaginary and manufacturers differ as to how they support the elements in the tubes they make.

You will no doubt question the soundness of the filament structure shown in Fig. 14(b). There is a good chance of the filament hitting the thimble and in some structures, as we shall shortly learn about where the filament is made like a hairpin,

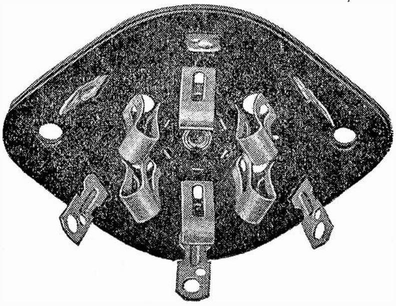


Fig. 16

the filament wires themselves may touch causing a short circuit. To overcome this, a slightly different construction is used as shown in Fig. 14(c). Here a ceramic tube (porcelain) with a hole large enough to allow the filament to pass through it, is used. A metal thimble treated with strontium, barium or caesium oxide fits snugly over the ceramic tube. The cathode lead is made from the thimble. Such tubes are slow heating as it takes at least 30 to 60 seconds to heat the ceramic tube.

Quite often tubes are made so the filament will operate at high filament voltage, and in this case a very long filament is required, wound on a ceramic strip as shown in Fig. 14(d) or wound up and down as shown by dotted lines drawn from a to b, the whole filament structure being covered with an insulating heat conducting material. The filament is then inserted in a long rectangular cross-section metallic sleeve which has been treated for cathode emitting properties as illustrated by Fig. 14(b).

* In the filament type tube, the filament is called the cathode.

of a receiver and the A.F. pentode designed for the A.F. section. In general, the internal structure of an R.F. pentode looks like a tetrode while the filament type A.F. pentode has the appearance of a filament type triode tube.

filament tubes. You should now imagine a 4 prong tube placed directly above the socket and learn how to spot the correct terminal prongs. You should imagine that you have a chassis upside down and again learn to spot the terminals. The same pro-

if grid No. 3 is connected to the cathode, we have a pentode; and if grids No. 1 and No. 2 are connected together and used as the control grid and grid No. 3 is connected to the plate, we obtain a special triode tube referred to as Class B amplifier.

It is worth mentioning that R.F. pentodes have been made with the control grid having a fine and coarse section. In this case, the tube is referred to as a super-control R.F. amplifier instead of variable mu pentode.

RECTIFIERS

The modern diode is essentially like the early two element tube, only engineering has brought it to a highly useful state.

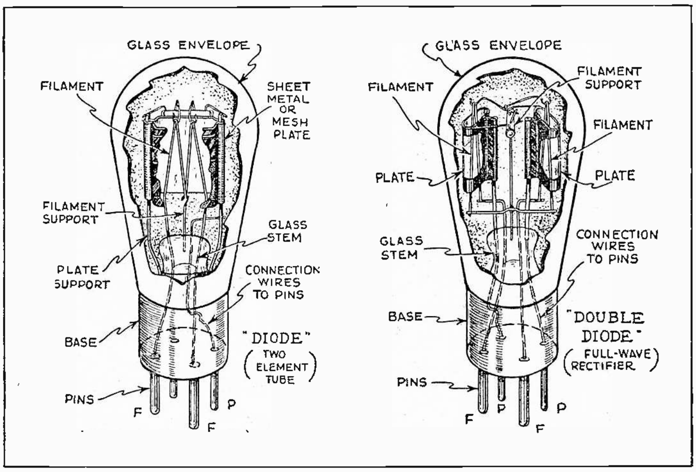


Fig. 22 Courtesy Radiocraft

Diode tubes are used for detectors as originally suggested by Dr. Fleming and as rectifiers to change A.C. current to D.C. current. To be sure, the ordinary triode tube may be used for this purpose by connecting the grid and plate together, but it is best to use a tube especially designed for a particular detector or rectifier purpose. Figure 22 shows to the left the ordinary two element power rectifier. Note the inverted W filament, usually a metallic oxide covered filament, and the rectangular cross-section plate. Figure 23(a) gives the symbolic notation for a single diode rectifier and the socket connections. Referring to Figs. 22 and 23(a), you will observe that the left-hand, small prong is dead because there is no need for it, and it is considered best to use a standard 4 prong tube base rather than make a 3 prong tube.

To the right of Fig. 22 is a double diode, that is, two diodes in one glass envelope. With such tubes, the filaments of both tubes are connected in series and lead to two prong terminals. Each filament is surrounded by its own plate and connects to a separate prong as shown in Fig. 23(b). In general, most rectifier tubes for radio receivers are made as shown in Fig. 22. The single diode shown to the left in Fig. 22 is called the half-wave rectifier because in the circuits in which it is used alone it merely cuts off from an A.C. current shown in Fig. 24(a), one-half the wave leaving what is shown in Fig. 24(b). However, the double

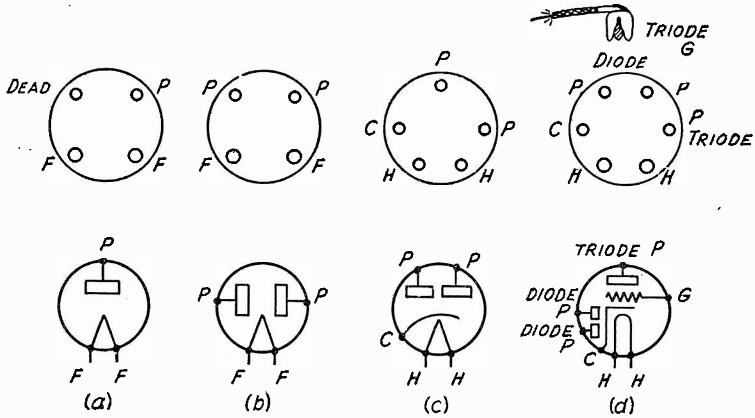


Fig. 23

diode, or full-wave rectifier, if properly used, makes use of both halves of the A.C. wave, giving a rectified output as shown by Fig. 24(c). Of course, two half-wave rectifiers may be used to get full-wave rectification. We will learn more about this in another text. We should mention that in some cases, rectifier tubes are filled with mercury vapor to improve the operation and increase their handling power.

Diode tubes are used extensively in modern radio receivers for detectors. Tubes shown in Fig. 22 are not used for this purpose. When a single diode is needed, a triode of the filament or heater type may be used connecting the grid to the plate. Special heater type double diodes have been made which consist of the central cylindrical cathode surrounded about a millimeter away by a cylindrical plate split in two so as to make two plates. The terminal connections are shown in Fig. 23(c).

SINGLE ENVELOPE MULTIPLE TUBES

We should not close our study of mechanical features of tubes without observing that two or more tubes may be built into a single glass or metal envelope, usually only two. Do not confuse this with the multiple use of tubes, for example, a triode used as a diode, or pentode used as a triode. The double diode may be strictly considered in this class. Perhaps the most interesting tube in this field is the double diode-triode, that is, two diodes and a triode, three tubes in all. From external inspection this tube looks like a triode, but in looking closer you observe that it has a single cathode of the heater type, a triode structure on the

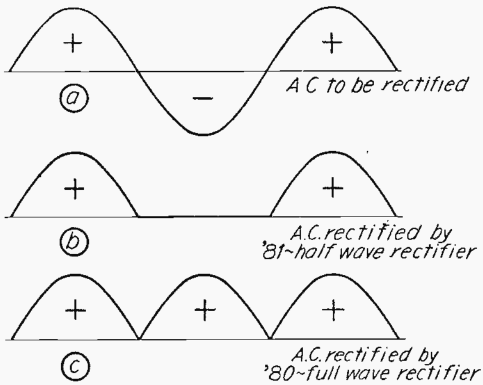
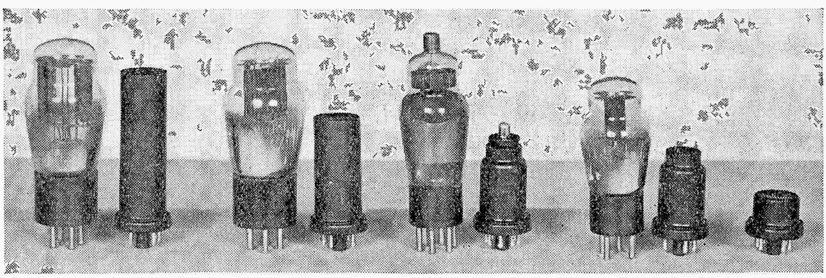


Fig. 24

upper part, and a double plate around the lower part. A metallic shield separates the two sets of elements. The tube connections are shown in Fig. 23 (d) and the tube is intended as a detector-audio amplifier.



A B C D E

Fig. 25—Four glass-enclosed Radio receiver tubes and corresponding metal-enclosed tubes; and on extreme right "Duo-Diode" tube, available only in metal envelope.

You will find a tube with two triodes in the same envelope, perhaps a small heater type and a large filament type triode. Many twin tubes have been proposed and some built, such as double diode-pentodes, twin grid triodes, etc. But the important thing to remember in every case is that you may classify any tube, whether it be alone in an envelope or one of several tubes in the envelope, as *first* of the filament or heater type, *second* as an A.C. or D.C. tube, and *third,* whether it is a diode, triode, tetrode or pentode. Let us emphasize, these three fundamental classifications are important.

The glass envelope is rapidly being replaced with a metal envelope, resulting in a more rugged tube. Metal tubes, as such tubes are called, do not differ in their operation or electrode construction from glass tubes, except that the metal envelope is used as a tube shield as well as a wall to keep out the air. All metal tubes fit into an eight-hole socket, although metal tubes may have 5 to 8 prongs depending on the type. A metal tube has one more prong than the glass tube equivalent, the extra prong connecting to the metal envelope or shield. In the center of each tube, you will find a pilot or a cylindrical key which guides the tube into its socket, in the correct way. In Fig. 25 we show 5 metal tubes, and the glass equivalent to four of them. From left to right you will see *A*, the double diode rectifier; *B*, the power triode; *C*, the super R.F. pentode; *D*, the heater type triode; and *E*, the duo-diode, which first made its appearance as a metal tube. Remember, metal tubes work in exactly the same way as glass tubes.

TEST QUESTIONS

Be sure to number your Answer Sheet 8 FR-2.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and the best possible lesson service.

1. What is the purpose of the filament when heated in a two element type tube as shown in Fig. 2?
2. Why are electrons attracted to the plate when a positive potential is applied to the plate?
3. What are the two types of electron emitting filaments in common use today?
4. What is the sole purpose of the filament in a heater type tube?
5. Why is a vacuum necessary in a radio tube?
6. Will a positive charge placed on the grid of a three element tube *increase* or *decrease* the plate current?
7. What kind of current will flow in the plate circuit of a vacuum tube if you apply a grid voltage that alternates?
8. How does the D.C. filament differ from the A.C. filament in a vacuum tube?
9. Could you use an A.C. tube with a D.C. supply?
10. In what three ways are vacuum tubes classified?

RADIO TRANSFORMERS AND THE PRINCIPLES OF TUNING

9 FR-1

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

LESSON MASTERY

Very many people have the peculiar habit of leafing through a new book and glancing at the illustrations before they start reading it. Ordinarily a procedure of this sort doesn't do any harm, but sometimes we see in technical text books, pictures that look somewhat complicated and the result is we tackle the book with the idea that the subject covered is going to be difficult to understand.

If you have by any chance looked at the illustrations in this lesson you will have noticed that some of them are peculiar looking things—but don't let them give you the impression that it is going to be hard to understand them.

This lesson, however, will require thought, as it is a scientific treatment of principles of Radio that are vital. Master them—if not the first time you go over the lesson, then the second or third time you go over it.

J. E. SMITH.

WASHINGTON, D. C.

1936 Edition

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Radio Transformers and the Principles of Tuning

MUTUAL INDUCTION BETWEEN COILS

When we studied inductance we learned a great deal about the effects of mutual induction between the turns of a coil of wire—we learned that by means of mutual induction a voltage could be induced in a second independent wire or coil by the action of the changing magnetic field about another wire or coil in which the current increased or decreased, or changed its direction of flow.

You will remember that when a voltage is induced in a second circuit, a magnetic field is built up about the conductors of the second circuit which in turn induces a back e.m.f. in the conductors of the first circuit. You will remember, too, that inductance in a coil is the result of the combined effects of self-induction in the individual turns and the mutual induction between adjacent turns of wire; and that the effect of inductance is only apparent when the current flowing through the conductors is changing in value.

Now we are going to study the effects of mutual induction between coils, a phenomenon that is put to many practical uses in Radio. The best way to go about studying these effects is to perform some very simple experiments using coils.

Let us take about 100 feet of No. 20 insulated copper wire and wind it on a cardboard tube about 3 inches in diameter. There will be about 127 turns. When the coil is completed we have what is called a helix (from the Greek word meaning "spiral"), or a solenoid, also from the Greek, meaning "like a hollow tube." The two words are often used interchangeably although a distinction should be made—the word solenoid referring either to a single or multi-layer air core coil while helix should be used only when referring to single layer air core self-supported coils.

If we attached two leads from a dry cell to the two ends of the coil winding and allowed the current to flow through the turns, a magnetic field would be built up through and around the coil. With a small compass we can determine in which direction the magnetic lines of force flow around the coil. (See Fig. 1.) Suppose we reversed the battery connections to the coil—the compass will show that now the lines of force are moving in the opposite direction.

Now to continue our experiments we shall have to wind another coil. Let us make this one smaller than the first one—let us say we use a coil form 2 inches in diameter instead of 3 inches.

Having built our small coil we connect the battery to the two ends of it and to the two ends of the large coil we connect a sensitive voltmeter, one which has its zero position in the center of the scale, as shown in Fig. 2. Then we are ready to continue with our experiments and start noticing what happens.

First we place the smaller coil inside the larger coil and then draw it out rapidly. If we keep our eye on the voltmeter we will notice that the pointer of the voltmeter deflects as we separate the coils. This deflection might be very small but even

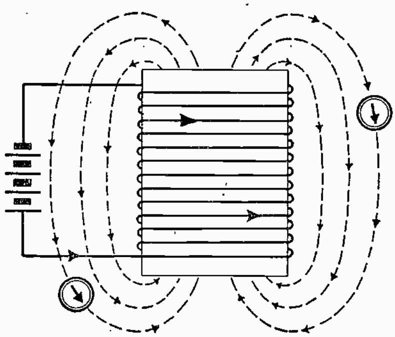


Fig. 1

the slightest deflection will tell us what we want to know—that a voltage has been induced in the large coil. But when the small coil was at rest inside the larger coil, there was no voltmeter deflection. Now what conclusions can we draw from this little experiment?

We know that there is a magnetic field about the small coil—the result of the battery current flowing through the coil windings. When this small coil is stationary inside the larger coil, no voltage will be induced in the large coil because the magnetic field is stationary and you learned in the lesson on Inductance that it takes a moving magnetic field to induce a voltage in another circuit. When we moved the small coil we obtained this moving magnetic field. The lines of force about the smaller coil cut the turns of wire on the larger coil and a voltage was induced in the turns of the larger coil.

There is a very important fact which you should remember before you go on with your studies, that is, if through any coil the number of magnetic lines of force (the flux linkage) changes, an e.m.f. will be induced in the coil. From this explanation it is easy to see that it makes no difference where we move the small coil or the large coil, if the flux through the large coil changes an e.m.f. will be induced in it. When the small coil is moved completely upward, the induced e.m.f. is in one direction, and when it is moved completely downward, the induced e.m.f. is in the other direction.

From this we can assume that by moving the smaller coil in and out of the larger coil, an A.C. voltage will be induced into the larger coil. If the battery was connected to the larger coil and the voltmeter connected to the smaller coil, an A.C. voltage would be induced in the small coil if we moved the small coil, or left it stationary and moved the large coil.*

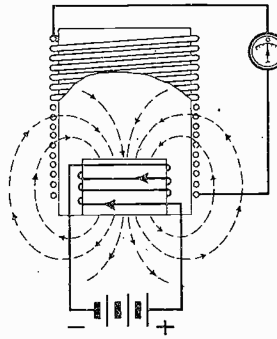


Fig. 2

Now instead of moving either coil, suppose the small coil is fixed inside the large one, the two ends of the large coil being connected to a battery in series with a variable resistance as shown in Fig. 3 (a).

To the small coil we connect a sensitive voltmeter, which has its zero position in the center of the scale. The variable resistance in series with the battery and the large coil enables us to vary the current flow in the coil from zero to maximum, let us say, from 0 to 1 ampere. Let us also say that with maximum current through the coil, 100 magnetic lines of force will thread through the large coil. We can reduce this number by increasing the series resistance.

* The coil in which the current is sent is called the primary. The coil in which the voltage is induced is called the secondary.

As the resistance in this circuit is decreased from maximum to minimum, the lines of force linking with the smaller coil will increase in number from 0 to 100. While the number of lines linking all the turns of the smaller coil (the flux linkages) is increasing, a voltage will be induced in it. In the same way, when the flux linkages are reduced—by increasing the resistance, a voltage will be induced in the smaller coil. From this we can see that it doesn't make any difference whether the flux linkages are increased or decreased, a voltage will be induced—provided they are *changing*. And the faster the flux linkages change, the higher will be the induced e.m.f.

Now instead of using a battery and a variable resistance, an alternating current is fed into the large coil is in Fig. 3(b). As the current varies in the large coil the flux linkages through

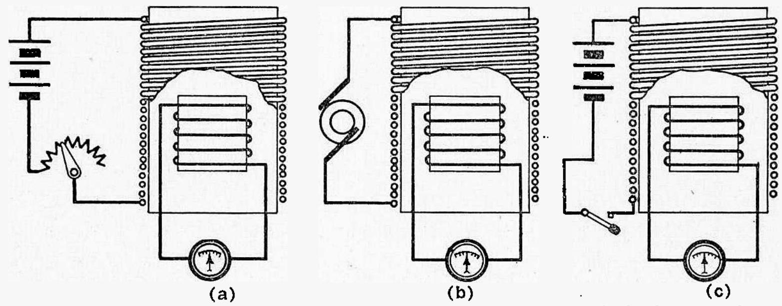


Fig. 3—Sketch showing three methods which can be used for inducing a voltage in a secondary coil when a varying D.C. current, alternating current or an interrupted current is applied to the primary coil.

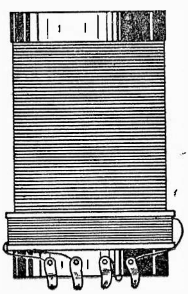
the small coil will change, with the result that an A.C. voltage is induced in the small coil. The large coil in this case is called the primary, the small coil the secondary, and it is generally stated that a voltage is induced into the secondary by induction.

Now instead of feeding the large coil with alternating current, we use a battery and a switch as shown in Fig. 3(c). With this arrangement we can easily start and stop the D.C. current, that is, we will have in this case a pulsating current flowing through the large coil. When the switch is closed—the pointer of the voltmeter connected to the smaller coil will show a slight deflection in one direction, but after a momentary deflection it will return to zero position. When the switch is opened—the pointer will show another deflection in the opposite direction, indicating we have an A.C. voltage in the small coil (secondary).

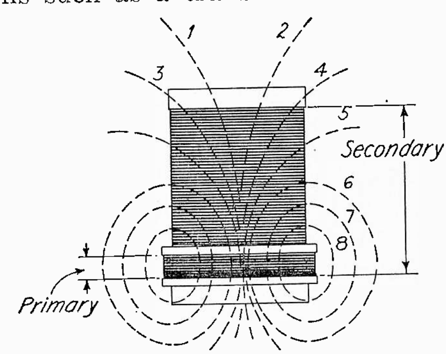
From what we know of induced voltages we can explain this very easily. At the instant we close the switch, current begins flowing through the turns of the large coil and a magnetic field builds up. As it builds up the increasing flux linkages through the larger coil induce a voltage into the small coil. When the inductance of the large coil no longer affects the value of the current flowing through it, the field has reached maximum and remains stationary and a stationary field will induce no voltage, therefore the pointer of the voltmeter returns to zero. But when we open the switch, the magnetic field about the large coil begins to collapse and as it collapses the decreasing flux linkages induce a voltage into the turns of the small coil in the opposite direction as will be shown by the pointer of the voltmeter.

SUMMARY

We may sum up what we have said in the following important fact. When two coils such as a transformer are fixed in



Standard Radio-Frequency Coil
(a)



(b)

Fig. 4

relation to each other one coil may induce an A.C. voltage into the second coil when the magnetic field linking both coils rises and
2 falls thus increasing and decreasing their flux linkages. This can be accomplished by making the current in the first (primary) coil a pulsating D.C., an interrupted D.C., or an A.C. current. In all such cases an A.C. voltage is induced in the second coil and an
3 A.C. current will flow in this secondary coil. Two such coupled coils give us a basic device used extensively in Radio and Electrical fields and is called a "Transformer."

TRANSFORMERS

Air core transformers used in the R.F. stages of Radio receivers are essentially like the one described although both windings are usually wound on the same form as in Fig. 4(a) and there are usually more turns in the secondary winding than in the primary winding. The primary is always connected to the source of electric power, usually the plate of a vacuum tube. Energy is, of course, transferred from the primary to the secondary by mutual induction. In other words, the primary is in the input circuit and the secondary is in the output circuit.

4X

When a transformer has more secondary turns than primary turns, it is said to have a step-up ratio.* By this we mean that if all the flux about the primary links with the secondary turns the output voltage would be greater than the input voltage, depending upon the ratio of secondary to primary turns. Thus if the primary consisted of 10 turns and the secondary of 100 turns (a 10 to 1 ratio), if the input voltage were 1 volt and if there were no loss of flux linkage, the output voltage of the secondary would be 10 $\times$ 1 or 10 volts. But in an air core transformer there is considerable loss of flux linkage, first because air is not a particularly good conductor of magnetic lines, and secondly, because of the position of the secondary with respect to the primary—both on the same form and separated from each other.

To visualize the reduction in flux linkages in radio frequency transformers, study Fig. 4(b). This is an exact schematic of a commercial radio frequency coil. The primary produces a flux which threads through the secondary as shown. Notice that only lines 1, 2, 3 and 4 link with *all* the secondary turns (complete linkage). Again observe that lines 5, 6, 7 and 8 cut fewer and fewer of the secondary turns, that is, flux-turn linkages are lost. This is referred to as leakage, which is an important problem in any transformer.

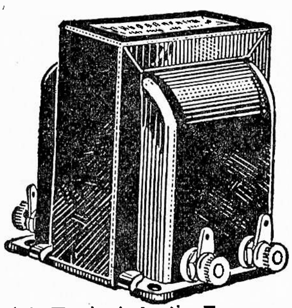
The output of the detector tube as you know is direct current which is pulsating at audio frequencies. In the detector tube the audio frequencies are separated from the radio frequencies. From the output of the detector to the loudspeaker we are interested in developing as much voltage as we can so there will be enough power to operate the loudspeaker. For this reason different types of transformers are used to connect the vacuum tubes in audio frequency stages—transformers having *iron cores* and having the secondary winding wound directly over the primary winding.

Soft iron is a much better conductor of magnetic flux than air and audio frequency transformers are designed so that the magnetic circuit is complete and the flux is confined to this circuit. In transformers of this kind in which "coupling" is said

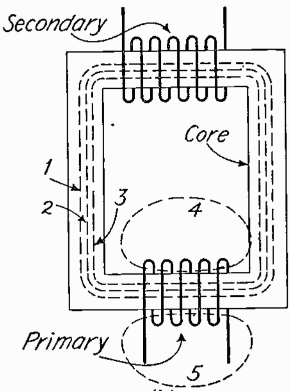
*A transformer with less turns in the secondary than the primary has a step-down ratio, which means that the secondary output voltage would be less than the input voltage.

to be close, because practically all the flux of the primary links with the turns of the secondary, the turn ratio of the secondary to the primary determines the ratio of induced voltage to input voltage. If the transformer has a turn ratio of 3 to 1, that is, the secondary has three times as many windings as the primary, *the voltage induced in the secondary will be three times the voltage fed to the primary.**

Without question the iron core transformer is one of the most valuable devices in Radio, in fact in all electrical circuits. A schematic diagram of a typical iron core transformer is shown in Fig. 5(b). When current flows through the primary, flux is created. Due now to the presence of the closed iron core, the magnetic lines are concentrated through its length as shown by lines 1, 2 and 3. Perhaps a few magnetic lines (and they are



(a) Typical Audio-Frequency Transformer. Construction very similar to Fig. 6.



(b)

Fig. 5

comparatively small) will not flow along the iron path but as shown by lines *4* and *5* so that there is a very small amount of leakage. Obviously lines 1, 2 and 3 link with the secondary and are responsible for the induced e.m.f. in the secondary. Now when the primary current varies, as for example when it is connected to an A.C. source, the flux linkages with the secondary will vary. Since leakage is reduced to a very small amount by the closed iron core, the turn ratio and voltage ratio will be almost exactly accurate.

You will notice that this *step-up* applies only to secondary A.C. voltage and because power is not generated in a transformer, an increase in the secondary voltage must not be accompanied by an increase in the secondary A.C. current.

Suppose we have a large transformer with a step-up ratio of 10 to 1—that is, it has ten times as many turns in the sec-

* For example, if 110 volts was fed to the primary of a 3 to 1 ratio step-up transformer, the voltage induced in the secondary would be 3x110 or 330 volts.

ondary as in the primary and we fed into the primary 100 watts of power at 10 volts. This means that in the primary circuit, there are 10 volts of pressure and 10 amperes of current and the power in watts is equal to the voltage multiplied by the current.* Assuming there are no losses in the transformer, the output voltage, that is, the voltage in the secondary will be 100 volts, because it has been stepped up from 10 to 100.

But what about the A.C. current in the secondary—has this been stepped up from 10 to 100 amperes? No, because the power in watts must be the same, 100 watts, according to the law of conservation of energy. In the secondary circuit the current is only one ampere for 100 multiplied by 1 equals 100 watts of power.

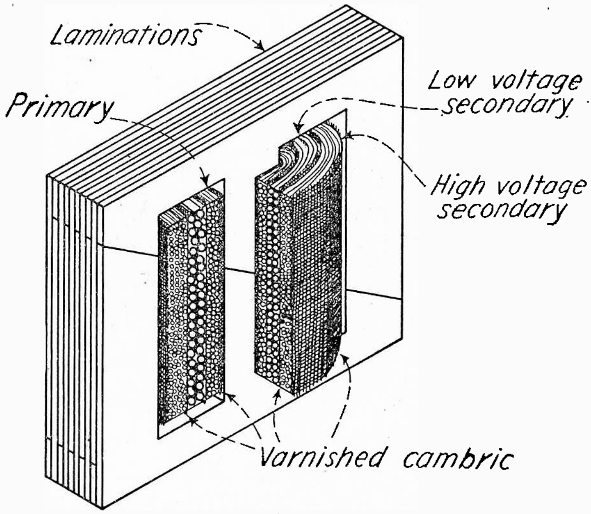


Fig. 6

The cores of modern audio frequency transformers are laminated, that is, they are made up of thin sheets of iron tightly clamped together but insulated from each other, usually only by the scale present on sheet iron. The purpose of the laminations is to reduce heat loss due to eddy currents which are currents induced into the iron core. The magnetic flux would induce very small currents in a solid iron core, which would result in losses due to the resistance of the iron. However, this matter of eddy current losses and another loss which is due to what is known as hysteresis, requires rather lengthy treatment so we

* This is only true if the load on the secondary is a simple resistor (which is true in power packs) and the transformer has no leakage flux.

can't go into it here—it will be considered in detail when we study magnetic circuits.

Now we come to another type of transformer used in radio receivers operated from the house lighting system—the transformer used in the power pack. (See Fig. 6.) This transformer is much larger than the ordinary audio frequency transformer. It is wound on a closed iron core and differs from the types of transformers we have been studying in that it has more than one secondary winding. These secondary windings (shown schematically in Fig. 7) are used to supply the various voltages to the receiver. As the voltages required to heat the filaments of the various vacuum tubes are comparatively small, 1.5, 2.5 or 5 volts, there must be a large *step-down* ratio between the primary and these secondary windings. As these transformers are

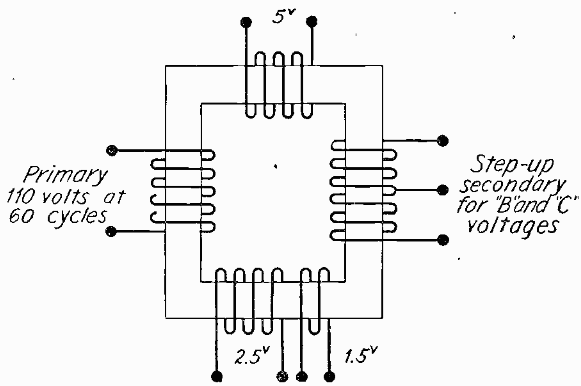


Fig. 7

usually designed to transform the 110 volt house lighting alternating current, the *step-down* ratio for the 1.5 (one and a half) volt filament winding will have to be 110 to 1.5, that is, if there are 1000 turns on the primary there will be 13.6 (thirteen and six-tenths) turns on the secondary,* *as the voltage in the primary divided by the voltage in the secondary must equal the number of turns in the primary divided by the number of turns in the secondary.*

The winding which supplies 2.5 volts (two and a half) will have a step-down ratio of 110 to 2.5 and the winding which supplies 5 volts will have a step-down ratio of 110 to 5.

There is only one secondary "B" winding because the high voltage alternating current in the output of this winding is rectified, that is, it is changed into direct current. Then various "B"

* $110 \div 1.5 = 73.3$ turn ratio. $1000 \div 73.3 = 13.6$ secondary turns.

voltages are obtained by tapping a resistor known as a voltage divider which is placed across the output of the rectifier tube.

Of course we must remember that we can't get any more power out of the transformer than we put into it. If there are five secondaries each drawing a definite amount of power, the primary must be supplied with the sum of all these powers plus whatever loss takes place in the transformer itself.

Each secondary winding acts as an individual secondary. The voltage is stepped down in them from 110 to 1.5, 2.5 and 5 volts as required. But the filaments require considerable current. Is it available? It is, because the power input equals the power output and if the voltage is stepped down the current will be increased. The plate circuits require high voltage and low current. This works out very well, because as the voltage is stepped up the current available is decreased.

THE EFFECT OF MUTUAL INDUCTION ON INDUCTANCE

It has been thoroughly impressed on your mind that inductance is the result of mutual induction between turns of a coil and self-induction in the individual turns. Bearing this in mind, we are going on now to talk about the effect of mutual induction between coils on the inductance of those coils and from now on whenever we speak of mutual induction we shall mean mutual induction between coils.

It is a simple matter to realize that when a transformer is used as a device to couple circuits the inductance of each winding is placed in the circuit to which it is connected. But that isn't all there is to it. The inductance of a coil is dependent on the magnetic field about the coil. Therefore if we have two coils with their magnetic fields interacting it is reasonable to suppose that the inductance of each coil will be changed because of this interaction.

The effect of mutual induction between coils on the inductance of the coils is called mutual inductance and the symbol is "M." The value of the mutual inductance naturally depends on the extent to which the fields about the two coils link. If the two coils were so far apart that there was practically no flux linkage, then the value of M would be zero.

Now let us imagine the two coils, L_1 and L_2, connected together in series. If they are placed so that their magnetic fields link they are said to be in *series aiding* connection. If they are connected so that their fields "buck" each other, the connection is said to be *series opposing*. See Fig. 8, which shows series aiding and series opposing connections as well as the conditions for field cancellation.

The total inductance L of two coils connected in series depends on the position which one coil bears to the other. When the two coils are placed, as in Fig. 8(a), so that their fields aid one another, the total inductance is the sum of the inductances of each individual coil, plus twice their mutual inductance. This can be stated more simply in equation form:

$$L = L_1 + L_2 + 2M \quad \text{(field aiding)} \tag{1}$$

When the two coils are at right angles (90 degrees) to each other as shown in Fig. 8(b) or so arranged that the field from one coil does not link with the other, the total inductance is only

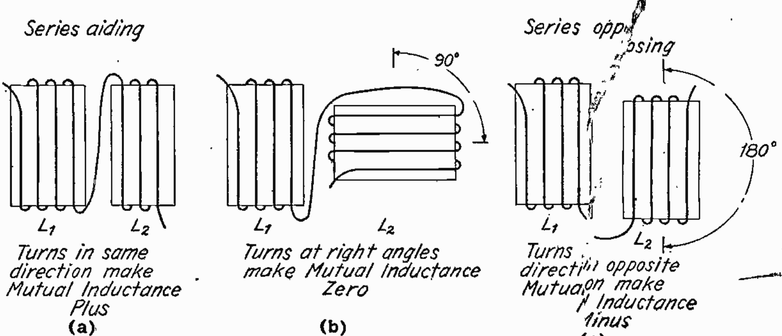


Fig. 8

the sum of the self-inductances of the two coils. In simple equation form this is:

$$L = L_1 + L_2 \quad \text{(no field linking)} \tag{2}$$

But when the coils are placed in such a position that the magnetic field of one coil opposes the field of the other coil, as in Fig. 8(c), the total inductance of the two coils connected in series will be the sum of each coil inductance minus twice the mutual inductance. In simple equation form this is:

$$L = L_1 + L_2 - 2M \quad \text{(field opposing)} \tag{3}$$

The fact that the total inductance of two coils connected in series also depends on mutual induction is made use of in a simple inductance device, called a variometer, which is used to some extent in radio measurements. It consists of two coils, usually spherical in shape, one placed within the other. One coil is stationary and the other free to move within the stationary coil.

The other coil, called the rotor, is so arranged that it can be rotated through an angle of 180 degrees, that is, from a condition of maximum field aiding to maximum field opposing. In this way, the inductance varies from maximum to nearly zero.

Mutual inductance between the two coils plays a very important role in Radio, especially in radio frequency amplifiers. Selectivity and sensitivity depend on the value of mutual inductance. Although the average service man will not have to measure the M of a radio coil, he should know how it is done. You cannot measure M directly—you have to get it by round-about methods. First you connect the two coils in series and measure the total inductance. Reverse the connections of one coil and again measure the total inductance. Subtract the smaller value from the larger value and divide by four. The result is the mutual inductance between the two coils for the position that they are in.

IMPEDANCE IN SERIES CIRCUITS

In previous lessons we learned about the magnitude of voltage and current in circuits containing resistances of different values, both in series and in parallel. We learned some extremely important principles which you must always bear in mind, such as Ohm's Law, which states that the current in amperes through any resistance multiplied by the resistance in ohms equals the voltage drop across the resistor. We learned that this holds true regardless of the position of the resistor in the circuit, no matter how complicated that circuit may be.

You will remember that when resistors are connected in series, the voltage across them is the sum of all the individual voltages across the individual resistors, and that the current through each resistor is the same; that when resistors are connected in parallel, the voltage across each resistor is the same and the current in the main lead connected to the parallel resistors is the sum of all the currents in the individual resistors.

In the lessons on inductance and capacity in A.C. circuits, we learned that inductive reactance is measured and expressed in ohms and it affects current and voltage in the circuit in quite a different manner, even though expressed in the same units (ohms) as pure resistance. The same is true of capacitive reactance which is also expressed in ohms.

You might rightly ask why inductive and capacitive reactance are measured in ohms just like resistance, if reactance differs from resistance. While reactance and resistance differ in their effect on current and voltage, they have this in common —they both act to limit current flow. It is even true that Ohm's Law can be extended for use in A.C. circuits.

We know that if we measure the current through any device in a D.C. circuit, and measure the voltage across the device, of course using D. C. instruments, we can calculate the resistance from Ohm's Law, by dividing the voltage by the current. This is true regardless of the construction of the device and regardless of its position in the circuit. Of course, if we know the current and resistance we can calculate the voltage drop, or if we know the voltage and the resistance we can calculate the current.

In A.C. circuits we can follow the same procedure. If we use an A.C. voltmeter and an A.C. ammeter and if with these we measure the A.C. voltage and the A.C. current through any device regardless of its position in the circuit (except devices that generate an e.m.f.), by Ohm's Law extended for A.C. use, we can calculate the extent to which the device holds back current flow. We divide the volts by the amperes and our answer is in ohms. But because we are dealing with an A.C. circuit, these ohms do not represent resistance but *impedance*.

The word *impedance* is a very useful one, as it includes everything in the circuit that holds back (impedes) the flow of alternating current—that is, it includes both ohmic resistance and reactance, inductive and capacitive. Our combination of resistance and reactance may be a series or a parallel combination, it doesn't make any difference, the voltage divided by the current is the A.C. impedance in ohms. The symbol used for impedance is (Z).

However, if we are considering the impedance of a single device, as of a condenser, we do not call it impedance but capacitive reactance (X_C). In the same way if our device is a coil, we call the ohmic value inductive reactance (X_L), never inductive impedance. If the device is a resistor, we call it merely a pure resistance. In this lesson we are going to learn to what extent reactances and resistances in series and in parallel impede the flow of current in A.C. circuits.

But before we go on to talk about impedance in series circuits, we must be sure we understand phase relations in A.C. circuits and what effect on phase a condenser or a coil will have.

You know that an A.C. voltage always starts from zero value and rises to a maximum value in what we call 90 degrees. In another 90 degrees it reduces to zero. In the next 90 degrees the voltage is at maximum again but acting in the opposite direction—you can call it negative voltage if you wish. In the final 90 degrees the voltage returns again to zero. Thus it took 360 degrees for the voltage to complete what we call a complete cycle. As far as the time is concerned, it might have been an hour, a minute, a second, anything. But whatever it is, the time is called the *period*.

An A.C. voltage applied to a device causes the current to flow through it depending on the impedance of the device. If the current is at a maximum when the voltage is maximum, zero when the voltage is zero, negative when the voltage is negative, then we say the current and voltage are in phase. But in many A.C. circuits the voltage and current are not in phase. The voltage may be at a positive maximum when the current is zero, just

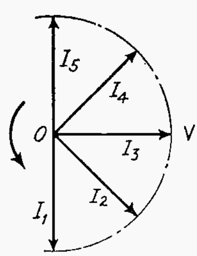


Fig. 9

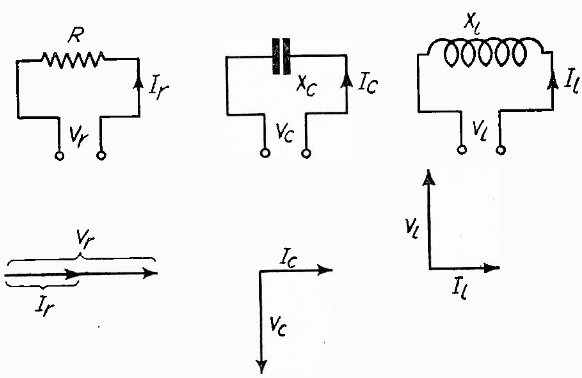
beginning to flow in a positive direction. Then we say that the current lags the voltage by 90 degrees.* Or the voltage may be zero, just entering the positive alternation and the current may be at maximum positive. Then we say the current leads the applied voltage by 90 degrees. From this we can see that the current may lag behind or lead the voltage. But the angle of difference, called the phase angle, is not often 90 degrees—in fact in a complete circuit the phase angle never is 90 degrees. It is always something between zero and 90 degrees, depending, as we shall see later, on the combination of reactance and resistance in the circuit.

In Radio we like to represent the electrical degrees denoting a phase difference by an actual angle on paper. To understand clearly what we mean by this statement look at Fig. 9 and read the following carefully. Visualize line I_1 rotating in a *counter-clockwise* direction (we say "counter-clockwise" because it is opposite to the way the hands of a clock move), taking posi-

* We might have said that the voltage leads the current by 90 degrees.

tions I_2, I_3, I_4 and I_5. Considering line OV as the reference line, it can be seen that I_2 lags behind OV by 45 degrees, therefore I_1 lags behind OV by 90 degrees. Now if we consider line OV as the voltage line and I_2 as current, then the current line I_2 will lag behind the voltage by 45 degrees. Line I_1 will lag behind the voltage by 90 degrees. If we consider line I_3 we see that in this case the current and voltage are in phase. Considering line I_4 we see that current is leading voltage by 45 degrees. Likewise line I_5 shows that current is leading voltage by 90 degrees. These relations as you can see are quite simple.

6 Every device in an A.C. circuit has a definite impedance, a definite voltage drop across it. There is a definite amount of current flowing through it. And finally there is a definite phase



(a) (b) (c)

Fig. 10

relationship between the voltage and the current. But no matter where a *resistance* is placed in a circuit and no matter what the phase angle between current and voltage might be in the rest of the circuit, the voltage across and the current through the resistor are exactly in phase. This is shown schematically in Fig. 10(a). Notice that the voltage V_r length is shown on the same line as the current length I_r. By this we represent that the voltage and current are in phase.

On the other hand, no matter where a *capacity* is placed in a circuit, the current I_C always leads the voltage V_C across it by 90 degrees. This is clearly shown in Fig. 10(b). Likewise, no matter where an *inductance* is found in a circuit, the current I_L through the inductance is always 90 degrees behind the voltage V_L across it as shown in Fig. 10(c).

What we have said about the voltage and current through resistors, condensers and coils is true whether the supply voltage is 60 cycles or 1500 kilocycles per second, provided the device is a pure capacity, a pure inductance or a pure resistance. And the voltage across the device divided by the current through the device is always the resistance in ohms (in the case of a resistor) or the reactance in ohms (in the case of a condenser or a coil). In other words, Ohm's Law is strictly applicable in all three forms:

$$\text{(a) } I = \frac{E}{R} \qquad \text{(b) } E = I \times R \qquad \text{(c) } R = \frac{E}{I} \qquad (4)$$

$$\text{(a) } I = \frac{E}{X} \qquad \text{(b) } E = I \times X \qquad \text{(c) } X = \frac{E}{I} \qquad (5)$$

$$\text{(a) } I = \frac{E}{Z} \qquad \text{(b) } E = I \times Z \qquad \text{(c) } Z = \frac{E}{I} \qquad (6)$$

which is strictly Ohm's Law even though we use Z as the symbol for impedance and X as the symbol for reactance instead of R for resistance.

Now suppose we have a series circuit containing a three ohm resistor and a coil having an inductive reactance of four ohms as in Fig. 11(a). Also connected in the circuit is a ten volt A.C. generator. What we want to know about this circuit is the voltage across the coil and the resistor.

Since both devices are in series, it is obvious that the same current will flow through each. What is the value of this current? From Ohm's Law we know it will be 10 volts divided by the impedance. But is this impedance 7 ohms $(3 + 4)$? Not at all. If there were two resistors in the circuit we could add their resistances to obtain the total resistance. But when there is a resistance in series with a reactance the total impedance cannot be obtained merely by addition.

The total impedance in this case can be determined very easily in this way—graphically. Starting out with two straight lines at right angles to each other as in Fig. 11(b), the horizontal line representing resistance and the vertical line representing inductance, we mark off on the resistance line three units (3 inches) representing three ohms. On the vertical line we mark off four units (4 inches) representing four ohms of inductance reactance. With a ruler draw the line x–y between 4 and 3. The length of this line represents the impedance. You will find that it is five units long (five inches) and as we have represented one ohm by one unit, the total impedance in the circuit is five ohms.

Knowing the total impedance and the voltage we can calculate the current from Ohm's Law for A.C. circuits. It is 10 divided by 5 which is 2 amperes.

Now that we know the voltage, the current and the impedance of the circuit we can make a number of calculations. For example, we can calculate the voltage across the resistor. If the resistance is three ohms and the current through the resistor is two amperes then the voltage across it will be 3 ohms multiplied by 2 amperes or 6 volts. We can calculate the voltage across the inductance in the same way, 4 ohms multiplied by 2 amperes equals 8 volts. But here we get into trouble for 8 volts plus 6 volts equals 14 volts. And the generator voltage is only 10 volts. Where did we make our mistake? We didn't take into

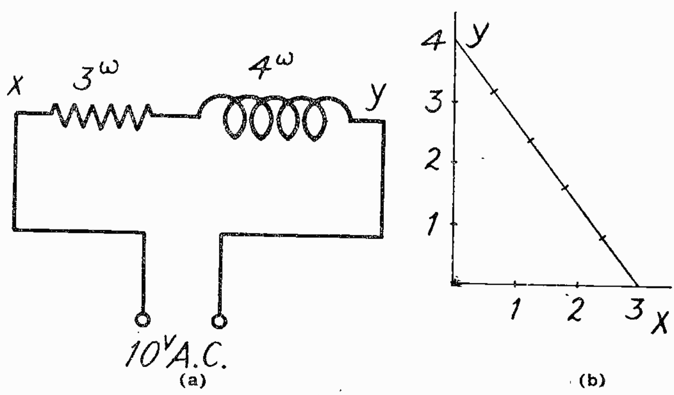


Fig. 11

consideration any phase shift. Knowing that the voltage can't be higher than 10 volts, we can reason that the phase difference must account for the difference between 14 and 10 volts.

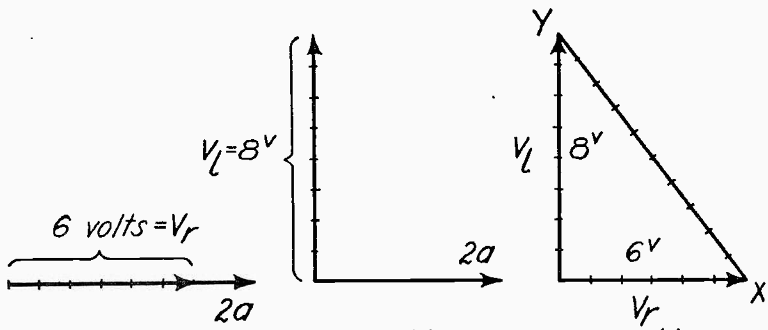
The 6 volts across the 3 ohm resistor are in phase with the 2 amperes of current through the resistor. This is represented in Fig. 12(a). The 8 volts across the inductance V_L are always 90 degrees ahead of the current which in this case is 2 amperes. See Fig. 12(b).* But the current through the coil and the current through the resistor are the same. Therefore we may represent them as in Fig. 12(c) both drawn to the same scale. This figure tells us that the voltage across the resistor is 90 degrees behind the voltage across the inductance. Now let us add

* Note in this case we considered the phase of the voltage in reference to the current. This is done because in a series circuit the current is a common reference.

6 volts plus 8 volts in this diagram, drawing a vertical line upward from the horizontal line on which we have marked 6 volts (6 units), the vertical line representing 8 volts (8 units). Then if we draw a line connecting X and Y, the line XY will represent the total voltage. In this way we add voltages and at the same time take into consideration the phase differences.

From this it can be clearly seen that voltages in A.C. circuits must be added in the same way as reactance and resistance are added.

Now let us refer to Fig. 13(a) in which is shown a series circuit containing 3 ohms of resistance and 4 ohms of capacitive reactance. What is the total impedance? Here again we start out with a horizontal line to represent resistance ($R = 3$) as shown in Fig. 13(b) and we draw a vertical line to represent



(a) (b) (c)
Fig. 12

capacitive reactance ($X_C = 4$), but in this case the line extends down from the resistance line to show that a capacity causes the voltage to lag behind current.* Then we lay off 3 units for the resistance and 4 units for the capacitive reactance and draw the line x–y. Measuring the length of x–y we find that it is again 5 units, or in other words the total impedance in the circuit is 5 ohms. From Ohm's Law we can see that the current will be 10 volts divided by 5 ohms which is 2 amperes.

We have taken small values of resistance and reactance in these examples to simplify these important radio problems. In practice, however, these values may be anything from a fraction of an ohm to thousands of ohms.

In Fig. 14(a) we have a combination circuit—a series circuit containing a coil having 4 ohms of inductive reactance, a condenser having 8 ohms of capacitive reactance and a resistor

* As we are dealing with a series circuit we use current as the common reference.

having 3 ohms of resistance. How do we go about obtaining the total impedance in a circuit of this sort? What is the current and what is the voltage across each part? This will be easy to determine if you have followed the previous explanation carefully.

The reactances and the resistance must be added in the same manner as before, but in this case we will have a vertical line extending upward and another vertical line extending downward from the reference line as shown in Fig. 14(b), because we have both capacitive and inductive reactance in the circuit. We lay off 3 units on our horizontal resistance line, 4 units on the X_L line and 8 units on the X_C line. But the capacitive phase shift is opposite to inductive phase shift. Therefore to find the total

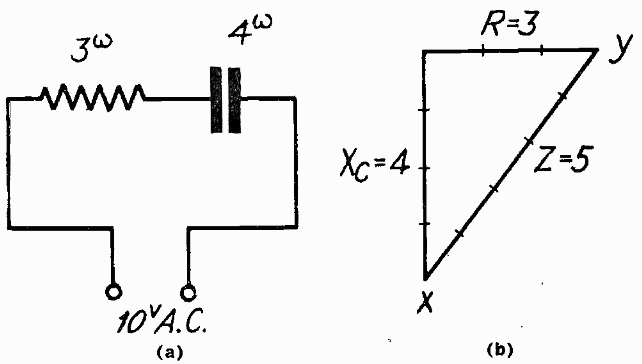


Fig. 13

reactance in the circuit we must subtract one from the other—that is, the smaller from the larger. We subtract 4 from 8 which leaves us 4 ohms of *capacitive* reactance. Therefore we count down on the X_C line 4 units and draw a line from x to y. The length of this line represents the total impedance in the circuit (5 ohms).

We might have done this same thing in a slightly different manner. We might have chosen some point as O in Fig. 14(c). Starting at O we draw a vertical line upward, 4 units long to represent 4 ohms of inductive reactance. Then from point A we draw a horizontal line 3 units long to represent 3 ohms of resistance to point B. From point B we draw a vertical line downward, 8 units long to represent the capacitive reactance. Connect points O and C and the line OC represents the total impedance in the circuit.

Compare this second method with the first method and you will find that it is essentially the same.

Measure line x–y in Fig. 14(b) or line OC in Fig. 14(c) and you will find that each is 5 units long, showing that the total impedance in the circuit is 5 ohms.

Knowing the impedance we can calculate the current through the circuit. It will be 10 divided by 5 or 2 amperes. From this we can calculate the voltage across X_L which is 2 multiplied by 4 or 8 volts and across X_C which is 2 multiplied by 8 or 16 volts and across R which is 2 multiplied by 3 or 6 volts.

RESONANCE

The line drawing in Fig. 14(b) you will notice looks very much like the line drawing in Fig. 13(b), from which we conclude that a circuit containing more capacitive reactance (X_C)

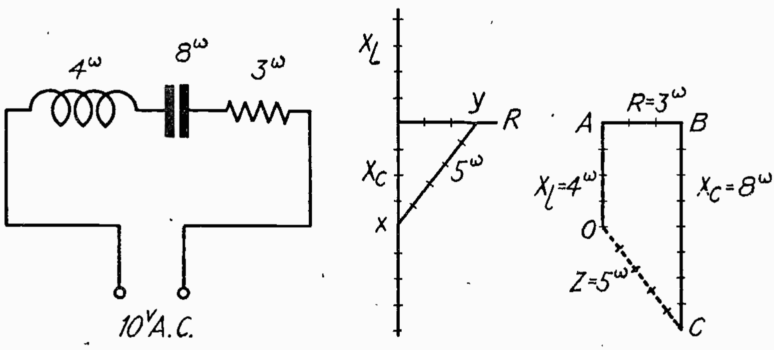
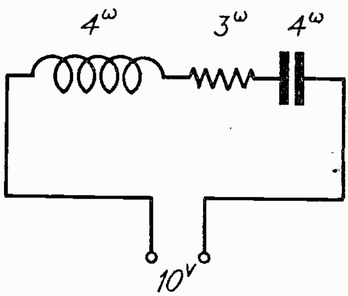


Fig. 14

than inductive reactance (X_L) along with resistance (R) will act like a circuit containing only capacitive reactance and resistance, the amount of the capacitive reactance being the difference between the inductive and capacitive reactance as shown in Fig. 14(b).

Now suppose we have a series circuit containing 3 ohms of resistance and 4 ohms of inductive reactance and we want to wipe out the inductive reactance. All we have to do is to place 4 ohms of capacitive reactance in series with the resistor and the inductance as shown in Fig. 15. The current in this circuit would be 10 volts divided by 3 ohms or 3⅓ amperes, because the inductive reactance (X_L) balances out capacitive reactance (X_C) and the resistance (R) (3 ohms) is the only impedance in the circuit. The voltage across the inductance would be 4 multiplied by 3⅓ or 13.3 volts; the voltage across the resistance equals 10 volts; the voltage across the capacity would be 13.3 volts.

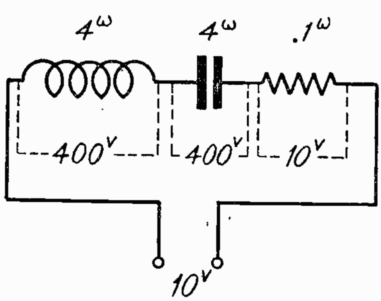
Again suppose we have a series circuit as shown in Fig. 16 with X_L equal to 4 ohms, X_C equal to 4 ohms and R equal to .1



A.C.

Fig. 15

ohm. What are the currents through and the voltages across the parts? You know X_L is cancelled by X_C so that the circuit is really equivalent to a circuit containing only .1 ohm of resistance. The current then will be 10 volts divided by .1 (one-tenth of an ohm) or 100 amperes. V_L equals 100 multiplied by 4 or 400 volts; V_C equals 100 multiplied by 4 or 400 volts and V_r



A.C.

Fig. 16

equals 100 multiplied by .1 or 10 volts. It seems queer that we apply only 10 volts and yet the voltage across the coil and across the condenser is 400 volts, 40 times the terminal voltage. But as you see, this is perfectly possible because the coil and condenser voltages are equal and opposite. This leaves only the voltage across the metallic resistance, which will be the voltage measured across the entire resonant circuit.

Whenever in a series circuit the capacitive reactance balances out the inductive reactance, the circuit is *in resonance.*

But resonance will occur at only one frequency. You remember from your study of inductive and capacitive reactance that *an increase in frequency results in an increase of inductive reactance*, but a *decrease in capacitive reactance.* Thus if a circuit is resonant at, let us say, 1500 kc. and if the frequency is increased to 1600 kc., the inductive reactance of the circuit increases and the capacitive reactance decreases, upsetting the balance between the two, with the result that the impedance to the 1600 kc. frequency is very high.

Keeping this in mind let us examine a typical resonant circuit, containing a coil and a condenser, the capacity of which can be varied. Of course there will be resistance in the coil, and

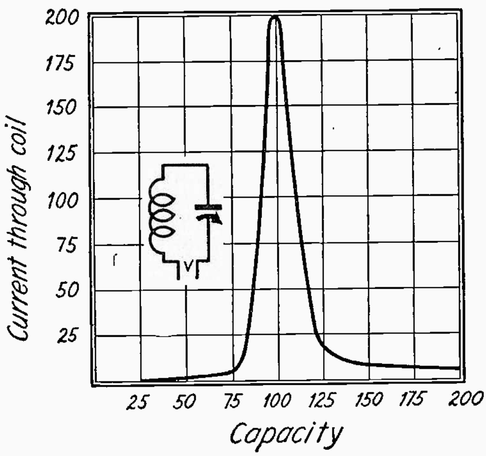


Fig. 17

there will be distributed capacity besides the inductive reactance. In order to obtain maximum current flow at a certain frequency, the capacity of the condenser must be varied so that the capacitive reactance will exactly balance the inductive reactance. This is exactly what you do when you tune a radio set. Of course we could also tune such a circuit to resonance by using a *fixed capacity* and varying the *inductance* of the coil, *therefore a circuit can be tuned to resonance by either varying the capacity or the inductance,* but it is customary in Radio receivers to use variable condensers to tune resonant circuits.

The transmitting station, to which you tune your radio receiver, broadcasts on a certain frequency. The signal induces a voltage into the series R.F. tuning circuit of your receiver and the reactance of the coil and condenser will depend on that frequency. If the capacitive reactance is very different from the inductive reactance, the total impedance in the circuit will be high and the signal will not be heard or if it is it will not be very loud.

But we tune the circuit of the receiving set by varying the capacity and as the capacitive reactance approaches the value of the inductive reactance the current in the circuit gradually becomes larger until the reactances balance causing maximum current to flow. At this point the circuit is in resonance with the frequency of the waves sent out from the broadcasting station. If you change the adjustment of the condenser beyond resonance the current will go down, for as you detune the circuit, the impedance increases to a point where no signal current can flow.

When the capacity is increased toward resonance at the frequency of a particular broadcasting station, the signal cur-

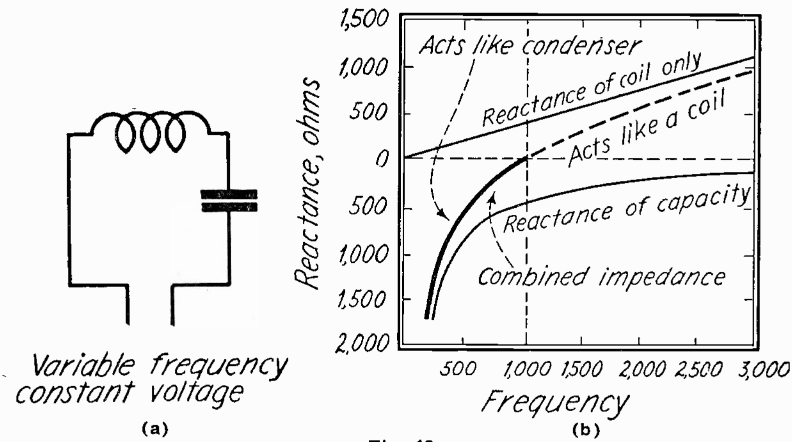


Fig. 18

rent from that station increases slowly at first, then rapidly to a peak which indicates resonance and then if the capacity is still further increased the signal current decreases. This action is clearly shown by the curve in Fig. 17 which is a typical *resonance curve*. Throughout your radio studies and your radio work you will use curves like this quite often.

In Fig. 18 (a) we have a circuit where both the capacity and the inductance are kept fixed but the frequency of a signal is increased. The result would be as shown in the graph of Fig. 18(b). Reading on the horizontal scale we see that as the frequency is increased from 250 to 3000 cycles; below zero on the vertical scale represents capacity reactance in ohms, while inductive reactance is represented above zero on the same scale.

Looking at the heavy "combined impedance" line you will notice that at first the circuit acts as though only a condenser were in it. And as the frequency is increased the impedance becomes less until the condition of resonance appears when the impedance is zero. As the frequency is increased beyond this point, indicated by the dashed line continuing the heavy curve, the circuit acts as though it has only a coil in it and the impedance gradually increases.

REACTANCES IN PARALLEL CIRCUITS

Coils and condensers are not always connected in series—in receivers and transmitters you will often find them in parallel. Of course in any circuit there is resistance but in resonant circuits it is undesirable and we keep it down to a minimum.

For the sake of completeness we have included a resistor in Fig. 19(a) which represents the resistance of the other devices and the conductors in this parallel circuit. Let us say that this resistance is 3 ohms, that the capacitive reactance in this circuit is 8 ohms, and the inductive reactance 4 ohms. The supply voltage is again 10 volts. Now we are interested in the current drawn by each and the current drawn by the three together.

It is very easy to determine the current drawn by each part; from Ohm's Law we know that the current drawn by the inductance will be 10 divided by 4 or 2½ amperes. The current drawn by the capacity will be 10 divided by 8 or 1¼ amperes and the current through the resistance will be 10 divided by 3 or 3⅓ amperes.

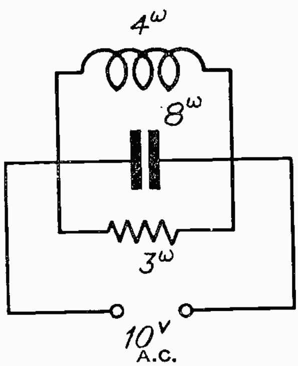
This of course follows from the rule we learned to the effect that no matter where a reactance or an impedance is in a circuit, the current through it is the voltage divided by the impedance, reactance or resistance as the case may be.

Now that we know the current drawn by each part, will the main current be 2½ plus 1¼ plus 3⅓ amperes? It would be if we did not have to consider phase. In calculating the total current we must remember that inductive reactance causes the current to lag the voltage by 90 degrees and capacitive reactance causes the current to lead the voltage by 90 degrees, that is, in the opposite direction.*

Each separate current has a definite phase relation to the voltage across that particular device. But we know that the voltage across each is the same. Thus we can refer each cur-

* In parallel circuits the terminal voltage is common, therefore it is simpler to consider the phase of the current in respect to voltage.

rent to a common voltage. Again, to determine the main current, we use a line diagram as shown in Fig. 19(b). Let the horizontal line OV in this diagram be our common voltage. Then current I_L lags behind its voltage by 90 degrees. On the line I_L we mark $2\frac{1}{2}$ units representing $2\frac{1}{2}$ amperes of current. The current, I_C through the capacity, leads its voltage by 90 degrees. On the line I_C we mark off $1\frac{1}{4}$ units representing $1\frac{1}{4}$ amperes. Because the current through a resistor is always in phase with its voltage we mark off on line OV $3\frac{1}{3}$ units representing the $3\frac{1}{3}$ amperes, through the resistor. Then, to get the total current through the inductive and capacitive reactances, we must subtract I_C from I_L. We do this by marking off I_C on I_L starting at point x. From point y to point z we draw a line and the length of this line represents the total current in the circuit.



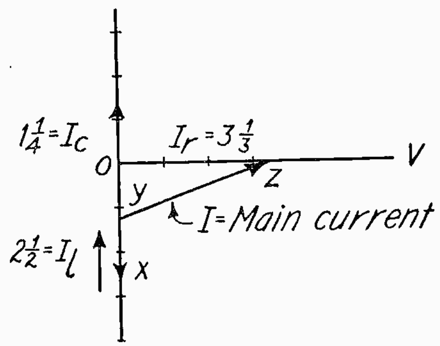


Fig. 19

Measuring it we find it is $3\frac{1}{2}$ units long from which we know that the total current is $3\frac{1}{2}$ amperes.

Now that we know the total current, it is a simple matter to calculate the total impedance—we merely divide 10 by 3.5 which is 2.85 ohms. In working with parallel circuits it is always much easier to find the total current by means of a line drawing and then to calculate the total impedance, than to calculate the impedance first. If you were to make a line drawing of the reactances and resistances as we did in the case of series circuits, we would find that the total impedance would be 5 ohms. This is obviously wrong for we have found that the impedance is only 2.85 ohms. If we think a minute, however, we will realize that this difference is to be expected, for in parallel circuits several paths are provided for the current to flow over, and the more paths, of course the less impedance.

From the line diagram in Fig. 19(b) we can see that part of the current through the coil was balanced out by the current in the condenser. We could go a step farther—we could vary the capacity until its reactance would be equal to 4 ohms. Then the current in the condenser would completely balance out the current in the coil and we could have parallel resonance. At parallel resonance, the total current that flows in the external circuit is less than the current in the parallel circuit. This is because the currents in the condenser and the coil are in opposite directions as regards the external circuit, and thus tend to neutralize each other in that circuit.

And now let us look at Fig. 20 where we have a coil in parallel with a condenser and 10 volts applied to the circuit. Let us say the resistance is not appreciable. The coil has a reactance of .1 ohm (one-tenth of an ohm) and the condenser is

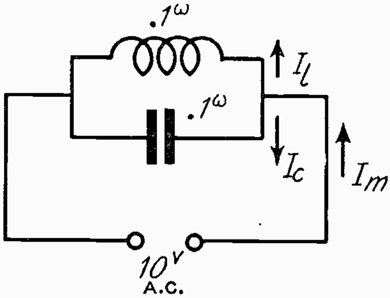


Fig. 20

adjusted to have a reactance of .1 ohm, so that we have here an example of parallel resonance.

The current through the coil will be 10 divided by .1 or 100 amperes. The current through the condenser will be 10 divided by .1 which is also 100 amperes. When these two currents I_L and I_C are added by means of a line diagram you will find that one balances out the other and the line current I_m is zero. This seems peculiar but it is true. And as no current flows in the main line, it is clear that the coil and condenser in a parallel resonant circuit act like one extremely large impedance to the applied e.m.f. Remember this last statement as the principle involved is very valuable in Radio.

In your radio work you will often find parallel circuits like this connected in various parts of receivers to prevent current from flowing. A parallel resonant circuit may be used as a choke or as a wave trap to eliminate the signals from interfering stations.

COMPARISON OF SERIES AND PARALLEL RESONANCE

It is interesting to compare the resonance phenomenon in a series circuit with the phenomenon of parallel resonance. In a series resonance circuit, the individual *voltages* across the coil and condenser are greater than the total voltage across the supply circuit, whereas in parallel resonance circuits the separate *currents* are greater than the total current through the supply circuit. The impedance of the series resonant circuit at resonance is very small, while the impedance of the parallel resonant circuit at resonance is very large.

You will never have any difficulty in identifying series and parallel resonant circuits in practice if you memorize the circuits shown in Fig. 21. If the coil and condenser are connected

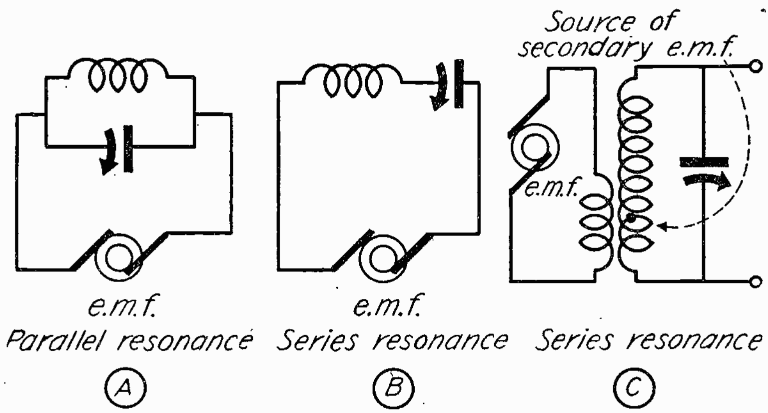


Fig. 21

together and the voltage is applied to the common terminals, as shown in (*A*), we have parallel resonance. If the coil and condenser are connected in series with the voltage as shown in (*B*) we have a series resonance circuit. If they are in parallel and a voltage is induced into the circuit by mutual induction, as shown in (*C*), we have series resonance. Remember also that in a series circuit which is resonant at a certain frequency, the impedance is limited to the resistance in the circuit. In parallel resonant circuits, in resonance at a certain frequency, the impedance is extremely high and the current flow is limited to the current flow through the equivalent parallel resistance, which is usually extremely high. We use a series resonant circuit where we want to obtain maximum current flow at a certain frequency. We use a parallel resonant circuit where we want to reduce current flow of a certain frequency to a minimum.

Fig. 22 shows part of the circuit diagram of a modern superheterodyne receiver, with the series and parallel resonant circuits circled. In the series resonant circuit the voltages arise within the coil itself due to mutual induction between it and the primary coil.

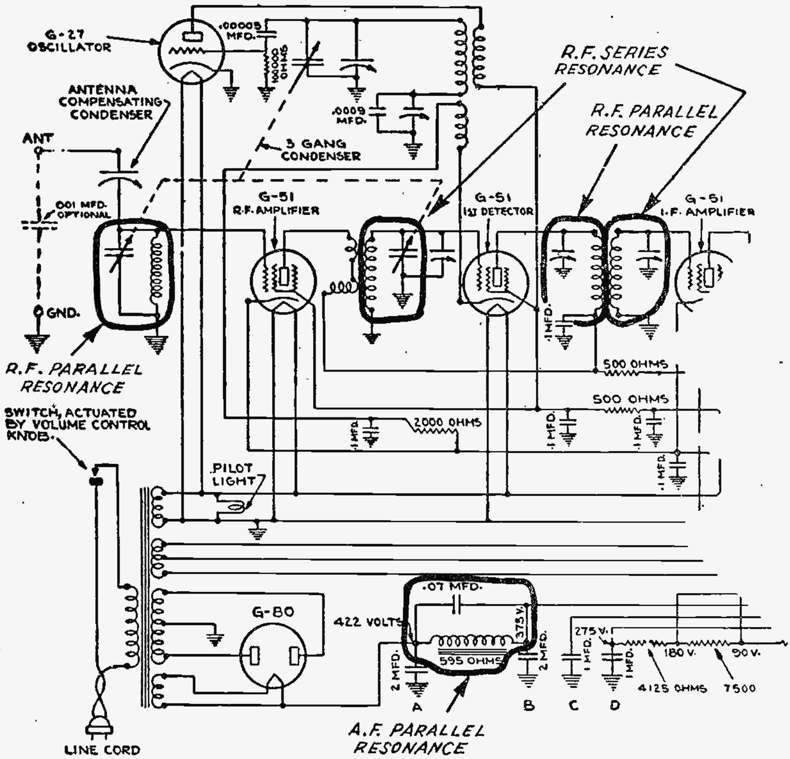


Fig. 22

In parallel resonant circuits the voltages are fed to both ends of the coil and therefore the condenser and coil are in parallel with the voltage supply. These series and parallel resonant circuits are included here merely as evidence of the importance of an understanding of series and parallel resonance. In a later lesson we shall analyze the complete circuit in considerable detail and then we shall see just why series resonance is used in one place and parallel resonance in another.

TEST QUESTIONS

Be sure to number your Answer Sheet 9 FR-1.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and the best possible lesson service.

1. What is the difference between mutual induction and self-induction?

2. What important fact permits an A.C. voltage to be induced in the secondary of a transformer—that is two coils fixed in relation to each other?

3. Does D.C., pulsating or A.C. current flow in the *secondary* of a transformer?

4. Explain the fundamental difference between a *step-up* and a *step-down* transformer.

5. Assuming you had built a *step-up* transformer with a turn ratio of 10 to 1, that is, with 1000 turns of wire on the secondary and 100 turns on the primary, what would the *secondary* voltage be when 110 volts were applied to the primary? (See example worked out in footnote * page 7.)

6. Define impedance.

7. Does the inductive reactance *increase* or *decrease* when the frequency of the current increases in the circuit?

8. When tuning the circuit of a receiving set what must be the relation between inductive and capacitive reactance to obtain maximum current flow at a certain frequency?

9. In what two ways could you tune a circuit to resonance containing a coil and a condenser?

10. If you measured the current (I) flowing through a certain device in an A.C. circuit and found it was 2 amperes and the voltage (E) across it was 110^v, solve for the impedance (Z) in ohms of the device? (Use Ohms Law (c) formula (6), page 16.

HOW A THREE ELEMENT TUBE AMPLIFIES

10 FR-2

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

ENTHUSIASM

Some fortunate people are just naturally enthusiastic—and they throw themselves body and soul into whatever they are doing. These people get what they want out of life—easily.

Other, less emotional, people are inclined to be lukewarm by nature. And yet, to get along in our modern world, enthusiasm is necessary. So what is a man to do if he is not naturally full of enthusiasm?

He must learn to be enthusiastic! He may even have to evolve some secondary reason for enthusiasm such as the desire to be wealthy, to have a better home, a better car, ease and comfort.

Of course the highest type of enthusiasm, the most satisfying to its possessor, is enthusiasm for one's work. If you can really be enthusiastic about your work, if you can get pleasure out of your work for its own sake, the other things will take care of themselves.

But if you are not doing the kind of work you particularly like, if your surroundings are not ideal, if your co-workers are not all you would have them be, it is much better to tackle your work enthusiastically, because you know it will bring you more money and advancement, than to do your work in a half-hearted manner each day.

And, it may be that if you keep up this kind of enthusiasm long enough, it will turn into a real enthusiasm, and you may begin to get a "kick" out of your work.

So, be enthusiastic about your work, no matter what kind of work you are doing and no matter what arguments you have to use to persuade yourself that your enthusiasm is justified. You will be repaid many times over.

J. E. Smith.

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How a Three Element Tube Amplifies

THE TRIODE

As you know, the triode is the 3-element vacuum tube. The very first vacuum tube, the Fleming valve, had only 2 elements, the filament and plate.* This diode took the place of the crystal rectifier as a detector, but it did not provide any amplification. Dr. Lee DeForest is responsible for the third electrode and his remarkable discovery made possible *amplification*, one of the most important functions of Radio tubes.

This third electrode, or element, is called the grid. It may be in the form of a perforated plate, but it is usually in the form of a mesh or *grid* of fine wire from which it takes its name. The grid of the tube is placed between the filament and the plate nearer the filament than the plate. It is important to realize the position of the grid in respect to the filament and the plate as tube amplifying action depends largely on this.

The grid of a vacuum tube can be compared with the trigger of a gun. It is really a control—and we shall go on to learn how it controls the plate current—and just a small varying grid voltage will result in a large change of plate current, just as moving a gun trigger a quarter of an inch or so will result in driving a bullet hundreds of yards—provided the gun is loaded. As you get to understand the action of the grid better, you will realize more and more how close this comparison is.

In an amplifying stage, whether it be radio frequency or audio frequency, in which a triode is used, three circuits meet in the tube—the filament circuit, the plate circuit, and the grid circuit. Look at Fig. 1 which shows these three circuits which have a common meeting point in the tube. From what you have already learned about the action of vacuum tubes, you know that when the filament is heated by the A battery, a cloud of electrons will be emitted from the filament and surround it. But because the plate is positively charged by the B battery, the electrons (negative particles) about the filament will be attracted to the plate. In fact, the electrons will stream from the filament to the plate and this stream of electrons constitutes an electric current just as though electrons were moving through a solid con-

* The filament is often called the *cathode* and the plate the *anode*, which accounts for the -ode part of triode.

ductor instead of through space. If we trace the course of electrons we will see that they go from the filament to the plate to the positive side of the B battery, through the B battery, back to the filament. This is, of course, opposite to conventional current flow—but as the difference between current flow and electron flow has been brought out so often in previous lessons, no explanation of this contradiction need be made here. And we can consider current flowing from the plate to the filament if we want to—as long as we remember that *electrons* move from the filament to the plate. Thus we say that the combination of the heated filament, the evaporation of electrons from the filament, and the positively charged plate, causes an *electric current* to flow from the plate to the filament.

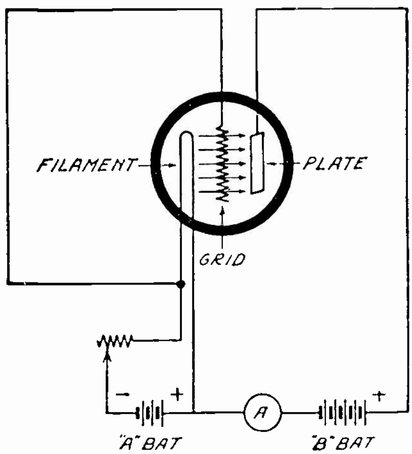


FIG. 1.—Filament, Grid and Plate Circuits of a Triode

It must be remembered that the filament is in both the grid and plate circuits; that is, it is common to both circuits. The A current flows through the filament only, for only one purpose—to heat it. The B current flows from the positive pole of the B battery (considering conventional current flow), through the plate, through the filament, back to the negative pole of the B battery. If we consider electron flow, we can imagine the B battery as a pump, pumping electrons out of the negative terminal, through the filament to the plate, and back through the circuit to the positive pole of the B battery.

The flow of current in the plate circuit can be measured by a meter placed in series with the circuit as shown at *A*. This current is naturally very small—five or six milliamperes in the case of an ordinary tube and so a milliammeter (an ammeter which measures thousandths of an ampere) must be used. The meter can be placed between the plate and the positive terminal of the B battery, just as well. In fact, it can be placed anywhere in the plate circuit in order to measure the plate current.

Now what about the grid? As previously stated, the grid exerts a control over the plate current. And we have said that only a small grid swing * will cause a comparatively large change in plate current. Exactly what this statement means we shall soon see. Suppose we connect a small C battery (shown as *C* in Fig. 2) between the grid and the negative A filament terminal with the positive terminal of the C battery connected to the filament and negative terminal connected to grid. The voltage of

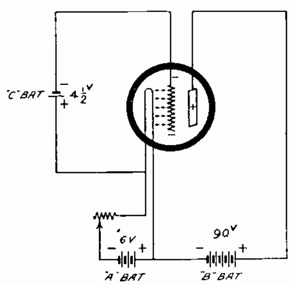


FIG. 2.—This Diagram Illustrates the Action of the Negative Charge on the Grid.

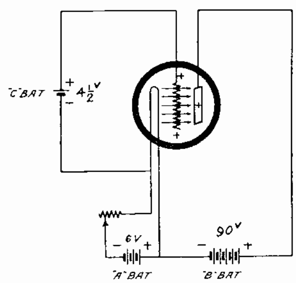


FIG. 3.—The Action of the Positive Charge on the Grid

the C battery (let us say it is 4.5 volts) is too small to cause a current to flow across the gap between the filament and the grid—the gap has what we call infinite resistance to our low voltage. So what happens? The grid and the filament inside the tube act as two plates of a small condenser and the grid becomes negatively charged with respect to the filament—that is, as far as the grid circuit is concerned. Now what effect will the negatively charged grid have on the plate current?

You know that the grid is negatively charged because there is an excess number of electrons on the grid. Electrons attempting to go from the filament to the plate will be repelled by the extra electrons on the grid, for *like charges repel* and *unlike charges attract*. As the grid is very close to the filament, this repelling action is quite strong so that only a very few electrons in this example actually move from the filament to the plate when the grid is 4.5 volts negative. The number of electrons that do

* A grid swing means the variation in grid voltage.

get across depends on the difference between the plate attraction and the grid repulsion. The effect of the grid position in the tube can be seen if we realize that in a '56 type tube a 16 negative grid voltage will reduce the plate current substantially to zero even with 180 volts positive applied to the plate.

Then suppose we reversed the terminals of the C battery as in Fig. 3. Now the grid has a positive charge and electrons will be attracted to it from the filament. This attraction is very strong because the grid is so near the filament. But when they get as far as the grid on their journey, they feel the greater attraction of the higher positive charge on the plate. So when the grid has a positive charge, it actually helps the electrons to pass from the filament to the plate, resulting in a larger plate current flow than if the grid had a negative charge—the density of the electron stream therefore is increased many times by the action of the positive charge on the grid and decreased by a negative charge on the grid.

GRID CURRENT FLOW

When we were studying Fig. 3 we learned that the positive charge on the grid actually helped electrons to move from the filament to the plate, but we did not say anything about the effect of current flow through the tube on the grid itself. The fact of the matter is that not all the electrons that pass through the grid go to the plate—some are attracted to the grid and flow through the grid circuit. This results in distortion in a Radio receiver as we shall learn later, and for this reason precautions must be taken to prevent grid current from flowing, or the distorting effect of a grid current made negligible.

Under actual operating conditions, a Radio or Audio frequency A.C. voltage is applied to the grid of the amplifier tube which has a certain steady D.C. negative bias (voltage) furnished by a C battery. This A.C. voltage changes from positive to negative many times a second—and so the negative grid voltage of the tube is alternately increased and decreased. When the charge on the grid of a triode is negatively increased, the plate current will decrease; when less negatively charged, the plate current will increase. But what about current flowing in the grid circuit if the grid was positively charged by a very large signal? Current would flow, of course, and as this is undesirable we may take steps to prevent this from occurring by using a sufficiently large negative grid voltage. Let us say that the A.C. generator in Fig. 4 causes the

2

grid to be two volts negative on one alternation and two volts positive on the other alternation. If we connect a 4.5 volt C battery between the generator and the grid as in Fig. 4 with its negative pole connected to the grid, the grid will swing from 6.5 to 2.5 volts negative. On the negative alternation, the generator voltage will *add* to the battery voltage—and on the positive alternation, the generator voltage will subtract from the battery voltage. When the generator voltage is zero, the grid voltage would be —4.5 volts, only the "C" battery voltage. And so it is clear that by using a battery to put a negative charge on the grid, it is possible to prevent the grid from swinging positive, which means that the grid swings more and less negative and therefore cannot draw a grid current. Used in this manner the battery voltage is called the *biasing* voltage, or the *negative C* bias on the tube and is used to improve the tube as an amplifier.

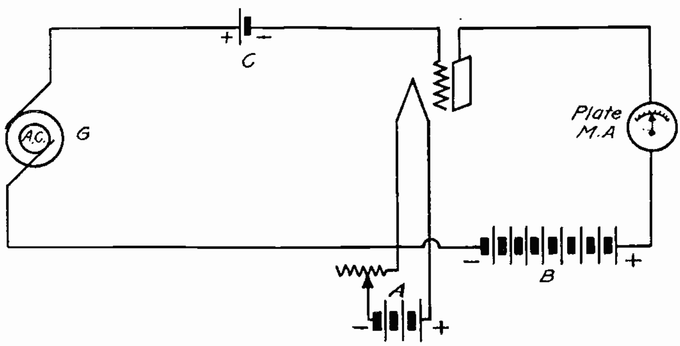


FIG. 4.—Diagram Showing an A.C. Generator (G) Connected to the Grid-Filament Input of a Vacuum Tube

E_g-I_p CHARACTERISTICS

Before we can go any farther in our study of the vacuum tube as an amplifier, it is necessary that we learn something about characteristic curves and how they can be used in our studies. Of course, the characteristic we are chiefly interested in is the relative change of plate current in accordance with changes in grid voltage. The symbol for plate current is I_p and the symbol for grid voltage is E_g—hence, the title of this chapter, E_g-I_p characteristics.

An arrangement as shown in Fig. 5 can be used to determine the E_g-I_p characteristics of a tube. An arrangement is provided to make it possible to vary the grid voltage quickly as well as the polarity of the voltage that is applied to the grid. When the movable arm of the potentiometer P is at C, there will be a negative potential applied to the grid, equal to the potential difference between the points *A* and *C*. When the arm is at *B*, a positive potential will be applied to the grid equal to the voltage between *A* and *B*. When the potentiometer arm is in a mid-position as shown, no voltage will be applied to the grid, as both positive and negative voltage will balance and so cancel each other.

If we were to move the potentiometer arm from *B* to *C* and from *C* to *B*, alternately, it is clear that we should have a slow-motion A.C. voltage—the voltage would go from zero to maximum in one direction, back to zero to maximum in the other direction, and back to zero again—and one cycle would follow the other as we moved the arm back and forth. In this testing arrangement we are making the C battery and the potentiometer

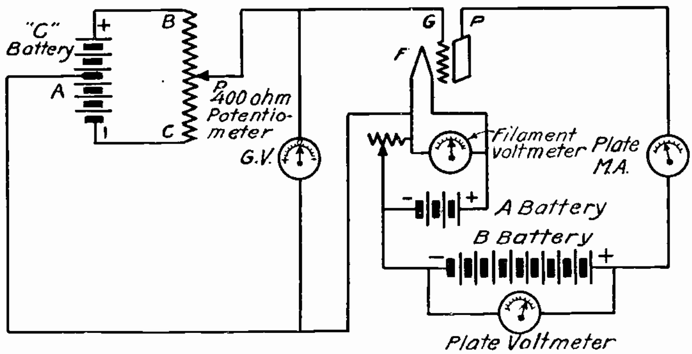


FIG. 5.—Circuit Diagram of Testing Set for Obtaining Tube Characteristics

take the place of a Radio signal, and of course the big advantage to this arrangement is that we can study the effect of the grid voltage on the plate current at any point between *B* and *C*. Notice that there is a grid voltmeter (*GV*), which will indicate a voltage in the grid circuit and its direction—and a milliammeter (*MA*) in the plate circuit which will indicate any changes in plate current which occur as the grid voltage is changed.*

Let us start with the potentiometer arm at *C*. Then we will move the arm from *C* to *B*, a short distance at a time, and at each setting we will note the reading on the grid voltmeter and the reading on the plate milliammeter. Let us say that our C battery

* In a filament type tube the C voltage is always measured with reference to —*F* (negative filament) terminal of the tube; in cathode heater type tubes the C voltage is measured with reference to the cathode (electron emitter).

consists of six 4½ volt batteries in series, a total voltage of 27 volts (4½ × 6). Therefore we will be able to vary the C voltage from —13.5 to +13.5 volts. Let us assume that the plate voltage is 90 volts. If we vary the C voltage in steps of 1½ volts we will get plate current readings as shown in Table No. 1.

The readings shown in Table No. 1 are purely imaginary. E_g-I_p characteristics for different tubes are widely varied and it will even be found that the E_g-I_p characteristics of tubes of the same types vary. Different groups of E_g-I_p readings can be taken with various B voltages. The main purpose of this experiment which we have pretended to carry out is to give you a clear idea of what we mean by E_g-I_p characteristics and how they can be obtained. At the same time it affords a means of reviewing again the action of a grid in an amplifying tube.

TABLE NO. 1

Grid Volts	Plate Current Milliamperes	Grid Volts	Plate Current Milliamperes
−13.5	0.0	+ 1.5	3.5
−12.	.1	+ 3.	4.0
−10.5	.18	+ 4.5	4.5
− 9.	.25	+ 6.	5.0
− 7.5	.5	+ 7.5	5.45
− 6.	1.	+ 9.	5.7
− 4.5	1.5	+10.5	5.8
− 3.	2.	+12.	5.9
− 1.5	2.5	+13.5	6.00
− 0	3.		

Fig. 6 shows the same facts we obtained from our experiment in Fig. 5 in graph form. You remember from the book on the Language of Radio-Tricians that in Radio we frequently use graphs as a short cut in the matter of presenting engineering information. In your Radio work you will frequently come across curves such as shown in Fig. 6, a typical E_g-I_p curve, and they will mean a great deal to you because you realize they present important facts regarding tube characteristics. For instance, the graph in Fig. 6 shows you exactly the same thing as the Table No. 1, but notice how much simpler it is to read the graph—you can get the whole story at a glance.

Grid voltages are read on the horizontal line and plate current in milliamperes is read on the vertical line. When "0" grid voltage is applied to the grid circuit, how much plate current is flowing? Find "0" on the horizontal scale—at the base of the center vertical line, then move up to the point where this line intersects the E_g-I_p curve. Then by noting the location of this point of intersection with reference to the vertical scale, we find that 3 milliamperes of current are flowing in the plate circuit. In the same way, when the grid voltage is —1, the plate current will be 2.65 milliamperes, as shown by the dotted line. When the grid voltage is —5, the plate current will be 1.35 milliamperes, and so on. This sort of curve, which is made by placing a tube in a special testing circuit, is known as a *static* E_g-I_p curve. When we study practical amplifiers we shall learn about *dynamic* E_g-I_p curves which are made with the tube in actual operation with a load (resistance or impedance) in the plate circuit.

Now look at the curve in Fig. 6 again—notice that between K and K_1 the curve is practically a straight line. Below K and above K_1 the curve bends sharply. In order that a tube may operate as an amplifier it must be operated on the straight portion of its E_g-I_p characteristic curve. The reason for this is that the plate current must increase or decrease in exactly the same proportion as the grid voltage increases or decreases. In other words, if a grid change of 2 volts causes a plate current change of 1 ma., then a grid change of 4 volts should cause a plate current change of 2 ma. Later in our course we shall learn that if the tube is operated either on the upper or lower bend, above K_1 or below K, the tube will act as a detector.

Now the question arises, how can we get our tube to operate on the straight portion of its E_g-I_p curve? Here is where our grid bias does its work—and it really has two functions—to prevent the grid from becoming positive, thus drawing current, and to set the operating point for the vacuum tube.

Compare Figs. 7 and 8 carefully. They tell the whole story of grid bias. Fig. 7 shows no grid bias—notice the signal swing *A-B-C-D*, the swing is from 2 volts negative to 2 volts positive. The operating point of the tube is at *A*—the point where the *OO'* line intersects the E_g-I_p curve. The heavy line *A-H* represents the normal plate current when no signal is being received. The grid swing, the variation in the grid voltage, causes the plate current to vary as shown by the curve *A-F-G-H*. It must be understood here that line *A-H* is not the zero I_p line—it is the 3 milliampere line, and that curve *A-F-G-H* does not show any reversal of current flow, it just shows how the plate current increases from 3 milliamperes to about 3¾ milliamperes, then decreases to 3 milliamperes and further decreases to about 2¼ milliamperes. This is a true pulsating current, having an average value of 3 ma.*

Would a tube operated in this manner provide satisfactory reception? Of course not, because when the grid is swinging positive current flows in the grid. This has the tendency of reducing the swing of the grid voltage *AB*—a very little it is true, but enough to distort the incoming signals.

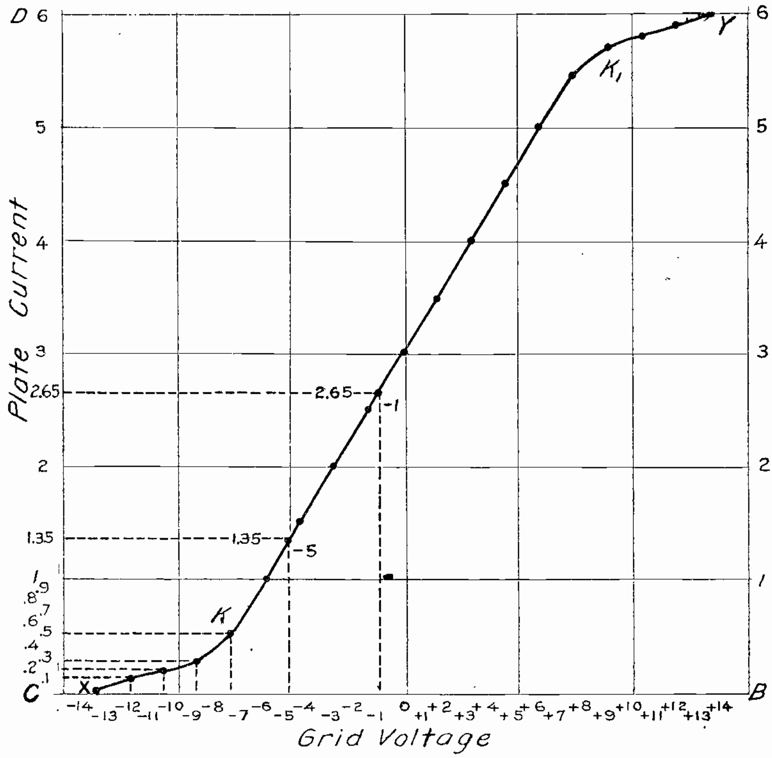


FIG. 6

In Fig. 8 we have the operating point set by a grid bias. Our signal is the same, swinging from 2 volts negative to 2 volts positive. But we place a negative grid bias of 3 volts on the grid—by connecting a 3 volt battery in the grid circuit. Our incoming signal as shown by *B-D-F* will swing from 2 volts

* It is worth stopping to learn that this pulsating plate current may be considered as a DC current (*AH*) of 3 ma. and an AC current (*AFGH*) having a peak value of .75 ma.

positive to 2 volts negative, but the grid itself will never swing positive. Between what two values will the grid vary? Fig. 8 makes this clear—because of the 3 volt negative bias, the grid will swing from —5 to —1 volts. Notice the operating point—it has dropped to B in Fig. 8, and the normal plate current, instead of being 3 milliamperes as in Fig. 7, is now 2 milliamperes. It is clear why this happens—we make the grid more negative, and from our previous explanation you know that the more negative the grid is, the less current will flow from the plate to the filament (fewer electrons will pass from the filament to the plate). If we were to use a 5 volt negative bias, our operating point would drop down to A, in Fig. 8. You might ask why we don't use a higher grid bias in this case, and then if the grid

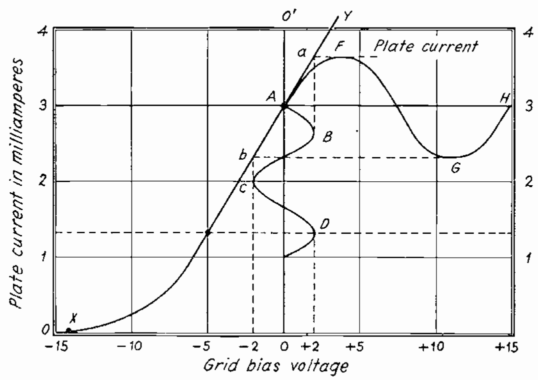


FIG. 7

swing should ever become more than from +3 to —3 volts, the grid still could not swing positive. But bringing the operating point down to A might cause G on the plate current curve to extend down past the curved portion of the E_g-I_p curve—then the changes in plate current would not be proportional to the changes in grid voltage and distortion would result.

Therefore, our problem, as far as grid bias is concerned, is to have a grid bias large enough to keep the grid from swinging positive and at the same time small enough so that the tube will operate on the straight portion of the E_g-I_p curve at all times.

Just a word about the plate current, shown as curve I_p in Fig. 8. You know that if a signal is not being received but the set is turned on, direct current will flow through the plate circuit. With a constant negative potential of 3 volts on the grid, the value of the plate current will be 2 milliamperes—for the grid bias causes the tube to operate at point B on the E_g-I_p curve. But when a signal is being received, and a Radio signal in the receiver is in the form of alternating voltage, the grid potential will vary—that is, it will swing from a higher negative value to a lower negative value following the changes in signal voltage shown in Fig. 8 by the E_g curve. When the incoming signal causes the grid to be more negative, the value of the plate cur-

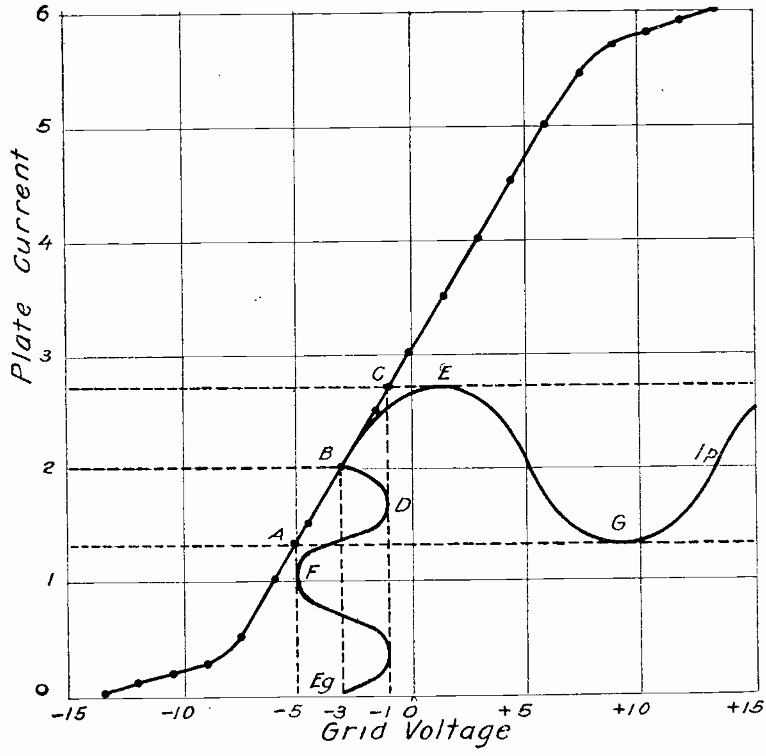


Fig. 8

rent will decrease; it will drop below 2 milliamperes. Likewise, when the incoming voltage causes the grid to swing less negative, more plate current will flow and the value will go above 2 milliamperes.

Another way of considering the plate current, and a more convenient one, is to consider it as direct current mixed with alternating current. And so we speak of the alternating *component* of plate current just as though the plate current consisted of two parts, the direct part and the alternating part. The alternating component in the plate circuit of an amplifier must have the same form as the incoming signal—otherwise, the output will be distorted.

AN AMPLIFYING TUBE AT WORK

Now that we have the theory of the three element tube well in hand, let us go on to examine tube amplifying action in an actual stage of amplification. Fig. 9 shows a stage of radio frequency amplification in detail. You know very well that the aerial serves to convert electromagnetic energy into electric current which is alternating at radio frequency. This radio frequency current flowing through coil L_1 causes a varying magnetic field to be built up about the coil L_1. The field acts on coil L_2, inducing, by mutual induction, a voltage in L_2. The alternating voltage induced in

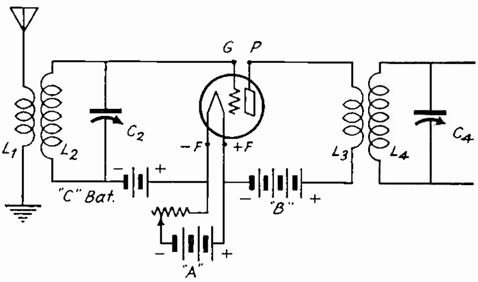


FIG. 9

L_2 causes an alternating current to flow in the circuit L_2 and C_2 which are in series. If the capacity of C_2 is varied (tuned until the current is at a maximum value), a very large voltage will appear across condenser C_2 which varies the voltage in the grid circuit of the vacuum tube, making it more negative or less negative than the voltage of the C battery. This increases the voltage amplification of the R.F. signal. These variations in the voltage of the grid cause more, or less, plate current to flow in the plate circuit. As the plate current pulsates, a varying magnetic field will be built up about L_3 which will induce an alternating voltage in the secondary of the transformer L_4. The varying current in L_3 will be greater than the varying current in L_1. Likewise the voltage across C_4 (when C_4 and L_4 are tuned to resonance) will be greater than the voltage across C_2. In this way the amplified voltage is passed along to the next stage—it may be another stage of R.F. amplification or a detector stage.

The main purpose of this amplifier, as you can see, is to amplify *voltage*. We want to have a larger voltage created across C_4 to feed the next tube, and therefore our tube in this case is a voltage amplifier. We shall study power amplifiers later on.

It is very important at this point to explain why we are so much concerned about the E_g-I_p characteristic of a tube. Any tube which will give a large plate current change for a small grid voltage change is considered a good amplifier tube. In the circuit shown in Fig. 9, a large current change in L_3 will cause a large voltage change to appear across C_4. If L_3, L_4 and C_4 were replaced by a resistance, we can easily see that a large plate current change will cause a large voltage change across the resistor. Furthermore, the greater the change in plate current the larger will be the change in power (I^2R) in the resistor. Remember in a vacuum tube we seek a large change in plate current, or a large change in voltage across the load.

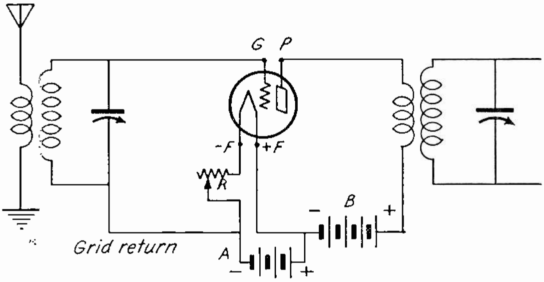


FIG. 10

There is still one question which may suggest itself to you at this point, and that is regarding the grid circuit. We talked about current flow in the grid circuit as being objectionable as it introduces distortion. But here is the question: Doesn't the voltage induced in L_2 result in a current flow in the grid circuit? It does, of course, but the current only flows through L_2 and C_2, the resonant circuit. The reason why no current flows in the grid return to the vacuum tube, is that the resistance between the grid and filament is so high when the tube is biased negative that it is not a load on the resonant circuit. Should current flow in the grid return circuit (when the grid is positive), the voltage across C_2 will be reduced and therefore not be identical to the voltage induced into L_2.

Table No. 2

AVERAGE CHARACTERISTICS OF TRIODE RADIO RECEIVER TUBES

2.0 Volt Filament Group—For Battery Operation

Type	Use	Base	Cathode Type	Filament Amps.	Plate Volts	Negative Grid Volts	Plate Current ma.	Plate Resistance Ohms	Mutual Conductance Micromhos	Amplification Factor	Load Ohms for Stated Power Output	Maximum Undistorted Power Output Milliwatts
19	Power* Amp.	6-3 (S)	Filament	0.26	135	0.0	27.0†	Class B	Operation	....	10,000¶	2,100
30	Det. Amp.	4-1 (S)	Filament	0.06	90	4.5	2.5	11,000	850	9.3	....	....
					135	9.0	3.0	10,300	900	9.3	....	....
					180	13.5	3.1	10,300	900	9.3	....	....
31	Power Amp.	4-1 (S)	Filament	0.13	135	22.5	8.0	4,100	925	3.8	7,000	185
					180	30.0	12.3	3,600	1,050	3.8	5,700	375
49	Power Amp.	5-2 (M)	Filament	0.12	180	0.0	4.0 (No	Signal) Clas	s B Operatio	n	12,000¶	3,500

2.5 Volt Filament Group—For AC or DC Operation

Type	Use	Base	Cathode Type	Filament Amps.	Plate Volts	Negative Grid Volts	Plate Current ma.	Plate Resistance Ohms	Mutual Conductance Micromhos	Amplification Factor	Load Ohms for Stated Power Output	Maximum Undistorted Power Output Milliwatts
27	Amp.	5-1 (M)	Heater	1.75	90	6.0	2.7	11,000	820	9.0	14,000	30
					135	9.0	4.5	9,000	1,000	9.0	13,000	80
					180	13.5	5.0	9,000	1,000	9.0	18,700	165
					250	21.0	5.2	9,250	975	9.0	34,000	300
45	Power Amp.	4-1 (M)	Filament	1.50	180	34.5	27.0	1,900	1,850	3.5	3,500	780
					250	50.0	34.0	1,750	2,000	3.5	3,900	1,600
					275	56.0	36.0	1,670	2,100	3.5	4,600	2,000
46	Power Amp.	5-3 (M)	Filament	1.50	300	0.0	4.0	Class B	Operation	....	1,300	16,000††
					400	0.0	6.0	....	....	....	1,450	20,000††
53	Power* Amp.	7-2 (M)	Heater	2.00	250	0.0	14.0	Class B	Operation	....	8,000	8.0
					300	0.0	17.5				10,000	10.0
56	Amp.	5-1 (S)	Heater	1.00	250	13.5	5.0	9,500	1,450	13.8	....	....
59	Power Amp.	7-1 (M)	Heater	2.00	400	0.0	60.0	Class B	Operation	....	6,000¶	20,000††
					250**	28.0	26.0	2,500	2,600	6	5,000	3,000
2A3	Power Amp.	4-1 (M)	Filament	2.50	250	42.0	60.0	765	5,500	4.2	2,500	3,500
					300	62.0	40.0	2 Tubes in	Push Pull		5,000	15,000

6.3 Volt Filament Group—For AC or DC Operation

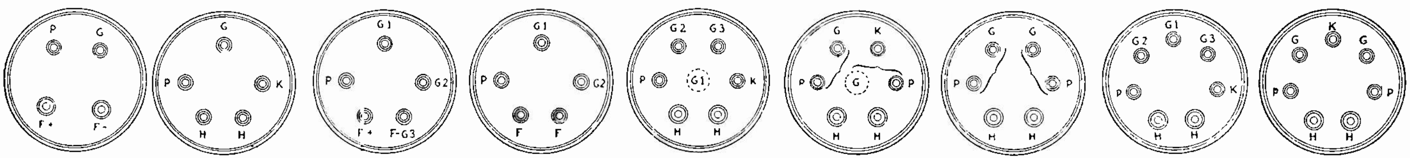
Type	Use	Base	Cathode Type	Filament Amps.	Plate Volts	Negative Grid Volts	Plate Current ma.	Plate Resistance Ohms	Mutual Conductance Micromhos	Amplification Factor	Load Ohms for Stated Power Output	Maximum Undistorted Power Output Milliwatts
37	Amp.	5-1 (S)	Heater	0.30	90	6.0	2.5	11,500	800	9.2	17,500	30
					135	9.0	4.1	10,000	925	9.2	14,000	80
					180	13.5	4.3	10,000	900	9.2	20,000	175
79	Power Amp.*	6-2 (S	Heater	0.60	180	0.0	44.0†	Class B	Operation		10,000¶	5,500
89	Power Amp	6-1 (S)	Heater	0.40	160**	20.0	17.0	3,000	1,570	4.7	7,000	300
					180	0.0	52.5	Class B	Operation	....	2,350	3,500††

Special Tubes

													Filament	
													Volts	Supply
01-A	Amp.	4-1 (M)	Filament	0.25	90	4.5	2.5	11,000	725	8.0	11,000	15	5.0	DC
					135	9.0	3.0	10,000	800	8.0	20,000	55		
10	Power Amp.	4-1 (M)	Filament	1.25	250	22.0	10.0	6,000	1,330	8.0	13,000	400	7.5	AC
					350	31.0	16.0	5,150	1,550	8.0	11,000	900		
					425	39.0	18.0	5,000	1,600	8.0	10,200	1,600		
12-A	Power Amp.	4-1 (M)	Filament	0.25	90	4.5	5.2	5,600	1,500	8.5	5,600	30	5.0	DC
					135	9.0	6.2	5,300	1,600	8.5	8,700	115		
					180	13.5	7.6	5,000	1,700	8.5	10,800	260		
20	Power Amp.	4-1 (S)	Filament	0.132	90	16.5	3.0	8,000	415	3.3	9,600	45	3.3	DC
					135	22.5	6.5	6,300	525	3.3	6,500	110		
26	Amp.	4-1 (M)	Filament	1.05	90	6.0	3.8	8,600	955	8.2	9,800	30	1 5	AC or DC
					135	9.0	6.3	7,200	1,135	8.2	8,800	80		
					180	13.5	7.4	7,000	1,170	8.2	10,500	130		
40	Voltage Amp.	4-1 (M)	Filament	0.25	135	1.5	0.2	150,000	200	30	------	----	5.0	DC
					180	3.0	0.2	150,000	200	30	------	----		
50	Power Amp.	4-1 (M)	Filament	1.25	250	54.0	35.0	2,000	1,900	3.8	4,600	1,600	7.5	AC
					350	63.0	45.0	1,900	2,000	3.8	4,100	2,400		
					400	70.0	55.0	1,800	2,100	3.8	3,670	3,400		
					450	84.0	55.0	1,800	2,100	3.8	4,350	4,600		
71-A	Power Amp.	4-1 (M)	Filament	0.25	90	16.5	12.0	2,250	1,330	3.0	3,200	125	5.0	AC or DC
					135	27.0	17.5	1,960	1,520	3.0	3,500	370		
					180	40.5	20.0	1,850	1,620	3.0	5,350	700		
X-99	Amp.	4-1 (S)	Filament	0.063	90	4.5	2.5	15,500	425	6.6	15,500	7	3.3	DC
842	Power Amp.	4-1 (M)	Filament	1.25	350	72.0	34.0	2,400	1,250	3.0	5,000	2,100	7.5	AC or DC
					425	100.0	28.0	2,500	1,200	3.0	8,000	3,000	7.5	

* Twin triodes. † 50 volts RMS applied to two grids. ¶ Plate to plate. ** Triode connection. †† For two tubes with 40 volts RMS applied to each grid.
S Small Base—1 5/32″ diameter. M Medium Base 1 3/8″ diameter.

Bottom View of Bases



4-1 5-1 5-2 5-3 6-1 6-2 6.3 7-1 7-2

SYMBOLS: F—Filament; H—Heater; P—Plate; K—Cathode; G, G1, G2, G3—Grid; } —Adjoining Elements

GRID BIAS WITHOUT A "C" BATTERY

In a battery operated receiver, a grid bias can be obtained from the filament circuit as shown in Fig. 10. The whole secret of grid biasing in this case depends on connecting the grid return to the $-A$ terminal or the $-F$ terminal of the tube filament.

When we talk about placing a negative bias on the grid, what we really mean is that we make the grid more negative than the $-F$ filament. Suppose our rheostat R cuts down the voltage of the A battery so that, instead of the full 6 volts across the filament terminals, we have only 5 volts. It is easy to see that 1 volt has been lost in the resistance of the rheostat. Therefore, the sliding arm contact on the rheostat, being on the negative side of the battery, is 1 volt negative with respect to the negative filament terminal. Now if we connect our grid to this sliding arm

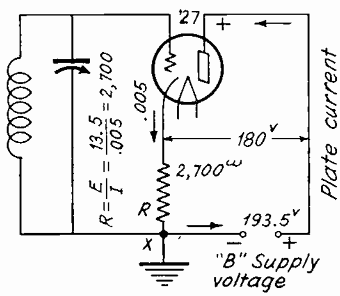


FIG. 11

contact through the coil, our grid is naturally going to be 1 volt negative with respect to the filament also.

With this negative bias of 1 volt, the incoming signal can swing from 1 volt negative to 1 volt positive and the grid itself will never be positive; that is, the grid will swing from 2 volts negative to 0. If the signal were to be larger than 1 volt at maximum in the positive direction, the grid bias would have to be increased in order to keep the grid from swinging positive at times. When a bias greater than what can be obtained in the rheostat voltage drop is necessary, it is customary to insert a C battery as shown in Fig. 9.

In Fig. 11 we show how a negative grid bias is obtained for a heater type amplifier tube using A.C. filament supply, by placing a resistor between the cathode and negative side of B supply and ground. It is obvious that we can't use the filament circuit as alternating current is flowing in it. In this circuit we have a

'27 tube, in which the filament serves only to heat the cathode. Here the filament is not part of the plate circuit—the D.C. plate current flows from the plate to the cathode through resistor R to $B-$.

Naturally there will be a certain voltage drop across the grid bias resistor R determined by the amount of resistance and the current passing through it. It is clear that point X will be negative with respect to the cathode itself. Now what will be the value of R if the drop across it is -13.5 volts? Our tube chart will tell us that 5 milliamperes (.005 ampere) of current flows in the plate circuit of a '27 tube, if we use 180 volts plate voltage and a -13.5 volt grid bias.*

By using our old stand-by—Ohm's Law ($R = E \div I$)—and substituting these values in our equation, we get:

$$R = 13.5 \div .005$$

Solving, we get $R = 2{,}700$ ohms, the value of the resistance.

Now, point X is 13.5 volts negative with respect to the cathode. The total voltage supply must be equal to 193.5 volts
10 ($13.5 + 180$).

The procedure given here for calculating R is very valuable in servicing, when a burned-out C bias resistor is to be replaced.

The grid is connected to point X through the secondary of the input transformer, and so the grid must be 13.5 volts negative with respect to the cathode too.

The resistance R is called a grid bias resistor. It must be shunted by a large condenser to by-pass the A.C. component of the plate current which would otherwise effect the grid circuit. Where a power pack is built as part of a receiver, the grid bias resistor is included in the power supply. We shall learn much more about this later when we study power packs and B supply systems.

TUBE FACTORS

Amplification Factor. By this time we have a clear idea of the trigger action of a grid—we know that just a small change in grid voltage will result in a comparatively large change in plate current. We also know that the plate current may be varied by varying the plate voltage. In radio we deal exclusively with small voltages and if we find that a definite change in grid voltage will give a larger change in plate current than a similar

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* The plate voltage is always measured between the cathode and the plate, or $-F$ tube terminal and the plate. Note, in Fig. 11, the voltage supply is 193.5 volts and the plate voltage is 180 volts.

change in plate voltage which is a direct action we have the basis for the amplification of a three element vacuum tube.

Let us say that our vacuum tube is operating at a fixed filament current—it may be a direct filament type or a heater type tube. We have placed on the grid a definite bias and in the plate circuit there is a suitable source of e.m.f. The plate voltage and the grid bias of course determine the operating point of the tube—and a definite plate current will flow in the plate circuit.

If we increase the plate voltage one volt, there will be a slight increase in plate current. But if we decrease the grid voltage one volt, the increase in plate current will be much larger. Right here is the whole story of tube amplification. If we made a test of this kind on the tube and found that a grid voltage change changed the plate current 9 times as much as a similar change in plate voltage, the amplification factor of the tube would be 9. The amplification factor (constant) is usually referred to as the mu (μ) of the tube.

There is another way of finding the amplification factor of a tube, other than by actual measurement as just outlined. This second method is graphical and the graphical procedure is given in Fig. 12.

The amplification factor of a tube does not vary under ordinary conditions, which explains why it is often called the amplification constant. It depends upon the physical construction of the tube and, primarily, the distance between the grid and filament, and between the filament and the plate. The closer the grid is to the electron emitter, the larger will be the amplification factor of the tube. The amplification is important, for, as we shall see later, it helps us to compute the equivalent voltage acting in the plate circuit when we temporarily neglect the grid circuit.

Plate Resistance and Impedance. From the fact that, even though we have 45 or 90 volts acting in the plate circuit, we have only a few milliamperes of current flowing, we can realize there must be considerable resistance between the cathode and the plate of a vacuum tube. The amount of this resistance affects tube operation. Therefore we must consider it in detail.

Tube resistance must be considered in two ways—first, as a direct current resistance, and second, as an A.C. resistance (impedance). For the time being let us disregard the grid. Then in our plate circuit we will have only the cathode-plate resistance and the plate voltage. From Ohm's Law, the resistance is the voltage divided by the plate current. If the plate voltage were 40 volts and the plate current were 2 milliamperes, the D.C. plate resistance would be $40 \div .002 = 20{,}000$ ohms.

Now having gotten clearly in mind how the cathode-plate resistance affects the direct current flowing in the plate circuit, we can go on to consider tube impedance—its resistance to A.C. current which we say is impressed on the direct current part of

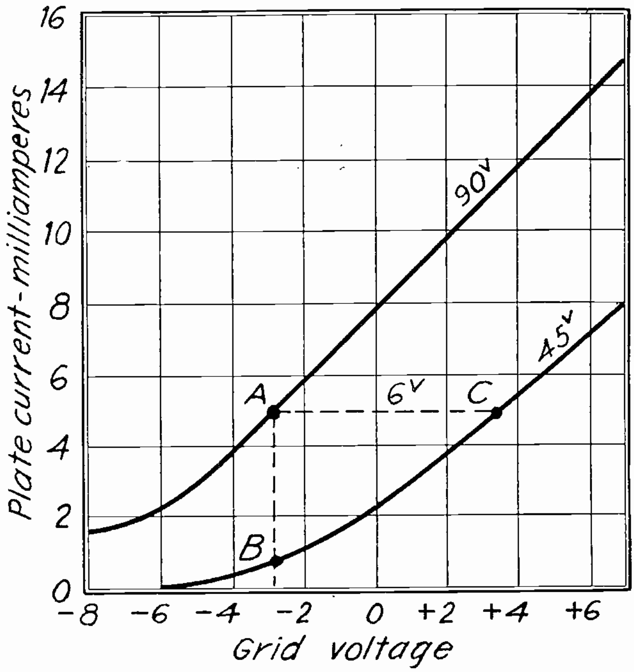

Fig. 12

Given an E_g-I_p curve for 45 and 90 volts applied to the plate. When the grid voltage is —3 volts, changing the plate voltage from 90 to 45 volts will cause the plate current to change from *A* (5 ma.) to *B* (1 ma.). Now with the plate at 45 volts, the C bias is varied from —3 to +3 volts, a change of 6 volts, the plate current will return to the original value (5 ma.). Clearly a C voltage change of 6 volts produces the same current change as a plate voltage change of 45 volts Therefore the amplification is $45 \div 6 = 7.5$—the mu of the tube is 7.5.

the total plate current by the action of the grid. If the A.C. grid voltage is 1 volt r.m.s.,* and if the amplification factor of the tube is 8, it is customary to consider that there is an 8 volt A.C. component in the plate circuit. That is, if the amplification of the tube is μ, and the variable A.C. grid voltage is E_g, the vary-

* Root-mean-square value, often called effective value.

ing A.C. voltage in the plate circuit is going to be equal to μE_g ($\mu \times E_g$) or E_p (alternating part of plate voltage).* Now we may consider A.C. plate resistance. By definition it is the change in plate voltage divided by the change in plate current.

If the plate voltage originally was 90 and, by the action of the grid, the voltage was boosted to 98 volts ($90 + \mu E_g$) and the change in plate current was 1 milliampere (.001 amp.), the A.C. plate resistance would be $(98 - 90) \div .001$—approximately 8,000 ohms. Very obviously, this plate impedance differs from the direct current resistance of the tube.

Fig. 13 shows the equivalent of a vacuum tube plate circuit in terms of an electrical circuit. The internal A.C. voltage (E_p) is considered as being μ times the A.C. voltage on the grid (μE_g). The load R_p is considered as being the A.C. resistance of the plate and the A.C. current (I_p) is equal to $E_p \div R_p$.

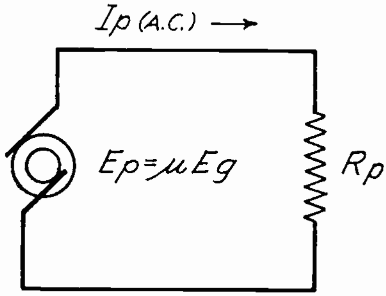

FIG. 13

MUTUAL CONDUCTANCE

Radio-Tricians talk about the A.C. voltage applied to the grid-cathode, the A.C. current flowing in the plate circuit, the A.C. plate resistance and load impedance—ignoring, in general, reference to grid bias and plate D.C. current. They are interested in these last only because they determine the operating point of the vacuum tube, and if this point is known, as from a graph, the determining factors can be disregarded.

As has been frequently brought out in this lesson, what we are most interested in, as far as amplifying tubes are concerned, is the plate current. And in this plate current we are interested only in the variations—that is, the A.C. component.

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* Thus if μ equal 8 and the A.C. voltage on the grid E_g equal 2 volts, the amplified and alternating plate voltage E_p will be 2×8 or 16 volts.

The magnitude of these variations is determined by the μ of the tube, the A.C. plate impedance and the incoming signal. The plate A.C. voltage then is μE_g. To find the A.C. plate current we divide μE_g by the plate impedance. Assuming that there is no load in the plate circuit, in series with the plate, plate current is determined from the formula:

$$I_p = \frac{\mu E_g}{R_p}$$

which may also be written:

$$I_p = E_g \times \frac{\mu}{R_p}$$

We rearrange the formula to get $\frac{\mu}{R_p}$ by itself, for the μ of the tube divided by the A.C. plate impedance gives us a very important characteristic of the tube, the *mutual conductance*. The symbol for mutual conductance is G_m—the unit is the *mho*. Mutual conductance is considered a factor of *merit*—as a tube becomes old or weak, its mutual conductance drops off and its efficiency decreases. The proper mutual conductance of a tube is given as so many mhos. By determining the G_m of any tube usually by means of a tube checker and comparing with its proper G_m, we can tell just about how soon the tube will be ready for the scrap heap—generally 20% below normal.

The mutual conductance of a tube can also be determined from its E_g-I_p curve. Fig. 14 shows the E_g-I_p curve, for a '01A tube. Let us say the tube is operating at a plate voltage of 90 volts and we apply a C bias of $-4\frac{1}{2}$ volts. This sets the operating point at *A*. Line *BC* is drawn tangent to the curve at point *A*, making a triangle, *BCD*. Line *CD* then represents a number of milliamperes, while line *BD* represents a number of volts. Divide the value of *CD* by the value of *BD* and the result will be the mutual conductance of the tube at point *A*, the operating point.

Let's work this out. Point *C*, reading on the vertical scale, is about 5.6 milliamperes. Point *D* is on the zero current line. Therefore the value of line *CD* will be 5.6 ma. Point *B* on the horizontal scale is 7.7 volts to the left of *D*. We convert 5.6 milliamperes to amperes—.0056 amp.—and divide by 7.7 volts:

$$G_m = \frac{.0056}{7.7} = .000727 \text{ mho. (727 micromhos)}$$

Now we can work it out the other way—from the known characteristics of the '01A tube. From a tube chart we find that μ, the amplification factor, is 8, and that the A.C. plate resistance (impedance) is 11,000 ohms. Dividing μ by R_p we get .000727 mho. Converting this to micromhos as is usually done, we find that G_m is 727 micromhos.

According to the E_g-I_p curve shown in Fig. 14, the grid swing should be limited to A_1 and A_2, if we want to operate the tube on its straight E_g-I_p characteristic. We shall see shortly that a plate load will straighten out the E_g-I_p characteristic.

Knowing the mutual conductance of a tube, all we have to do, to find the value of the A.C. plate current, is multiply G_m by the A.C. grid voltage (E_g). Of course, whenever we speak of A.C. voltages and currents in formulas, we must consider r.m.s. values.

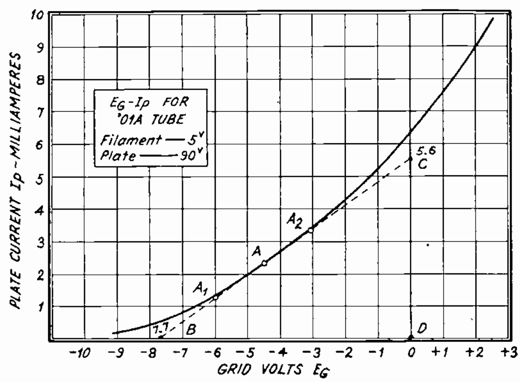


FIG. 14

This G_m factor is of great importance to Radio-Tricians because of its convenience—it takes into consideration the A.C. plate resistance and the amplification factor of the tube; thus, knowing the mutual conductance, we can forget about these other factors.

Remember, however, that mutual conductance, as we have spoken of it, is only considered when there is no load in the plate circuit of the tube.

VOLTAGE, POWER AND CASCADE AMPLIFIERS

Later on we are going to study various loads in the plate circuits of amplifying tubes in detail. For the present it is sufficient to know that the load may be a transformer, a loudspeaker, a glow lamp, a relay. Some loads require that the greatest possible voltage be put across them—others that maximum current flow through them. It is this requirement that determines whether a voltage amplifying tube will be used or whether the tube will have to act as a power amplifier.

For the present we shall consider the simple circuit in Fig. 15. Here we have an alternator to supply an alternating voltage which we say takes the place of the incoming signal. The tube is biased by the C battery; filament current is supplied by the A battery, and the B voltage is supplied by V_B. To find the value of the A.C. plate current, we must consider that in the plate circuit there is an A.C. voltage (μE_g) ; and a double load—the resistance of the plate and the resistance of the load R. From Ohm's Law we know that the A.C. plate current will be

$$I_p = \frac{\mu E_g}{R_p + R}$$

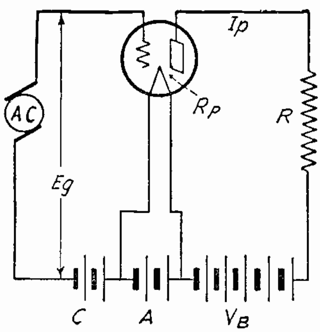


FIG. 15

Notice that this formula for plate current is the same as that given before, except that it includes both loads.

Now if R is considerably larger than R_p, the voltage across R will be extremely large and will approach the value of μE_g. When this is the case, our vacuum tube is acting as an efficient voltage amplifier. On the other hand, if $R_p = R$, maximum power will flow in the plate circuit. In other words, for maximum current, the load impedance must match the tube impedance. We can't go into this too deeply at this point, but we shall meet this idea often in later lessons.

Under most conditions, when R_p and R are equal, the tube acts as a power amplifier and the sole purpose of the tube is to feed as much power as it can to the load R.

One great advantage in the use of vacuum tubes, is that several tubes may be used, one following the other. They must be connected by suitable coupling devices—that is, resistors, coils, and condensers in a variety of arrangements. The original signal voltage is amplified and reamplified many times. Such an arrangement is referred to as a *cascade* amplifier. The original signal feeds the grid of the first tube. The voltage developed in its plate load is fed to the grid input of the next tube—all down the line. The voltage amplification of such an arrangement is the product of the individual stage amplifications. For example, if a stage amplifies the grid input forty times, three similar stages will amplify $40 \times 40 \times 40$ or 64,000 times. If the input voltage to the cascade amplifier is 10 microvolts, then the output

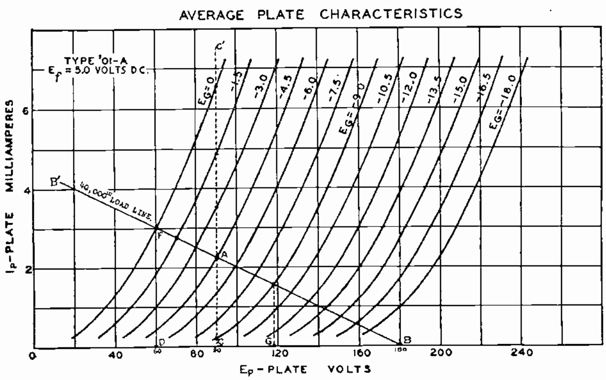


FIG. 16

voltage will be $10 \times 64{,}000$ or 640,000 microvolts. This is equivalent to .64 volts.

In the usual radio frequency receiver the audio amplifier will be divided from the R.F. amplifier by a detector. In the superheterodyne receiver, a detector will divide the R.F. system from the intermediate frequency system and another detector will divide the intermediate frequency system from the audio frequency system. The last tube in the audio amplifier is the power amplifier. Its duty is to take a large grid swing and produce a large current swing in the load, thus providing a large power output. Two or more tubes may be used simultaneously in the output stage. In recently designed receivers the power stage is preceded by a smaller power stage which is intended to prevent distortion due to grid current flowing in the last stage.

Cascade amplification is found in every branch of Radio: receivers, transmitters, television, sound pictures, public address systems, and electronic controls—and special voltage and power amplifier tubes have been developed to serve in the best possible manner.

E_p-I_p CHARACTERISTICS

Although the E_g-I_p curves are very valuable for reference purposes, they do not give the true behavior of the tube as an amplifier, when a load (resistance) is placed in the plate circuit. Perhaps the most valuable curve in practical Radio is the E_p-I_p curve; that is, the curve showing how the plate current varies when the plate voltage varies. Of course, the characteristic of

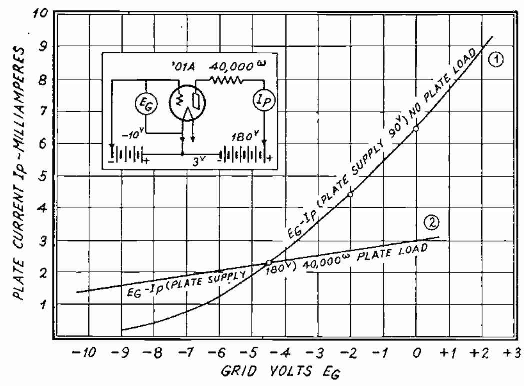


FIG. 17

the tube will depend on the C bias (we are assuming that no A.C. voltage is applied to the grid). As there may be any C bias value, we, of course, will need several curves—one for each representative C bias (E_g). A family of E_p-I_p curves for an '01A tube is shown in Fig. 16. These curves may be taken with the hook-up shown in Fig. 5, only in this case the potentiometer P is set for a definite C bias for each curve, and the plate voltage is varied.

These curves will give a large amount of information and they are supplied by the manufacturer (curve Fig. 16 was taken by the R.C.A. Radiotron Co.) for set designers. Of course, we are not at this time interested in design but we are interested in the behavior of tubes. The curve shown in Fig. 14 may be obtained from Fig. 16. For example, let us say that the tube is to operate with 90 volts between the plate and cathode ($-F$ for an '01A tube) and a bias of -4.5 volts. In Fig. 16, select the -4.5 E_g curve. Select the 90 volt point—point A. This is the operating point. Draw a line vertically through point A—line CC'. The information we obtain is that when E_g is zero volts, I_p is 6.5 ma.; when E_g is -1.5, I_p is 4.8 ma.; when E_g is -9 volts, I_p is .2 ma. Check this with Fig. 14 and curve (1) in Fig. 17.

What will the E_g-I_p curve be when a load is placed in the plate circuit? Let's find out by considering a $40{,}000^{\omega}$ plate load as shown in the insert of Fig. 17. Let us say for comparison that when the tube is biased with -4.5 volts, the plate to cathode ($-F$) voltage is 90 volts. This again sets the operating point at A in Fig. 16. Note that the plate current is 2.25 ma. What will be the plate supply? It will have to be 90 volts plus the voltage drop in the 40,000 ohm resistor. Clearly, this drop will be $40{,}000 \times .00225$ or 90 volts. Note that we changed 2.25 milliamperes to .00225 amperes. This is always necessary if we do not want to make a mistake in applying Ohm's Law.

If you study the circuit in Fig. 17 you will realize that if the C bias is made sufficiently negative to cut the plate current to zero, then the 180 volts supply will be applied between the plate and cathode of the tube. (If the plate current is zero, the drop across the 40,000 ohm resistor is zero.) This gives us B, the second operating point in Fig. 16. Now draw a straight line through A and B. With this line, BB', called the *load line,* we can draw an E_g-I_p curve of a tube with a load in the plate circuit. Note that when E_g is zero, I_p is 3.0 ma.; when E_g is -3, I_p is 2.6 ma.; when E_g is -9, I_p is 1.6 ma. This information is shown as curve (2) in Fig. 17 and is the *dynamic* E_g-I_p characteristic.

When you compare curve (1) and curve (2) in Fig. 17, you are immediately convinced that adding a plate load resistance in the plate circuit straightens out the dynamic E_g-I_p characteristics.

From the curves in Fig. 16 we may actually calculate the amount of amplification developed by a vacuum tube stage having a 40,000 ohm load. From the curves we observe that if the grid swings from zero to -9 volts, the plate to $-F$ voltage will vary from 60 (point D) to about 118 volts (point G), a variation of 58 volts. That is, a grid change of 9 volts causes a load voltage change of 58 volts. That is, the actual amplification is 58 divided by 9 or about 6.4. Note that this is less than the amplification of the tube, which is 8.0. This is because part of the voltage variation in the plate circuit is lost in the tube plate resistance.*

TYPES OF TRIODES AND TUBE DESIGNATION

Table No. 2 (pages 14 and 15) gives a list of all important three element tubes with their important characteristics. Refer to it when necessary. A careful study of this chart shows that there are a number of different kinds of triodes in use. The following features are interesting.

1. Tubes may be classified as to their filament voltage rating. The important voltages in modern practice are the 2 (battery), 2.5 (A.C.), and 6.3 (automobile) volt types. The older tubes operating at 5, 7.5, 3.3 volts and any of the new types other than 2, 2.5 or 6.3 volts may be considered as in a special class.
2. Tubes are classified as to filament (types 30, 45, 2A3) and heater (types 53, 56, 59, 37) types.
3. They are classified as to their use as voltage or power amplifiers. It is to be remembered that these tubes may be used as oscillators (generators), detectors and rectifiers when suitably connected in a circuit.
4. Tubes like the 19 and 79 are essentially two triodes in one glass envelope.
5. Tubes like the 49, 79 and 89 are basically multi-grid tubes which may be made to operate as triodes by proper external socket connections.
6. It is interesting to note that most triodes have a low amplification factor, and the power tubes have low A.C. plate resistance.
7. That a triode tube may employ a 4, 5, 6 or 7 prong base of the small or medium size.
8. Triode tubes may be operated alone; or in parallel—that is, two or more tubes (grid connected to grid, plate to plate, etc.) but only for power purposes. Two triodes may be connected in a circuit so that while one tube has its plate current increasing, the other has its plate current decreas-

* These curves will give other information: for example, the power supplied to the load resistance. Again suppose the grid varies from 0 to —9 volts. The plate voltage varies 58 volts as shown above, and the current varies from 3.0 ma. (.0030 ampere) to 1.6 ma. (.0016 ampere), a change of 1.4 ma. or .0014 ampere. Power fed to the load is $58 \times .0014 \times \frac{1}{8} = .010$ watt or 10 milliwatts. The factor ⅛ is to change voltage and current swing to R.M.S. volts and current.

The value of line *DB* divided by the value of line *DF* is the resistance of the load. In this case, it equals (180 — 60) divided by .003; equal to 120 divided by .003 equals 40,000 ohms. The load line may be established in this manner instead of the way given in the text.

ing, referred to as PUSH-PULL operation. Two triodes may be operated in a circuit so that one tube operates while the other is inactive, the action shifting from one tube to the other. This is referred to as PUSH-PUSH operation and tubes are operated in class B fashion.

9. In Radio receivers, tubes are operated as class A; that is, the operating point is so set that the grid never swings positive and it operates over the straight portion of the E_g-I_p dynamic characteristic. Or they are operated at a negative C bias so that the plate current is nearly zero, but any decrease in negative bias produces a proportional increase in plate current. This is referred to as class B operation.
10. Tubes like the 19, 49, 46 and 89 are designed for class B operation and the outstanding feature is that the plate current is essentially zero with no grid bias. Grid current will flow, but the input circuits to such tubes are so designed that the effect of grid current on distortion is negligible.
11. The maximum undistorted power is only obtained when the load is of a definite ohmic value. These facts are obtained in practice by use of the curves shown in Fig. 16.
12. Triodes (in fact any tube) must be operated at correct filament, plate and C bias voltages to get rated current, mutual conductance, plate resistance, power output, etc.
13. Tubes are given a definite type *number*. In the past, there was no apparent reason for selecting a given number, except that in some cases tubes operating at the same filament voltage would have the same first digit, like the 30 and 31. A letter quite often followed the number to show that some change in the initial tube was made. Various manufacturers used a 2, 3, 4, 5 or a letter or letters, or both, such as 245, 545, NU45, T45 and RCA-245 to indicate a certain make. The present practice is to use the two numbers with a letter following and to use some letter or trade letters if of commercial value, ahead of the tube type.
14. In the future, tube type designations will have some meaning. See 2A3. A number, a letter and a number meaning:
    (a) The first digit (or two digits) shall indicate the filament voltage in steps of 1 volt, using figure 1 to mean any voltage below 2.1; 2 to mean 2.1 to 2.9 volts, 3 to mean 3.0 to 3.9 volts, etc.
    (b) The third digit (number following the letter) shall

Radio Vacuum Tubes with Metal Envelopes

. . . .

YEARS ago, when the manufacture of Radio receiving sets and vacuum tubes became a problem of large scale production and distribution, the Radio industry and the buying public could not understand why the vacuum tube had to be so fragile.

Tube engineers, it must be conceded, have improved on the original two and three element tube in which there was very little metal within the glass envelope, until at the present time the glass tube is a remarkable assembly containing several grids, plates, and cathodes, the weight of which is greater than the glass envelope. Although the tube's internal construction is sturdy and rugged, the glass envelope is still more or less fragile.

Tube engineers and manufacturers have, for some time, felt that tubes should be improved upon by doing away with the glass envelope, especially nowadays when vacuum tubes are being used more and more for industrial purposes, where tubes of rugged construction, which will withstand mechanical shock, must be available.

So, by the latest introduction of vacuum tubes enclosed in metal, Radio tube engineers have eliminated the long-standing objection of the Radio industry and have fulfilled the needs of the future.

It should, however, be clearly understood that the only important new feature in the so-called "all-metal tube" is the metal envelope. To be sure, the ability to enclose several electrically isolated elements in a tube of steel and draw out all the gas to a high vacuum is an engineering feat worthy of every recognition.

In introducing a radically different type of vacuum tube, the tube manufacturers in cooperation with the Radio industry as a whole, decided that certain previous errors and poor design which crept in the development of the glass tube should be eliminated. So, in making these new metal tubes the first design change was to make them somewhat smaller than the present type of glass tube.

The bulb or shell diameter is 1" except at the base where the maximum diameter is $1\frac{5}{16}$". The shell is all metal, and the lead wires from the internal elements are brought out through glass beads fused to eyelets in the "header" which is the metal disc that seals the steel shell at the bottom. The shell is connected to a base pin and operates at ground potential to eliminate any danger of electrical shock. The overall length of the tube is also reduced.

The metal tubes were made smaller, not solely to reduce the chassis size, but for the following reason:

Since the elements are smaller, the internal capacity between the grid and cathode; grid and plate; and plate and cathode becomes smaller—without materially changing any of the other characteristics—so that the tubes become more useful in all-wave receivers, especially in the 20 megacycle band.

Another feature of the new tube is its base. A new type of octal base has been developed which has provisions for eight pins, or prongs, uniformly spaced with an aligning or locating plug and key. The plug is slightly longer than the tube pins.

Where fewer than eight pins are required, by the tube, the unnecessary pins are omitted and the spacing of the remaining pins is unchanged.

This arrangement makes it possible to use one type of socket for all tubes, to set up a universal pin numbering system, and also makes installation of tubes very easy under difficult circumstances, such as poor light or in sockets not easily accessible.

To insert a tube in a socket, all you have to do is to place the central aligning plug in a hole centrally located in a special 8 hole socket which has a key-way cut in the insulated material of the socket, rotate the tube until the key slips into its key-way cut or groove, and push the pins into their holes.

As all the new metal tubes will go into any 8 hole socket, (the pins and socket arrangement make this possible) it is advisable to be very

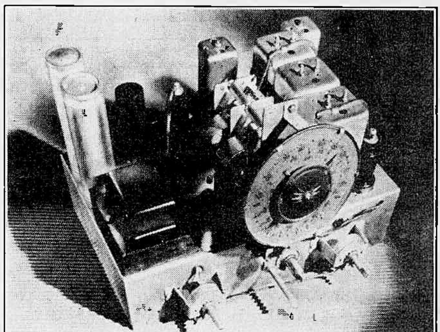


Fig. 1 Chassis of modern all-wave Radio receiving set using metal tubes.

(Courtesy Stewart-Warner Company)

careful and replace the proper tubes in the right sockets when servicing Radio receivers using metal tubes. Therefore, when removing these tubes from the chassis, make a note which socket each tube was taken from, otherwise you will need a chassis layout of the receiver to get all the tubes back into their proper sockets.

Numbering of the pins begins at the shell connection, which is always the first prong to the left of the aligning key when the base is viewed from the bottom with the key toward the observer. This is prong No. 1. In an 8 prong tube, the remaining prongs are numbered 2, 3, 4, 5, 6, 7, 8, when traced in a clockwise direction. For tubes with less than 8 prongs, any prong will have the number corresponding to the same position in an 8 prong tube.

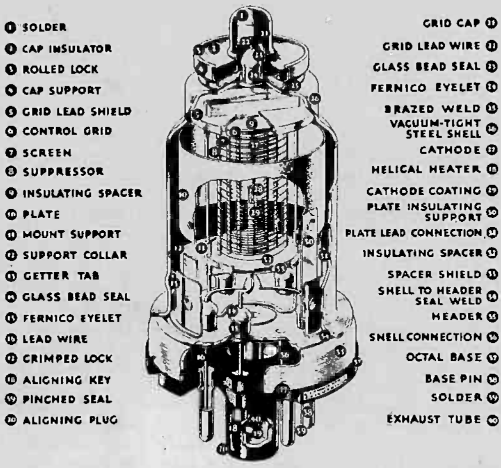


Fig. 2—Internal Structure of All Metal Tube

(*Courtesy RCA*)

Characteristics and operating conditions of the first ten metal tubes and the bottom views of the bases with pin numbering and schematic arrangement of the tubes are shown in Table No. 1.

In general, the metal tube characteristics are very similar to the popular 6.3 volt filament glass tube types. However, in no case are standard glass tubes and metal tubes interchangeable.

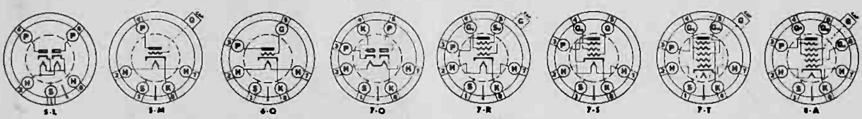
The similar types of glass tubes you will notice are listed in the last column of Table No. 1, opposite the metal tube types.

The following is a summary of the advantages of the new metal tubes:

Type	Use	Base	Dimensions In Inches		Filament Rating		Plate Volts	Negative Grid Volts	Screen Volts	Plate Current ma.	Screen Current ma.	Plate Resistance Ohms	Mutual Conductance Micromhos	Amplification Factor	Load Resistance Ohms.	Milliwatts Undistorted Output	Similar Glass Type
			Lgth.	Dia.	Volts	Amps.											
5Z4	F. W. Rectifier	5-L	5 1/8	1 5/16	5.0	2.0	400	RMS Volts/ Plate		125	......	......	......	......	......	......	80
6A8	Converter	8-A	3 1/8	1 3/8	6.3	0.3	250	3.0	100	3.0	3.5	500,000	†650	......	......	......	6A7
6C5	Amplifier	6-Q	2 5/8	1 3/8	6.3	0.3	250	8.0	......	8.0	......	10,000	2,000	20	......	......	76
6D5	Power Amplifier	6-Q	3 1/4	1 5/16	6.3	0.7	275	40.0	......	31.0	......	2,250	2,100	4.7	7,200	1,400	45
6F5	Amplifier	5-M	3 1/8	1 5/16	6.3	0.3	250	2.0	......	0.9	......	66,000	1,500	100	......	......	*
6F6	Power Amplifier	7-S	3 1/4	1 5/16	6.3	0.7	250 ‡250	16.5 20.0	250	34.0 31.0	6.5	80,000 2,600	2,500 2,700	200 7	7,000 4,000	3,000 850	42
6H6	Rectifier	7-Q	1 5/8	1 5/16	6.3	0.3	100	RMS Volts/ Plate		2.0	Maximum		......	......	......	......	*
6J7	Detector, Amplifier	7-R	3 1/8	1 5/16	6.3	0.3	250	3.0	100	2.0	0.5	1,500,000	1,225	1,500	......	......	77
6K7	Amplifier	7-R	3 1/8	1 3/8	6.3	0.3	250	3.0	100	7.0	1.7	800,000	1,450	1,160	......	......	78
6L7	Mixer	7-T	3 1/8	1 5/16	6.3	0.3	250	6.0	150	3.5	8.0	2,000,000	†325	......	......	......	None

†Conversion Conductance. *Type 6F5 is similar to the Triode Section of Type 75, and Type 6H6 is similar to the Diode Section of type 75. When used together they become equivalent to the 75. ‡Triode operation.

Bottom View of Bases



SYMBOLS—H-Heater; P-Plate; K-Cathode; S-Metal Shell; G-Control Grid; Gs-Screen; Ga-Anode Grid; Go-Oscillator Grid; Gm-Modulator Grid; Su-Suppressor Grid; □ Top Cap; ——→Locating Pin.

Table No. 2—Characteristics

(A) An increase in stability, especially on short wave, because of more efficient shielding, and lower inter-electrode capacity.

(B) Rugged construction.

(C) Vacuum sealed in metal with its improved gas removal from the elements insures normal operating characteristics for a longer period of time.

(D) Octal base which allows ease of installation and universal prong numbering.

(E) Efficient heat radiating shield which conducts heat away from interior of tube insuring long useful life.

designate the number of useful elements (filament, cathode, grid, plate, etc.) brought out through prongs or tube caps.

(c) The letter shall be a serial designation. Amplifiers will start with A and when the first and third digits are alike because of identical filament voltage and number of electrodes, then B, C, etc., shall be used to designate a different tube. Rectifiers will start with Z and work backward through the alphabet.

TEST QUESTIONS

Be sure to number your Answer Sheet 10FR-2.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and the best possible lesson service.

1. When we increase the negative charge on the grid of a triode, what effect does this have on the plate current?
2. How may we prevent current flowing in the grid circuit of a triode?
3. On what part of the E_g-I_p characteristic curve should a vacuum tube be operated as an amplifier?
4. When you tune the secondary of a tuned R.F. transformer what effect does this have on the voltage amplification of the R.F. stage?
5. Where would you place a resistor to obtain a negative grid bias for a heater type amplifier tube using A.C. filament supply?
6. What is the A.C. voltage in the plate circuit, if μ of the tube is 9 and the A.C. voltage on the grid E_g is 2 volts?
7. What factor of merit would you consider when comparing efficiency of tubes.
8. What effect has the introduction of a plate load resistance on the dynamic E_g-I_p characteristic, Fig. 17?
9. In table No. 2, tubes are grouped under their filament voltage rating. What *filament voltage, grid bias voltage* and *plate voltage* would you apply to a '45 type power amplifier tube to get the maximum undistorted power output?
10. What is the amplification factor of the '27 type tube?

IRON CORE A. F. AND POWER TRANSFORMERS

11 FR

PIONEER HOME STUDY RADIO SCHOOL

NRI

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

THE IMPORTANCE OF A KNOWLEDGE OF MAGNETIC CIRCUITS

I remember very well how my old Professor in the Technical School I attended hammered home to us the subject of Magnetic Circuits. He always claimed that a man who understood Magnetic Circuits thoroughly could understand the action of more than half of all the devices used in Electricity. I didn't realize it then and we used to think our Professor was just particularly interested in this one subject and was making us suffer for no good reason.

It wasn't long after I left school, however, before I realized how right he was. And I claim that one reason I found it so easy and enjoyable to work with Radio and follow its development, was just that I had had such a thorough training in magnetic circuits.

Anyone who understands the material presented in this lesson will never have any difficulty in understanding radio transformers, chokes, motors and generators, the action of meters, etc.

You may not be able to see the practical application of this subject right at the start. So just take my word for it that the subject is important. It deserves your most earnest study. Then as you progress with your studies, and after you get out into the Radio game you will realize, as I did, that my old Professor was right when he insisted on our getting a thorough knowledge of his pet subject.

J. E. SMITH.

WASHINGTON, D. C.

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Iron Core A. F. and Power Transformers

THE MAGNETIC CIRCUIT

Previous lessons which you have studied explain that an electrical or Radio circuit provides a complete path for moving electrons, that is, current flow. In other words, an electric circuit is the path taken by moving electrons. Similarly, a magnetic circuit is the path taken by magnetic lines of force through a magnet or a coil and through the field of the magnet or coil.

If a bar magnet is surrounded by air, the magnetic forces act in curved paths, connecting the N and S poles, as indicated in Fig. 1 in which only a few lines of force are represented. The common assumption is that the forces act from a north pole and toward a south pole, through the surrounding air; *in* at the south pole, and through the magnet to the north pole. This is

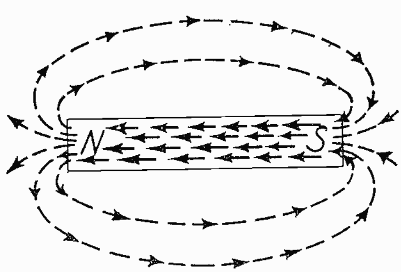

Fig. 1

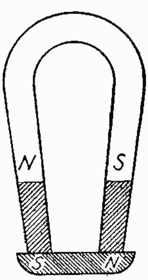

Fig. 1 (a)

called the direction of the lines of force and the complete path is called the magnetic circuit. The total magnetism or all the lines of force collectively surrounding a magnet is called the flux of the magnet, or magnetic flux.

Since the ends of a magnet are of opposite polarities, it is evident that when the poles of the magnet are free as shown in Fig. 1, the effect of the magnet as a whole is weakened because the lines must act over a long distance.

Consequently, in order to obtain the full strength of a magnet, connect its poles with a piece of soft iron. This is often called a keeper. Incidentally this preserves the life of permanent magnets. If the bar be in the U form, the keeper is straight and rests on the ends, as shown in Fig. 1a.

If the magnet be straight, the bar is placed near a similar bar in the reversed position, and two keepers are placed across the ends, as shown in Fig. 1b. In this way a closed circuit of the magnetic material is formed, which is called a *magnetic circuit.* An iron ring constitutes such a closed magnetic circuit.

Some students of electricity and radio find it difficult to gain a satisfactory conception of magnetic flux because it seems so mysterious. Since it affects none of our senses, it is difficult to believe in it as a reality. And yet many examples may be cited of commonplace things which are just as mysterious. There is light flux; for example, the streaming of light out of light sources, of which we are quite unconscious unless our open eyes happen to receive it.

Just as dust particles in a room will indicate the presence and direction of light rays, so will iron filings (small particles

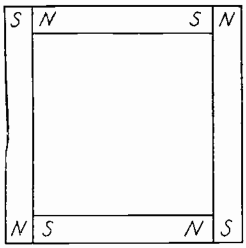

Fig. 1(b)

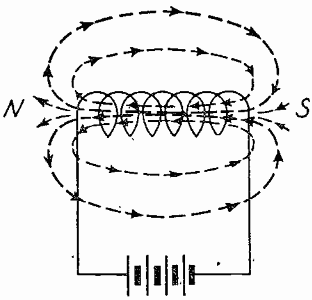

Fig. 2

of iron) when scattered on a sheet of paper and placed in a magnetic field indicate the direction of magnetic lines of force. Tapping the paper slightly with the end of a pencil will cause the iron particles to arrange themselves in lines which indicate the direction of flow of magnetic lines.

In Fig. 2 the small arrows indicate the path or circuit of the magnetic flux or lines of force through and around an air-core coil carrying an electric current. The lines of force around the different turns of wire unite and form straight lines within the coil. Outside the coil these lines curve around from one end of the coil to the other. Figure 3 illustrates the field of the lines of force outside various shaped coils carrying a current. Compare this with the lines of force in Fig. 1 produced by a permanent bar magnet and notice that they are quite similar.

WHERE MAGNETIC CIRCUITS ARE USED

Magnetic circuits are used in a variety of ways in the following radio devices and for that reason a thorough understanding of them is of vital importance to you as a student of Radio:

(a) Power transformers
(b) Auto transformers
(c) Chokes (Radio, Audio and Filter)
(d) Audio transformers, coupling coils
(e) Radio frequency transformers
(f) Relays, bells and magnetic lifts
(g) Testing Instruments

1. Ammeters
2. Voltmeters
3. Oscillographs
4. Flux meters

(h) Arc and Spark transmitters
(i) Motors and generators
(j) Loudspeakers and phones, phono-pick-ups
(k) Magnetic talking tape
(l) Magnetic shielding
(m) Electromagnetic scanning in Television

Also in many other electrical and radio devices too numerous to mention.

In each of the above mentioned devices there are definite magnetic paths—circuits in which magnetism is said to flow, also all conductors carrying current are surrounded by magnetic lines which form a magnetic circuit, so it is very important to have a good insight to magnetic circuits, just as it is important to know electrical circuits in great detail.

Just as an electric current is caused to flow in an electric circuit, so magnetic flux can be set up in a magnetic circuit. In Fig. 4a the dry cell acts as a source of *electromotive force* and forces an electric current through an electric circuit consisting of a metal wire. Similarly a coil of wire carrying an electric current as shown in Fig. 4b acts as a source of *magnetomotive force,* and sets up magnetic flux in an iron core which constitutes a magnetic circuit. It can be seen then that these two circuits are very similar and the laws governing them may be written in the same form. However, there are some important differences between them, some of which are as follows:

In an electric circuit the current produces a heating effect on the wire, even when the current flow is absolutely steady. A magnetic flux once established and which does not change does not cause a heat effect. Only when the magnetic flux varies in the magnetic circuit does heat appear.

In an electrical or Radio circuit we are primarily interested in a proper current flow, in order to do the desired work. If we do not have enough current we can get more by increasing the "electromotive force" or by reducing the "resistance" in the circuit, or we may do both and get still more current in our electrical circuit if it is needed. The circuit and apparatus are built to handle such an increase of current.

In a magnetic circuit we have similar conditions. We are primarily interested in getting enough magnetism to do the work we want it to do. If we do not have enough magnetism we can

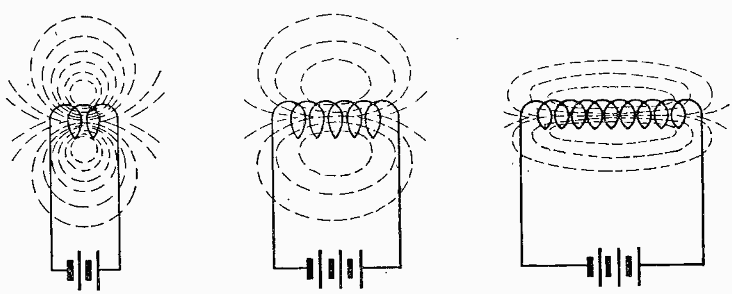

Fig. 3—Magnetic fields around different shape coils carrying a current.

get more by increasing the magnetic force, or decrease what we might call the magnetic circuit resistance. This will be the subject of this lesson—how to set up and control a magnetic circuit.

LAWS OF THE MAGNETIC CIRCUIT

The laws of a magnetic circuit are similar to (but not the same as) those of the electric circuit. However, the general underlying principles which govern electrical circuits will help us understand what happens in magnetic circuits. In a magnetic circuit we have magnetic flux or simply flux (lines of force) which corresponds to the current in an electric circuit; also magnetomotive force—the force (usually set up by an electric current flowing in a coil) to which the flux in a magnetic circuit is due—which corresponds to the electromotive force, or voltage (pressure) of an electric circuit, which may come from a battery or a generator.

In an electric circuit we have a property which is termed "resistance"; likewise every magnetic circuit has an analogous property which has been termed "reluctance." Therefore, instead of having to become familiar with new principles and ideas in order to understand magnetic circuit phenomena, the student will only have to apply a new group of quantities and units to the same old general principles which you have already learned in connection with the study of electrical and Radio circuits. However, it must be understood that the phenomena, units and quantities for magnetic circuits are not the same as those for electric circuits, they are merely analogous, for the same essential underlying general ideas apply for both.

This similarity between an electric circuit and a magnetic circuit can best be understood by first comparing all of the elec-

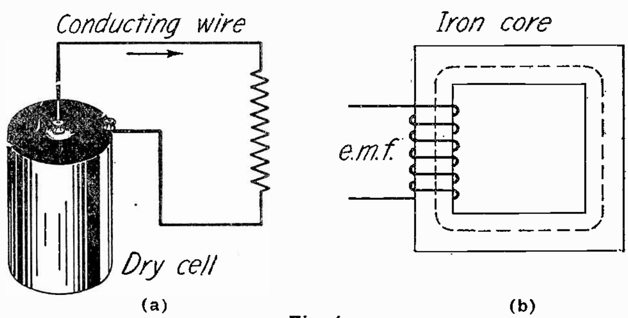

Fig. 4

trical terms and symbols with the corresponding magnetic terms and symbols side by side, as shown in Table No. 1.

TABLE NO. 1

ELECTRIC CIRCUIT	MAGNETIC CIRCUIT
Electromotive force (E) or (EMF)	Magnetomotive force (F) or (MMF)
Current (I)	Flux (Φ)
Resistance (R)	Reluctance (R)

The magnetomotive force, flux and reluctance are measured in units, just as the electromotive force, current and resistance are measured in units of volts, amperes and ohms.

There are two sets of units for measuring these and sometimes more, just as we have two sets of units, for measuring almost every other quantity. For instance, *length* is measured in "inches" or "centimeters"; one centimeter is equal to .3937 of an inch. So you will note that magnetomotive force is measured in units called "ampere-turns" or else in "gilberts" (named after William Gilbert, the English Physicist); one gilbert is equal to .796 ampere-turns.

A "turn" implies one wrap of a conductor around a core, which may, in the case of a solenoid be an air core, or, in the case of an electromagnet an iron core.

When a wire passes around a core several times, its magnetizing force is proportional both to the strength of the current and to the number of turns in the coil. The product of the current passing through the coil multiplied by the number of turns composing the coil is called the ampere-turns. Example: If you have a coil of 50 turns through which ½ ampere of current is flowing, the result in ampere-turns equals $50 \times \frac{1}{2} = 25$.

The main purpose of this lesson is to show the relation between magnetic terms and similar electric terms so that you will readily be able to form pictures in your mind when they are mentioned and used in some advanced text-books.

To determine the actual amount of flux, or reluctance in a magnetic circuit, is a very tedious procedure and even in most cases gives only approximate results unless very elaborate equipment is used so we will not concern ourselves with the details of actual measurements. Actual measurements are seldom made outside the manufacturer's laboratory. The relation of the two sets of magnetic units and the corresponding electrical units is shown in Table No. 2. This will be helpful to you before proceeding.

TABLE NO. 2

ELECTRIC CIRCUIT	MAGNETIC CIRCUIT
Volt	Ampere-turn
Ampere	Line
Ohm	Ampere-turn per line
Volt	Gilbert
Ampere	Maxwell
Ohm	Oersted

COMPARISON OF ELECTRIC AND MAGNETIC CIRCUITS

The total number of magnetic lines of force, or magnetic flux, produced in any magnetic circuit will depend on the magnetic pressure (m.m.f.) acting on the circuit and the total

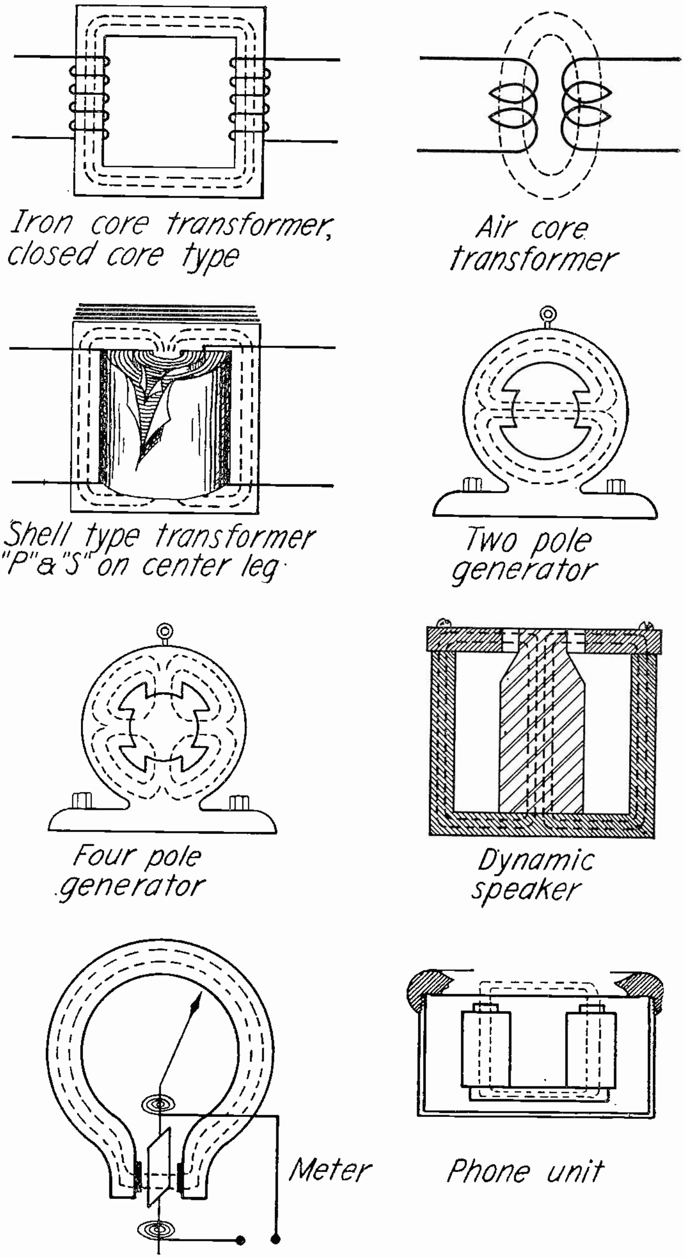

Plate I

Typical magnetic circuits in electrical and Radio devices.

reluctance of the circuit, just as the current in the electrical circuit depends upon the electrical pressure and the resistance of the circuit, that is—

ELECTRIC CIRCUIT	MAGNETIC CIRCUIT
$\text{Amperes} = \dfrac{\text{Volts}}{\text{Ohms}}$	$\text{Maxwells} = \dfrac{\text{Gilberts}}{\text{Oersteds}}$

It should be understood, however, that in the electric circuit, the resistance causes heat to be generated and therefore energy is wasted, but in the magnetic circuit the reluctance does not involve any similar waste of energy.

Now let us learn more about each of these terms that we have presented. First, we will have to know where magnetic flux exists. Where does flux originate? The answer to this question is easy for you now, because it has been stated many times before—magnetic flux originates within any coil carrying

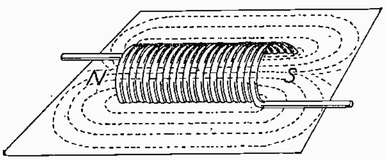

Fig. 5—Magnetic field of an air core coil.

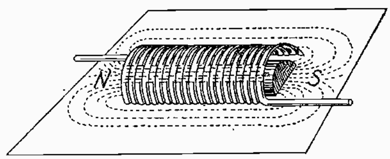

Fig. 6—Magnetic field of a coil of wire having an iron or steel core.

an electric current. Therefore, any coil of wire whether it is used in a door bell, testing instrument, motor or generator, or in a radio circuit is a *source of magnetic flux.* Magnetic flux or lines of force cannot exist without a complete circuit exactly like electric circuits. The flux of a magnetic circuit starts within the coil, then exists all around the coil as shown in Fig. 2. The path—that is, the magnetic circuit shown in Fig. 2—is through air. So we find that air is a *conductor* of flux and its distribution around a coil of wire is very similar to that of a bar magnet with two poles. We can easily obtain a picture of the magnetic circuit about a coil by sprinkling iron filings on a sheet of paper which passes through the coil as shown in Fig. 5.

The little lengths of iron filings become little compasses which point out the magnetic circuit—they point out where the flux exists. The crowding together of the iron filings also gives an idea of the amount of flux. In Fig. 5 it can be seen that the greatest flux exists within the coil and that there is less flux at greater distances from the coil; also it has magnetic polarity. If a piece of steel is placed in the vicinity of an electromagnetic field, many of the lines of force of the field are bent out of their natural direction and converge into the steel. The number of lines is also increased. In other words, there will be more lines of force as well as more passing through the space occupied by the steel than when the entire space was occupied by air alone. The capability of any substance for conducting magnetic lines of force is termed "its permeability"; therefore the permeability of steel is much greater than that of air.

If a piece of soft iron is substituted for the steel, even more lines of force will pass through the same space showing that the *permeability* or conducting power of iron is greater than steel. If an iron core is placed inside the coil of wire in Fig. 6 the iron filings will be attracted more closely together, illustrating the greater density or number of lines of force due to the iron core.

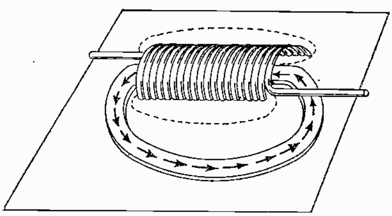
Fig. 7

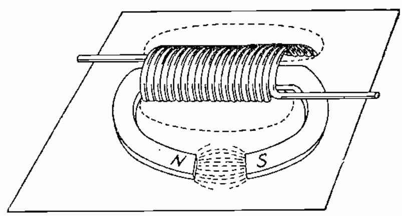

Fig. 8

If the iron core is pulled out of the coil a little way, and iron filings be again applied, the magnetic lines will be found to be conducted farther away from the coil before returning to it.

Now if we place an iron ring inside the coil as shown in Fig. 7 it will not show any external N and S poles, since the magnetic lines have a complete circuit through the iron. If, however, we cut a small section from the iron ring, as shown in Fig. 8, the lines of force will then be compelled to pass through the air gap to complete their circuit, so that strong N and S poles are produced where the cut has been made, and the space is permeated with lines of force. The lines of force in this case through the iron ring will not be so dense as before because the reluctance of the entire magnetic circuit has been increased. With the same magnetizing force the magnetic lines diminish as the reluctance of the circuit increases, just as in an electric circuit the current decreases when, with a constant e.m.f.. the resistance is increased.

If we replace the section cut from the ring we will find that a great many iron filings will be attracted at the two joints, indicating a magnetic leakage. The flux density in the ring is not now as great as when the ring was solid, since the joints offer opposition to the magnetic lines and some of them are forced through the air across the joint.

While the unbroken ring or closed magnetic circuit gives us by far the strongest magnet for the material and energy employed, there are many uses of the electromagnet which require that it should have polarity—that its lines of force should pass, for a portion of the distance at least, through an air space into which may be introduced substances to be acted upon by these lines; but it is an unchanging law of magnets that a magnet which most nearly approaches the closed magnetic circuit will be the most efficient. For this reason magnets, whether permanent or electromagnets, are usually bent around so that their poles approach each other, and the object to be acted upon is introduced into the gap between the two poles.

The object to be acted upon is usually some sort of armature, as a motor or a generator armature. This consists of a winding usually on an iron core so that the magnetic lines of force can be kept as close as possible through the gap. Of course, all leakage lines, or those which do not pass through the armature, are wasted, and whatever current was required to generate the leakage lines was uselessly expended. From the above it can be seen that when a portion of the magnetic circuit passes through air instead of iron, then a considerably greater magnetomotive force (in ampere-turns) must be used in order to overcome the reluctance in sending a definite flux through the circuit.

SERIES MAGNETIC CIRCUITS

The same laws apply to series magnetic circuits as to series electric circuits in which all of the parts are in series.

(a) The magnetic flux through all parts of a series circuit is the same.

(b) The magnetic force (gilberts) necessary to send a certain magnetic flux through a series circuit is the sum of the forces necessary to send it through the several parts.

The force which sends the magnetic flux through the magnetic circuit is measured in gilberts just as the pressure which sends the electric current through the electric circuit is measured in volts. The coil wound on a portion of the magnetic circuit then corresponds to a generator or battery placed in an electric circuit. We do not have to place generators or batteries all along the line, one at each place where we wish to send current, but we place one generator in the most convenient place and make it large enough to send the current through all the different paths of the circuit. Similarly we need not wind a coil on each separate part of a magnetic circuit where we wish to set up a magnetic flux, but we may wind it in the most convenient place and make it large enough to send the magnetic flux through all the different parts of the circuit.

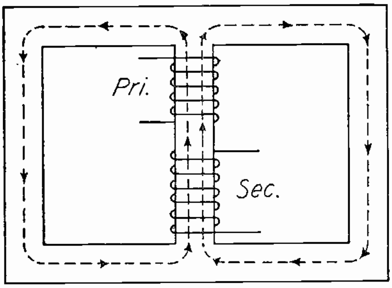

Fig. 9

PARALLEL MAGNETIC CIRCUITS

In magnetic circuits we also have parallel paths in which the flux will flow. In dealing with these parallel magnetic paths it is only necessary to keep in mind that the general laws for the flow of electric currents through parallel electric circuits apply equally well to the flow of magnetic flux through parallel magnetic paths. It is particularly important to keep in mind that the same voltage which forces an electric current through one path in a parallel circuit also forces electric currents through all the other parallel branches of the circuit.

This same law applies to the ampere-turns needed to force magnetic flux through parallel circuits.

In Fig. 9 we have shown a typical parallel magnetic circuit. Here the primary and the secondary windings of the transformer are placed on a center leg of a core so that the flux has a double path as indicated by the dotted lines. This type of construction is employed in a great many audio frequency transformers in which the primary and secondary coils are wound one upon the other, then placed on the center leg of the core.

This parallel type of magnetic circuit is often used in order to reduce the reluctance by providing a large cross-section of iron, yet keeping the size of the core small so that it can be conveniently handled in manufacture.

In connection with this, Kirchhoff's law for magnetic circuits states that the amount of flux to a point in the circuit equals the amount of flux leaving a point. This is similar to the statement of Kirchhoff's law for electric circuits: that the amount of current to a point equals the amount of current leaving the point.

FLUX DENSITY (B)

In speaking of the amount of flux in any cross-section of a magnetic circuit we speak of the *total flux* and the *flux density.* The "total flux" refers to all of the magnetic lines within the area of a cross-section of the magnetic circuit. In speaking of the "flux density" of the magnetic circuit, we mean the number of lines per unit of area* of a cross-section, that is, the number of lines per square inch or per square centimeter, and either is usually designated by the capital letter B. The symbol for representing the total flux is the Greek letter Φ pronounced "fee." There is a definite relation between flux, flux density and area.

$$(1)\ \text{Flux density (B) (per sq. cm.)} = \frac{\text{total flux (maxwells)}}{\text{area of cross-section (in sq. cm.)}}$$

$$\text{that is, } (2)\ B = \frac{\Phi}{A}$$

$$\text{or } (3)\ \Phi = A \times B$$

$$\text{or } (4)\ A = \frac{\Phi}{B}$$

where B is the lines per sq. cm.
Φ is the number of flux lines in maxwells
A is the area in sq. cm.

Try to conceive of flux through an area as follows: Imagine a square area two centimeters on a side. This is the same as four square centimeters and corresponds to the cross-section area (A). Imagine 500 needles piercing through the area vertically up from the area and for simplicity uniformly distributed.

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*For example, if the total flux was 10,000 lines and the cross section was 10 square centimeters, the unit cross section would be one square centimeter and the flux density 10,000 ÷ 10 or 1,000 lines per sq. cm.

This corresponds to the magnetic flux lines (Φ). It is not difficult to see that if there are 500 needles in 4 square centimeters in one square centimeter, there will be 500 divided by 4, or $500/4 = 125$ needles per square centimeter. This corresponds to flux density (B). The unit of magnetic flux is the *maxwell*, which is equal to one line of force. The *gauss* is the unit of flux density, and it is equal to one line of force per unit of area.

MAGNETIZING FORCE (H)

In figuring the value of the total flux in a magnetic circuit the flux density is first assumed and this is usually a matter of experience in designing. Then it is easy to compute the other factors.

It has been stated that the total flux (Φ) depends upon the amount of magnetomotive force (m.m.f.). It naturally follows that the flux density (B) also depends upon the m.m.f. The flux density also varies with the length of a typical magnetic circuit. This is similar to conditions in an electrical circuit where we realize that the amount of current will depend upon the e.m.f. and the length of a typical wire. Therefore, the length of a magnetic circuit should be kept as short as possible in order to get the greatest flow of flux. Otherwise, a greater amount of m.m.f. (in ampere-turns) will be required to send the same amount of magnetism through a longer magnetic circuit.

Twice the m.m.f. is required when the circuit is doubled in length, three times when the circuit is three times as long and so on in regular proportion for the same flux density. Consequently, we arrive at an expression, used with magnetic circuits, which is called the *magnetizing force*. The magnetizing force may be measured in "ampere-turns per unit length." This expresses the amount of m.m.f. required for every unit length of the magnetic circuit, in order to produce a given flux density. The symbol for magnetizing force is H.*

The amount of magnetizing force (H) needed to produce a given flux density (B) is best understood by referring to a graph like that shown in Fig. 10 where actual values for several materials are shown. Such a curve is called a B-H curve and it is very useful in determining magnetic properties, such as

*The student should also realize that if the m.m.f. is expressed in gilberts the corresponding magnetizing force (H) will be gilberts per centimeter of length.

permeability and saturation points for the different grades of magnetic iron and steel. The engineer uses these magnetic values in designing magnetic circuits for electrical and radio apparatus.

Except in the case of air, it will be noted from Fig. 10 that doubling H will not double B. In other words, B and H are not in constant proportion except when the magnetism conducting material is air.

PERMEABILITY

The ratio of B to H expresses the magnetic permeability of the material or "the conducting power of a magnetic medium for lines of force."

The permeability shows how well a material performs as a conductor of magnetic lines compared to air. The permeability of non-magnetic materials is a constant and equals $\frac{1}{1}$ or 1, or we may say one gilbert will set up one line of force in a cross-section one centimeter square and one centimeter long of a non-magnetic material. Thus *one* is the permeability factor of a non-magnetic material. You will recall that the number of magnetic lines produced inside a coil with an air core, can be greatly increased by introducing a piece of iron or steel, even though the current in the winding remains constant. This is due to the fact that iron and steel are better conductors of magnetic lines than air. The relation between the number of lines of force per unit area inside the coil after the iron or steel has been introduced, designated by (B), to the number of lines per unit of area for an air core, which is the field strength, designated by (H), is called the permeability factor, designated by (μ), pronounced mew. Then:

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

The permeability of a given sample of iron or steel is not constant because the value of B does not increase at the same rate H increases.

Curves showing the relation between the B and H quantities for wrought iron, annealed steel, soft steel casting and cast iron are shown in Fig. 10. The premeability of these different kinds of metal can be determined for any value or B or H by dividing the value of B for any point on the curve by the corresponding value of H. Let us consider a point on the curve in Fig. 10, which represents soft steel castings where B is equal to 13,000 gausses, H is equal to 20 gilberts. Then $\frac{B}{H}$ μ or is found by dividing the value of B and H, or $\frac{13,000}{20}$, which equals 650, which is the permeability for soft steel castings when working under this condition—that is to say when there are 13,000 lines (13 kilolines) flowing in it.

The sharp bend in the curve is called the "knee" of the curve or saturation point. The metal is very nearly saturated at this point because any further increase in H produces a small increase in B as compared with a corresponding increase in H below the knee of the curve.

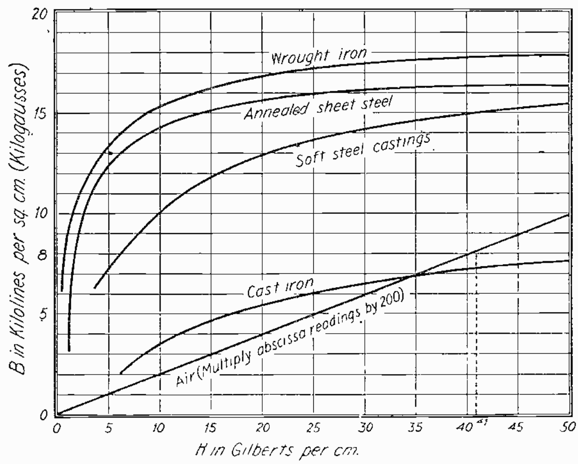

Fig. 10—Characteristic curves of magnetization, or B-H curves *

Many units of measurements are used in magnetic circuits and if included in this text would be very confusing. For your convenience we are listing here how to change from one to the other. For our purposes the maxwell (total flux), the gauss (maxwell per sq. cm.), the oersted (unit of reluctance) and the gilbert (the unit of m.m.f.) is used in this text.

To reduce gilberts to ampere-turns multiply by 0.796.
" " gilberts per cm. to ampere-turns per in. multiply by 2.02.
" " Ampere-turns to gilberts multiply by 1.257.
" " Ampere-turns per in. to gilberts per cm. multiply by 0.495.
" " gausses to lines per square inch multiply by 6.45.
" " lines per square in. to gausses multiply by 0.155.

MAGNETIC SATURATION OF IRONS AND STEELS

Pieces of iron and steel can be saturated with magnetism just as a sponge can be saturated with water. When there is

* The horizontal scale represents the increase in Gilberts per cm. and the vertical scale represents the increase in magnetic flux in kilolines per sq. cm.

8

very little water in a sponge it will readily soak up more water but when the sponge is almost full of water or nearly saturated, it will absorb additional water only with difficulty. Likewise with iron or steel (Fig. 10) when the flux density is low, a slight increase of magnetomotive force H in gilberts per centimeter will cause a material increase in the flux density or in the number of lines of force per square centimeter. However, when the flux density or magnetic saturation is high, it requires a great increase in H to produce a material increase in flux density.

RELUCTANCE

When we are interested in knowing how much magnetomotive force will be required to produce a given flux in a magnetic circuit, we must know in addition to the total flux, the *reluctance* of the circuit. As a point of comparison if we wanted to force two amperes through a circuit, and we wanted to know how much e.m.f. was needed, to solve our problem we would have to know the *resistance* of the circuit.

The chances are 99 in a hundred that the electrical circuit would be a round wire of a certain size and by looking up in a wire table we could find how much resistance that sized wire had per foot and knowing the total length, the product of these two facts would give us the total resistance. Then from ohms law we could calculate the needed e.m.f. in volts.

Suppose, however, we had a rectangular bus wire and no wire table available how would we find the resistance if it were of a definite length. Every metal will have a certain resistance for every square centimeter, one centimeter long. Tables will tell us that much. It is called the volume resistivity, or the table of conductivity would give the volume conductivity which tells us how good a conductor the metal is. Dividing this volume conductivity into one (taking the reciprocal) we obtain at once the important fact, how much resistance in ohms a cubic centimeter of material has. Naturally if the actual bus wire is 2 square centimeters in cross-section, one centimeter length would have a resistance of ½ of the volume resistivity. Thus for any value of area merely dividing by the area would tell us how much resistance in ohms one centimeter of wire would have. Of course, if the wire was 100 centimeters long, the resistance would be 100 times as much. All this we studied before. How about magnetic circuits? They are treated in the same way.

The cross-section of a magnetic circuit is generally rectangular so it is easy to calculate the reluctance. With wire the resistance does not depend on how much current flows in the wire; in magnetic circuits, however, the reluctance varies as the flux varies. Suppose we have a rectangular iron core in the form of a large ring whose length can be considered as the average circumference. How would you proceed to find the magnetomotive force needed to produce a given flux through the core? First we would have to find the reluctance.

Knowing the cross-section of the core in square centimeters and the total flux we find by simple division the flux density (B). From the manufacturers who made this magnetic material you would find from his B-H curve the required magnetizing force (H) for a cubic centimeter of the material. Then B divided by H is μ, the permeability of the material, that is, how good a magnetic conductor the material is. The reciprocal of μ is the reluctance that one cubic centimeter of material would have. From now on it is a matter of common sense. If the area was 10 square centimeters, the reluctance for a unit length would be one-tenth, and if the core was 100 centimeters long the reluctance would be 100 times as much. Reluctance is usually expressed as $R = \frac{l}{\mu A}$. If the length "l" is in centimeters, the area A in square centimeters, and the permeability is found as we explained, the reluctance will be in oersteds.

If the reluctance is multiplied by the total flux, the required m.m.f. in gilberts for the magnetic circuit will be obtained. If the value of m.m.f. in gilberts is multiplied by .796 the ampere-turns needed is known.

EFFECT OF AIR GAPS

In the above example, the magnetic circuit was entirely of iron. It is very common to introduce air gaps intentionally or unintentionally in such circuits. Let us first consider a case where a gap one centimeter in length is introduced in the circuit. (See Fig. 11.)

Let us again suppose that the flux density in the circuit will have to be 8,000 gausses per square centimeter (8 kilogausses). Referring to Fig. 10, where the curve for air crosses the 8 kilogauss line, we see that the magnetizing force corresponds to approximately 41 gilberts per centimeter. However, this value of 41 must be multiplied by 200 in order to give the correct value of H, in gilberts per centimeter, because the curve has been so drawn as to place it on the same graph with the curve for iron. Therefore, 41 multiplied by 200 gives us 8,200 gilberts which are necessary for every centimeter in length of the magnetic circuit when passing through air. At once we realize that a tremendous amount of magnetomotive force is required in order to overcome the reluctance of the air for $8{,}200 \times .796 = 6{,}527$ ampere-turns per cm. of air gap.

In considering the total amount of magnetomotive force necessary for a magnetic circuit, we must take into account the values required by the iron and the air separately. In this we must not overlook the places where the ends of the iron core join each other in the corners of the core. Often a considerable

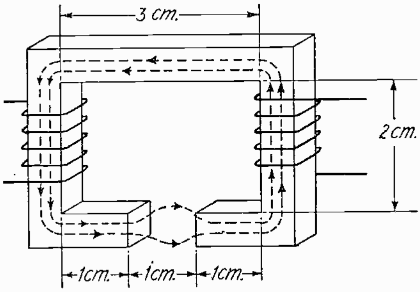

Fig. 11

air gap is introduced unintentionally at these points and considerable reluctance is introduced due to careless construction. One can readily realize that the greatest value of magnetomotive force is needed to force the flux through the air gap.

HYSTERESIS*

So far we have concerned ourselves with a constant current being used in the coils of an electromagnet. The information we have so far studied is of importance in electromagnets, such as used in dynamic speakers, motors, generators, magnetic lifts and blow-out magnets in arc transmitters. What happens when the coil is supplied from an A.C. source is very important in our study of radio.

Suppose we had a magnetic core such as shown in Fig. 12, with a means of sending current through the magnetizing coil in

*Hysteresis is magnetic inertia.

either direction and in varied values. Let us assume that we have a method of measuring the flux in the magnetic path. (The method is too involved for presentation in a Radio course and is only needed in special laboratories where iron and steel are tested electrically.) We are going to reproduce "in slow motion" what would happen if an A.C. current was present in the coil.

Refer now to Fig. 13. We assume that the core is newly constructed and has never been subjected to an m.m.f. As we proceed to force a current through the coil, the m.m.f. goes up and from our knowledge of the B-H curve we can see that the flux will go up as shown by *1, 2, 3,* and *4* in Fig. 13 At conditions represented by point *4*, we start to decrease the current in the coil and the flux for various m.m.fs. is represented by points *5, 6,* and *7*. Why? When the core is magnetized, the particles of iron or steel act like little magnets which line up along the lines of force. When the m.m.f. is removed they tend to remain in the same position as much as possible with the result that when the current through the coil is reduced to zero, as represented by point *7*, flux actually exists in the core (magnetic circuit). This flux is called RESIDUAL FLUX, often called residual magnetism. Residual magnetism is caused by a property of the metal which causes it to retain some of the lines which have been made to flow in them just as a sponge has a tendency to retain water which has been put into it. This property is called *retentivity.*

To bring the flux to zero, current must be forced through the coil in the opposite direction as shown in Fig. 13 by points *8* and *9*. Now as the current is further increased in the opposite direction, conditions depicted by points *10, 11, 12* and *13* exist. Again reducing the current to zero point *16* and sending current in the opposite direction, the relation between flux and m.m.f. is given by points *14, 15, 16, 17, 18, 19, 20* and point *4*. This variation in current (*4* to *13* to *4*) represents one cycle of current change. The loop shown in Fig. 13 showing the different relations is called a hysteresis loop. If the current cycle is repeated, the path of change is over *4* to *7* to *9* to *13* to *16* to *18* to *4* and not over *1, 2, 3* and *4*. It takes energy to overcome the residual magnetism at points *7* and *16* and heat will appear in the magnetic material, referred to as hysteresis loss. The loss depends on the flux density, the amount of magnetic material (volume) and the nature of the material.

There is practically no hysteresis loss in air; good silicon steel has less loss than soft iron, which is better than hard cast steel which is in turn better than tungsten steel. Hysteresis has other effects on audio signals when present in audio transformers as we shall shortly see.

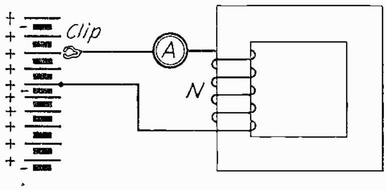

Fig. 12

The student should realize that the presence of an A.C. magnetomotive force results in what might be termed an A.C. magnetic flux. It is this A.C. flux that make possible the induction of an e.m.f. in another coil linked to it.

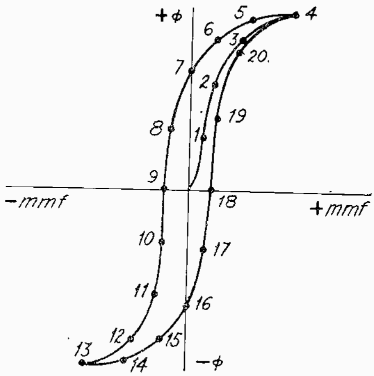

Fig. 13—Typical cycle of magnetization called a hysteresis loop

EDDY CURRENTS

Another loss is present when A.C. flux variations are present. Suppose we turn our attention for a moment to the elementary principles of electromagnetic induction, and take for example the coil in Fig. 12. If the current is started to flow in this coil, magnetic lines will be set up in the iron core. If these lines are allowed to stop, a counter-electromotive force will be set up in the coil due to these lines cutting the turns as they shrink up or stop, and if the coil circuit were closed, current flow would be established. Now, let us imagine the coil of wire removed and a tubular piece of metal put in its place, then is it not true that if lines of force were started or stopped in the iron magnetic core, currents would flow around in a circular path within the cylindrical metal tube? Now, let us take the next step and imagine this cylindrical metal tube removed. Could we not consider part of the solid iron core itself as forming a metal cylindrical tube which would conduct current that would

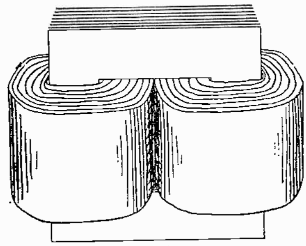

Fig. 14—Core type transformer and winding arrangement.

be induced by the magnetic lines stopping and starting in this solid iron core? Results prove that this is true and currents do actually flow in little circular paths within the iron core. These are called eddy currents. Of course you know that when a current flows in a circuit heat is generated because of the I^2R loss.

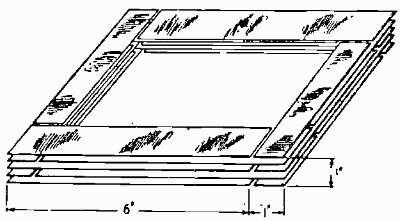

Fig. 15—Illustration showing how a core is built up.

METHOD OF MINIMIZING EDDY CURRENT LOSS

In order to reduce the eddy current losses to a minimum, the
10 core of the transformer is made up of thin sheets of iron, called *laminations*, each sheet being electrically but not magnetically insulated from its adjoining one by the resistance of its natural oxide or by a thin coating of shellac, varnish or lacquer. These eddy currents tend to flow in a direction at right angles to the length or axis of the core, so that the high resistance between the laminations very effectually limits the magnitude of the cur-

rent. Therefore, in assembling a core for a transformer or other type of machinery in which there is a varying flux, it is only necessary to see that one sheet is insulated from the other.

It is interesting to note, that even when laminations are used eddy current loss will increase as the frequency of flux variations, as the flux density is increased and as the laminations are made thicker. For example, if any one of these factors is doubled the loss will be increased four times.

IRON LOSSES

It is very difficult to measure the hysteresis and eddy current losses separately, therefore they are usually treated together and called the iron losses. These iron losses can easily be measured with ordinary electrical instruments, such as the wattmeter and the ammeter. The watts necessary to supply the

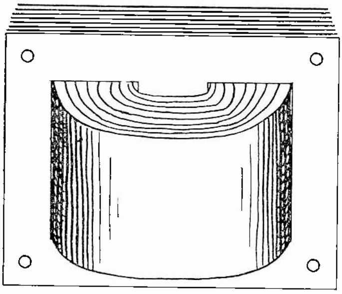

Fig. 16—Shell type transformer.

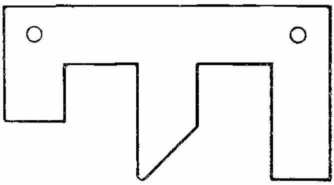

Fig. 17—Shape of one lamination.

proper magnetic flux to the circuit without any load are measured, and then by subtracting the *copper losses** for the coil from this, you have the iron losses.

CONSTRUCTION OF IRON CORES FOR A MAGNETIC CIRCUIT

Various forms of construction are found in magnetic circuits used in different types of transformers. One method of assembling a series magnetic circuit is shown in Fig. 15, where the iron core consists of rectangular sheets, placed one upon the other in alternate order, so that there is a minimum amount of air gap at the joints. One layer is insulated from its neighbors in order to reduce the eddy currents. Some are made with L shaped laminations or punchings; each adjacent layer is reversed to stagger the joints.

The construction of a parallel magnetic path, similar to that shown in Fig. 9 is given in Fig. 16. This type of core is found

* The energy dissipated as heat in conductors (I^2R loss).

in a great many of the modern audio frequency transformers. The windings of the coil are wound on a form of the same cross-section as the core and placed on the center leg of the transformer.

The laminations or punchings are shaped as shown in Fig. 17, each one being reversed when inserted in the winding in alternate order so as to fit together as shown in Fig. 17a.

LEAKAGE FLUX

In an electric circuit the current can be confined entirely within a fixed path because materials are available through which the currents will flow (called conductors) and through which they will not flow (called insulators). Consequently, the conductors can be separated by the insulators and the current made to flow where it is desired.

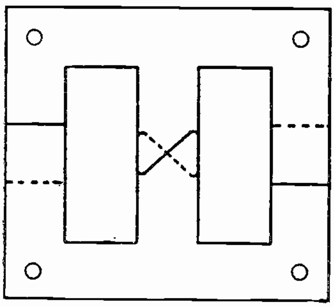

Fig. 17(a)—Laminated core, each lamination reversed and then alternately reversed.

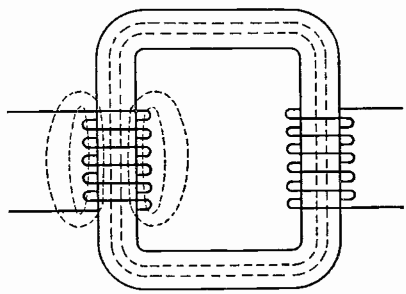

Fig. 18

In a magnetic circuit we are not so fortunate in having materials through which the flux will not pass. This means that all materials are conductors of magnetic flux. It is evident, therefore, that all of the flux can not be made to follow a confined path in the same way as in an electric circuit. Some of the flux leaks away from the desired circuit, returning to the source of magnetomotive force without linking with a secondary coil. This can readily be understood by referring to Fig. 18 where it can be seen that some of the lines do not pass through the entire path of iron but return through the air to the source of magnetomotive force. These lines are called *leakage flux* and must be taken into account when figuring the magnetomotive force available from the coil. Incidentally this *leakage flux* with the turns it links acts as an inductance and is called *leakage inductance.*

Leakage flux is made up of those lines which failed to flow through the entire circuit and, therefore, failed to affect all the turns of wire in both the primary and secondary coils. This would have two effects; first, to decrease the induced volts in the secondary coils; and second, to reduce the counter e.m.f. in the coil itself, which is really the inductive effect and, therefore, reduces the inductance of the circuit. Both of these have a tendency to reduce the efficiency of the apparatus.

The leakage flux becomes greater as the reluctance of the main magnetic circuit is increased. Increasing the reluctance of the desired path means that the flux will find a return through air or other materials more readily than before, resulting in greater leakage flux. To offset this condition as much as possible the primary and secondary windings of a transformer are kept as close to each other as construction permits, the one wound over the other in many instances. Even with these precautions there is some leakage due to the separation of the wires by insulation and due to the fact that some wires are necessarily farther away from their adjacent turns than others.

From the above it can be seen that a large ratio in the turns between the primary and secondary will mean greater flux leakage. This is not serious where only one frequency is used, such as in power transformers for supplying current to the tubes in a radio set, but it is of greater significance where the frequency varies over an extremely wide range, as in an audio frequency transformer. Consequently, large turn ratios are not used in audio frequency transformers.

RATIO OF PRIMARY VOLTAGE TO SECONDARY VOLTAGE

The purpose of a magnetic circuit in a transformer is to provide a link between two electrical circuits. Thus, the electrical energy in "circuit *1*" of Fig. 19 can be transferred to "circuit *2*." The advantage in this arrangement is that the voltage in "circuit *2*" can be made any value desired simply by choosing the correct number of turns in the two coils of the transformer. For instance, if the generator in "circuit *1*" supplies a voltage of 100 volts to the primary coil, then the voltage in "circuit *2*" can be 2 volts, 10 volts, 100 volts, 1000 volts or any other value that may be desired, simply by using more or less turns in the secondary coil.

If there is no magnetic leakage, the "volts per turn" in the *primary* of a transformer will equal the "volts per turn" in the *secondary.*

Let us say that the primary has 50 turns and the generator supplies 100 volts. Then we have 2 volts per turn. Now, if we use one turn in the secondary, a voltmeter will register 2 volts in circuit *2*. Adding another turn in the secondary, so that we have a total of two turns, then the voltmeter will register 4 volts. For every additional turn in the secondary we obtain an increase in voltage at the rate of two volts per turn. It can be seen that here is a convenient way of raising or lowering the voltage of a source of alternating e.m.f., simply by changing the number of turns in the coils of a transformer.

In case there is flux leakage in the magnetic circuit additional turns can be added to make up for the difference in volt-

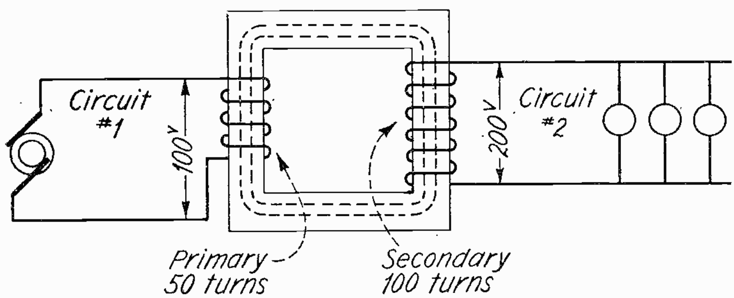

Fig. 19

age. However, in power transformers of good design, operated on a single frequency, the secondary voltage can be considered to vary in proportion to the number of turns. This means that if we want the same voltage in the secondary as we have in the primary, then the same number of turns should be used in each coil. If half the voltage is desired in the secondary then half the number of turns should be used, so that the ratio of turns is 1 to 2. If twice the voltage is desired, as shown in Fig. 19, the ratio of turns is 2 to 1.

At once we can see how to arrange a transformer so that various voltages can be supplied to the filaments and plate circuits of vacuum tubes when 110 volts A.C. is available from the power mains of a house lighting circuit. The 110 volt source is connected to a primary of a transformer, and several secondaries, with the required turn ratios selected to give the desired voltages, are provided for each group of similar tubes requiring a common value of voltage. Referring to Fig. 20 secondaries are shown arranged so that 2½ volts, 5 volts and 600 volts are available. By providing a center-tap (*C.T.*) in the 600 volt secondary, 300 volts are available to either side of this tap, for supplying a voltage to the rectifier circuits, suitable for the plate circuits of the tubes in a Radio receiver.

RATIO OF PRIMARY CURRENT TO SECONDARY CURRENT

The current in the secondary of a transformer of course is dependent upon the amount required by the load in that circuit. Let us say that 2 amperes are required in circuit *2* of Fig. 19. This means that 400 watts are consumed because we have 2 amperes at 200 volts. The 400 watts have to be supplied by the primary, so in this case, with 100 volts in the primary, we must have 4 amperes flowing there.

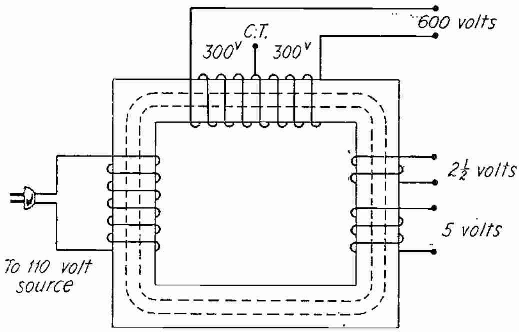

Fig. 20

The above example shows that the current in the secondary is half of that in the primary. Therefore, we see that when a voltage is stepped-up in the secondary, the current will be stepped-down or reduced in proportion to the ratio of turns or the inverse ratio. In other words, as the ratio of the turns is increased then the current will be decreased, or if the ratio is decreased then the current will be increased.

Therefore, if the 5 volt secondary in Fig. 20 is supplying the filaments of two '71A type tubes, drawing a total of ½ ampere (500 milliamperes) then the current in the primary is 110 volts divided by 5 volts, which equals 22 and 500 divided by 22 equals 23 milliamperes (approximately).

9 In the above cases, no allowance is made for the various losses encountered, such as eddy current, hysteresis, magnetic

leakage and losses due to the resistance of the wire itself. Therefore, additional current is taken by the primary in an actual case to take care of the above mentioned losses.

AUDIO FREQUENCY TRANSFORMERS

The audio frequency amplifier is a large part of the modern Radio receiver, phonograph, talking film and public address system. Here transformers are of importance in establishing a link between tubes and apparatus and it is necessary to use magnetic circuits that faithfully provide changes in flux which keep in step with the changes in current which represent the original sound. Otherwise, distortion and unnatural reproduction will result.

The current which must be handled by an audio transformer is a varying current made up of a large number of individual currents whose frequencies may be from 35 to 8000 cycles per

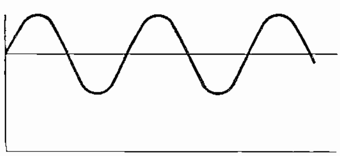

Fig. 21

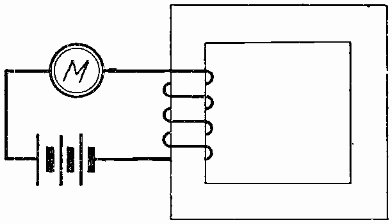

Fig. 22

second. This composite current is known as an audio frequency current because it will cause corresponding air vibrations, which fall within the range of the ear, when used to operate a loudspeaker or other sound-producing device. The magnetic circuit should be able to follow these individual changes of flux at 35 cycles per second, as well as all other frequencies including 8000 cycles per second.

Not only are steel core transformers used in the amplifiers, but so are steel core inductances, called audio chokes. They are usually made by winding many turns of insulated wire on a laminated sheet steel core. Steel cores are used because they increase the inductance of the coil many hundred times.

Nevertheless, the use of steel cores has the undesirable effect of altering the form or characteristic of the current it acts on or passes on in the case of transformers. That is why transformers are designed for a definite circuit, so saturation cannot take place under ordinary conditions.

In vacuum tube and rectifier circuits the windings pass a direct current as well as an alternating current. After all this is nothing more than a pulsating current portrayed by Fig. 21. The heavy, wavy line represents the pulsating current, and the light, straight line through the wavy line represents the direct current part or component.

The presence of the direct current greatly alters the magnetic action of the core. Instead of having the magnetic lines flow first in one direction and then in the other, as would be the case if only alternating current flows in the windings; the magnetic lines always, with pulsating current, flow in the same direction but they are at one moment large in number, then less in number.

Figure 10 shows the magnetic characteristic of various magnetic materials—in a completely assembled choke or transformer the current will determine the value of H. Just as in a vacuum tube amplifier, the transformer must work in the straight portion of its characteristic, or the current variation must be small so the curvature of the characteristic will not distort the signal. That is why a steel core inductance must be designed for a definite direct current, or the direct current adjusted to give the least distortion.

It is the curvature of the characteristic, the bending, that determines the permeability of the steel and it varies with the direct current; usually the greater the current the less the permeability. Actually this permeability is less than you would expect, because the alternating current causes the flux to lag a little. This is referred to as the A. C. permeability, a term you may often hear.

TEST QUESTIONS

Be sure to number your Answer Sheet 11 FR.
Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson.

In that way we will be able to work together much more closely, you'll get more out of your course, and the best possible lesson service.

1. What is a magnetic circuit?
2. Draw a simple magnetic circuit.
3. Define "magnetomotive force."
4. What is reluctance in a magnetic circuit?
5. Define "magnetic permeability."
6. What is meant by "flux density?"
7. State the usefulness of B-H curves.
8. Explain the meaning of "magnetic saturation."
9. Name some of the causes for the loss of power in transformers.
10. How are eddy current losses reduced in transformers?

HOW THE A.C. RECEIVER GETS ITS POWER

12FR-1

PIONEER HOME STUDY RADIO SCHOOL

NRI

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

CASHING IN ON DISCONTENT

Discontent — dissatisfaction — these are not pleasant words. Yet it is to discontent that the world owes practically all advancement. If Columbus had not been discontented with the accepted ideas of geography in his day, he would not have started out to prove that the earth was round — and the whole course of history would have been changed.

If the early Americans had been content to dwell at their ease in the eastern part of America, the far west with all its rich natural resources might never have been discovered.

If you had not been discontented with your lot, you would never have enrolled for the N. R. I. Course — and you would never have had similar opportunities for Success.

So — discontent is a good thing — if it makes you want to do something worth while.

Practically everyone is discontented — we are all the same in this — and we all have the same starting point. But some of us are "floored" by discontent, we develop into complainers, we find fault with anything and everything. We end up as sour and dismal failures.

Those of use who are wise use our discontent as fuel for endeavor. We keep striving toward a goal we have set for ourselves. We are happy in our work. We face defeat, and we come out the victors.

At this minute you may be discontented with many things — your progress with your Course, your earning ability, yourself.

Make that discontent pay you dividends. Don't let it throw you down. If you do, you may never be able to get up again. Keep striving to remove the cause of your discontent. Remember that it's always darkest before the dawn. And a real N. R. I. man works hardest and accomplishes most when he is face to face with the greatest discouragements.

J. E. SMITH

NATIONAL RADIO INSTITUTE

WASHINGTON, D.C.

1936 Edition

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How the A.C. Receiver is Supplied with Power

SIGNAL AND POWER CIRCUITS

So far I have explained to you how the essential parts that go to make radio equipment (coils, condensers, resistors, transformers, vacuum tubes) work. In later lessons you will learn how vacuum tubes work—as radio frequency amplifiers, as generators (oscillators) of A.C. currents, as audio frequency amplifiers, as modulators that mix radio and audio frequency signals, as demodulators or detectors that separate two signals, as automatic volume controls, as a device that squelches or stops reception when the signal is too weak (quiet automatic volume controls or noise suppressors), and so forth. But before a tube can perform the function it is designed for, it must be supplied with local power. The filament or cathode must be heated to drive off or emit the electrons. the electrodes (grids, screens and plates) must be supplied with a positive or negative charge to assist or control the electrons in the tube while in motion. The filament source may be A.C. or D.C., depending on the tubes used; but the voltages applied to the electrodes must be *continuous,* which is a D.C. voltage without a fluctuation. Let me repeat, the power supply system of a vacuum tube radio device must furnish the following electrical power: A.C. or D.C. for the tube filaments and continuous current (D.C.) for the tube electrodes.

My present discussion will be limited entirely to the local power supply system. You might well ask: can we discuss the supply circuit without the other radio circuits? Indeed we can. When you come to trace radio circuits as an expert, you will automatically divide a radio sound or television receiver, or an amplifier, or a radio transmitter, or a radio testing device, into two parts, namely: *a,* the signal circuits; *b,* the power supply circuits. In fact, the separation is so important that special parts called filters, blocking condensers, bypass condensers, and chokes are used to keep these two circuits from acting on each other. Let me also stress that if you master the important functions of the power supply system, learn to trace them in radio equipment, you will be able to handle many of the common service complaints. I am taking this opportunity to caution you to read this book slowly, as it is full of important radio information.

FILAMENT POWER

Let us study, more closely, what voltages are required to make a triode, a tetrode, and a pentode operate properly. I am omitting, for the moment, the diode and twin diode as they require special consideration.* Referring to Figs. *1A* to *1D* you will observe what voltage supplies are needed, presented in the usual schematic or circuit symbol method. Figure *1A* represents the simplest triode, a tube extensively used as a power amplifier. The filament, when heated by a D.C. current, will emit electrons. A continuous D.C. voltage connected between *K*, the filament, and *P*, the plate, will draw the electrons from the filament to the plate; and a continuous D.C. voltage connected between the cathode (in this case the filament) and *G*, the grid, will electrically set the tube at the best operating condition. Observe that the grid is connected to the negative terminal of the C supply and this voltage is referred to as the "C bias" because it places a potential difference between the grid and the filament.

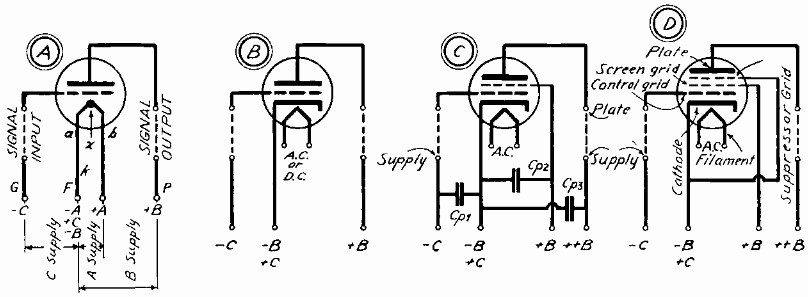

Fig. 1

The supplies required for a triode, tetrode and pentode

Heating with an A.C. Source. If A.C. current is fed to the filament the current rises to a peak twice for each cycle, once on the positive and once on the negative alternation. There is no difference which alternation does the heating. Thus the filament will come to peak heat 120 times a second, if standard 60 c.p.s. (cycles per second) current is used. If the filament is very thin, it will heat and cool rapidly and the electrons going from the filament to the plate will be varied by something else besides the input radio A.C. signal; and the loudspeaker will emit a power supply hum.

To remove the varying heat (twice the frequency of the source) the filament is made large so it will not cool off or heat up rapidly. And this is exactly how so-called A.C. filament tubes are made.

This is not all that is required to operate a tube satisfactorily; it is important that the "C" bias and plate supply voltages remain constant at all times, for the A.C. radio signal at the input (grid circuit) is the only varying quantity that should produce a varying (plate circuit)

* When diodes are used in the signal circuit they usually require only filament power. In this lesson the diode is important as it is used to convert A.C. power to D.C. power. I will come to this shortly.

output. When the filament is fed with a D.C. current, the $+C$ and $-B$ connections of the electrode voltages may be connected to either $-A$ or $+A$ filament terminals.* But suppose an A.C. source is connected to the filament; terminal *a,* Figure *1A,* will at one moment be negative with respect to terminal *b;* and the next alternation of the A.C. supply *a* will be positive with respect to *b.* The electron path from the filament to the plate will have to encounter this voltage drop between *a* and *x* and *x* and *b,* and thus vary the steady "C" bias and plate voltage supply. Now should the $+C$ and $-B$ connections be made at point *x,* which is midway between *a* and *b,* this drop is avoided and the "C" bias and plate voltage remain fixed regardless of the use of an A.C. filament supply.

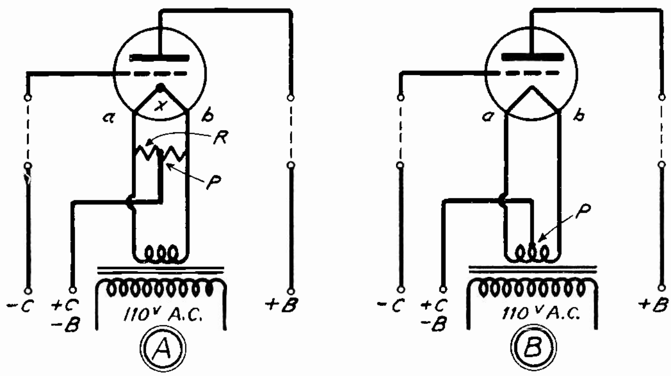

FIG. 2

The connection to *x* is inside of the tube, but it is not necessary to bring this connection out to a special prong on a tube base. There is another way of getting a mid-potential. If you shunt terminals *a* and *b* with a potentiometer *R* as shown in Figure *2A,* you have duplicated a condition which is similar to the internal (point *x*) filament connection. If the control *P* is set to the center of resistor *R,* it will always be at the same potential as point *x.* Now there is a general circuit law that says that terminals of equal potential may be connected without a change in the circuit currents. Therefore, points *x* and *P* may be considered as being the same. Figure *2A* is the accepted connection for a filament type tube, such as the 45, when the filament is heated by an A.C. current.

Figure *2B* shows a less expensive connection for A.C. filament type tubes. In this case the filament is again connected to the low voltage secondary of a 110 volt A.C. step-down transformer. The secondary

* Although either may be used, the —A terminal connection has become standard.

is provided with a center tap P, so located that when the A.C. voltages between P and a, and P and b are measured, they are equal. For this reason point P is called the electrical center. It is the $+C$ and $-B$ terminal as far as the supply circuit is concerned.

A step-down transformer is generally needed with A.C. receiver tubes,* as the filament voltage is rarely above 30 volts, the most common voltages being 1.5, 2.5, 6.3, 12 and 25 volts. The center tapped secondary is not required for heater type tubes, but when supplied is usually connected directly to the cathode of the tube.

Multiple Filament Connection. Now I am going to explain how more than one tube may be supplied with filament power. Where several tubes of the same filament voltage rating are used in radio equipment, the filaments may be connected in parallel as shown in Fig. *3A,* and to the low voltage secondary of a power transformer. Where heater and filament type tubes or tubes of different filament voltage ratings are used in the same receiver, generally separate filament secondary windings are used for each group, as shown in Fig. *3B*. For example, a 2.5 volt tube cannot be connected in parallel with a 6.3 volt tube for the filament of the 2.5 volt tube will draw too much current and burn out. Quite often an inexperienced serviceman by mistake, puts a 2.5 volt tube in a socket where a 6.3 volt tube is intended, and "puff", out goes the tube; or to be exact the filament of the tube will burn out. Not always will you find similar tubes connected to the same filament supply secondary, for special circuits may require separate secondary windings. You will encounter such conditions as you learn more about radio, but now it is the usual conditions that I want you to master.

Figures *3C* and *3D* illustrate two simple multiple tube connections. Here the filaments are connected in series, and the voltage required at xy is the sum of all the individual tube voltages. In this case each tube should have the same current rating. If the source has too large a voltage, then a series resistor R_1 is used.† Very often tubes in the same voltage group are to be connected in series but not all the tubes in a group draw the same current, for example, you will find that some 6.3 volt tubes draw 0.3 ampere, while another draws 0.8 ampere. A simple series connection cannot be used, because the high current tube will probably draw too little, while the low current tube will draw too much current. Where such tubes must be connected in series this difficulty is avoided by shunting (connecting across) the low current filament with a resistor so the resistor will conduct the extra current, R_2 in Fig. *3C* shows such a shunt resistor.‡ Tubes of different voltage ratings may be connected

* In universal receivers where 110 volt A.C. or D.C. is used, in transformerless A.C. receivers the series filament connection, to be described shortly, is used. The voltage is reduced by a series resistance.

† The ohmic value of this resistor is the *extra voltage divided by the series current* (volts ÷ amperes).

‡ Its ohmic value is the *filament voltage* of the shunted tube *divided by the extra current.*

in series, if their currents are the same. For example, a 6.3 volt, 0.3 ampere filament may be connected in series with a 12.6 volt, 0.3 ampere tube.

Most A.C. socket and battery operated receivers have their tube filaments connected in parallel; while most universal (meaning sets operated from either an A.C. or D.C. supply) and most D.C. socket powered receivers have their tube filaments in series. Whenever a filament is intended for an A.C. source, the connecting leads are twisted as shown in Figs. *3A, 3B,* and *3D,* to eliminate stray A.C. magnetic fields which may create an A.C. hum output. Also set designers prefer heater type tubes, for in this way the filament circuit is separated from the signal circuits.

Observe that no variable filament current controls are shown in Figs. *3A to 3D.* In the light of modern radio experience it has been found that varying the filament current to change tube characteristics or volume is a very poor method. Too much filament current weakens the filament and burns it out; too little current in addition to making the electron

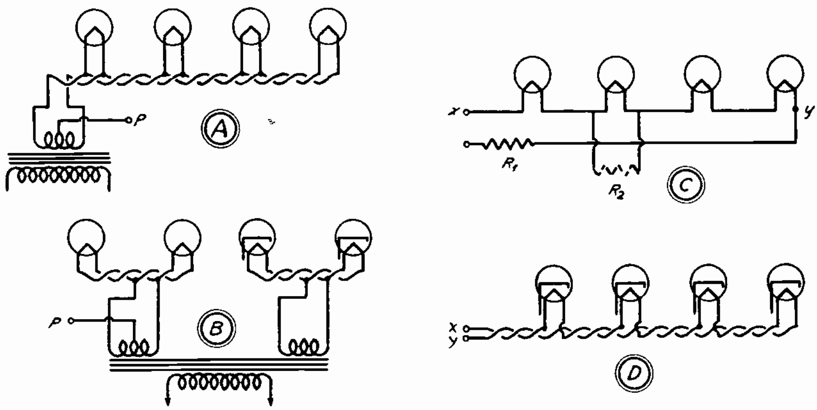

FIG. 3

emission extremely low, causes the filament to become brittle and break. You will rarely find filament current controls in modern, well-designed receivers, although you may find them in some battery receivers, particularly the very old ones. In the latter case you will find one or more tubes connected in parallel and a variable resistor (a filament rheostat) connected between one common filament terminal (usually negative for amplifier tubes) and the battery binding post.

PLATE, SCREEN AND GRID VOLTAGE SUPPLY

For the average three, four, five, and multi-element tubes in a radio receiver the plate, screen and grid supply must be a continuous; that is an unvarying, direct current. No better source than the dry or storage battery can be found; in fact, most laboratory vacuum tube equipment employ battery supplies. A complete *A* (filament), *B* (plate), and *C* (grid) battery supply is shown in Fig. *4*. A storage battery filament supply source is shown, although dry cells in parallel, series, or series-parallel, or an air cell battery may be and often is used. The connection is so obvious that little further explanation is necessary. Any of the tube circuits shown in Figs. *1A* to *1D* may be connected to these battery supplies. Where several tubes are used in the radio device the filaments are connected in parallel and to the A battery. The grids, screens and plates are connected together at the *supply* terminals (see Fig. *1C*) and to the $+B$ and $-C$ supply terminals. Where different values of +B and —C voltages are needed, separate connections as indicated in Fig. *4* are provided. To prevent the A.C. radio signals from passing through the power supply, condensers, shown as C_{p1}, C_{p2}, C_{p3} in Fig. *1C*, are used. Of course, the capacity of the condensers should be large so the signal which is high frequency alternating current, will go through the condensers and not through the power supply. Here is another example of how the A.C. signal and the D.C. power supply circuits are isolated.

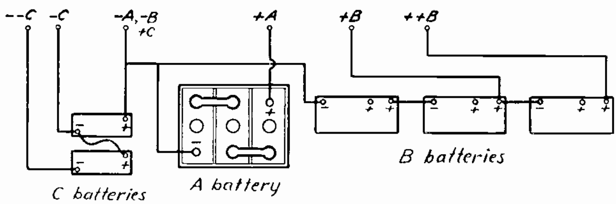

FIG. 4

Every radio expert will agree that no better high voltage D.C. supply than batteries can be obtained. Batteries would be used more often if it were not for: *a*, the expense; and *b*, the bother of changing them when their voltages drop below the useful limit. To give you some idea of cost, let me consider the A battery as a typical case. You can buy a dry cell for about 25 cents. It is rated to give 40 watt-hours. You can buy electric socket power for about 10 cents per 1000 watt-hours. Both values are top figures. Clearly you buy 1.6 watt-hours of battery energy for one cent; but a power company will furnish you 100 watt-hours for a cent, and probably less. It is no wonder that when radio first became popular, many experts worked on the problem of converting cheap A.C. to continuous current power. At first they tried to get pure D.C. current to heat the filaments, but they gave the plan up as too costly and developed A.C. tubes to be used in the manner I have described. High D.C. voltages are more economically produced and it is a simple matter to divide it so the grids, screens and plates are properly supplied. I will come back to this after I explain to you how A.C. socket power is converted (changed) to high D.C. voltage power.

For the average radio receiver and amplifier, 110 volt, 60 c.p.s. power must be converted to about 400 volts D.C. without an appreciable ripple.* In a general way this is how it is done. The low voltage A.C. socket power is first raised to a high A.C. voltage by using a step-up power transformer, because it is not simple to step-up a voltage after it has been converted to D.C. Next the A.C. is passed through a device which we call a rectifier, which allows current to flow only in one direction. A radio rectifier tube is invariably used. This output voltage from a rectifier tube is pulsating direct current varying from a peak (the largest) value, to zero. To remove the variation, the power is passed through an electrical filter consisting of condensers and choke coils, which smooths or wipes out the variation or ripple, leaving a pure D.C. source. Finally the high D.C. supply voltage is divided as required. The changes from A.C. to divided D.C. are portrayed in Fig. 5. The entire device is often called a "power pack."

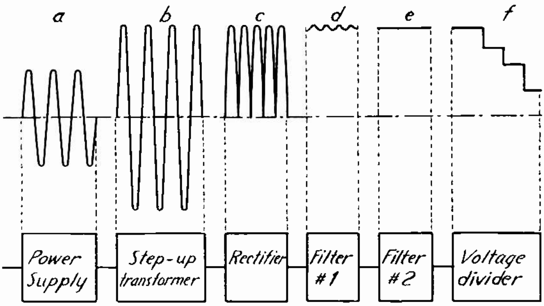

Fig. 5
Sketch showing changes that take place in the B-C section of a power pack

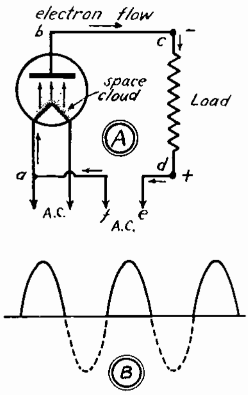

Fig. 6

THE HALF-WAVE RECTIFIER

Before we consider a practical A.C. to D.C. converting system let me first present the diode tube (two element tube). The simplest diode has a filament which emits electrons when heated. The electrons "hang around" the filament. Technicians call it the electron cloud or space charge. Now when an appreciable positive charge is applied to the plate the electrons in this electron cloud are attracted to the plate, leave the tube at the plate and go through the external load in the plate circuit, and return to the filament to be used over again, as shown in Fig. *6A*. When the plate is negatively charged the electrons in the space near the fila-

* Theoretically you cannot take out all of the variation; practically you can reduce it to an insignificant value. The final test is how much hum you get from the loudspeaker.

The rectified voltage is a pulsating voltage, consisting of a D.C. component and several A.C. components, called ripple components. The important A.C. component is the original frequency of the source usually 60, 40 or 25 cycles per second, and the other A.C. components are 2, 4, 6, etc., times the original source frequency. For example, if a 60 c.p.s. source is used the A.C. components will have 60, 120, 240, 360 c.p.s. frequencies.* The important frequency is the lowest value, because an electrical filter called a low pass filter must follow this rectifier, which removes all variations above and including this minimum. Remember that for a half-wave rectifier the lowest ripple frequency equals the frequency of the A.C. supply. You will see the importance of this when I take up filters.

THE FULL-WAVE RECTIFIER

You should have no difficulty in realizing that with a single diode tube only one-half of the supply wave is being used. This does not mean that we are wasting power, because when the tube passes no current, the source supplies none. Nevertheless if both halves of the original wave can be put to work, a higher rectified voltage is obtained, and then, too, it is easier to smooth out the ripple components from the rectified output.

Full-Wave Bridge Rectifier. Without making any change in the power transformer, but using four half-wave rectifiers (single diodes) a system as shown in Fig. *8A* could be used. Observe that four indirect heated cathode tubes (*1, 2, 3* and *4*) are used, and each filament is connected to the low voltage secondary S_L.† The tubes are connected in what is referred to as a bridge arrangement, merely because it resembles a bridge or balancing circuit extensively used in radio laboratory equipment. You will find it easy to remember this circuit by following the electron flow. Let us assume for example that electrons flow from the supply terminal x of S_H to the rectifier terminal a, and seek a path through the bridge circuit to terminal y of the secondary S_H, which will be positive with respect to terminal x, as the latter is assumed as negative. From a two paths are possible, through tube #*1* or tube #*4*. Of course, you know that the only electron path through a normal acting tube is from the cathode to the plate, hence the electrons pass through tube #*1* to point b. The electron path so far considered is represented by the solid arrows. Leaving point b the only electron path is through the load resistor R to point d, because the path through tube #*2* is blocked because electrons cannot pass from a plate to a cathode. From point d, the electrons travel through tube #*3* to point c and back to the supply terminal y of S_H, the positive

* This may be proved by higher mathematics, or by an intricate laboratory test.

† If filament type diodes were used, tubes *1* and *2* would require separate secondaries, but tubes *3* and *4* could be operated in parallel; three secondaries in all. Thus short circuits are prevented.

secondary terminal for this instant, and to the starting point x. On the other hand electrons will leave the supply terminal y when it becomes negative every half cycle and they must take the $y \rightarrow c \rightarrow b \rightarrow d \rightarrow a \rightarrow x \rightarrow y$ path, indicated by the dash-dash arrows.

Now the most important fact about this circuit is that the electrons flow from point b to point d no matter which terminal of the supply they leave. Therefore, point b is the negative (—) and point d is the positive (+) load terminal. Although the A.C. supply voltage is as represented by curve V_{xy} in Fig. *8B*, the load voltage is as represented by V_{bd}, which is the full-wave rectified voltage.

The full-wave rectified voltage has twice as many peaks as the half-wave rectified voltage portrayed by Fig. *7D*. Naturally the lowest ripple frequency in this pulsating voltage has a value of twice the supply frequency, although ripple frequencies of 4, 6, etc., times the supply frequency exist. Such a pulsating voltage is easier to smooth out than a half-wave source.

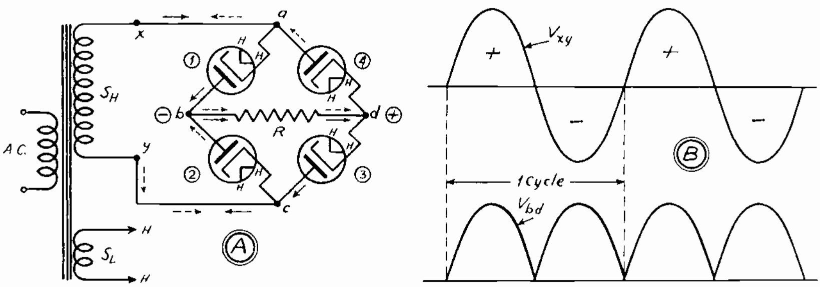

FIG. 8

Full-Wave Twin Diode Rectifier. Cost of equipment and parts, and permissible space is limited in the case of radio receivers and power amplifiers. The less equipment used, the less the chance of a breakdown. Good radio design indicated a need for a simpler full-wave rectifier. By using a supply source of twice the A.C. voltage required for a bridge rectifier and center tapping this source, two half-wave rectifiers may be used in a full-wave rectifier as shown in Fig. *9A*.

You will learn more about this circuit if we trace the electron flow. Starting with tube *#1* trace the electron flow from the filament to the plate, from terminal x to c, the center tap of the high voltage secondary. The electrons cannot go from c to y as at y they could not go from a plate to a cathode. Therefore, the path taken is from $x \rightarrow c \rightarrow a \rightarrow b$ back to the filament. The path for tube *#2* is $y \rightarrow c \rightarrow a \rightarrow b$ to filament. But the plates of the tubes are connected to the end terminals (x and y) of the secondary of the transformer and when one end is negative the other is positive with respect to the center terminal c. Hence the tubes, due to

Multi-Section Filters. Even though the filter shown in Fig. *10B* is superior to the one shown in Fig. *10A*, the inductance and capacity must be unusually high to reduce the ripple to a satisfactory amount. Is it not natural to say that if one filter will reduce the ripple, two will be better? This sort of reasoning is correct, and cascade (one after the other) filters, as shown in Fig. *10C*, are universally used. If filter *#1* will reduce the lowest frequency 100 times, and filter *#2* will also reduce what is supplied to it 100 times, then the total reduction is 100 times 100, or a reduction of 10,000. Quite often three sections in cascade are used, but generally only in high fidelity and all-wave receivers. Here is a little technical fact; the ripple reduction * of each filter section roughly equals the reactance of the coil divided by the reactance of the condenser. The reactance is determined for the ripple frequency to be suppressed.

Filters with Input Capacity. Experts in the design of rectifiers will tell you that the average D.C. voltage from a rectifier system is a certain amount of the applied peak voltage. For a half-wave rectifier it is about 32 percent; for a full-wave rectifier it is about 64 percent.† And thus all you can get from a filter of the type shown in Fig. *10C* are these amounts. The reason for this is that filters suppress all the components in the ripple frequencies. But the question arises, can we boost the output voltage? Yes we can, and by the simple means of connecting a condenser C_1 to the rectifier output, or what is the same thing the filter input, as shown in Fig. *10D*.

Here is what happens. The voltage produced by the rectifier, charges the input condenser and continues to charge it until the rectified voltage reaches its peak value. As soon as the input voltage reduces the charge starts to feed into the load. If the load resistance is low this discharge takes place rapidly, if it has a large value (in ohms) the discharge takes place slowly. In other words, the input condenser is supplying energy to the load long after the rectified source has stopped to supply energy. This information is graphically presented in Fig. *10E*. I have taken a half-wave rectified voltage as our example, which is represented by curve *#1*. The average output voltage, the D.C. voltage when the input condenser C_1 is omitted in the circuit (shown in Fig. *10C*) is given by curve *#2* (a straight line) of Fig. *10E*, and as you see is quite low. When the input condenser C_1 is inserted, as in Fig. 10D, the voltage across the input condenser follows dotted curve *#3*. Its average *value is quite high,* and the ripple, that is its variation from the average, is small.

Many Radio-Tricians often measure the A.C. voltage of the power transformer and then the D.C. voltage of the output. Where a condenser

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* Ripple input divided by the ripple output.

† The peak value is 1.41 times the effective value (which you measure with a commercial voltmeter).

input is used, the D.C. voltage may be greater than the A.C. voltage. With a condenser input filter you may, with a small load (low current drain) obtain a D.C. voltage nearly equal to the peak input, which is 1.41 times the A.C. value that is measured.* Another reason why a condenser input is desirable may be gained by the following reasoning. If the input condenser reduces the ripple, then the following filter has less work to do and its components need not be as large as when the input condenser is omitted.

The system has disadvantages. One I pointed out, namely that as the load increases the D.C. voltage drops. That is exactly what happens in an audio amplifier when it is first amplifying weak and then loud sounds. A condenser input filter might cause distortion if the output voltage drops too much.

Another difficulty is the sudden rush of current at the beginning of each cycle (point x in Fig. *10E*), when the condenser is being charged.

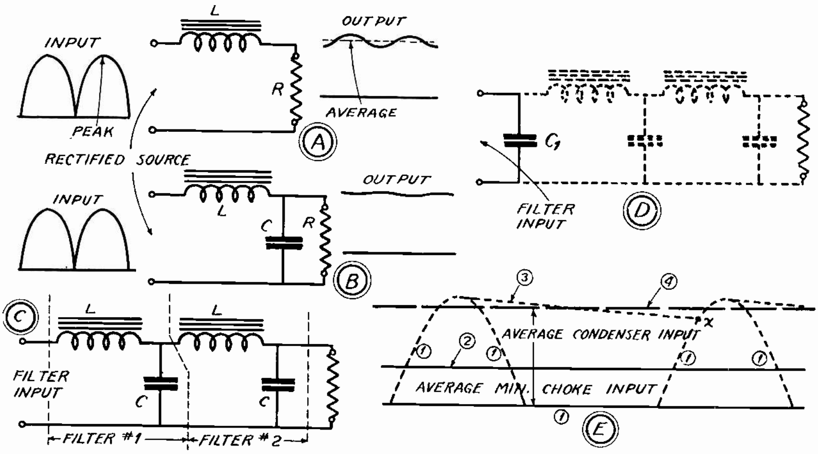


FIG. 10

This sudden rush of current may ruin the rectifier tube. Fortunately this current rush is of little importance in ordinary vacuum tube rectifiers used in radio receivers and amplifiers. Where this effect is important coil input filters are used. In considering the input condenser, it is important to realize that should it (and as a matter of fact any of the other filter condensers) become shorted or leaky (have low resistance) the entire A.C. voltage will be thrown across the rectifier tube and the tube will be destroyed. If you encounter a *vacuum* rectifier tube that glows blue (indicating that the tube is receiving too high an A.C. voltage) be sure to test the input and other filter condensers, replacing if necessary before you put in a new rectifier tube. A grounded choke may be the cause, so test them too.

* A larger input condenser, a lower current drain, a higher ripple frequency will tend to give a D.C. output voltage nearer the peak A.C. input.

Tuned Filters. Early in the development of radio, engineers naturally asked themselves why they could not tune out the ripple which created the most trouble. Indeed this is often done. As the most prominent frequency is the lowest, circuits resonating to this frequency were developed. Figure *11A* shows the parallel resonant circuit through which the D.C. and all A.C. components must pass. Now circuit L_1 and C_1, when tuned to a definite frequency will offer a very large impedance to the current of that frequency. This is the nature of parallel resonant circuits and this opposition, queerly enough, increases as the series resistance of the coil and condenser is decreased. The capacity of C_1 should be small so the passing action shall be low for higher ripple frequencies.

Another possible filter circuit is shown in Fig. *11B.* Here we find a series resonant circuit bridged across the filter. When L_2 and C_2 are in resonance with the lowest ripple frequency, it offers very little opposition to that component. Naturally that component passes through this "leg", as it is called, instead of going to the load. Although this circuit is effective

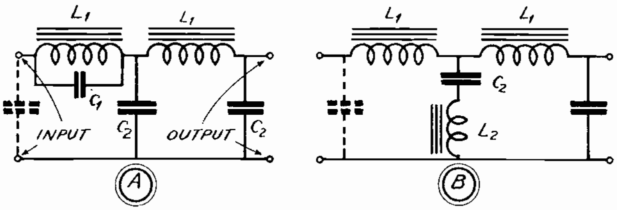


FIG. 11

at the frequency for which it is designed, the lowest ripple frequency, it actually destroys filtering at higher frequencies. At frequencies above the resonant value, the leg is principally inductive and the shunting effect of C_2 is totally destroyed. Thus you really have only one filter section with two chokes working.

Either resonant filter circuit may be used with a condenser input, the condenser shown in Figs. *11A* and *11B* by dotted lines and symbols. For 60 cycle, half-wave rectifiers, the circuit L_1-C_1 or L_2-C_2 would be made to resonate to 60 c.p.s.; for a 60 cycle per second full-wave rectifier these circuits should resonate to 120 c.p.s. Quite often you will find radio receivers and amplifiers with such a filter incorporated in the power supply that seems to defy hum correction. This is often due to the change in the inductance value of the iron core choke (shift in the laminations due to rough handling), or more often due to the fact that the frequency of the supply main does not agree with the designed resonant frequency. You should try various small condensers in shunt with condenser C_1 or C_2 or open the air gap in the iron core choke, although the latter procedure should be done only after a little radio experience.

6

WHAT TO EXPECT FROM A RECTIFIER TUBE

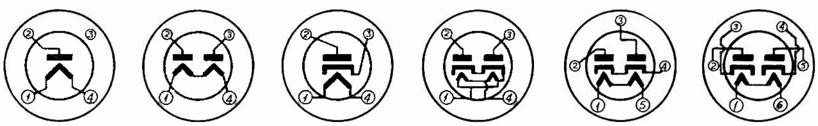
Not every radio receiver or amplifier uses the same type of rectifier tube. Different types are used for a particular set of reasons. The features that make different types necessary are: *1,* filament voltage; *2,* cathode-heater insulation; *3,* voltage output; *4,* current output; *5,* full or half-wave; and *6,* regulation. Items *1* and *2* are dictated by the type of power supply that is to be used; items *3, 4* and *5* by the D. C. supply required; and item *6* by the maximum signal changes you expect to incorporate in a radio device. Regulation in a power supply is a new term which I will shortly clear up. Improved regulation is obtained by using a gaseous (mercury vapor) rectifier which will be considered after we take up the vacuum type rectifier. Table No. 1 lists the characteristics of vacuum and gaseous rectifier tubes in general use, and is included in this lesson so you may refer to it as needed.

TABLE NO. 1

AVERAGE CHARACTERISTICS OF SMALL RECTIFIER TUBES

Type Number	H. W. or F. W.	V or M	Base Number	F or H	Filament		Max. A. C. Voltage Per Plate	Max. D. C. Output Current	Max. Output Voltage		Inverse Peak Voltage	Peak Current
					V	I			Choke Input	Condenser Input		
5Z3	F. W.	V	4–2	F	5	3	500	250	360	475	1400	....
12Z3	H. W.	V	4–3	H	12.6	.3	250	60	N. U.	250	700	....
25Z5	F. W.	V	6–1	H	25	.3	125	100	N. U.	108	350	....
1V	H. W.	V	4–3	H	6.3	.3	350	50	N. U.	400	1000	....
80	F. W.	V	4–2	F	5	2	400	125	290	390	1100	....
81	H. W.	V	4–1	F	7.5	1.25	700	85	530	780*	1960	....
83V	F. W.	V	4–4	H	5	2	500	250	425	600	1400	....
84	F. W.	V	5–1	H	6.3	.5	350	50	300	430	1000	....
82	F. W.	M	4–2	F	2.5	3	500	125	500	N. R.	1400	400
83	F. W.	M	4–2	F	5	3	500	250	500	N. R.	1400	800

Explanation of table: F. W.—full wave; H. W.—half wave; F—filament tube; H—heater tube; N. R.—not recommended; N. U.—generally not used; V—vacuum tube; M—mercury vapor tube; *—in full wave connection; filament voltage in volts; filament current in amperes; plate voltage in volts; plate current in milliamperes; inverse peak voltage based on F. W. connection.



4-1 4-2 4-3 4-4 5-1 6-1

Pin Arrangement—Base Numbers; Bottom view of tube connections

Vacuum Rectifiers. The performance of any radio device is best shown by curves, and vacuum tube rectifiers are no exception. Fig. *12A* shows a number of curves for a half-wave rectifier, and for a condenser input filter. Each curve is for a definite A.C. voltage supply and in the diagram is the voltage $V_{\text{A.C.}}$ which you would measure with an A.C. voltmeter connected across the high voltage secondary. The D.C. current would be measured with a D.C. milliammeter connected in series with the load as indicated, but the D.C. voltage would be measured across the filter input, because the resistance of the iron core choke is a part of the load. Observe that for a filter with a condenser input the output voltage is quite high even for large currents, but the D.C. voltage drops rapidly as the load is increased from a small to rated value. This is primarily due to the inability of the input condenser to maintain its charge after the rectified voltage starts to drop from its peak.

Figure *12B* is the same type of information for a typical full-wave, vacuum tube rectifier, and in this case I am showing the difference between choke and condenser input. Observe that when the input condenser is omitted, that is we have a choke input, the D.C. output voltage is initially low for low load currents, but as the load is increased the variation is not as marked. This change is primarily due to the D.C. resistance within the rectifier tube which in turn is the result of the electronic space charge. If it were not for the tube resistance, the decrease in voltage would be much less. This variation in D.C. output voltage with load current is *regulation,* and is considered good when the least change is obtained.

Table No. 1 presents the general characteristics of the important tubes and the maximum A.C. voltage and D.C. load current. What D.C. output voltage to expect for a *condenser* input and for *choke* input is then given for these maximum conditions. For any other condition you must refer to operating curves similar to those given in Figs. *12A* and *12B* for the particular tube to be used. The latter are supplied by the tube manufacturer. Of course, when you service radio equipment you are guided by the voltage and current charts supplied by the maker of the receiver, amplifier or transmitter.

Mercury Vapor Rectifiers. If you trace the circuit shown with Fig. *12A,* you will see that D.C. current flows through the tube, the iron core choke, the load and the high voltage secondary. To get improved regulation, or what is more obvious, to keep the voltage across the load R as nearly constant as possible with changes in current, the remainder of the circuit should have low resistance. It is easy enough to make the secondary and the iron core choke with low ohmic resistance, but it is not so easy to obtain a vacuum tube rectifier with low ohmic resistence. However, a mercury vapor diode does exhibit a desirable quality and that is its voltage drop (current through it times its resistance) is constant and very nearly equal to 15 volts. Clearly, if a mercury vapor rectifier is used with low resistance chokes and a low resistance secondary exceptionally good regulation will be realized. How do these tubes, extensively used in radio transmitters, high powered audio amplifiers and many radio receivers, work?

In the first place, this tube is a vacuum tube rectifier with a small amount of mercury included, and for this reason is called a mercury vapor tube. Usually a little ball of mercury is enclosed which creates mercury vapor at ordinary room temperature, and when the tube heats up more vapor is automatically produced. Usually oxide coated filaments are used to produce the electrons that are drawn to the plate. When the tube

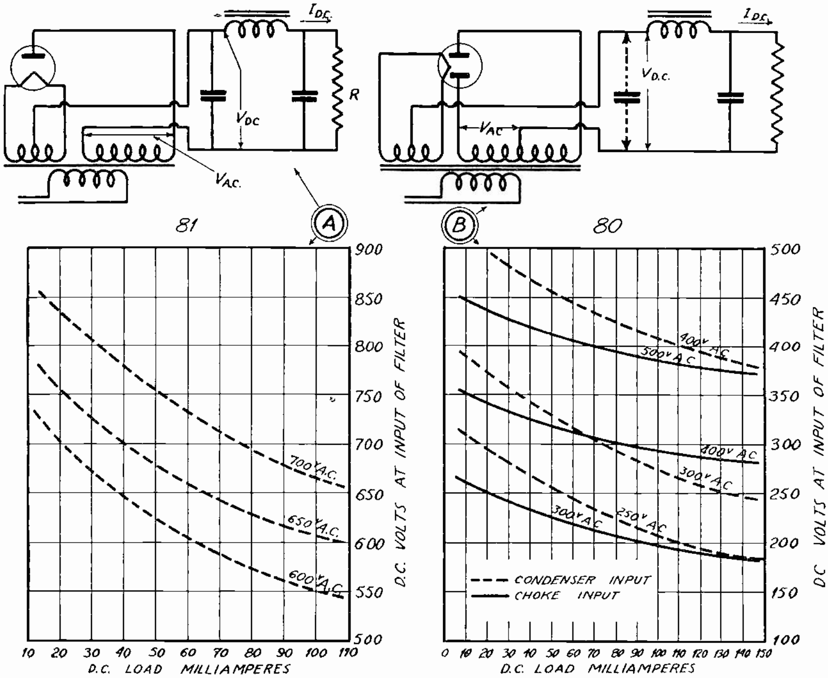


FIG. 12

is placed in operation, the high speed electrons leaving the filament bombard (strike) the mercury atoms and deprive the latter of their free electrons. This leaves a positive gas ion (mercury atom without its free electrons) and an extra electron which moves toward the plate. The positive ion moves slowly (about 1/600th as fast as the electron) to the filament and in doing so gets into the electron cloud (space charge) surrounding the filament. In fact it partly neutralizes (destroys) the electron cloud and nearly all of the electrons leaving the filament have an open path to the plate. The higher the plate (anode) voltage the greater the space current, but this voltage must not be too large (22 volts in a voltage between K and P_b is the same as that between a and b. The peak inverse voltage is twice the peak voltage of $V_{A.C.}$ or 2.82 times $V_{A.C.}$. Strictly speaking you should subtract the tube drop, about 15 volts for a mercury vapor tube, from this computed value which is lost in the path from K to P_a. You will find that the largest $V_{A.C.}$ (root mean square) that you can apply to a full-wave diode, as given by most tube tables, is the inverse peak voltage divided by 2.8. Check this in Table No. 1. The peak inverse voltage rating of a tube determines the greatest A.C. voltage you can rectify.

DIVIDING THE VOLTAGE

Now that I have shown you how A.C. is converted to D.C., I am going to consider an important phase of power supplies, namely how the D.C. power is distributed. This will be important to you as a Radio-Trician.

It makes little difference to the rectifier how this power is distributed to the vacuum tubes in a radio device, for it is merely called on to deliver a definite D.C. voltage output and a definite load current. To be sure, the radio designer works "in reverse." He determines what is the maximum D.C. voltage and current, and depending on whether he uses one type of rectifier or another, refers to a set of curves, as shown in Figs. *12A* and *12B* and determines from these two values (current and voltage) how much A.C. voltage should be supplied by the power transformer. If one type of rectifier is unable to supply the demand, a larger tube is used.

Usually the D.C. voltage is equal to the largest plate voltage (probably the plate voltage for the power audio tubes) plus the largest C bias. To this must be added the voltage drops in the iron core chokes in the filter, as they are really a part of the load. The current demanded from the power supply is the sum of all the electrodes (plates, screens, grids, etc.) currents of the tubes in the device except the diode power rectifiers. The computed voltage divided by the computed current is the load resistance R that I have constantly referred to.

How is this total load divided or distributed to the various tubes? Basically there are two methods: *1,* the parallel voltage divider as shown in Fig. *15A;* and *2,* the series voltage divider as presented in Fig. *15B.* There are a number of variations which combine the two basic methods.

Circuit Laws to Remember. In order to fully understand how the divider circuits work I want you to recall a number of important circuit laws. They are:

1. The currents to a terminal must equal the currents away from the terminal.

2. In *any complete* circuit the generated (supply) voltage must equal all the voltage drops.

3. The voltage drop across any device is the current times the resistance (Ohm's Law).

4. Current flows from the positive (+) to the negative (—) terminal.

This is just the opposite for electron flow. (In the following discussion I am going to switch to current flow, not electron flow, as this is the way radio men analyze circuits. I want you to be able to do things the way experts do them.)

5. If terminal A is positive with respect to terminal B, terminal B will be negative with respect to terminal A.

Parallel Voltage Dividers. Referring to Fig. *15A*, observe that the total voltage and current demanded from the rectifier is indicated by V and I respectively. The voltage divides itself between resistors R_5, R_4, R_3, R_2, R_1, R_{c1} and R_{c2} because of the currents flowing through them. The total current flows through R_5 and R_4. At point *1* the current through R_3 is I less I_1. I_1 is the current that passes through the triode tube indicated, returning to the main circuit at point *4*. The current at point *2* divides, part going through R_2 and part going through another tube, and in this case indicated by I_2. Again the current through R_2 divides into two paths, the one indicated by I_3 and the other through R_1 Although

A calibrated adjustable resistor tester which enables a service-man to determine proper replacement values of defective resistors, measure unknown resistors by the substitution method, can be used as a calibrated variable resistor for adjusting voltage, as a potentiometer or voltage divider

the current indicated by I_2 and I_3 may go through a tube, it may also be the supply to a screen grid or tube electrode whose plate is supplied through the I_1 path. These facts do not concern us in a general study of supplies but you must recognize that regardless of the path they all come back to terminal *4*. This common terminal is the filament or cathode tube terminal and is the —B supply connection. Incidentally, it is connected to the chassis frame which in turn is grounded. As terminal —B is common to all tubes it is the reference or ground terminal; as all currents flow to it from the chokes, terminals *1, 2* and *3* will be positive with respect to terminal *4*. That is why these points are marked +B, ++B and +++B, the number of "+" marks to indicate which is the higher positive terminal.

From terminal *4*, the current from all the tubes (marked $I_1 + I_2 + I_3$) joins the current from R_1 and flows through R_{c1} and R_{c2} back to the supply. There are two important facts at this point that I want to clear up. What is the potential of points *5* and *6* with respect to —B or point *4*? Point *4* is, of course, positive with respect to point *5*, but what is the grid through this connecting wire it would have to pass through the C bias resistor R_c, unless condenser C is inserted. Condenser C is a bypass condenser and offers practically no reactance to the A.C. signal. There is another important reason for using condenser C. When the grid is actuated by an A.C. signal the current from a to d will vary. Therefore the voltage across R_c will vary, and the applied steady direct C bias voltage will be made to vary. Recall that I said that when a condenser is placed across a resistor, across which a pulsating voltage is applied, the energy in the peaks will be stored in the condenser and discharge into the resistor when the voltage is a maximum, thus greatly reducing the voltage variation. This is the second reason why C is used across R_c.

All tube circuits return to point d, and this becomes the common terminal of the receiver or amplifier. Hence it is connected to the chassis and grounded. Point d is not the —B connection; each tube has its own —B. The important facts to remember about series voltage dividers are that every tube is connected to the main supply terminals and the voltage drops in that tube circuit equals the total voltage available.

Modified Voltage Dividers. A combined parallel and series voltage divider is shown in Fig. *15C*. In this case, the choke coil L and the bleeder resistor R_b form a potential divider. The R.F. pentode tube is fed from points *2* and *3*. The total voltage equals the sum of the plate voltage *4* to *7* and the C bias voltage *7* to *6*. But to get an intermediate voltage for the screen grid another voltage divider consisting of R_1 and R_2 is used. To be sure, it is possible to tap bleeder resistor R_b, but as the latter is usually some distance (in the chassis) away from the tube, a separate divider near the tube is used. The triode tube is connected between the input of choke coil L and point *3*, the return terminal. In this way an unusually large voltage may be obtained. This is permissible only when the power for the tube does not have to be well filtered. Quite often L is the field coil of a dynamic loudspeaker,* a subject you will study later. Thus the field coil serves several purposes; a choke, a voltage reducer, and an electromagnet for a loudspeaker.

Another use for a choke is shown in Fig. *15D*. Here L, which may be the field of an electromagnetic loudspeaker, is used as a filter choke and a voltage divider but in this case to supply the C bias voltage. A resistance voltage divider resistor is often used across the coil as shown, or the resistor may be omitted and the connection made to a tap on coil L. Either method works well.

CONTROLLING THE LINE VOLTAGE.

The voltage fed to filaments of the tubes in the radio device and the high A.C. rectifier voltage must be substantially constant if the radio receiver or amplifier is to work efficiently. Should the voltage be too

* D.C. current for the loudspeaker field of a dynamic unit is an important supply. The scheme shown in Fig. 15 C, is the usual one for A.C. Receivers.

low, the filament or cathode will emit insufficient electrons, and furthermore the filament will in time become brittle and break with a severe jar; if the filament voltage is too high the emission characteristic of the filament or cathode may be quickly exhausted and perhaps the filament will eventually burn out. The D.C. voltage output of the power pack will rise or drop as the A.C. voltage delivered from the high voltage secondary of the power transformer increases and drops. All this is dependent on the voltage of the A.C. supply mains. No designer expects the A.C. line voltage to remain constant, but he does assume that it will not vary more than 5 percent,† that is if the line voltage is rated at 110 volts A.C., the designer assumes it will not vary more than 5.5 volts or
10 from 104.5 to 115.5 volts. When you go on a job, a difference of about 5 volts should be considered as normal.

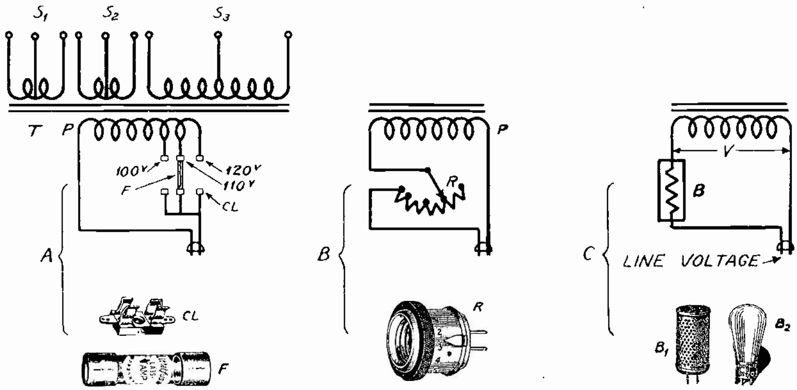


FIG. 16

To take care of different line voltages, and the line voltage in one town may be 110 volts, 115 or 105 in another, it is customary to incorporate in a well designed radio device some provision to adjust the receiver or amplifier to the voltage available. The most universal practice is shown in Fig. *16A*. As you observe, the primary *P*, of the power transformer *T* has three primary taps allowing a change in the primary to secondary turn ratio. The more turns on the primary the lower the secondary voltage will be. Two and sometimes three adjustments are provided, namely: for 120, 110; or 120, 110 and 100 volt inputs. As a further protection the ratio is changed by resetting the fuse *F* in the clips *CL*. When you run across such a receiver in an installation or service job, measure the line voltage with an 0-150 volt A.C. voltmeter and

† Percentage will be extensively used in the course. To find the exact value indicated: multiply by the percentage and divide by 100. In this case you should multiply 110 by 5 and get 550. Then you would divide by 100 and get 5.5 volts, the answer.

SPECIAL POWER SUPPLIES
FOR
RADIO EQUIPMENT

13 FR-1

PIONEER HOME STUDY RADIO SCHOOL

NRI

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

GETTING PRACTICAL EXPERIENCE

After you finish this lesson, you are in a position to start, or at least prepare to start servicing radio receivers. Of course, your first attempt to repair a receiver may result in your getting into difficulties. But that will be a healthy state of affairs. As you continue with your studies the *reasons* for the trouble you may have had will gradually be cleared away.

In servicing a radio receiver, you will find that defective tubes and breakdowns in the power supply system cause more than half of the troubles you encounter. Now is the time to get your first impression of the work. When you get a chance, take a discarded receiver and study it, just like a student doctor examines, disects (takes apart) and studies a human corpse. Only you have the advantage of putting the receiver together and making it work. Consider this receiver as a subject to be experimented on.

The rest of your Study Course, the Extra Money Job Sheets the Experimental Outfits and the special Reference Texts that you have or will receive, will supply many ideas that you may want to try out on this discarded receiver. Experiment as much as you can for in this way you will be getting practical experience, so essential for radio success.

J. E. SMITH.

NATIONAL RADIO INSTITUTE

WASHINGTON, D.C.

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Special Power Supplies for Radio Equipment

A VARIETY OF SUPPLY CONDITIONS WILL BE ENCOUNTERED

What will supply power to the radio receiver in the farm home where often no local electric power is available; and when electric power does exist, it is usually 32 volts D.C. current? What should supply the power in an automobile or truck where a radio receiver or a public address amplifier is to be installed? What changes are necessary, or what special receivers are required when you are called on to install a radio set or amplifier in localities where: 110 volts D. C.; or 110 volts, 40 or 25 c.p.s. (cycles per second); or where 220 volts, 60 c.p.s. power is delivered at the wall or floor outlet socket? What should you do if radio equipment is to be installed in a place where no electric power of any kind is at hand? Are you to say that no radio equipment can be installed, because you and others might be inclined to think that 60 c.p.s., 110 volt equipment is the only type available? Not at all. It is the ability to handle these special conditions that will make you a better radio technician, increasing at the same time your earning capacity.

Vacuum tube equipment must have D.C. or A.C. power to heat the filament, and continuous current to apply to the tube electrodes. The signal circuit, that is the circuit that actually handles the incoming signals, may not be different for different power supply conditions; nor need the tubes in a D.C. powered receiver be different than the tubes for an A.C. powered receiver. To be sure, one group or series of tubes may be better adapted for battery operation, another set for A.C. operation and another series for D.C. sources. Yet if you study these series or groups usually referred to as the 2 volt (battery), the 2.5 volt (A.C.), and the 6.3 volt (A.C.-D.C.) series of tubes, you will find that there are diodes, triodes, tetrodes, pentrodes and multi-grid tubes which are apparently physical duplications but designed to meet a special supply condition. Receivers and amplifiers are on the market to handle any power condition, and you or any buyer can get these special instruments merely by asking for them. But don't you want to know why they are different? That is the purpose of this lesson.

What are you to do when no power at all is available? As you will shortly learn, two procedures are possible. You may use equipment designed for battery operation or you can install a gasoline engine driving an A.C. generator. If the latter is advisable, then it is a matter of common sense to use a 110 volt, 60 c.p.s. A.C. generator so that standard equipment may be used.

With this short introduction, I hope I have convinced you that there is a definite need for radio apparatus other than that intended for 110 volt, 60 c.p.s. So let us investigate the different ways of supplying the filament and electrode voltages.

THE MODERN BATTERY RECEIVER

When radio equipment has to rely on batteries as the source of power, it is important that the most economical use be made of the batteries. Any tube made, even an A.C. tube will operate from batteries, but the power required may be excessive. For example, the filament of a typical 2.5 volt A.C. triode tube will draw 1 ampere, a total of 2.5 watts for filament power; the same tube will require 250 volts on the plate and draw .005 ampere (5 milliamperes) or a total of 1.25 watts for plate power. Compare these figures with a 2 volt triode tube designed for batteries. The filament of this tube draws .060 ampere when connected to a 2 volt source, a total of .12 watt; the plate draws .003 ampere when connected to a 135 volt source, a total of .405 watt for its plate supply. To be sure the A.C. tube is more powerful, but the battery tube will do almost as well under all conditions except power output. You can make battery receivers and amplifiers with as much amplification (signal build up), but you cannot get a large power output without resorting to many large batteries. This is the sacrifice you have to make to use batteries economically.

So in the modern battery receiver you will find special battery tubes employed. The filament voltage is usually 2 volts and the plate and other electrode voltages are supplied from batteries, and are rarely over 180 volts. I shall limit my discussion to 2 volt tubes.*

Air Cell Filament Battery. The 2 volt series of tubes became popular because of the development of the so-called "air cell battery." A cross sectional illustration is shown in Fig. *1*. This cell, like the dry cell, has a zinc and carbon electrode. However, the cell is so designed that the hydrogen, which forms in both the *dry* and *air* cells, when deposited on the carbon electrode, combines with oxygen which is "breathed" through porous carbon to form water. In the hermetically sealed dry cell, a special chemical is required to free the hydrogen bubbles from the carbon plate which, as you know, reduces both the voltage and current. This chemical is referred to as a "depolarizer," and produces the necessary oxygen to free the hydrogen bubbles. None is used in the air cell, as oxygen is drawn directly from the surrounding air for this purpose, and

* The 30 triode, 31 power triode, 32 screen grid, 33 power pentode, 34 super R.F. pentode, 19 class B twin triodes and the 1A6 and 1C6 pentagrid converters are in this group. Formerly the 99 and 120 type, 3 volt tubes were used in battery sets but are rarely used in recently designed equipment. The first receiver, even before the advent of A.C. receivers, used the 01A, 71A and 12A battery tubes (triodes), but these are now discarded because they take too much power to operate.

therefore the hydrogen bubbles cannot affect the generating ability of the cell.

The air cell battery has two cells built into a one-piece, molded, hard rubber case, the two cells permanently connected in series, giving about 2.5 volts. Only two terminals, a "+" and a "—" binding post exist. The battery is shipped dry to the radio dealers with the chemical inside each cell. The vent plug is unscrewed, the thin rubber membrane cut away, the cells filled with ordinary drinking water. About six quarts are required. The cellophane covering the breathing carbon electrodes is removed, and the battery is ready to use.

At the start the battery will deliver 2.53 volts to an average battery receiver, and for a period of 1,000 hours the voltage will gradually reduce to 2.2 volts. Then the voltage drops quickly to a value that renders the

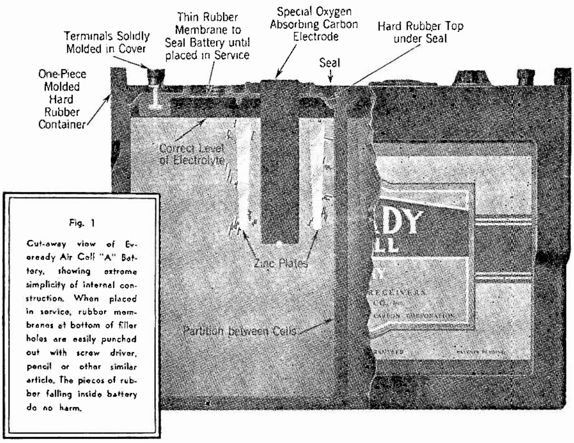

FIG. 1.—Air Cell "A" Battery

battery useless. After this the battery is "dead" and a new one must be used. But 1,000 hours is a reasonably long time. For example: if the receiver is used 3 hours a day, the battery will serve for 1,000 divided by 3 or 333 days, nearly one year. As the total energy available from this source is limited to 600 ampere-hours the battery will even last longer on sets with few tubes. The average sensitive receiver requires about .55 ampere and the battery will last over 1,000 hours. You should never draw more than .75 ampere from an air cell battery as its life will be considerably shortened.

Fortunately the air cell or 2 volt series of tubes will operate satisfactorily if the voltage is maintained below 2.2 volts and above 1.9 volts. Therefore the filaments of all the tubes are connected in parallel and a resistor placed in series with the main supply so the tube filament voltage will never exceed 2.2 volts. The whole story is graphically shown in Fig. *2*. The tubes may draw different values of current, and the exact value required by each type may be determined by referring to a tube table. A total of .62 ampere is required for this 6 tube receiver. Each tube filament must have 2.2 volts applied and as a value of 2.53 volts is supplied by the air cell battery, a resistor *R* must supply a voltage drop of .33 volts. This resistor may be determined by Ohm's Law and is equal to .33 divided by .62, which equals .53 ohms. A resistor having a value of ½ ohm will do; there is no need of "hitting the nail too close on the head." A difference of 5% is quite all right. Of course, if the resistor happened to figure out .59 ohms, you would probably have difficulty in getting that exact size. This is what I would do. I would procure a 1 ohm (2 watt or more) resistor of the sliding clamp type, connect one lead to *a* and the sliding clamp to *b*. Before I would connect the air cell battery I would make sure that the entire resistor was in the circuit. Then I would connect a reliable 0-10 volt D.C. meter across one of the tube filaments and reduce the resistor value until the meter read 2.2 volts. To be sure, I would use a brand new air cell battery.

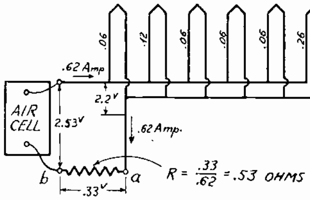

Fig. 2

Why have I gone into all this detail? Simply because there are many "old time" battery receivers that work well enough except, the batteries have to be replaced too often. These older sets use 01A, 71A and 12A type tubes.* Usually you do not have to make very many alterations to change over to tubes which draw less power. Place a 30 tube wherever there is an 01A, a 31 tube wherever there is a 12A or 71A tube. Figure up the total filament current (a 30 tube draws .06 ampere, a 31 tube draws .13 ampere) and divide .33 by this total. Insert the new resistances in any lead from the air cell battery. Short all the filament resistors or rheostats in the old receiver, as they should not be used. Now for the volume control; later on you will be able to recognize the R.F. stages. Locate the second R.F. stage and connect a 5,000 ohm variable resistor between the plate and the plate supply. If the set happens to be a neutrodyne you will have to rebalance the set so it will not squeal. You will probably have to reduce the C bias and plate voltages. A tube table will tell you the correct values. All this will be familiar as you progress with the course.

* Some of the receivers use 99 and 120 tubes. Replace a 99 with a 30, and a 120 with a 31.

Storage and Dry Battery Filament Supplies. Although the air cell battery was developed to overcome the difficulties experienced with storage and dry cells, the latter are nevertheless used quite regularly in receivers employing the 2 volt tubes, mainly because the air cell battery is not readily obtained.†

An ordinary automobile battery and the older radio storage battery will deliver about 6 volts, that is because three 2 volt cells are used connected in series. One cell can be used on a 2 volt tube receiver. A 100 ampere-hour fully charged cell will supply filament power to an ordinary battery receiver for about two months, without charging. If the three cells are connected in parallel, the battery will last six months. Of course, the customer will not be able to charge the battery, for if he had this facility he would be better off with some other type of receiver. If you furnish or service the modern battery receiver and use a 2 volt storage battery, you should supply it on a rental basis or at least on some plan

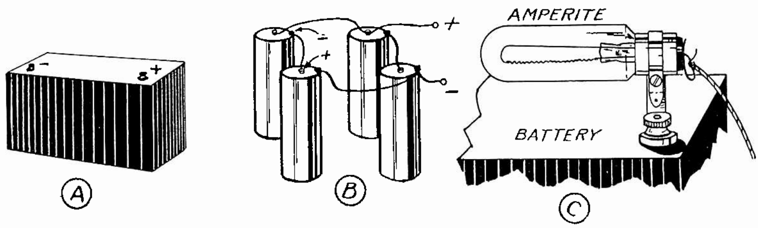

FIG. 3

where a freshly charged battery is installed regularly. The average life of a storage battery if kept in good condition is about two years. In using a storage battery the series resistor (*R* in Fig. *2*) is omitted.

Until recently it was not considered wise to connect dry cells to a 2 volt battery receiver. Dry cells lose their voltage too quickly under constant use of 2 to 3 hours. However, there is now available a ballast resistor designed especially for dry cells used with 2 volt tubes, which will compensate for this voltage drop. Either a 3 volt *A pack* as shown in Fig. *3A*, or 4 dry cells connected in series-parallel, as shown in Fig. *3B* may be used. The ballast* shown in Fig. *3C* is connected in series with the filament battery and has the job of keeping the voltage within the range of 1.9 to 2.2 volts for battery voltage changes of 3.4 to 2.2, the usual variation of two dry cells in series during their useful life.

B and C Batteries. In checking tube tables and the circuit diagrams of several modern battery receivers I found that the usual B (electrode)

† You can procure an air cell battery from most wholesale radio supply houses doing business by the mails.

* If you plan to use this ballast, write to the Amperite Corporation, 561 Broadway, New York City, for technical information and the correct sizes to use.

voltages are 180, 135, 90 and 67.5 volts. The required C bias voltages varied considerably, the usual values being —3 —4.5, —9, —13.5, —18, —22.5 and —30 volts. Nevertheless, all these values are quite easy to obtain from regular B and C batteries, because these batteries are made up of a number of 1.5 volt cells connected in series. Figure *4A* illustrates a typical B block having +45, +22½ and —B volt terminals; Fig. *4B* shows a 4.5 volt C battery; Fig. *4C* a 4.5 volt C battery with —1½ and —3 volt terminals; Fig. *4D* a 7½ volt C battery with —1½, —3, —4.5, —6 and —7½ volt terminals; Fig. *4E* a 22½ volt C battery with —3, —4½, —16½ and —22½ volt terminals.

You will rarely encounter a receiver that employs a plate voltage of less than 90 volts. Remember that for every 45 volts required, a standard

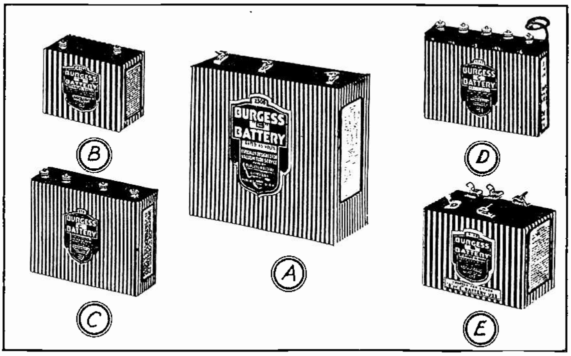

Fig. 4

45 B block should be used, and be sure to get the type with a 22½ volt tap. Where 90 volts are required use 2 blocks, where 135 volts are needed use 3 blocks and where 180 volts are specified connect 4 B blocks as shown in Fig. *5A*. The usual 67½, 90, 135 and 180 volt taps are clearly indicated.

As I previously mentioned, the C bias voltages required for a modern battery receiver will be quite varied. Personally I have found that if you buy two 4½ volt types with the —1½ and —3 volt taps, and one of the 22½ volt type with the —3, —4½, —16½ and —22½ volt taps, you will be able to meet all cases. Figure *5B* shows how a receiver requiring —3, —4½ and —22½ volts is supplied with one large (with only a + and a —22½ terminal) and one small C battery; while Fig. *5C* shows how all these voltages are supplied with a single large C battery with several intermediate taps. You will generally find that where the largest C bias is —22½ volts the largest B voltage is 135 volts; but where 180 volts B are required, the C bias voltage will be about —30 volts.* Figure

* Except in class B push-push output amplifiers, where no C battery is required.

5D shows how the latter condition may be fulfilled. With these examples I feel sure you can figure out other conditions as they arise.

A Typical A, B, C Supply. To illustrate a typical supply system for a modern battery receiver I have drawn Fig. *6*, the supply circuits of a 5 tube receiver.† I purposely left out the coils, resistors, condensers, transformers and other signal circuit parts, so you may concentrate on the supply system. The filament circuit is drawn with heavy lines. Observe that the —A battery terminal connects directly to one terminal of all the tubes, the +A battery terminal traces through the ballast resistors, two being used. One ballast feeds 3 tubes, while the other controls 2 tubes. Both ballasts are built into a glass envelope and the entire

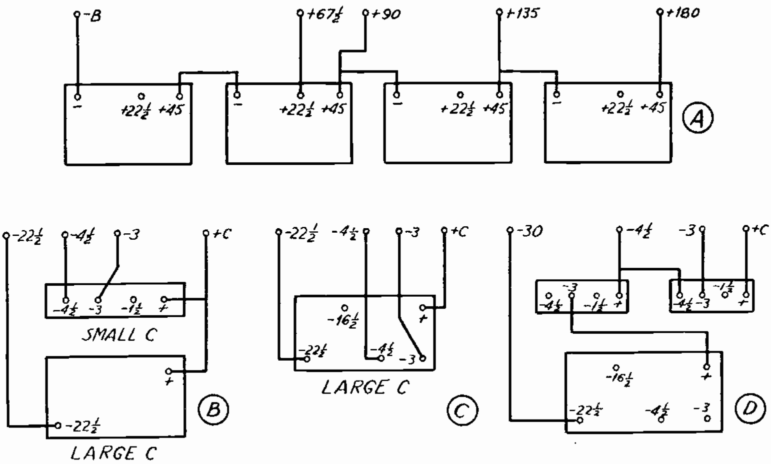

Fig. 5

device looks like a tube. In this receiver a 135 volt supply (taps not used) is required, the lower voltages are obtained within the receiver by resistance drops (all resistors are not shown). Reading from left to right, the second tube requires no C bias (a special detector connection which you will eventually learn about). The plate and screen grid currents flowing through resistor *R* produces a voltage drop in *R;* this voltage is used to supply the "C" bias for the last tube. The first and fourth tubes require a —4½ volt C bias voltage; the third tube is supplied with a —3 volt C bias. A small 4½ volt C battery will suffice.

Connecting a battery receiver to a set of batteries is a very simple task. The receiver is usually supplied with a cable having different colored wires, or wires with two colors as indicated in Fig. *6*. Either the end of each wire in the cable has a small metal tag indicating the voltage

† Battery receivers employ loudspeakers which require no special field power supply before they will operate. They are called magnetic loudspeakers.

and whether it is an A, B or C connection; or the set is supplied with connecting information. With this information, the batteries required and the connections to be made are simple.

THE MODERN 110 VOLT D.C. RECEIVER

Now I shall consider the receiver or amplifier that is designed to operate from a 110 volt D.C. socket outlet, a type of supply that you will encounter in the business sections of some large cities or in a small community where a small power house has been locally erected. In this case we have direct current to operate tube filaments and to supply the electrode voltages. More than enough voltage is available for heating filaments, but not enough voltage is provided for the plates of the output tubes which should be as near 250 volts as possible. Even in the battery receiver, at least a 135 volt supply is generally used. As it may be inad-

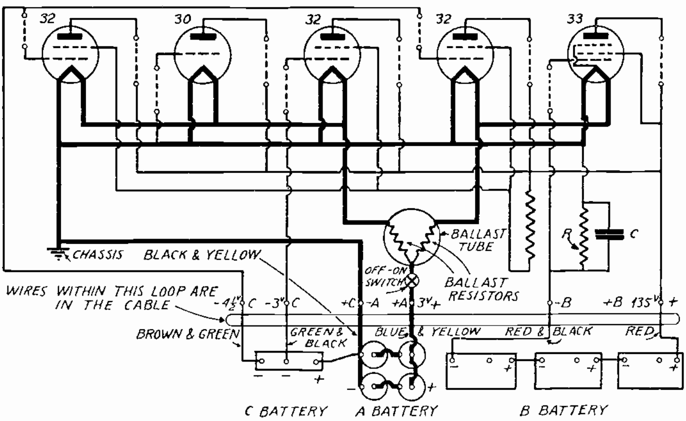

Fig. 6

visable to raise D.C. from a low to high value by using some complicated system, the designer of 110 volt D.C. receivers must be satisfied with what he can get with the available tubes. Tube manufacturers have tried to meet this condition with special power tubes; for example the 43 power pentode will deliver 0.9 watt of audio power when the plate voltage is 95 volts and the C bias voltage is —15 volts (a total of 110 volts). Some of the designers of radio equipment prefer to use standard tubes, even at the sacrifice of power output, so replacement tubes will be easier to get.

The tube filaments of a 110 volt D.C. set are always connected in series, for in this way the applied voltage can be used in the filaments rather than wasted in a resistor. As a rule the 6.3 volt series of tubes are employed, and if possible a high filament voltage power tube (the 43 power pentode requires 25 volts). The tubes in a modern 110 volt D.C. receiver are of the heater type, which simplifies the design of the supply system. The filaments may therefore be connected in series without regard to the other circuits. For example, Fig. *7A* shows 5 tubes, four 6.3 volts and one 25 volt (power) type tubes in series. Their net voltage drop is 50.2 volts and as the line is 110 volts, the resistor R must be inserted to take up the difference of 59.8 volts. As these tubes draw .03 ampere resistor R will be equal (by Ohm's Law) to 59.8 volts divided by .3 ampere, or very nearly 200 ohms. The power wasted is 59.8 volts multiplied by .3 ampere, which equals 18 watts. A 25 watt resistor exposed to the air is used.

4

Now let us turn to the electrodes' voltage supply. If they were connected directly to the 110 volt D.C. source, a "whine" would be emitted from the receiver. This is the A.C. ripple introduced by the commutator of the generator at the power house. To eliminate this whine, a simple filter shown in Fig. *7B* is used. Above everything else, it is important that the iron core choke has a low resistance, otherwise there would be too much reduction in the voltage fed to the electrodes.

A typical D.C. socket power receiver is shown in Fig. *8*, and in this case too, only the supply circuits are shown. (You should master the details of this circuit, as well as the other typical circuits given in this

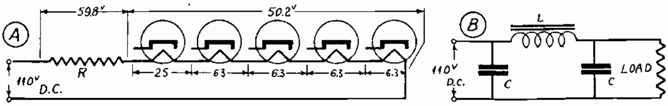

Fig. 7

lesson, as in this way you will learn an important difference between receivers and amplifiers.) Again the solid black lines indicate the filament supply circuit, and resistor R_1 is used to limit the current flowing to a normal value. Observe that all plates connect to the + supply terminal. From each plate you can trace the circuit through the tube, through the cathode or C bias resistors (R_2, R_3, R_4 and R_5). Resistor R_2 is variable and as you will eventually learn is a very common type of manual (hand) volume control. Furthermore R_2 controls the C bias of the first and third tubes (reading from left to right is the usual procedure). To utilize the voltage drop provided by these resistors each grid (after tracing through the input devices) connects to the terminal which is negative with respect to the cathode.

The screen grid of the last (power) tube is connected to the *plate supply* terminal, but the screen grids of the other tubes must be operated at a voltage lower than the plate voltage. Therefore their common terminal is connected to the intermediate tap of a voltage divider, in this case R_6 and R_7. The negative terminal of the main supply is obviously a common terminal to all the electrode supply circuits. Therefore it should be grounded. But it would hardly be safe to make a direct connection so this negative terminal is grounded through the condenser C.*

I have been asked so often why this condenser is used that I am including Fig. *9* to help answer this question. I have shown a three wire distributing system for 110 and 220 volt power distribution.† Note that

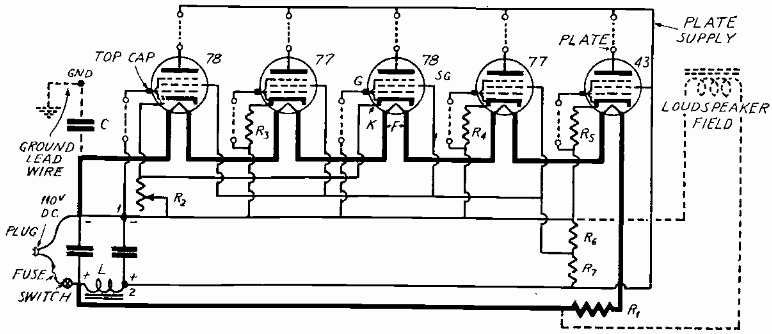

Fig. 8

the mid-wire is grounded, a connection made by the power company. When the receiver power plug is inserted into the wall socket you do not know whether you have made the right connection. If you happen to connect the — terminal to the + line, as shown in Fig. *9,* and the receiver has a direct ground, the line will be shorted, and the house fuses will blow out. By using condenser *C,* as in Fig. *8,* the short would not occur. The

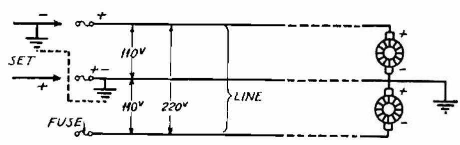

Fig. 9

receiver or amplifier would not work until the plug connections were reversed. While I am on the subject, I would like to explain why some sets show a spark when the ground wire is being connected. Refer to Fig. *8.* When the ground lead wire is attached to the GND receiver post, A.C. current in A.C. receivers and a charging current in the case of D.C. receivers flows to the condenser and creates the spark while a connection is being made. If you touch an ungrounded post you may get a slight shock as the current passes to ground through your body.

* Must have low reactance to the A.C. radio signal.

† May be A.C. or D.C. The condenser is also required in A.C. or universal receivers where the power transformer is omitted.

The only other power supply required for a D.C. receiver would be for the field of the dynamic loudspeaker. The field winding would normally be designed for 110 volts D.C. and connected directly to the main supply, as shown by the dotted lines in Fig. *8*.

THE UNIVERSAL RECEIVER OR AMPLIFIER

A radio receiver or amplifier for use only on a D.C. power outlet is the exception rather than the rule. People hesitate to buy a D.C. receiver, realizing that they may eventually move to a location where A.C. is available. The problem of making an amplifier or radio receiver work on either A.C. or D.C. power was first solved by engineers, when the midget portable receiver first made its appearance. This receiver was made to work in hotels (where D.C. power is usually found), in the home, or where 110 volt power of any type is to be found; and where the designer considered general utility (use) more important than good sound quality with volume (loudness).

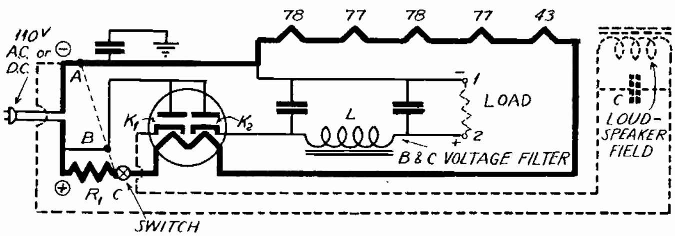

FIG. 10

Universal radio receivers and amplifiers for that matter, are designed just as if they were to be used on a D.C. line and then a half-wave diode rectifier is connected in series with the + supply lead to the tube electrodes. When the receiver is connected to an A.C. supply the rectifier tube converts the A.C. power to pulsating D.C. current and the filter (which must be better in a universal receiver than in a D.C. receiver) removes the ripple frequencies; when the receiver is connected to a D.C. supply the rectifier tube acts just like a resistor and reduces the available plate voltage. As the tubes used are of the heater type and the filaments have no connection to the signal circuits, either A.C. or D.C. power may be used.

Figure *10* shows the only changes required in the D.C. receiver given in Fig. *8*, to convert it to universal use. A twin heater type diode rectifier is employed, so one diode will furnish D.C. power to the tube electrodes, and one rectifier will feed D.C. current to the field coil of the dynamic loudspeaker. If you trace the rectifier circuits starting from the + line terminal you will in one case pass through the filament circuit (heavy black line); or going to the rectifier plate to cathode K_2, pass through the B and C voltage supply filter.

Although the dynamic loudspeaker field could be designed to have a very large ohmic resistance and connected to the output of the filter (terminals *1* and *2*), every attempt is made by the designer to reduce the filter load, so a large rectified output for the tube electrodes can be obtained. You, of course, know that where a condenser input filter is used, low loads (little current drain) will keep the voltage up to near peak A.C. value. Even when D.C. is used a large current will produce a large rectified voltage drop, which naturally is undesirable. Condenser C is connected across the field windings to bypass the ripple frequencies, while the inductance of the field chokes the ripple currents. But the coil and the condenser must not resonate to any ripple frequency component.

If you were to draw the tube circuits (except the loudspeaker field) to the right of terminals *1* and *2* of Fig. *8* (in light lines) connected to terminals *1* and *2* of Fig. *10,* you will have the power supply circuit diagram of a universal (A.C. or D.C.) receiver.

There are a few circuit details in a universal receiver or amplifier that I should like to have you recognize. As an extra filament is used in the circuit, which would not be required in a D.C. receiver, (in this case a tube having a 25 volt filament drop is used), current limiting resistor

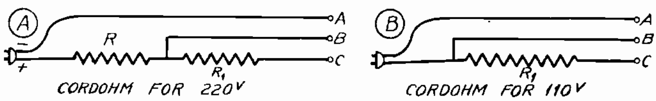

FIG. 11

R_1 cannot have as large an ohmic value as for a D.C. receiver. Furthermore, this resistor is quite often placed in the power cord. One commercial product is called a "cordohm." This scheme is quite good as the heat developed is quickly cooled by the air; the cord, of course, being exposed. Then too, the cord can be quickly removed and a cord with a large resistor used, so the universal receiver can work on 220 volts A.C. or D.C. Power cord connections are shown in Figs. *11A* and *11B,* connections A, B and C of the "cordohm" are made to the corresponding points in Fig. *10*.

A universal receiver or amplifier in which the rectifier feeds into a well designed condenser input filter, works better on A.C. than on D.C., simply because with rectified A.C. the peaks are used to give increased voltage. If a universal receiver supplies higher electrode voltages on A.C. than for D.C. will the C bias voltages be incorrect in one or the other condition? As the C bias resistors are in series with the plate supply (see resistors R_2, R_3, R_4, R_5 in Fig. *8*), a larger supply voltage will produce a greater plate voltage, which will produce a larger plate and C bias resistor current (both are about equal for a series divider connection) and hence the C bias voltage (resistance times current) will increase. By referring to any tube table you will learn that a higher plate voltage calls for a higher C bias voltage. This action for a series cathode resistor is automatic (within reasonable limits) and accounts for the ability of the circuits to adjust themselves to either A.C. or D.C. use. Incidentally, this type of C bias is often called "automatic C biasing," and is extensively used in all vacuum tube circuits.

THE MODERN AUTOMOBILE RADIO RECEIVER

The automobile receiver is no exception to the rule. It, too, must have a filament, a plate, grid, screen, and if necessary a loudspeaker field supply. Now, every car, bus or truck using a gasoline engine has a 6 volt storage battery, to supply the ignition voltage and to start the engine. This very same battery may be used to heat the filaments of tubes and to supply the exciting current to the field* of the dynamic loudspeaker. The real problem arises in getting high voltage continuous current. At first, B and C batteries were used but they were finally replaced by vibrator or small combination motor-generator supply systems which I am about to consider. The modern auto receiver still uses the car battery to supply power to tube filaments, and the loudspeaker field, and furthermore has a power conversion system which changes 6 volt D.C. current to about 250 volts D.C. current. The car battery is the primary source of electrical power.

But before I go into the supply system let me clear up a few misleading ideas that have crept into the average student's (and serviceman's) mind. The signal circuit of an auto radio receiver or amplifier is no different than any other receiver or amplifier. To be sure, the auto radio must work off a small antenna (usually a copper mesh in the roof of the car, or a V antenna under the body of the car), and therefore must be far more sensitive than the home receiver. Sensitive receivers are no different than those with less pick-up ability, except perhaps another radio frequency amplifier, or as is usual in an auto radio, a more sensitive radio frequency stage. But I am getting ahead of my study plan. Signal circuits are taken up in future lessons, yet I do want you to realize that there is no real important electrical difference, other than the supply system.

An auto radio is subject to constant mechanical vibration; so it must be assembled with lock washers or by rivets to keep the parts together; it must be water-proof and weather-proof to withstand all kinds of atmospheric conditions. Automobile tubes (the 6.3 volt series) are best because they were designed to withstand vibration. The receiver must be quite compact, because there is little room for a large machine. The circuits must be economical in their use of high voltage power, as

* Ampere-turns is the important factor, hence high voltage, low current; or low voltage, high current fields are possible.

the battery is the only source of power. But all this is a problem for the radio designer, and he has solved the problem with great success.

The spark plugs and the battery charging generator, the loose parts of the car body introduce interfering noises, which are readily picked up by a very sensitive receiver. This calls for a well shielded receiver and well shielded leads. Metal casings (shields) will block A.C. magnetic fields. And if these precautions do not suffice the interference must be reduced at the source, with condensers, resistors and coils. This is a subject that all students specializing in radio servicing will take up.

The 6 Volt Circuits. As the primary power source is a 6 volt storage battery capable of giving 10 amperes under continual load, the 6.3 volt filaments are connected in parallel, as indicated by the heavy lines in Fig. *12*. The 6 volt dynamic loudspeaker field is connected in parallel, as if it were an extra filament, and the input of the 6 to 250 volt D.C. converter is likewise connected in parallel.

This circuit shows the negative terminal of the battery connected to the car chassis. Hence a single lead from the + terminal to the receiver is required, the other receiver lead may connect to any metal

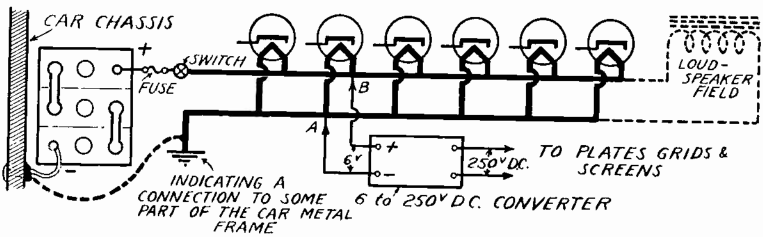

FIG. 12

part of the automobile provided it is welded, bolted or riveted to the car chassis. The return circuit (indicated by the heavy dash-dash line) is through the car, and is the usual procedure for all car electrical wiring. In some cars, the + battery lead instead of the — lead is connected (grounded) to the chassis. As far as the filaments and loudspeaker field are involved, the reversed connection is of no importance, simply because the signal circuit and the filament circuit are isolated by using the heated cathode type tube. But the converter connection may be incorrect. So when this condition is encountered in car installations, all you need do, in most cases, is to reverse the converter connections (*A* and *B* in Fig. *12*). A number of auto receiver makers are supplying battery leads long enough to connect directly to the car battery, in which case the battery lead connections may be reversed if necessary; and in other receivers the connection is immaterial. Although these are general instructions, I caution you to always follow the instructions sent with the auto receiver that you will install.

The Dynamotor. When the first automobile radio receiver was designed to operate without B batteries, a "dynamotor" was quite often used. As the word implies, this is a combined motor and generator. A dynamotor is a single unit, having one frame, one rotor and one electromagnet (field); but two armature windings and two sets of commutators each with its own brushes. One set of windings is designed for 6 volts and when connected to the car battery will set the rotor in motion. With the rotor set into motion the other windings while passing through the magnetic flux produced by the field develop a voltage. By building the second winding with many turns (about 42 times the 6 volt winding) it will generate 250 volts D.C. After passing the power through a filter to eliminate the commutator ripple, the high voltage system of the receiver may be fed by the usual series or parallel voltage divider methods.

A typical dynamotor now used in automobile radio receivers and receivers used on aircraft is shown in Fig. *13A;* a typical circuit diagram is given in Fig. *13B.* The dynamotor used for auto radios weighs about 10 pounds and is generally located near but not on the receiver chassis, although a number of receivers and power audio amplifiers have been made with the dynamotor fastened to the chassis of the device. In the latter case the dynamotor is suspended on a floating (spring) support.

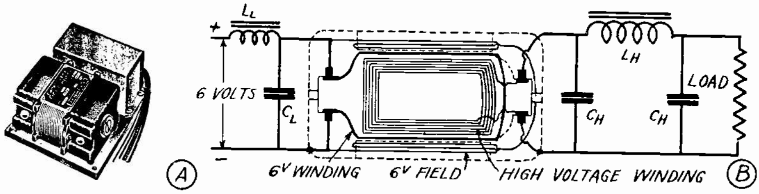

FIG. 13

Referring to Fig. *13B,* you will see the circuit diagram details. The output filter consists of the choke L_H and the condensers C_H. Sparking at the brushes is bound to create strong electromagnetic fields and shielding of the motor housing (using a closed frame) is important. Sparking results in sharp current changes which will get into the 6 volt and high voltage lines. At the output, the filter will suppress this possibility. At the input, a condenser C_L is always used to bypass any interfering current going out by this path, and quite often a low resistance iron core choke L_L is used. The latter is usually installed by the serviceman when its need is indicated. As a serviceman, you should see that the commutator is clean, level and the brushes fit snugly to the commutator.*

Incidentally, dynamotors are used to operate off of 2, 6 or 32 volts

* Place a piece of sandpaper around the commutator (dynamotor disconnected from the 6 volt supply) with the sandpaper towards the brush. Rock the rotor until the brush cuts clean and to shape. Rub *a little* vaseline on the commutator. If the commutator is badly worn, it should be taken to a motor repair man who will turn it down so it will have a smooth, round, uniform surface.

D.C. so battery receivers used on the farm may work without B and C batteries. No change in connections is required as these dynamotor units incorporate a voltage divider to supply all the necessary electrode voltages.

The Vibrator-Tube Rectifier Supply. Even though the modern dynamotor designed for mobile (automobiles, trucks and aircraft) use, is a model of mechanical quietness, the use of rotating machinery is not particularly favored by auto radio manufacturers. Engineers developed the vibrator which chops the 6 volts D.C. into A.C. and D.C. components (pulsating current) and then a transformer steps up the A.C. component before it is rectified with a tube rectifier.

A simple circuit is shown in Fig. *14A*. The primary of a step-up transformer is connected in series with a vibrator (or buzzer). Normally the spring of A, the armature (moving reed) keeps C_t in contact, thus completing the low voltage circuit (shown by heavy lines). If the primary circuit is connected to the battery, current will start to

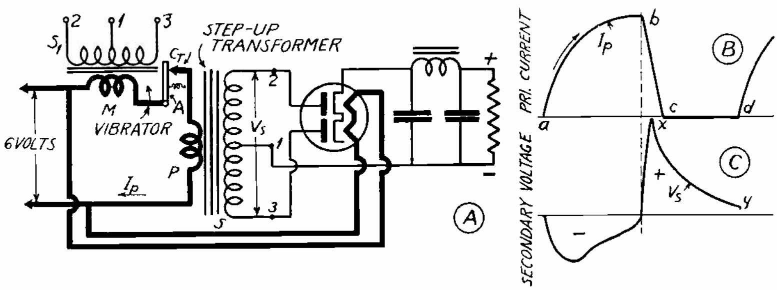

FIG. 14

flow, gradually reaching a maximum value as portrayed by a to b in Fig. *14B*. This delay in reaching maximum is due to the resistance in the circuit slowing up the storing of magnetic energy in the coil. Now the current in the electromagnet is sufficiently large to pull the armature A away from contact C_t, and the primary circuit opens. The current in the primary drops rapidly, as shown by the b to c portion of the curve in Fig. *14B*. Even after the current has reduced to zero value, the armature is moving away from the contact, and finally returns to its original position, in contact with C_t. This last travel or armature "excursion" is portrayed by portion c to d of the curve. The cycle then repeats itself.

Recall, if you will, that whenever the primary current changes, a voltage will be induced in the secondary of a transformer. While the current increases the voltage acts in one direction and when the current decreases the voltage will act in the opposite direction. With these facts in mind you can see that the secondary voltage curve could be like Fig. *14C*. This curve is a reproduction of what has been observed by a cathode ray oscillograph (the circuit eye) and represents a condition for a resistance load, which is exactly what exists when the rectifier is working into the supply circuits of a radio receiver. If it were not for this load, the peak at x would be much sharper, and higher, and the "drag out" from x to y would not exist. The resistance attempts to redistribute the energy originally in the peak.

Figure *15A* shows a modern vibrator supply circuit. You will observe that three contacts K_1, K_2 and K_3 exist at the vibrator, the primary circuit is mid-tapped, and the primary and secondary are shunted by condensers C_1 and C_2. I will explain R and K_p shortly. The condensers are used to store energy so the secondary voltages will be more regular, the primary condenser is also used to reduce sparking and the secondary condensers to protect the tube from sudden high voltages. The vibrator circuit $a \rightarrow K_4 \rightarrow K_1 \rightarrow C \rightarrow b$ is independent of the primary circuit; and normally has a high resistance so as not to short the source. In vibrating, the armature alternately connects contacts K_2 and K_3 to the source. Each half of the primary receives the full battery voltage, and the magnetic

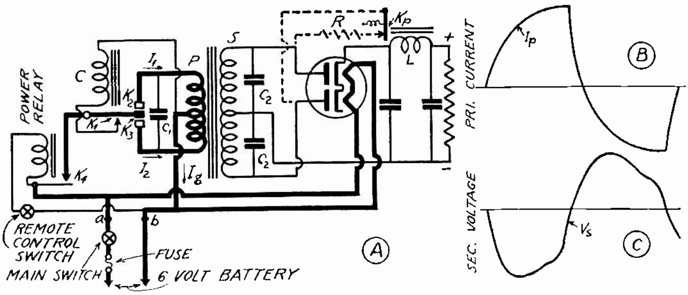

FIG. 15

flux produced in the iron core is in opposite directions. Thus a full-wave secondary voltage is produced. By using this circuit greater efficiency is obtained, more voltage is produced and the output wave form is more regular, see Figs. *15B* and *15C*.

To protect the rectifier tube from large voltages, relay K_p is used. Either a combined relay and choke, or a separate filter choke and relay are employed. When choke-relay L is not conducting current (the receiver tubes have not heated up), the relay spring closes the relay contact and resistor R (about 5,000 to 20,000 ohms) is shunted across the secondary. After the tubes heat up current is flowing through coil L, relay contact K_p opens and the receiver is then the only rectifier load. Condensers C_2 and relay K_p are often omitted in power packs where high vacuum rectifier tubes are used, but are absolutely needed for mercury vapor rectifier tubes.

Contact K_1 is always shunted by a condenser (omitted in the diagram for simplicity) to prevent sparking. Although a main switch suffices, quite often a remote control switch is used (in which case the main switch is omitted). In this case a power relay is used to close the supply circuit, actuated by the remote off-on switch.

If you will refer again to Fig. *14A*, you will observe a secondary marked S_1. In a number of vibrator supplies the vibrator is a part of the power transformer, in which case connections *1, 2, 3* of the rectifier tube are made to connections *1, 2, 3* of the vibrator-transformer.

Vibrator-Vibrator Rectifier. Shortly after the vibrator-tube rectifier appeared in auto radio receivers, radio engineers started to develop the mechanical rectifier, reasoning that if one-half of the primary was carrying current, a corresponding half of the secondary could be mechanically connected with the proper polarity to the load. The vibrator-vibrator rectifier system is shown in Fig. *16*, and in this case only the necessary details are shown. The buzzer circuit works through contact K_1, which opens and closes the buzzer circuit as well as one-half of the primary. (This is modern practice for all vibrators to eliminate needless contacts.) When the armature A is to the right contacts K_1 and K_3 are made, a pri-

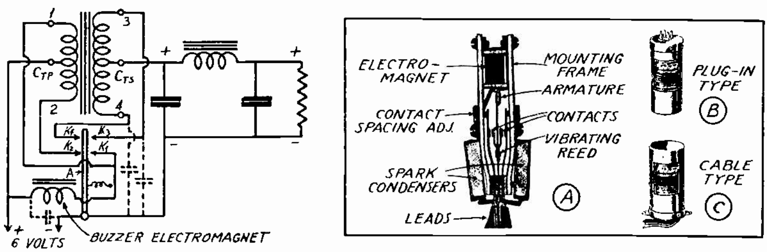

FIG. 16

mary and a secondary; when the armature is forced to the left contacts K_2 and K_4 are made. The transformer is so connected through the vibrator so the center tap C_{TS} of the secondary is always the plus terminal of the load. Condensers are shunted across each secondary contact, and a large condenser across the primary input. Additional chokes and resistors are often used to help reduce sparking, which if allowed to exist would cause serious radio interference.

In actual practice all three types of high voltage supplies are used in low power mobile installations, namely: *1,* the dynamotor; *2,* the vibrator-tube rectifier; and *3,* the vibrator-vibrator rectifier. Their electrical efficiency rarely exceeds 75% with the vibrator-vibrator rectifier slightly superior for small powers only. Both vibrator systems seem to be more popular than the dynamotor systems in factory made receivers. Vibrators are subject to wearing out, and although an expert can repair them, the only servicing that should be considered is cleaning the contacts with a fine hard flat file or a tool sharpening stone, adjusting the contact spacings, and if this does not suffice a replacement vibrator should be used. As a matter of fact, most servicemen prefer an immediate replacement, as repaired vibrators do not stand up well; and in most auto receivers a quick replacement is made by removing the vibrator unit which is supplied with prongs that fit into a tube socket.

32 VOLT D.C. FARM RECEIVERS

When a farm is equipped with a small power plant, you will generally find that a 32 volt D.C. system exists. This voltage is used for reasons of economy, initial cost and upkeep. A gasoline engine operates a 32 volt D.C. generator across which is connected a 32 volt storage battery (16 — 2 volt cells). The engine driven generator is used to keep the battery fully charged, and is set in motion only when the charge reaches a minimum value. A 110 volt D.C. system would be more satisfactory but 55 storage cells would be required, which in itself prohibits this voltage. A number of 110 volt, 60 c.p.s. A.C. engine driven systems are being installed, and the system is arranged so the turning on of a switch starts up the system. In the latter case regular 110 volt, 60 c.p.s. receivers or electrical farm equipment should be used.

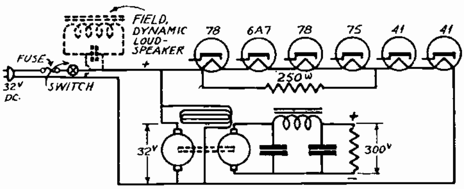

Fig. 17

However, the problem of supplying a 32 volt D.C. radio receiver equal in performance to any A.C. receiver is by no means a difficult task. From what I have already presented, I imagine you know what is done. The filaments are connected in series, or in series-parallel, the series connection not to exceed a 32 volt drop; the high D.C. voltage is produced by means of a dynamotor or a vibrator with a tube or vibrator rectifier; and the field of the dynamic loudspeaker is designed for 32 volt D.C. operation.

A typical power supply circuit as shown in Fig. *17* will help you fix the method in your mind. All tubes are of the 6.3 volt type, and here advantage is taken of the fact these tubes will work well with from 5 to 7 volts applied to the filaments. In this case there are 6 tubes, hence each tube normally gets about 5.3 volts. But as the 41 power pentode tubes require .4 ampere, while the others need .3 ampere, the extra .1 ampere is shunted through the 250 ohm resister ($6.3 \times 4 \div .1 = 252$ ohms). The field of the dynamic loudspeaker shunts the 32 volt D.C. line; while a 32 to 300 volt dynamotor produces the necessary high D.C. voltage.

I would like to mention that a number of storage battery receivers are being built along similar lines. A 6 volt storage battery feeds several 6.3 volt tubes connected in parallel, while a small dynamotor or vibrator-vibrator rectifier converts the low D.C. voltage to high D.C. voltage. In this case every precaution is taken to use as little battery power as possible, so the storage battery will not have to be charged too often.

ENGINE DRIVEN GENERATORS

Many situations arise when no source or an inadequate source of power to operate radio equipment exists. I have already indicated that when no power is available, a battery operated radio receiver or amplifier may be used. Where high power outputs are needed, these devices would be inadequate. Even though a car battery will satisfactorily operate an automobile receiver or public address amplifier, here too the possible power output may be insufficient if projecting sound (a public address

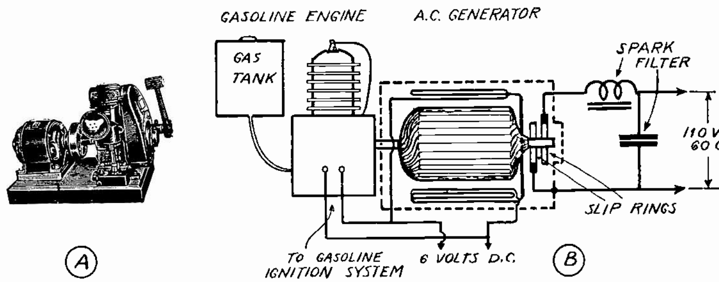

Fig. 18

or loudspeaker system) is the object of the installation. In such cases the logical procedure is to use a gasoline driven generator, and as electrical power is to be generated it seems logical to develop 110 volt, 60 c.p.s. power, so standard equipment may be employed. This frequency and voltage is considered standard because this power is universal in the U. S. A. Where other conditions are standard, a suitable generator should be considered.

A typical gasoline engine driven A.C. generator used by servicemen in mobile public address installations, is shown in Fig. *18A*. The unit is entirely self contained and is furnished with a gasoline storage tank. A switch-board is optional equipment. Although various sizes can be obtained, a 300 watt unit is quite common and satisfies most needs. The electrical connections are quite simple, as can be seen from Fig. *18B*. A 6 volt battery (usually a storage battery) is the only auxiliary equipment. It is needed to excite the electromagnets of the generator and to operate the ignition system of the gasoline engine. In an automobile installation the car battery may be used. The output of the generator has a simple spark filter (coil and condenser) to suppress interference. The engine ignition is treated like any automobile installation for elimination of interference, and this is usually made by the manufacturer of the power equipment. The gasoline engine is started by turning off the generator load, turning on the ignition and field source, and stepping on the pedal. Then the electrical load is applied. Power sources of this type are also used in aircraft, but the equipment is designed to have the lowest possible weight. The engine revolves at approximately constant speed as special speed governors are used, but as the frequency may not be exactly 60 c.p.s., the power pack of the radio equipment should not incorporate tuned filters.

If inefficiency of power development is not objectionable in a mobile installation, the gasoline engine of the automobile or truck may be used. Figure *19A* is a typical A.C. generator which is mounted so the fan belt of the gasoline engine runs over the generator shaft pulley. The car

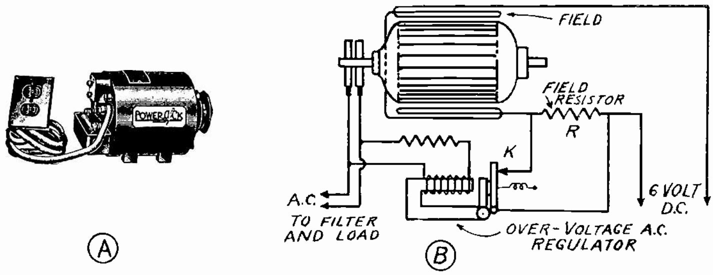

Fig. 19

battery furnishes the generator field current and the A.C. output is cabled to regular wall socket outlets. In this case the car engine must be in operation at all times when the radio equipment is used. As the engine speed will vary with the position of the car throttle and whether the car is at rest or in motion, the radio equipment must not incorporate power packs with tuned filters, and the generator must have some voltage regulator. The generator is designed to give from 50 to 70 c.p.s., from which well designed 60 c.p.s. equipment works.

A typical voltage regulator is shown in Fig. *19B*. An electromagnet designed for A.C. operation is shunted across the generator slip rings, having a current limiting resistor. When the voltage exceeds 110 volts the magnet draws the armature to its core, opening contact *K* which in turn allows resistor *R* to exist in the field circuit. When the resistor is in the circuit the field current is reduced and so is the generated A.C. voltage. The armature vibrates faster as the engine speed increases, tending to lower the voltage more times each second. Although the regulator is not exactly a radio subject, service and maintenance technicians should be acquainted with the means of getting constant voltage and current. I have therefore included this short description. Furthermore, relays can be made to operate on excessive current or voltage, or insufficient current or voltage, by using a low or high resistance field and locating the contact so a pull by the magnet either closes or opens the control circuit or the circuit of the control device.

THE TRANSFORMERLESS A.C. POWER PACK

Occasionally you will run across vacuum tube equipment which operates from an A.C. source and which employs no power transformer of any kind. You will find small radio receivers and audio amplifiers, and electronic (photocell or electric eye) equipment with such a power pack system or power supply unit. The elimination of power transformers reduces the weight and initial cost of the equipment, factors which are often very important. The output D.C. voltage, when the device is operated on 110 volt A.C. supplies, will vary from 280 to 120 volts, depending on the current load. The transformerless A.C. power pack

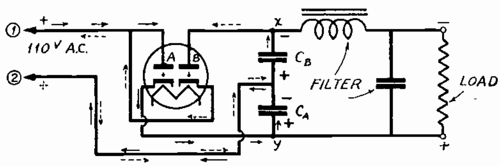

Fig. 20

system employs two rectifier tubes, alternately charging two condensers. The latter are connected in series and if they feed a high resistance load their charge will leak off slowly enough so the voltage across each condenser will add. Only a limited load † (low D.C. current) may be realized from such a power pack.

You will understand how this is done by following me in the analysis of the typical "voltage doubler" circuit shown in Fig. *20*.* As you know, the A.C. source has two terminals and each is positive for a half cycle. When terminal *1* is +, the current (not the electron flow) travels over the path shown by solid arrows. Observe that rectifier *A* operates and condenser C_A is charged with the polarity shown. For the next alternation of the cycle, terminal *2* becomes positive and the current flows through rectifier *B* and the path indicated by dash-dash arrows. Condensers C_B is charged with the polarity indicated. Notice that the condensers are in series so a + connects to a — terminal and their voltages add to twice

* In radio circuits it is customary to use a twin or double diode rectifier tube.

† For this reason a permanent magnet loudspeaker is generally used as no power is required for a field.

the voltage across each condenser, hence the name "voltage doubler." Terminals x and y are the new source of rectified voltage, which is filtered before being led to the load. It is the high resistance of the load that prevents the condensers from rapidly losing their charge. Condensers C_A and C_B should be as large as possible (16 to 32 microfarads). As the required voltage rating is low they are inexpensive.

The filament of the twin rectifier tube is connected in series with the filaments of the other tubes in the vacuum tube device and a series current limiting resistor used before this circuit is connected to the 110 volt supply; similar to a 110 volt D.C. receiver.

OPERATING EQUIPMENT ON SUPPLIES OTHER THAN FOR WHICH THEY WERE DESIGNED

I now want to tell you a few details that will be helpful and profitable in service work. You are bound to run across situations where a certain piece of radio apparatus was not designed for the power supply at hand. This condition usually arises when a customer has procured a receiver at some attractive price and without knowledge whether he can use it in his home; or the customer has moved to a place where a different

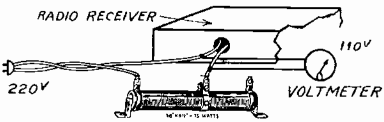

FIG. 21

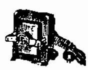
FIG. 22

power supply exists. No sensible serviceman should recommend the rewiring of the receiver if the set can be adapted by some commercial device, or a simple adjustment can be made. I am now going to discuss these problems.

220 D.C. Volt Adaption. When a 110 volt D.C. receiver is to be connected to a 220 volt D.C. line, a series variable line resistor should be connected as shown in Fig. *21*. As the average modern 110 volt D.C. receiver draws about .5 ampere, a 75 watt — 250 ohm variable resistor should suffice. Mount the resistor in the cabinet, preferably on a rectangular piece of thin tinned sheet iron (to protect the wood from the heat); set the variable contact to the extreme right (all resistance in circuit); connect a 0-150 D.C. voltmeter as shown to the power supply input of the receiver; insert the plug in the wall; and move the contact to the left (reduce resistance) until the voltmeter reads 110 volts (the voltmeter will start with some low reading, 50 volts, and increase in value). When the meter reads 110 volts tighten the contact and the job is finished. Throughout these adjustments the receiver should play. If you get a shock, pull the plug out from the wall socket before making an adjustment.

220 Volt A.C. Adaption. If you run into a job where a 110 volt A.C. receiver is to be adapted to a 220 volt A.C. line, the scheme shown in Fig. *21* may be used. However, the set may draw as much as 1 ampere. You should first make the adjustment using a 250 ohm resistor, and when the adjustment has been completed measure the amount of resistance used with a ohmmeter and procure a 75 or preferably a 100 watt variable resistor with nearest higher resistance value. The resistor may be worked slightly over rated value, but if fully exposed to the air, and the wood of the cabinet protected by sheet iron, a little overload will do no harm.

But the best plan is to use a 220 to 110 volt step-down transformer, a typical one shown in Fig. *22*. Be sure you get one for the frequency of the line.* Merely insert the receiver plug in the receptacle on the transformer, and the transformer cord plug into the wall socket. As a transformer will conserve power, its initial cost will be paid back many times by the power saved. Some step-down transformers have a variable contact switch so the system can be adapted to line voltages of 150 to 240 volts.

Adapting to a Line of a Different Frequency. Occasionally you will have to install a radio receiver on a line having a frequency other than that for which the receiver was designed. In general you will encounter 25, 40 and 60 c.p.s. lines. Can a receiver designed for one frequency be used on another? Yes and no! Transformer equipment designed for low frequency will work at higher frequencies (within reasonable limits)
10 but the reverse condition is not true. That is a 25 or 40 c.p.s. A.C. receiver will work with a slight change on 60 c.p.s., but a 60 c.p.s. receiver should never be run on 25 c.p.s or 40 c.p.s. ‡ They may operate for a while but in a short time the transformer will burn up. Here is the reason. Low frequency transformers require many more turns per volt † (about 2.5 times) for a given core area (cross section) when used on 25 c.p.s. than for 60 c.p.s., or for the same number of turns per volt the core area must be greater; otherwise large useless currents will be drawn from the line. Usually a compromise is made between turns and core cross section but you will find the low frequency transformer quite large and heavy. If a 60 c.p.s. transformer is connected to a 25 c.p.s. line the fact that there are insufficient turns (low reactance) will cause large, useless current to flow, overheating the transformer. Furthermore a radio receiver designed for 60 c.p.s. will not have a ripple filter sufficient to handle 40 or 25 c.p.s., although additional condensers can be easily inserted in shunt with those used (tuned filters must be carefully adjusted for the new frequency).

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* I will shortly consider sets operating off of other than the designed frequency.

‡ A change-over may be made by installing a 25 or 40 c.p.s. transformer with equivalent outputs and improving the filter system.

† The primary turns divided by the primary voltage.

When a 25 c.p.s. or 40 c.p.s. receiver or amplifier is to be operated from a 60 c.p.s. line, it is wise to use a line regulator (variable resistor). Connect a 0-10 A.C. voltmeter across the filament terminals of one of the tubes and adjust the resistor until slightly less than normal voltage is indicated across the filament.

D.C. Equipment on A.C. Lines. More often than any other condition, a person moves from a 110 volt A.C. district to a 110 volt D.C. district, or from a D.C. to an A.C. region. It is the latter case that I want to discuss first. Frankly I would personally recommend getting an A.C. receiver because the latter will be so much better than the D.C. receiver. But if the customer is satisfied with his D.C. receiver (and it is a D.C. set, not a universal receiver) you could, although I doubt if you would, recommend a small A.C. motor driven D.C. generator. This equipment is so costly that many expert servicemen prefer to rewire the supply system if an A.C. receiver cannot be sold. Study carefully what I have said about universal receivers and make a change to this system.* You will need a twin rectifier tube of the cathode type, a larger

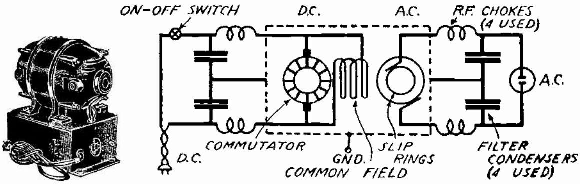

FIG. 23.—The rotary converter, employing a D.C. motor and an A.C. generator winding in the same armature slats. Filter housed in the steel box supporting the rotary converter. Input and output spark filters used.

choke but with low resistance, and perhaps larger filter condensers. Each conversion job will require special study; but be sure that an inexpensive A.C. receiver would not be more acceptable. When you run across an old D.C. receiver with filament type tubes, do not try to convert it to A.C. operation, unless you have enough design ability to make the change, in which case you will know what to do.

A.C. Equipment on D.C. Lines. Without doubt this problem will, as an average, be encountered more often than any other receiver adaption. As a rule, A.C. receivers are so much better than D.C., universal and battery receivers, that it is quite common to adapt a new good A.C. receiver to 32, 110 and 220 volt D.C. lines by means of the two devices I am about to discuss, instead of buying a receiver designed for these special voltages. Two procedures are possible. Use a D.C. to A.C. rotary converter, a combination D.C. motor and A.C. generator; or a magnetic vi-

* So if the customer moves to a D.C. district, no change will be required.

brator type D.C. to A.C. converter (often called an inverter). Both devices are shown in Figs. *23* and *24*, and the general scheme of connections is given to the right of each illustration.

For the average receiver a 100 watt converter or inverter will suffice. The adaption is simple. Insert the receiver power plug into the receptacle of the converter; push the plug of the converter into the D.C. line; and if a ground terminal is provided on the converter connect a wire from it to the regular ground. The rotary converter is costly, but has a long life and can be had in any power rating for receivers or public address equipment; the magnetic vibrator inverter is comparatively inexpensive, its power capacity is limited to 200 watts maximum and the vibrator must be replaced about once a year, a simple task if a plug-in vibrator is used.

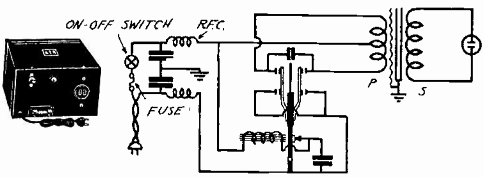

FIG. 24.—A magnetic vibrator type converter or inverter. Similar to auto radio vibrators except secondary rectification is omitted, thus providing A.C. output. Vibrator usually made with double contacts to handle high voltage. Input spark filter required, as well as contact spark eliminating condensers. An electrostatic shield is wound between the primary and the secondary, a wire mesh, or a thin sheet of copper which does not make a contact where they lap. Often a variable primary resistor, or secondary taps are provided to regulate the output voltage.

Loudspeaker Field Supplies. Although it is customary to design radio receivers so the power pack supplies the necessary excitation current for the field of the dynamic loudspeaker,* this practice is not generally followed in public address amplifiers. In this case a separate supply unit is used with the loudspeaker. Although the field may be designed for any D.C. voltage, standard designs are for 110 and 6 volt sources. Where D.C. is available the problem is merely a matter of making a connection; if A.C. is the only source then a rectifier system is required.

For the high voltage field a tube rectifier is used, a typical circuit and supply unit shown in Fig. *25*. But for a low 6 volt field, a special, so called copper oxide rectifier is used.

* In some receivers, particularly battery types, magnetic or permanent dynamic loudspeakers are used. They require no current for producing a magnetic field, the necessary magnetic field being produced by permanent magnets.

No one has fully explained the behavior of these devices but from long experience it is known that if a pure copper disc is oxidized on one side and a voltage supply is applied, one terminal to the copper surface and the other terminal to the copper oxide surface, electrons will flow

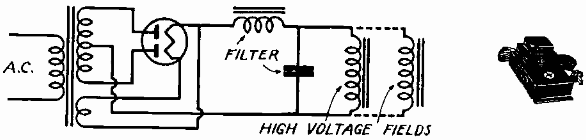

FIG. 25

from the copper to the copper oxide under normal applied voltage, but not in the reverse direction. If the voltage is made high enough electrons will flow in either direction. When large voltages are to be rectified (100 volts would be high) several elements are used in series. In an actual rectifier, a rectifier unit is made by processing copper washers so

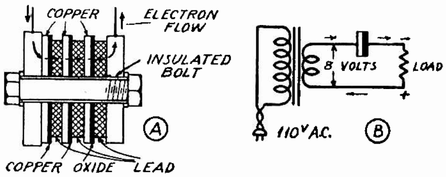

FIG. 26

one surface is oxidized, stringing each such element on an insulated bolt, separating each element by a lead washer (to get better over all contact to the oxide surface) and bolting the elements together, as shown in Fig. *26A*. A simple rectifier circuit is shown in Fig. *26B*.

However, it is customary to build copper oxide rectifiers for full-wave operation and Fig. *27* is a typical full-wave bridge circuit. Note particu-

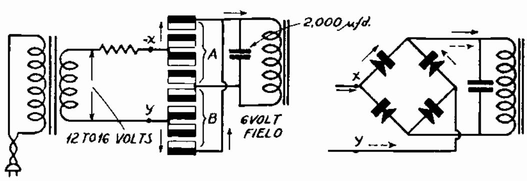

FIG. 27

larly that two (*A* and *B*) units are used placed "back to back" so electrons can flow from the center to the ends. Study the connections of the load (field) and the low A.C. voltage supply, as you may sometimes have to make a connection to one of these rectifiers. (Note: The two ends are connected together to one terminal of the load, the center to the other load terminal; the A.C. source is connected to the two off center terminals.) For purposes of simplicity, the special symbols shown to the right are used in circuit diagrams.

Large copper processed washers are used for large current rectifiers, small washers are used for low current rectifiers, particularly in A.C. rectifier voltmeters. In the loudspeaker supply system, a large electro-

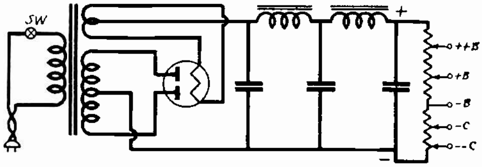

Fig. 28

lytic condenser of the dry type having a capacity of 1,000 to 2,000 microfarads is shunted across the field for ripple bypassing.

B Eliminators. Although the so called B eliminator (a device which operates from an A.C. power outlet replacing B batteries) is now a rare device you may encounter it on some jobs. From what I have already explained, no further details are necessary. In general you will find a full-wave rectifier, a condenser input filter and variable voltage divider as shown in Fig. *28*. The cable leads from the battery receiver are connected to the various $++B$, $+B$, $-C$ and $-B$ terminals and the potentiometers varied so correct voltages are applied. A high resistance D.C. voltmeter should be used in making these adjustments.

TEST QUESTIONS

Be sure to number your Answer Sheet 13FR-1.

Place your Student Number on every Answer Sheet.

Never hold up one set of Lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson. In this way, we will be able to work together much more closely, you'll get more out of your Course, and the best possible lesson service.

1. Should a battery supply lead resistor be used when an air cell battery is connected to 2 volt tubes?
2. What is the purpose of resistor *R* in Fig. *6?*
3. How are the tube filaments of a 110 volt D.C. receiver connected?
4. What would be heard if the electrodes of a D.C. receiver were operated directly from the 110 volt D.C. line?
5. How does the half-wave diode rectifier act in a universal receiver when it is connected to a D.C. source?
6. What is the primary source of electrical power in an auto receiver?
7. What three types of high voltage supplies are used in low power mobile installations?
8. If an engine driven generator is to be used, what kind of electrical power should it supply?
9. What is employed in the transformerless A.C. power pack?
10. May a 60 c.p.s. receiver be safely operated on a 25 c.p.s. line?

RADIO RECEIVER TROUBLES

THEIR CAUSE AND REMEDY

14X-1

REFERENCE BOOK

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

IMPORTANT

Instructions in How to Use This Reference Book

This reference book is divided into four parts: **A**, an index of radio receiver troubles under the usual symptoms (effects), under which are listed the probable causes; **B**, a discussion of general defects and tests; **C**, a section devoted to general troubles of receivers, their cause and remedy; and **D**, a section on receiver alignment and balancing.

In using this text as a means of shooting trouble, refer to the index. The main headings give the symptoms or other obvious results of a defect. For example: Receiver squeals, howls, or putputs; hums, smokes, etc. After you locate the proper section according to the defects you observe, you will find a list of probable causes. The causes listed should indicate to you some part or connection to check. In the beginning all the references given should be studied. In trouble shooting, select first the causes you think most likely to give the trouble in the receiver you are servicing. After most of the probable causes you will see a number followed by a letter. The number refers you to the section; the letter to the paragraph in that section.

If incorrect alignment or an unbalance is given as the cause of trouble the proper procedure for realigning or balancing a receiver is given in the section on alignment.

You should carefully read the sections on general defects and tests, general receiver troubles, and alignment and balancing, so you will be familiar with the contents. Select any section that interests you. Read especially section 22, "Voltage and current measurements as an aid in locating the defect."

When reference is not made in the index to an explanation in the following selections, the information in the index is sufficient to indicate what is to be done. For example: The customer complains that: "Stations are not received at the proper points on the dial." Referring to the index the probable cause "Dial slipped on condenser's shaft" fits this case. No further instructions are needed, as the cause itself is an indication of what you should do—reset the dial and tighten the set screw.

Remember, this reference text will be more and more helpful as you study and learn more about radio and radio receivers.

NATIONAL RADIO INSTITUTE

WASHINGTON, D. C.

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A: INDEX OF RADIO RECEIVER TROUBLES BY EFFECTS OBSERVED, FOLLOWED BY PROBABLE CAUSE

BALLAST GETS TOO HOT OR BURNS OUT

Shows White Heat or is Too Hot to Touch

Natural Condition; *24b*
Ground or Short in Filter System; *31a*
Filter Condenser Shorted; *13a, 14f, 14h*
Choke Coil Grounded; *17c, 31a*
Shorted Rectifier Tube; *6b, 43e, 43g*
Power Transformer Defective; *17d*
Shorted Line Filter Condenser in Power Transformer Primary Circuit; *13a, 36b*
Selecting the Proper Ballast; *9a, 9c*
Incorrect Ballast; *9b*

BROAD TUNING

Several Conditions Arise. *Condition A.* Receiver Tunes Broad on Local or Semi-Local Stations; But is normal in other respects; *Condition B,* Receiver Broader Than Usual and "Pep" of Receiver Gone; Finally, *Condition C,* Tunes Broad and Only Local and Semi-Local Stations Received.

The Ability of the Receiver Must Be Carefully Borne in Mind in Judging a Condition of Broad Tuning. Read *28n*. When the Defect Causing Broad Tuning is Not Readily Fixed, or Has no Appreciable Effect When Fixed, the Worst Offender May Be Suppressed With a Wave Trap.

Condition A: Usually a Natural Condition:

Inexpensive Receiver, Broad Tuning Normal; *23d, 23e*
Too Close to Local Stations; *28e*
Antenna Too Long; *29d*
Station Tuning Broad is Unusually Powerful; *28c*
Grid Leak-Grid Condenser Type Detector; *28n*

Condition B: Generally Due to High Resistance in Signal Circuit or Abnormal Tube Operation:

Loose and High Resistance Connections; *3a, 3d, 5a to 5f*
High Resistance in Grid Circuit; *5a to 5f*
Poor Tube Prong to Socket Contact; *3f*
Improper R.F. Alignment; *45f, 45i*
I. F. Stage Improperly Aligned; *45g to 45k*
Return Signal Circuit Leads Not Grounded; *1f, 1d*
Grid and Plate Leads Out of Place; *do not try to correct, pep up receiver*
No Ground to Receiver; *check*
Variable Condensers Dirty; *15b*
Ineffective or Defective Volume Control; *10a*
Storage Battery Charge Low; *21c*
"B" Batteries Run Down; *21i*
Low Line Voltage; *30c*
Open or Shorted Bypass Condenser; *12a, 12b, 12c, 13a*
Weak Tubes; *6b*
Shields Not Firmly in Place, or a Good Chassis to Shield Contact Does Not Exist; *19a, 3f, 20d*

Condition C: Usually Due to no Supply Voltage to Some Stage, or an Open Circuit:

Dead or Defective Tube; *6f, 6a*
No Plate Voltage on an R.F. Tube; *study section 22*
Open Grid Circuit; *1d*
Variable Condensers Partially or Totally Shorted in Some Section; *15g*
Control Grid Clip Loose, Corroded or Grounded; *3f, 5c*
See Causes Creating Condition B.

CONDENSERS LEAK WAX

Poor Ventilation; *26g*
Condensers Leaky; *13a, 12c*
Defective Condenser; *13a 12c*
Voltage Rating of Condenser Used Too Low; *11c, 26g*
Excessive Wax Used in Manufacture; *No Harm Done*

CONDENSERS HISS OR SIZZLE

Sound Coming Directly From Electrolytic Condenser

Loudspeaker Cable Not Plugged or Connected to the Main Chassis; *14j*
Excessive Voltage Across Electrolytic Condenser. (Producable by Any Defect or Open in the Receiver Which Will Cause Excessive Voltage at This Filter Condenser.) *14j*
Condenser Defective or Not Used for Some Time; *14k*
Electrolytic Condenser Improperly Connected; *14i*
Electrolytic Condenser Incompletely Formed; *14k*

DEAD SPOTS SHORT WAVE CONVERTER

Reception Peculiar to Short Wave Bands; *25a to 25k*
Incorrect Receiver Adjustment; *25c*
Oscillator Not Working; *section 40*
Shorted Tuning Condenser; *15g*
Incorrect Coil Plugged in (plug-in coils used).

DEAD SPOTS, ONE BAND OF ALL-WAVE RECEIVER

Switching Arrangement Defective; *18b, 18c*
Improper Matching in All-Wave Antenna System; *29e*
Oscillator Tube Fails to Oscillate; *section 40*
Oscillator Cathode Resistor Open or Too High; *8d*
Reception Peculiar in Short Wave Band; *section 25*
Ability of Receiver Over-Estimated; *23f*
All-Wave Antenna Not Used; *29l, 23f*

DEAD SPOTS, SEVERAL BANDS OF ALL-WAVE RECEIVER

Defective Switching; *18b, 18c*
Oscillator Tube Fails to Oscillate; *section 40*
Oscillator Cathode Resistor Open or Too High; *8d*

DEAD SPOTS

Receiver Ineffective at Some Tuning Points, Normal Otherwise

Natural Condition for Your Locality; *25i*
Oscillator Cuts Off at Some Tuning Point; *section 40*
Poor Connection Between Tuning Condenser Rotors and Chassis; *15c*
Shorts Between Tuning Condenser Plates at Some Tuning Points; *15b*
Improper Alignment of R.F. Stages; *45e*
Preselector and Oscillator do not Track; *40d*
Regeneration at Dead Spot; *32f to 32j*
Primary to Secondary Sensitivity Equalizing System in R.F. Transformer Open; *1c*

DISTANT RECEPTION POOR

See Sections on "Signals Weak"

Reception Peculiar in Short Wave Bands; *read section 25*

FUSE BLOWS

Defective or Gassy Rectifier Tube; *43d*
Defective Power Tube; *6e*
A Power Line Wiring Ground to the Chassis; *4b*
A Defective Power Transformer; *section 17*
Line Voltage D.C. Instead of A.C.; *30a*
Defective Electrolytic Condenser; *14f* to *14k*
Short or Ground in Filter Circuit
Defective Line Switch; *18a, 30g*
Defective Filter Condenser Across Power Transformer Primary; *13a, 36b*
Pitted or Dirty Vibrator Points; *44b, 44d*

FADING, DISTANT STATIONS ONLY

Far Distant Stations Get Louder and Weak, Alternately, or When Normally Set to Average Sound Volume Gets Weaker or Fades Out and Then Gets Normal Again Repeatedly. Stations 50 to 150 Miles Away Alternately Fade In and Out and Reception Also Gets Muffled or Distorted.

A Natural Receiving Condition; *25i*
Aerial Swaying; *29g*
Power Line Voltage Varying; *30e*
A.V.C. Tube Improperly Chosen; *6h*

FADING OR INTERMITTENT RECEPTION

When Local as Well as Distant Stations Come in and Fade Out or Come In and Grow Weak Alternately; or the Receiver Plays and Cuts Off to Come Back Almost Immediately or Not at All, or by Tapping the Chassis or Touching Some Part or Snapping Power Switch —A Circuit or Part Defect is Indicated. Several Conditions Arise.

Condition A: Unstable Circuit in Oscillator or A.V.C. controlled stage, Tube Starts and Stops.

Gassy Tube; *6c, 6d, 6h, 41a*
Tube Overloads and Blocks; *37b*

Condition B: Thermostatic Connection or Joint, Appears After Receiver Heats Up Resulting in Fading or Intermittent Reception—Has a Definite Time Period

Any Connection or Part Defective; *read section 1*
Tube With Thermostatic Joint; *3i*

Condition C: Opens, Shorts, High Resistance Connections Plus Vibration, Condensers Are a Very Common Source of This Trouble

Poor Connecting Joints in Antenna System; *29b, 29f, 29s*
Poor Tube Prong and Socket Contacts; *3f*
Coupling Condensers Defective; *12a*
Condenser Defects a Common Source of Trouble; *sections 12, 13, 14*
Resistor Defective; *8d*
Transformer or Coil Defective; *section 16*
Volume Control Defective; *10a*
Dirt or Metal Flakes in Tuning Condenser; *15b*
Corroded or Poorly Soldered Connections; *3d, 5c*
Improper Wiping or Pressure Contacts; *5c*
Loose Trimmer or Adjustable Parts; *20d, 15f*

Condition D: Normal Defects

Weak A, B, and C Batteries; *section 21*
Defective Copper Oxide Rectifier Elements; *38b*
Rectifier Tube With Low Emission; *6b*

GROUND CONNECTION, SPARKING AT

Natural Condition; *24d*

HUM, BATTERY RECEIVERS

Condition A: Tunable Hum, Tubes or R.F. Stages Capable of Modulation

Aerial Close to High Voltage A.C. Wire; *35f*
Improper Ground; *35f*
Induction Into Circuits from Nearby A.C. Lines; *35f*

Condition B: Direct Hum Pick-up

A.C. Lead Near a Sensitive Detector; *35f*
Direct Pick-up by Audio Stage; *35f*

HUM, A. C. RECEIVERS

Hum That is Heard From the Loudspeaker at All Times

Condition A: Ineffective or Defective Filters and Power Supply

Defective Rectifier Tube; *31a, 6b*
Improperly Grounded Filament Circuits; *1c, 30k*
Open Filament Mid-Tap Resistor; *8f*
Defective or Open Filter Condenser; *32f*
Open or Shorted Bypass Condenser; *sections 12, 13, 14*
Resistor-Capacitor Supply Lead Filter Defective or Ineffective; *sections 12, 13, 14*
Grid Bias Resistor Condenser, Open or Inadequate; *12a*
Conductive Coupling Between Circuits; *5f*
Grounded or Shorted Filter Choke; *31c, 31d*
Power Transformer Turns Shorted; *17d*
Power Transformer Secondary Voltages Not Electrically Center Tapped; *17e*
A.C. Power Plug Reversed; *30h*
Loudspeaker Field Coil Defective; *38a*

Condition B: Low Voltage, Old Tube and More Circuit Defects

Open Grid Circuit; *1d*
Open Antenna Choke; *1g*
Grounded A.F. Transformer; *16e*
Ground Post Not Secure to Chassis; *3e*
Grounded or Open: Choke Coil, Resistor or Plate Circuit; *section 1*
Volume Control Defective; *10a, 1d*
Lack of Ground on Iron Core Coils and Transformers; *add connections*
Open in Ground System; *1d*
Open R.F. Transformer Secondary; *1g*
Loose Connections; *3d*
Incorrect Voltages; *section 22*
Tubes Weak or Defective; *6b*
Gassy Power Tube; *6b, 6c*
Cathode to Heater Leakage in Tube; *6b*
Resistor Grounded, Open or Defective; *section 8, 1c*

Condition C: Circuit or Tubes Out of Balance

Unmatched Power Tubes; *6j*
Over Sensitive Detector Tube; *6b*
R.F. Tube Oscillating; *32f to 32i*
Neutralization Adjustments Out of Balance; *32d, 45d*
Hum Adjuster Defective or Out of Adjustment; *35g*
Hum Bucking Coil or Other Loudspeaker Hum Balancers Out of Adjustment or Defective; *35g, 1c*
One Half of a Full Wave Rectifier Tube Defective or Weak; *6j*

Special Conditions and References

Normal Hum Amplified by Room or Cabinet Resonance Effects; *39a, 39b*
Localizing Hum, Procedure; *section 35*
Minimizing Hum by Baffle Adjustment; *35l*
A.C. Operated Loudspeaker in Which: Defective Rectifier, Defective Filter Condenser or None Used; *38g, 14c, 14l*
See Hum, Battery Receivers

HUM IN UNIVERSAL RECEIVERS

Only When Used on A.C.

Defective Filter System; *section 31*
Defective Filter Condensers; *sections 11, 12, 13*
Defective Tube; *6b*
Defective Bypass Condenser; *sections 11, 12*

HUM RESONANT OR TUNABLE

Hum From Loudspeaker Only When Tuned to a Broadcast Station or Its Carrier

Open Control Grid Return; *1d*
R.F. Stages Oscillating; *32d to 32j*
Defective or Weak Tube; *6b*
Defective Cathode Bypass Condenser; *12a, 13a*
R.F. Filament Improperly Center Tapped; *8f, 30m, 30n, 17e*
R.F. Bias Resistor Incorrect Value; *section 22*
Resonant Effect in Room; *39a, 39c*
Cathode-Heater Leak in Tube; *6b*
Incorrect Screen Grid or Pentode Tube Used; *28f*
R.F. Plate Voltage Too Low; *section 22*
Receiver With Choke or Resistor Aperiodic Input Hum Readily on Locals; *Use Wave Trap*
Any Defect in the R.F. Section Which Would Create Normal Hum (See "Hum in A.C. Receiver")

HUM FROM PARTS

How to Identify; *35e*
Loose Laminations on Transformer; *35e*
Loose Parts, *35e*
Resonant Condition of Cabinet or Room; *39a*

NOISE, CODE INTERFERENCE

Can be Tuned; *28i*
Cannot be Tuned; *28j*

NOISE INTERNAL, WHEN RECEIVER IS ADJUSTED

Plates of Tuning Condensers Short; *15b*
Defective Pig-Tail Connections or Bearing Contacts on Variable Condenser; *15c*
Dirt or Flakes in Variable Condenser; *15b*
Any Wire or Part Having a Poor Connection Disturbed Mechanically When Set is Tuned: *20d*
Volume or Tone Control Defective; *section 10*
Power or Band Selector Switch Defective; *section 18*
Any Manual Control Defective; *20d*

NOISE, INTERNAL

Station Tuned In, No Part Touched or Adjusted, and Hiss, Scratches, Rattles and Racket Noises Heard.

Test for Internal Noise; *36a, b, and c*
Loose or Poorly Soldered Connections; *section 3*
Poor or Corroded Ground Connections; *section 5*
Tubes, Noisy, Defective; *6g*
Natural Circuit Noise; *23h, 23i*
Leaky Fixed Condenser; *12d*
Defective Resistor Across Secondary Terminals of Audio Transformer; *12d*
Defective Loudspeaker Cord or Cable Resistances, Defective; *section 8*
Power Transformers, Defective; *1b*
Variable Condenser Connections Defective; *3h*
Volume Control Connections Defective; *1b*
Partially Shorted Circuits; *1b*
Audio Transformer Defective; *1b*
Incompletely Grounded Shields; *19a*
Pilot Lamp Loose in Socket; *7c*
Control Grid Clips Loose or Partially Grounded; *3f*
Defective Loudspeaker; *1b, 38c*
Defective Electrolytic Condenser; *14l*
Storage Battery Weak or Too Freshly Charged on Supersensitive Receivers; *21c*
Battery Terminals Corroded; *3e, 21e*
"B" Batteries Run Down or Cell Defective; *21j, 21k*
Defective "A" Battery; *21a to 21g*
Dirty Contacts on Inductance Switches of All-Wave Sets; *18b*
Defective R.F. and I.F. Transformers; *1b*
Plate Chokes of Mercury Vapor Rectifier Tubes Defective; *31b*

NOISE, EXTERNAL

Noise Comes Through Loudspeaker And is Not in The Chassis

Test for External Noise; *36a, b, and c*
Static, Natural; *section 27*
Aerial Rubbing or Close to High Voltage Wire; *29f, 29h*
Poor Connections or High Resistance Joints in Antenna or Ground Systems; *29b, 29o to 29s*
Partially Grounded Lead-in or Antenna; *29f*
A.C. Plug Prongs or Cable Connection to it Loose; *36e*
Lightning Arrester Defective; *29k*
Improper Emergency House Line Fuse; *36g*
Two or More Sets on Same Aerial, Other Receiver Defective; *29n*
Poor Connections to Electrical Outlets in House; *36f*
Autos and Trucks Interfering in Short Wave Band; *27c*
Noise Entering Through Power Line; *36b*
Inter-Station Noise (AVC Receivers); *41b; 23i*
Importance of Noise-Reducing Antenna; *36c, 36d, 29e*

NOISE, MECHANICAL

Noise is Not Emitted From Loudspeaker and Heard Only With Set Playing

Loose Parts in Cabinet; *39b*
Resonant Cabinet Effects; *39b*
Resonant Room Effects; *39b*
Transformer Laminations Loose; *17f*
Tube or Coil Shields Loose; *19a, 20d*
Microphonic Tubes; *34b*

NOISE, INTERNAL; AUTO RADIO

The Defects Listed Below Are Only Peculiar to Auto Radios. But an Auto Radio Also is Subject to Defects Producing Noise Like Other Receivers. Hence See "NOISE INTERNAL."

Incomplete Noise Suppression, Ignition Noise; *44e*
Suppressor Defective or Not Completely Connected; *44e*
Noise Reducing Condensers Defective; *44e*
Ignition Wire Out of Place; *44e*
Motor Badly Out of Balance; *job for auto mechanic*
Body Loose; *job for auto mechanic*
Wheel or Brake Producing Noise; *44g*
Defective Commutation in Charging Generator; *44i*
Antenna or Its Lead-in Rubbing Against Car Body; *44h*
Defective Vibrator or Leads to Vibrator; *44b to 44d*
Noise When Running Over Rough Road; *44f*
Car Electrostatic Noise; *44f, 44g*
Poor Ground Connections; *44e*
Dirty Vibrator Points; *44b to 44d*

OSCILLATIONS

See Sections on "Squeals"

PILOT LIGHT BURNS OUT TOO OFTEN

Inferior Quality of Pilot Light Used; *7f*
Voltage Rating of Pilot Light Too Low; *7b*

Pilot Light as a Fuse, Overloaded; *7d*
Resistor in Series With Pilot Lamp Shorted; *7d*
Resistor in Shunt With Pilot Lamp Open; *7d*

PILOT LIGHT FLICKERS OR TOO DIM

Pilot Light Loose in Socket; *7c*
Lamp Rating Too Low; *7b*
Line Voltage Fluctuates; *30e*
Power Transformer With Poor Regulation Used; a Better Transformer Must be Used, and Change Unwise
Defective Connection or Lead to Lamp; *7c*

RECTIFIER TUBE PLATES GET RED

Output of Rectifier is Shorted; *section 31, 43d*
Defective Filter Condenser; *31a*
Defective Rectifier Tube; *31a*
Filter Choke Grounded; *31a*
See Section "Ballast Gets Too Hot"

RESISTOR OVERHEATS OR EMITS SMOKE

Resistor Defective; *8e to 8g*
Incorrect Size or Wattage Rating Used in Repair; *8b, 26f*
Shorted to Chassis; *43e, 4b*
Extra Current Due to a Defect in Associated Equipment; *section 43*

RESISTORS GET WARM

Natural Condition; *24a*

RECEIVER SMOKES

Shorted Tube; *6b*
Shorted Condenser; *13a, 43a, 43b*
Shorted Power Transformer; *17d*
Part of Circuit Overloaded; *section 43*
Receiver Operated on Other Than Recommended Supply Line; *30a*
Defective Insulation; *17c*
See "Resistor Overheats or Emits Smoke"

RECEIVER UNSATISFACTORY (INEXPENSIVE MIDGET)

Natural Condition; *23a to 23e*
Refer to Specific Trouble if Reception is Considered Below Normal

POOR SELECTIVITY

See Broad Tuning

SHOCK WHEN AERIAL IS TOUCHED

Receiver Not Grounded (Natural): *24d*
Static Electricity; *27b*
Antenna Touching Nearby Power Line; *29h*
Two Sets on One Antenna; *29n*

SHOCK WHEN CHASSIS IS TOUCHED

If Ground Connection Sparks on Connecting; *24d*
Universal and D.C. Receivers, Natural; *30i*

SIGNAL DISTORTED OR MUFFLED

Several General Conditions Arise. *Condition A:* Signal is Distorted All The Time; *Condition B:* Signals Distorted at High Sound Levels; *Condition C:* Signals Distorted at Low Sound Levels—Otherwise Normal.

CONDITION A: Signal Distorted or Muffled Regardless of Receiver Adjustment

Located in R.F. System

Oscillation Occurring; *section 32*
I.F. or R.F. Peaked Too Sharply; *45h*
Natural, When Accompanied by Fading; *28l, 25i*
Interference Between Stations of Nearly Same Frequency; *28l*
Oscillator Tube Weak; *40b*

Located in Detector or A.V.C. System

Detector Defective; *6b*
Controlled Tube Bias Shorted or Incorrect; *41a*
A.V.C. Not Working; *section 41*
Defective A.V.C. Bypass Condenser; *41a*

Located in Audio System

One-half of Push-pull (Input or Output) Shorted or Grounded; *6j*
Defective A.F. Transformer; *16e*
Resistance Across A.F. Transformer Secondary Open; *8e*
Push-pull or Push-push Tubes Not Properly Matched; *6j*
Bias Resistor Filter Condenser, Open or Value Insufficient; *sections 11, 12, 13*
Push-Pull or Push-Push Stage Regenerating; *33d*
One Push-Pull or Push-Push Tube Weak or Dead; *6b*

Located in Loudspeaker Unit

Defective Loudspeaker; *section 38*
Loudspeaker Voice Coil Grounded; *4a*
Rectifier Unit Defective (Separately Excited Units); *38b*
Voice Coil or Armature Off Center; *38d*
Voice Coil Circuit Partially Completed; *38c*
Voice Coil Turns Loose; *38c*
Iron Filings or Dirt in Voice Coil or Armature Free Space; *38d*
Voice Coil Spider Defective; *38e*

Located in Power Supply System

Excessive Voltage From Power Supply; *30b to 30e*
Excessive Filament Voltage; *30e*
Defective Rectifier Tube; *6b*
Incorrect Voltage Applied to Power Tube; *section 22*

Incorrect Grid, Plate, Screen Voltages; *section 22*
Defective Electrolytic Condensers; *section 14*
A Storage Battery Charge Down; *21c*
Battery Terminals Corroded; *21e*
High Resistance in Battery Supply; *21j, 21k*
Defective A, B, or C Supply; *section 21; section 30*
Defective Power Transformer; *16b to 16d*
Too High or Too Low a Line Voltage; *30b to 30c*

General Defects Causing Distortion or Muffled Signals

Wrong Tube in Socket; *26j*
Tube or Tubes Defective or Weak; *6b*
Grid Resistance Shorted; *8d, 8e*
Open or Grounded Grid Bias Resistor or Grid Circuit, *1d, 8e*
Grounded or Open Resistor; *1d, 8e*
Open or Shorted Condenser; *sections 11, 12, 13*
Volume Control Defective; *10a*
A High Resistance Connection; *section 5*

CONDITION B: Signals Distorted at High Levels, Volume Control on Towards Full

Inexpensive Receiver, a Natural; *23d, 23e*
Detector Overloaded; *37b*
Loudspeaker Overloaded; *37e*
Power Tubes Overloaded; *37d*
Weak Tubes; *6b*
Defective A.V.C. System; *section 41*
Improper Supply Voltages; *section 22*
Defective Cone, Voice Coil or Armature of Loudspeaker; *section 38*
Oscillations; *section 32*
Receiver Not Tuned Correctly; *37a*
Manual Volume Control Advanced Too Far; *37a*

CONDITION C: Signals Distorted at Low Levels, Volume Control Towards Low

No Field Excitation to Loudspeaker; *38b*
Incorrect Grid Leak in Detector Stage; *37b*
Power Tubes Insufficiently Excited; *operate set louder*
Supply Voltages Incorrect; *section 22*
Detector Output Overloaded With R.F.; *37c*
Weak or Defective Tubes; *6b*

SIGNALS, NONE; TUBES DO NOT LIGHT

See Section "Tubes Do Not Light"

SIGNALS, NONE; SOME TUBES LIGHT

Poor Socket Contact; *3f*
Poor Soldered Filament Connection; *3h, 3d*
Open Filament Resistor; *1c*
Burned Out Tube; *6b, 6f*
Part of Ballast Tube Defective; *9d*
Shorted Secondary Winding of Power Transformer or Shorted Filament Lead; *17d*

SIGNALS, NONE; ALL TUBES LIGHT

Defective Tubes; *section 6*
Short Circuited Lightning Arrester; *29k, 29o*
Grounded Lead-in or Antenna; *29f, 29o*
Short-Circuited Antenna Coil; *29o*
Poor Contact in Tube Socket; *3f*
No Plate Voltage; *section 22*
Incorrect Supply Voltages; *section 22*
Transformer Defective; *section 16*
Open Circuit; *section 1*
Defective Choke Coil; *section 16*
Defective Filter Condenser; *sections 11, 12, 13, 14*
Open or Shorted Bypass Condenser; *sections 11, 12, 13*
Variable Condenser Shorted; *15g*
Defective Loudspeaker; *section 38*
Tube in Wrong Socket; *26j*
"A" Battery Polarity Reversed; *21d*
"B" Battery Polarity Reversed; *21h*
"A" and "B" Batteries Run Down; *section 21*
Line Plug Reversed (Universal A.C.-D.C. Sets); *30h*
Oscillator Tube or Stage Defective; *section 40*
Coupling Condenser Open, Shorted, Grounded or Leaky; *sections 11, 12, 13*
Defective A.V.C. System; *41a*
Gassy Tubes; *6b*
Volume Control Defective; *10a*
Antenna to R.F. Line, or R.F. Line to Receiver Transformer Defective; *29p to 29r*
Receiver Alignment Has Been Tampered With; *45f to 45j*

SIGNALS HEARD OTHER THAN FROM LOUDSPEAKER

Loose Audio Transformer Laminations; *17f*
How to Trace Defect if Loudspeaker Emits no Sound; *37f*

SIGNALS NONE; SHORT WAVE CONVERTER USED

Noise Heard Indicating Broadcast Receiver O. K. But no Signals When Tuning Converter.

No Antenna Connection to Converter; *25c*
Defective Oscillator Tube; *6b*
Improper Connections to Broadcast Receiver; *25c*
Wrong Plug in Coils; *check coils*
Reception Peculiar in Short Wave Bands; *section 25*

SIGNALS WEAK, DAY TIME ONLY

Natural Receiving Conditions; *section 25*
Aerial Too Short; *29a*

Line Voltage Low; *30e*
Receiver Inexpensive; *23d, 23e*
Also see "Signals Weak"

SIGNALS FADE

See Sections on "Fading"

SIGNAL AT MORE THAN ONE POINT ON DIAL

Two Conditions Arise. *Condition A*, Broadcaster Heard Clearly at Assigned or Not Assigned Frequency; *Condition B*, Local Station Riding in on Distant Station, a Condition Called Cross Modulation. When the Defect Causing This Condition is Not Readily Fixed, a Wave Trap Should be Tried.

Condition A:

Natural or Harmonics of Broadcaster; *28g, 28h*
Two Chain Stations, Same Program; *28k*
Inexpensive Receiver; *23d*
Insufficient Preselection; *28c*
Defective Preselection; *1d*
Image Frequency Trap Defective; *1d*

Condition B:

Wrong R.F. or I.F. Tubes Used; *26j, 28f*
Too Near Local Station; *28e*
C Bias of First R.F. Tube Too High, or Plate Voltage Too Low; *28f*
First R.F. Tube Oscillating; *32f to 32j*
Antenna Too Long; *29d*
Choke and Resistor Antenna Input; *29m*
Weak First R.F. Tube; *6b*

SIGNALS WEAK

Symptoms Observed Are Important As They Indicate to Some Extent The Location of The Defect. Thus You Will Find: *Symptom A*, Distant Stations Weak Locals Rather Normal, Indicating a Defect in The Antenna System or in The R.F. Section; *Symptom B*, Plenty of Stations Picked Up and All Stations Including Locals Are Weak; Indicating a Defect in The Last Detector, Audio System or Loudspeaker; *Symptom C*, Local Stations Only Received, Indicating in General a Circuit Defect Particularly in The R.F. and Pickup Sections, or Low Supply Voltages; *Symptom D*, General Weak Signals in Which Any of The Above Defects May be Indicated.

Location A: Pick-up

Poor or High Resistance Connections in Antenna or Ground; *29b*
Short Circuited Lightning Arrester; *29k*
Open in Ground System; *29o*
Open Antenna Choke or Coil; *29o*
Aerial Too Short; *29a, 29c*
Aerial to R.F. Line, or R.F. Line to Receiver Transformer Incorrectly Connected or Defective; *29p to 29r*

Location B: R.F. Section Defective

Receiver Improperly Neutralized; *45d*
Excessive Oscillation; *32f to 32j*
Tuning Condensers Not Aligned; *45g*
Volume Control Defective; *10a*
Open Secondary R.F. or I.F. Transformer; *16e*
Shorted Primary R.F. or I.F. Transformer; *16e*
I.F. Stages Incorrectly Aligned; *45g, 45h*
Preselector and Oscillator Do Not Track; *45i*
Defective or Dirty Variable or Trimmer Condenser; *15f, 15g*
R.F. Choke Coils Defective; *16e*
Gassy R.F. or I.F. Tubes; *6b*
Oscillator Tube Not Functioning Properly; *6b*

Location C: Detector and A.V.C.'s

C Bias Incorrect, Accompanied With Distortion; *37b*
A.V.C. Tube Weak or Improperly Selected; *6b, 6h*
Grid Leak Defective or of Improper Value; *37b*
Defect in The A.V.C. Circuits; *41a*
Natural Weak Reception Due to A.V.C. Action; *41b*

Location D: Audio Circuits

Audio Transformer Defective; *16e*
Open or Defective Audio Plate to Grid Coupling Condenser; *12a*

Location E: Power Supply

Low Line Voltage; *30c*
Shorted Secondary Power Transformer; *17d*
Storage Battery Charge Run Down; *21c*
"C" Battery Run Down or Incorrect Voltage Used; *21i*
"B" Batteries Run Down; *21i*
"A" Battery Polarity Reversed; *21d*
Battery Terminals Corroded; *21e*
Defective A, B, and C Batteries; *section 21*
Defective Filter Condenser in Power Supply; *sections 13, 14*
No Plate Voltage to Some Stage; *section 22*
Incorrect Voltage; *section 22*

Location F: Loudspeaker Defect

Permanent Magnets Weak; *38i*
Field Circuit Open or Shorted: *38a, 38b*
Voice Coil Open; *38c*
Rectifier Unit in Self Excited Loudspeaker Defective; *38b*
Polarity of Magnetic Loudspeaker Reversed; *38i*

General Defects Producing Weak Signals

Poor Contact at Tube or Tube Socket; *3d, 3f*
Leaky Condensers; *section 12*
Open or Shorted Condenser; *sections 12, 13*
Loose Connections; *section 3*

Defective or Weak Tube; *6b*
Open Circuit; *section 1*
Shorted Circuit or Part; *section 4*
Grounded Circuits; *4b*
Open C Bias Resistor; *8d*
Defective Resistor; *8d*
An Inexpensive Receiver; *23d, 23e*
Open Grid Circuit; *1d*
Control or Top Cap Clips Loose or Grounded; *3f*

SQUEALS, HOWLS, PUT-PUTS

Often Referred to as Regeneration, Oscillation, Whistling, Spilling Over, Instability, Growling, Motor-Boating, Feed-Back and Parasitic Coupling. In the Following Cause List We Refer to the Condition Where This Disturbance is Continuous or While Receiver is Tuned or Playing. These Squeals Are Not a Feature of a Regular Receiver, as it Would Be in Regenerative Receivers and Beat Frequency Locaters in Short Wave Receivers. In the Latter Case The Squeals May Be Stopped at Will. Squealing, Howling and Put-Puts Are an Indication That Undesirable Audible Frequencies Are Present. Squeals and Howls are Generally an R.F., I.F., and Detector Defect; While Put-Puts Referred to as Motor-Boating, Indicates Audio Stage Trouble. This Type of Interference Arises From Several Basic Conditions: *Condition A,* Open, Short or Undesirable High Resistance Causing One Stage to be Coupled to Another Producing Feed Back; *Condition B,* Change in Setting, or Defect in the Oscillation Suppression System, or Change in Voltages; *Condition C,* a Defect in the Receiver; and *Condition D,* Mechanical or Acoustical Feed Back, Detected By a Gradual Rising Whining Sound.

Condition A: Electrical Feed Back Due To Part or Circuit Defect

Undesirable Inductive Coupling Between Circuits; *32k*
Grid Leads Out of Place; *32d, 32c*
Poor Ground Connection; *32j*
R.F. Bypass Condenser Poorly Grounded; *32i*
Open or Shorted Bypass Condenser; *32i, 12d, 13a*
Open Condenser in Power Pack Bleeder Resistor; *32i*
Shorted R.F. Choke or Choke Resistor; *4c*
High Resistance or Corroded Connection; *4f, 4e*
Variable Condensers Not Grounded; *32j*
Poor Connection at Rotor of Variable Condenser; *32j*
Poor Connections in Circuit or Chassis and Shields; *32j*
Open or Shorted Resistor; *8d*
Incorrect Resistor; *8g*
Weak or Defective "A" Battery; *21c*
Run Down "B" Batteries or a Defective Cell; *21i, 21j, 21k*
Insufficient Bypassing and Filtering; *11b*
Incorrect Bypass Capacity; *11b*
Motorboating; *section 33*

Condition B; Change in Adjustment or Incorrect Receiver Operation

Aerial Too Short or Antenna System Open; *29c, 29o, 45k*
Receiver Improperly Neutralized; *32d, 45e*
Grid Suppressor Shorted or Its Value Incorrect; *32d*
High Line Voltage; *section 22*
Excessive Output Voltage of Power Pack; *section 22*
Excessive or Incorrect Plate, Grid, Screen, and Filament Voltage; *section 22*
Defect in A.V.C. System; *41a*
Wrong Tubes in Socket; *26j*
Regeneration Control Improperly Set; *45d*

Condition C: Receiver or Tube Defect

Defective Tube; *section 6*
Gassy Tube; *6c, 6b*
Filament Not Grounded; *30l*
Open Secondary R.F. Transformer; *17b*
Resistor Across Secondary 1st Audio Open; *8e*
Open Grid Circuit; *1d*
Control Grid Cap Making Poor or No Contact; *3f*
Shorted Bias Resistor; *8d*
Grid Leak Open, Defective, Incorrect; *8d*
Shorted Loudspeaker Field (Hum Too); *31c, 17b*

Condition D: Mechanical Resonance and Coupling

Microphonic Tube; *34b*
Loudspeaker Too Close to Receiver or Too Rigidly Mounted in Cabinet; *33d*
Receiver Not Cushioned on Rubber; *33c*
Condenser Plates Too Thin; *15d*

SQUEALS, HOWLS, PUT-PUTS; ONLY WHEN SET WARMS UP

Slow Heater Detector or First A.F.; *6b*
Audio Transformer Primary Connection Reversed; *16d*
Gassy Tube; *6b*
Resistor Across First A.F. Transformer Secondary Open; *8e*

SQUEALS, HOWLS; DISTORTION ON SOME DISTANT STATIONS

Natural Condition; *28l*
Lack of Selectivity; *24e, 45f to 45n*

SIGNALS WEAK, AT ONE END OF DIAL

R.F. or Oscillator Not Tracking; *45i*
Oscillator High Frequency Trimmer Improperly Set; *45i*
Oscillator Low Frequency Padder Improperly Set; *45i*
Coils Improperly Matched; *16h*

Coil Turns Shorted; *16e*
R.F. System Used to Give Equal All-Band Reception Defective; *16e*
Grid Suppressor Shorted or of Improper Value; *32d*
Coils and Condensers Damp, Dirty and Leaky; *16g*
Improperly Neutralized; *45d, 45e*
Wrong Connection to Noise Reducing Antenna Transformer; *29l*

STATIONS NOT RECEIVED AT PROPER POINTS

Receiver Not Correctly Aligned to Dial Scale; *section 20*
Dial Slipped on Condenser Shaft; *section 20*
Cable Slips Auto Sets; *section 20*
Receiver Improperly Aligned; *45i*

TONE CONTROL, INOPERATIVE MANUAL

Open Circuit in Resistor, Condenser, or Lead Associated With Control; *1g*
Variable Resistor Defective; *section 10*

TONE CONTROL ADJUSTMENT MAKES SET DEAD

Shorted Condenser in Tone Control; *13a*
Connections Shorted or Grounded; *1g*

TUBE OR TUBES DO NOT LIGHT

Defective Tube; *6b, 6f*
Poor Contact Between Tube and Socket; *30j*
Open or Short Circuit; *sections 1 and 4*
Grounded Filament Circuit; *30k*
Open Primary Power Transformer; *17a, 17b*
Open Secondary of Power Transformer; *17a, 17b*
Open Lead in A.C. Plug Cord; *30j, 30f*
Storage Battery Weak (Tubes Apparently Do Not Light); *21c*
Battery Terminals Corroded; *21e*
Tube in Socket Having Lower Than Required Voltage; *section 22*
"A" Batteries Run Down; *21g*
Pilot Light Burned Out; *7d*
Set Fuse Burned Out; *use new one*
Filament Cord Resistor Open; *30j*
No Line Power Supply; *check power outlet*
Burned Out House Fuse; *use new one*
Off-On Switch Defective; *30f, 18a*
One Tube Burnt Out in The Series Circuit Universal Receivers; *6b, check each tube*
Filament Resistor or Ballast Open or Burned Out; *section 22*
Open in a Series Circuit Universal Receiver; *1b*

TUBES GO BAD OR BURN OUT TOO OFTEN

Tubes Have a Limited Life and They Terminate Their Useful Service Generally By Losing Emission or Becoming Gassy. Often After Hard Use the Filament Burns Out. Defects or Improper Operation of a Receiver Shortens Their Useful Life, Often Roughly Figured as One Year of Fairly Constant Use.

High Line Voltage; *30e*
Poor Quality of Tube Used; *23g*
Tube Had an Inherent Defect; *23g*
Low Line Voltage Plus Vibration; *30e*
Ballast Tube or Resistor Defective or Incorrectly Chosen; *9a, 9b*
Ballast Shorted; *9e*
Tube Placed in Wrong Socket; *26j*
"C" Bias Too Low, Emission Reduced Quickly; *section 22*
Excessive "A" Battery Voltage or Customer Pushes Filament Current Up For Volume; *21g*
Pilot Lamp in Shunt With a Filament Open or Burned Out (A.C.-D.C. Receiver); *7d*
Series or Shunt Resistor in Filament Shorted or Open (A.C.-D.C. Receiver); *7d*
Customer's Opinion; *23g*

TUBES GET BLUE ON GLASS

Natural Condition of Fluorescence; *6c*

TUBES GET BLUE INSIDE AMONG ELEMENTS

Natural in Case of Mercury Vapor Tubes

More Often Due To:

Shorted Stage; *1b*
Grounded Filter Choke; *17c*
Shorted Filter Condenser; *13a, 14h*
Open Bleeder Resistor; *1d, 8d*
Shorted or Grounded Loudspeaker Field Coil; *31a*
Open Grid Return in Power Stage; *section 22, 1d*
Excessive Plate Current; *section 22*
Excessive Plate Voltage; *section 22*

Less Often Due To:

Shorted Bias Resistor; *section 22*
Positive Grid Voltage; *section 22*
Excessive Screen Voltage; *section 22*
Defective Coupling Condenser; *12d*
Defective By-Pass Condenser; *13a*

TUNE, CANNOT

Defect Clearly Mechanical and Easily Located by The Action Observed

Dial Slips; *20a*
Bearings Frozen; *20b*
Cable Broken or Off Pulleys; *20a*
Wire Laying in Path of Condenser; *20d*
Chassis Too Far Into Cabinet; *20d*

Condenser Plates Bent; *20d*
Chassis Not in Proper Position; *20d*
Gears Worn—Back Lash; *20e*
Gears Improperly Spaced; *20d*
Cable Loose; *20a*
Set Screws Loose; *20d*
Tuning Locked; *20b*
Defective Tuning Apparatus; *20d*
Cable Improperly Restrung; *20c*

VIBRATOR DOES NOT LAST

Typical of Auto Radios and 6, 32, and 110 volt Vibrator "B" Eliminators Continuous Operating With Excessive Sparking Causes Burning of Contacts.

Condition A: Overload

Defective Rectifier Tube; *6b*
Defective Filter Condenser; *13a, 14h*
Defective Bypass Condenser; *13a*
Defective Tube in Receiver; *6b*
Open Bleeder Resistance; *1d*
Defective Transformer Into Which Rectifier Feeds; *17b, 17c*

Condition B: Underload

Weak Tubes in Receiver or Rectifier; *6d*

Condition C: Improper Adjustment of Contacts; 44b

VISUAL TUNING INDICATOR, NO ACTION OF

When a Strong Broadcaster is Tuned in The Needle (Meter Indicator) or The Shadow Width (Shadowgraph Indicator) Neon or Blinker Lamp Shows No Change, It is Understood That The Receiver Has A.V.C. and Reception is Normal Except for A.V.C. Indicator Defects.

Case A: Meter and Shadowgraph

Gassy Control or Controlled Tube; *6d, 6b*
Insufficient Signal Pick-up; *42b*
Needs Realignment; *45f to 45k*
Shorted Tuning Meter; *42c, 42d*
Shadowgraph Pilot Lamp Burnt Out or Not Secure in Socket; *42c*
Open Circuit (Meter Burnt Out); *42c*
A Defective A.V.C. System; *42g, 41a*

Case B: Neon Indicator

Defective Indicator Tube; *42c*
Shorted or Defective Neon Lamp Current Limiting Resistor; *8d*
Low Supply Voltage to Neon Indicator; *42e*
A Defective A.V.C. System; *42g, 41a*

Case C: Blinker Lamp System

Defective Lamp; *42c*
Defective Transformer to Blinker Lamp; *42f*
Defective Blinker Transformer Filter Condenser; *42f*
A Defective A.V.C. System; *42g, 41a*

VOLUME GREATER WITH GROUND WIRE DISCONNECTED

Poor Antenna—Pickup via Power Line; *29i*

VOLUME, LOWER WITH ALL WAVE ANTENNA

Improper Matching of Impedances; *29l*
Antenna Poorly Designed or Erected; *29e, 29l*
Defect in All Wave Antenna System; *29p to 29r*
Improper Connection of Receiver, Line Transformer; *29l*
Customer Expects Too Much; *23f*

B: GENERAL DEFECTS AND TESTS

1. OPEN CIRCUITS. (*a*) In testing a radio circuit an "open circuit" is taken to mean a break in the path of D.C. supply currents or signal currents.

(*b*) As any path for a D.C. current must be continuous over a conductor, an open or break is tested with an ohmmeter. This device is indispensable and no serviceman would think of tackling a job without it. Between any two points or terminals of a D.C. path there must be a definite value of ohmic resistance. If you test between these two points and merely observe that the ohmmeter reads a resistance value, you have proved that the path is continuous—you have tested for continuity; if you get no resistance reading the circuit is open and defective; if you get a varying reading, a make and break connection exists; if you compare the resistance value with what it should be, you have gone a step farther and may be able to tell if some part is shorted.

(*c*) An ohmmeter is essential to prove that a circuit is continuous, shorted or open. A circuit diagram of the receiver you are working on is of great help, as you may trace each circuit for continuity or for exact resistance by referring to the diagram.

(*d*) When a circuit diagram is not available it is possible to check a D.C. path for continuity if the following rules are remembered. Continuity in any tube circuit should exist between: *1*, a plate and the filament (or cathode) of the rectifier tube; *2*, a screen grid and the cathode of the rectifier tube; *3*, a control grid and the chassis; *4*, a suppressor grid and the chassis; *5*, a cathode and the chassis. Continuity may or may not exist between the chassis and the filament (or cathode) of the rectifier tube, depending on whether a power pack bleeder resistor is or is not used (check the circuit diagram).

(*e*) As the electrodes of most tubes in a radio receiver are series fed (through the signal circuit parts) in general a continuity check for D.C. supply will be a check on signal circuits. The exception is inductive and capacitive coupling between stages or sections.

(*f*) As a rule a break in a D.C. supply circuit destroys reception, a break in a signal circuit may create many forms of troubles, which are pointed out in the index on receiver troubles. A circuit disturbance test will indicate the defective stage of a dead receiver.

(*g*) Any part in a circuit may be checked for an open by merely connecting an ohmmeter to its terminals. Coils, resistors, and transformers may be checked for continuity and exact resistance, if you know what its value should be. Usually the circuit diagram gives the ohmic value. Condensers should test open (see section on condensers).

(*h*) An absolute check on any part with an ohmmeter should be made with one of its terminals disconnected from the chassis, for if that part is shunted by some other part or circuit which conducts a D.C. current a true reading will not be obtained. A circuit diagram will help you decide whether this procedure will be necessary. If no diagram is available, and you question the reading you get while the part is in the circuit, disconnect it for the test.

(*i*) Several ohmmeters which you can construct will be mentioned in the Course. You can build one from the parts supplied with your Experimental Outfits.

2. THE CIRCUIT DISTURBANCE TEST. (*a*) When a receiver is dead—does not play, then there are no symptoms to help you locate the trouble. A test should be conducted to find out which stage is defective. Realizing that a radio receiver is nothing more than a chain of stages (R.F., Detector, A.F., Loudspeaker sections in cascade), a simple test is possible. It is called the circuit disturbance test, and is based on the principle, that if any stage is disturbed or shocked, the current change in that stage will be relayed on towards and through the loudspeaker, coming out as a click—if the stages following the one disturbed are in working order. You can create a disturbance by *1*, pulling out and returning a tube from its socket; *2*, touching the control grid of a screen grid tube; *3*, in the case of tuned R.F. stages touch the stator section of the variable condenser in the stage being tested; or *4*, remove and return the control grid cap of the screen grid tube. Any one of these should produce a click or squeal, and as the test proceeds from the loudspeaker to the antenna the clicks should, in general, become louder.

(*b*) In locating the defective stage by means of the circuit disturbance test, start with the power output stage. Pull out the tube, and immediately insert it back into its socket. A click means: a normal section from the power tube through the loudspeaker; no click means: lack of power supply, defective loudspeaker, defective tube, or an open circuit—tests you will find in this reference book. Repeat this test for the other power tube, if one is used. If the output stage is working according to this click test, proceed to test the A.F., Detector, and T.R.F. stages for a tuned radio frequency receiver; test the second detector, I.F., oscillator, first detector, and preselector stages in the case of a super. Use any of the four methods of getting a disturbance, previously mentioned. When you go from a click to no click, the defective stage is isolated. Test the tube, and check the continuity of that stage.

(*c*) Checking the oscillator in a superheterodyne receiver by the click method may be a little confusing. A sure test is made as follows. If pulling out the first detector tube produces a click, and connecting the antenna to the grid of the first detector (set normally tuned to a local station) doesn't produce signals in the loudspeaker, the oscillator is defective. Test the oscillator tube and the continuity of its circuits.

3. LOOSE CONNECTIONS. (*a*) By a loose connection we usually mean, a connection that appears to be properly made, but actually is not a solid one. All connections must either be soldered, or securely clamped together. Only antenna and ground connections should be made through a binding post. Power supply, loudspeaker and isolated sections (R.F. and detector chassis separated from the A.F. and power supply) are connected by prong and receptacle connections.

(*b*) Any connection which is insecure, that is, its contact resistance varies, is a loose connection. When the connection opens electrically it may be considered an open connection, and a physical jar or a vibration will often restore the connection.

(*c*) When noise is emitted from a receiver, and still exists when the antenna and ground leads are disconnected, and the noise will change when the chassis is violently slapped with the palm of your hand, a loose connection probably exists—a connection whose contact resistance is varying.

(*d*) Loose or improperly soldered connections can usually be located by touching the various joints in the receiver with a wooden stick. Of course, the receiver chassis and loudspeaker are removed from the cabinet, the chassis set on one of its ends so all parts are easily seen and touched, and the receiver is turned on. An orange wood stick can be used as they are very durable and can be bought at any drug store. Press firmly on each joint. Very often joints that appear to be well soldered are held only by rosin. If the receiver is properly connected for operation, the pressure on a suspected joint will usually produce a crackling sound in the loudspeaker. Another frequent cause of trouble is broken wiring under the insulation of flexible wire. Manipulation of the wire from side to side will usually indicate where the trouble occurs.

(*e*) Wiggle all cable plug connections, the A.C. plug, antenna and ground binding posts and leads, and battery lead connections; if the receiver is of the battery type.

(*f*) When the loose connection is disturbed the noise will be more violent, or may be produced at will. Quite often the loose connection may be inside the part, particularly fixed condensers. Be sure to wiggle and snap with your fingers: all tubes; tube top caps; and those parts covered with a can, case or shield; and all controls. A loose connection may be internal. If the loose connection is inside some part and the connection cannot be rectified, a new part should be used. Check socket contacts and connections.

(*g*) If with the noise, definite receiver troubles are observed (hum, oscillation, weak signals, improper control, etc.), the symptom will very likely indicate the probable cause and location of the defect. Refer to the probable causes in the index under the symptom observed.

(*h*) A total break in a connection which cannot be seen, hence called a loose connection, will not produce noise. Usually by pulling on the various leads the connection will break or noise will be heard. These loose connections can be traced with a continuity test. Furthermore, the symptom will often lead you to the probable location of the defect.

(*i*) Quite often the heat of the chassis will cause a connection to open and close. This difficulty is handled in the same way, although actual tracing of the defect may be difficult because the connection may, while testing, become secure.

4. (*a*) **SHORT CIRCUITS** may or may not destroy reception, depending of course on where the short exists. When a short destroys reception, the defective stage may be isolated by the circuit disturbance test. Read section 2. Then an ohmmeter check on each part in that stage will show up the shorted part; the ohmmeter will read zero or abnormally low resistance. If the short cannot be rectified, use a new part.

(*b*) In a number of cases a part will be grounded to the chassis and in this way becomes shorted. This is often caused by a part being pushed from its correct position, or the insulation of its lead through the chassis becoming worn, thus creating the short. Repositioning the part or replacing the defective insulation removes the short.

(*c*) If the short does not destroy reception, only ruins it, the symptoms observed will help localize the short, and then the parts in the circuit can be checked with an ohmmeter.

5. HIGH RESISTANCE AND CORRODED CONNECTIONS. (*a*) A connection or joint of only a few ohms is not wanted as it produces many undesirable effects. Anything above a near zero ohm connection is referred to as a high resistance connection. Although a low range ohmmeter (0 to 10 ohm range) will allow you to check such joints, it is easier to spot these poor connections and make new ones. Here are a few hints in spotting high resistance joints.

(*b*) Joints that have an excessive amount of rosin, are likely to become poor joints. Resolder such connections.

(*c*) A greenish covering on a joint indicates corrosion and eventually a high resistance connection. Resolder such connections, or clean corrosion off if only a pressure contact is used.

(*d*) A connection made with excessive solder may have a high resistance if the two parts or wires to be connected are separated by a lump of solder instead of being soldered close together. Such joints are particularly objectionable in short wave circuits.

(*e*) A good solder joint may be made if the two surfaces to be connected are cleaned, tinned and physically clamped together before being soldered. Acid or acid core solder must not be used.

(*f*) High resistance and corroded connections will result in feed back, poor selectivity, lack of sensitivity and many other defects indicated in the index of receiver troubles.

6. TUBES. (*a*) It is safe to say that a majority of receiver troubles are caused by tubes which are bad in one way or another. The filaments of tubes may burn out, may lose their emission, their elements may short, the tube may become gassy, its characteristics may change and poor connections inside the tube may develop.

(*b*) The most satisfactory test of a tube is to try a new one in its place. A test in a tube tester is not always sufficient because although the tester may indicate that the tube is good it may not be satisfactory for certain purposes.

(*c*) For example, a tube may have a slight amount of gas. It would be entirely unsatisfactory for use in an automatic volume controlled or oscillator stage, as the output volume would vary. (It might work fine in another stage of the receiver.) Power tubes should show no glow between elements and they will if gas is present. A blue glow on the glass is natural, a condition of fluorescence.

(*d*) In many service shops the first thing which is done to a set coming in for repairs is to remove the old tubes and try an entire new set. Should the trouble clear up, the old tubes are reinserted one at a time until the bad one is located by recurrence of the difficulty.

(*e*) Elsewhere in the Course, we show how tubes may be tested in regulation tube testers and if you have such a tube tester, you need only follow the manufacturer's instructions. Also, we show how short checkers can be made and operated. An ohmmeter, however, will enable you to check a tube for shorts. The only two prongs which should show continuity are the filament prongs.

(*f*) By placing your hand on a tube while the receiver is operating, you can often-times tell whether it is working. If the tube is cool it has no plate current and a new one should be tried. Excessive heat may indicate the presence of improper control grid voltage or circuit defects which would result in excessive plate or screen voltage and this would lead you to make actual voltage and current measurements on that stage.

(*g*) Noisy tubes can be tested by snapping them with your finger when the set is operating. If this causes the noise to show up, a new tube should be tried.

(*h*) When choosing a tube for use in an automatic volume stage, tune in a weak signal and then try a number of tubes. Use the one which reduces the volume the least but cuts the volume down on powerful stations.

(*i*) When several similar type tubes are used in the same receiver (for example, three type 58 tubes) interchange the tubes for the best results.

(j) Whenever tubes are used in pairs (push-pull, push-push), it is important that two tubes each with the same characteristics be used, otherwise hum and distortion may result. Full-wave rectifier tubes should have equal emission per plate. Balanced tubes are best checked in a tube tester, but they must also be checked in the receiver as a receiver short or ground may exist.

7. (*a*) **PILOT LIGHTS** are a source of nuisance and trouble. They burn out or cause receiver troubles. Their voltage rating should be equal to the voltage of the filament line to which they are connected, if a shunt connection is used; or their current rating equal to the line current if a series connection is used. Check the voltage with a low range A.C. voltmeter, if a large number of burn outs occur; or check the circuit diagram and determine by referring to a tube table what the filament current should be of the tubes with which the lamp is in series.

(*b*) A pilot lamp with higher voltage rating than the source voltage may be used, if sufficient light is obtained; but a low voltage lamp must not be used on high voltage source. For example; a 6.3 volt pilot lamp may be connected to a 5 volt source, but a 5 volt lamp must not be connected to a 6.3 volt source. A lamp with higher voltage rating than its source will burn dim.

(*c*) Loose connections in the pilot lamp circuit or failure to screw the lamp tightly into its socket will cause a flicker. It is possible to solder these lamps in place, if they get loose too often. A loose connection in the pilot light circuit will often times cause noise. You should be sure that the pilot lamp leads cannot be hit by the tuning condenser mechanism as it revolves.

(*d*) In some sets the pilot light may be used as a fuse, being connected in series with the filaments of the tubes. As a replacement you can use a lamp rated at a slightly lower voltage than the original. (These lamps require more current to light brightly.) In universal receivers the pilot lamp may be used as a shunt across one or more tubes. If the lamp burns out the set will continue to play but excessive filament voltage will be applied to the tube which was shunted by the lamp. Always replace any burned out pilot lamp in universal receivers. In many cases particularly where the lamp is used as a fuse none of the tubes will light when the lamp is burned out.

(*e*) In receivers using a center tap filament circuit care must be taken that the pilot lamp does not become grounded as this would unbalance the center tap and hum would be heard.

(*f*) To be on the safe side always use high quality pilot lamps for replacements.

8. (*a*) **RESISTORS** are made in three general forms: *1*, wire wound on a tube (porcelain or bakelite) and often coated with baked vitreous enamel; *2*, resistance material like carbon mixed with a binder (bakelite resin or a ceramic), extruded into rods, cut and baked; *3*, glass or porcelain coated with a resistive material. Of course, these elements are capped with terminals, coated with enamel and labeled to improve their appearance, and to help identify their value. A resistor is rated as to resistance and power dissipation. For ordinary radio receiver use, wire wound resistors are accurate to 5 percent, ceramic and coated (metallized) resistors are accurate to 10 percent. These facts are important in checking their ohmic value. The exact value is dictated by the use to which a resistor is put. For replacement be governed by the service diagram, or label or color code on the resistor found defective.

(*b*) Power rating is important if you want the resistor to stand up. Grid resistors may be 1 or 2 watt types, plate resistors 2 watts, bleeder resistor 5 watts and power pack resistors must be calculated or manufacturer's specifications followed. In the final analysis the watts dissipated in a resistor is the current through it in amperes, times the voltage drop. If the resistor is under the chassis or covered, the resistor should have a rating 4 times this computed value; if the resistor is well exposed to air a safety factor of 1.5 to 2 times, will suffice. It is a good idea to never use a resistor less than 1 watt rating where space will permit.

(*c*) There are other ways of judging a resistor: voltage, temperature, and age tests; but if a reliable make of resistor is used, these items may be ignored.

(*d*) There is only one simple way of testing a resistor—with a multi-range ohmmeter (one part of a multimeter). It should be able to test as low as one ohm and at least as high as 2 megohms. When a good ohmmeter is not available, you may use a 0-50 voltmeter connected in series with a 45 B Battery block. Of course, only continuity may be checked. The free end of the voltmeter and the battery are connected to two probe leads. Bring the two probe points together and note the deflection: it should be about 45 volts. Now when you connect the probes to a resistor and get maximum reading the resistor is either shorted or has a very low resistance; if no reading is obtained the resistor is open; any in-between reading indicates continuity and the resistor is *probably* o. k. If you use an ohmmeter (calibrated to read directly in ohms) there is no guessing about the resistor value. Now for a few hints.

(*e*) In testing any resistance, always be sure that it is not connected to other apparatus, such as a coil; as this would give an apparent short-circuit reading. If the resistance is in a receiving set this can be determined by very carefully checking over the entire circuit to which the resistor is connected, using the schematic diagram if one is available. In case of doubt on this subject, it is the best policy to disconnect one lead of the resistor from the circuit for test purposes.

(*f*) In the case of tapped resistors such as those used in many power packs and also the hum adjustors on many sets, it is necessary to test each individual section of the resistance.

(*g*) It sometimes happens that a resistance may not burn out, but may change in value, either increasing or decreasing. Occasionally an incorrect resistor may accidentally be placed in a circuit. In such cases it is necessary to use an ohmmeter in order to check the resistor with the value specified in the manufacturer's service data.

9. BALLAST RESISTORS. (*a*) Unless the ballast has been chosen correctly, either the ballast itself or the tubes will burn out too often. Ballasts are rated as to their current carrying capacity and average voltage drop. The latter means that if you set the primary of a power transformer to 100 volts, the ballast takes up the voltage difference in the line supply. Receivers using 5, 6, 7, 8, etc. tubes require ballasts of different current capacity. Be sure to order and use a ballast for:

A: the wattage or number of tubes in the receiver, and

B: for either 100 volt or 85 volt primary transformer voltages.

Buy from a distributor or manufacturer willing to give you help in selecting the proper size ballast.

(*b*) The ballast will burn out if it was designed for a receiver of less wattage or tubes —or for a lower primary voltage. If the ballast was designed for a set with more tubes, the ballast action will be less and more chances for tube burn outs exist.

(*c*) A number of line voltage controls are either variable resistors or resistors of fixed ohmic value. They do not have any ballast action. A ballast of reliable make is preferred on a line of varying voltage.

(*d*) Modern battery receivers employ filament supply ballast resistors. In some receivers, the filament system is divided into two sections each controlled by a ballast; both ballast resistors in the same ballast tube. If one burns out the tubes in that section do not heat up. Check the radio tubes, if found o. k. check the ballast. A check consists of a continuity test and inspection of the part value used in the receiver. A ballast resistor of the glass envelope type should burn a deep cherry red.

(*e*) If the ballast resistor has been shorted accidentally or intentionally because the latter has to be replaced too often, the radio tubes will quickly burn out. If the correct ballast is used and burns out too often, the receiver is defective (see index for probable causes).

10. VOLUME CONTROLS OR VARIABLE RESISTORS. (*a*) Volume controls usually are some form of variable resistance. They are either of the wire wound or coated type. First inspect the volume control for mechanical perfection. No wires should be loose and the resistor coating should not be flaky. The movable contact should be firm against the resistor element, and make a good contact. The arm should turn freely. Then connect an ohmmeter to it and see that as the movable arm is rotated the resistance varies without sudden changes. If the resistance element is broken or worn it should be considered as defective and the entire volume control replaced.

(*b*) A popping, cracking noise heard in the receiver only when the volume control is adjusted is positive indication that the device is defective. (An exception—a good volume control in the c bias or grid circuit of a gassy tube will give this action—try a new tube) Generally speaking, it is not practicable to attempt to repair a volume control. It should be replaced with a new one which can be obtained from the distributor of the receiving set in your locality or from any large radio supply house, if you give them the exact name and model number of the receiver.

(*c*) Before removing the old control prior to replacement draw a picture diagram of the connections—then it will be easy to connect the new control.

11. CONDENSER, FIXED. (*a*) Most fixed condensers used in radio receivers either use wax paper or mica as the dielectric and are therefore referred to as paper or mica condensers. Paper condensers are either housed in aluminum, tinned sheet steel, moulded bakelite or paper containers with suitable lugs protruding as the terminals; mica condensers are moulded inside of bakelite forms. Moulded condensers are usually small capacity devices, rarely over .05 microfarads; the paper condenser values range from .05 to 10 microfarads.

(*b*) Condensers are first rated as to their capacity—in microfarads. A variation of 10 percent (except padding condensers used in the oscillator circuit of a superheterodyne receiver) is of no importance. Although a capacity checker is used by a few servicemen, it is not an essential service device. Be governed by the service diagram for the correct value to use; the capacity on the condenser label or case put on by the condenser maker is a sufficient guide. If no service diagram is available use: .1 to .25 mfd. for R.F. and I.F. bypasses; .25 to 1 mfd. for A.F. bypass; 1 to 10 mfd. for C bias resistor shunt capacitors in A.F. circuits; .00025 for grid leak detectors; .0001 for R.F. coupling condensers; .01 to .25 for A.F. coupling condensers.

(*c*) The voltage rating of a fixed condenser is important. The voltage across the terminals to which the condenser is connected is your guide. It's rating should be greater than this value. Good servicemen never use a fixed (paper or mica) condenser with less than a 200 volt rating; some insist on a minimum 400 volt rating. Filter condensers of the paper type should have a 600 volt rating. These are good replacement rules to use.

12. OPENS AND LEAKS. (*a*) The easiest way to locate an open condenser in a receiver is to place the receiver in such a position that the connections to the various condensers can be easily reached. Turn the receiver on and then connect a condenser of approximately the same size and known to be in good condition across the connections to the condenser which you are testing. If normal reception is obtained when making the connection it is an indication that the condenser under test is defective.

(*b*) Another method of testing a condenser is to entirely disconnect the condenser from the receiver and to then charge the condenser by momentarily touching the connections of a 45 volt "B" battery across the condenser terminals. A condenser, not of the electrolytic type, should hold a charge for several minutes, which can be checked by shorting it and observing the spark. If the charged condenser being tested is of small capacity, the cord tips of a head-set can then be touched to its terminals, care being exercised not to touch the cord tips or the condenser terminals with the fingers. A sharp click in the phones when the contact is made indicates that the condenser is in good condition and has held the charge. In the case of paper condensers having a capacity of .5 mfd. or larger, merely short circuiting the terminals after the condenser has been charged should produce a bright spark accompanied with a loud snap. Such a condenser should be able to hold a charge three or four minutes between the time it is charged and discharged.

(*c*) If the condenser does not hold its charge and no spark or a very feeble spark is obtained it indicates that the condenser is leaky or open and it should be replaced with a new condenser. If a high voltage, high range ohmmeter is available, capable of measuring up to 30 megohms, a good 1 mfd. condenser should show not more than 30 megohms leakage resistance.

(*d*) If the leak in a fixed condenser varies, noise will result. After prying parts and connections with an orangewood stick to be sure they are not at fault, then unsolder each fixed condenser and listen if the noise has disappeared (set turned on). Resolder connection before testing another condenser. If reception stops, a temporary perfect condenser should be used. Defective resistors causing noise may be located in the same way provided opening the circuit does not stop the receiver. Don't solder or unsolder with the set turned on.

13. SHORTS. (*a*) Condensers, not of the electrolytic type, can best be tested for shorts and leaks by connecting an ohmmeter, or a voltmeter in series with a battery, across their terminals. A steady reading should not be obtained. A momentary deflection of the pointer of the meter, which then returns to zero, indicates that the condenser is neither open or shorted. If a steady deflection is obtained it indicates that the condenser is defective and it should, of course, be replaced.

14. (*a*) **ELECTROLYTIC CONDENSERS** are made in two forms for use in radio receivers: the wet type in a long cylindrical aluminum can; or the dry (paste electrolyte) in a paper container. Although some are made with 2, 3 and 4 units in one container, the usual form is a single unit electrolytic condenser. An electrolytic condenser has polarity. In the metal container unit the can is invariably negative, the insulated electrode the positive terminal; in the case of paper wrapped electrolytics the container near each lead or lug is marked + or −. If no marking is to be seen the red lead is invariably +.

(*b*) Electrolytic condensers are rated as to capacity and working voltage. For filter use the most common sizes are 4 and 8 microfarads, although smaller and larger capacities are readily obtained. Use only condensers with a rating of 475 to 500 D.C. working volts.

(*c*) A.F. bypass condensers are often of the dry electrolytic type. As the required voltage rating is low, and the capacity high, a small compact unit is available. Units of 10, 25 or 50 microfarads with 25 to 75 volt ratings are used. For filtering rectified A supplies 15 volt-1000 or 2000 microfarad dry electrolytics are employed.

(*d*) In replacing an electrolytic be guided by the specifications given on the service circuit diagram, wherever possible; otherwise be guided by the information given elsewhere in this book.

(*e*) Electrolytic condensers develop shorts and opens and may also develop trouble which is not made evident by tests the ordinary serviceman has facilities to make. For this reason, it is recommended that, if a large amount of service work is done, a 4 and 8 mfd. electrolytic condenser with a high voltage rating be carried with you on all jobs for test purposes. The leads of the condenser suspected of being defective can be unsoldered and the one you know to be in good condition can be connected in the circuit in its place. This will give you a check on the original condenser.

(*f*) To test for short circuits or excessive leakage through an electrolytic condenser, a 0-100 milliammeter should be connected in series with the condenser while the receiver is in operation. However, before turning on the power a 6 or 10 ohm rheostat should be connected across the terminals of the milliammeter. The rheostat should be of the type that has an open end; in other words, so that the rotating arm can slide off of the resistance winding which, in effect, means the rheostat is not connected across the milliammeter. The rheostat shunts the meter and increases its range, which will prevent burn-out of the meter if the condenser is entirely shorted or while the film of the condenser is building up.

(*g*) The receiver is then turned on. At first the current through the condenser is likely to be as high as 85 or 90 milliamperes. However, this high value of current should only be evident momentarily and after three or four minutes of operation, the current through the condenser should reduce to less than ¼ milliampere per microfarad. In other words, if the condenser under test is an 8 mfd. electrolytic condenser, the total current flow as measured by the milliammeter after five minutes of operation should not be more than eight times ¼ or 2 milliamperes. If more than 2 milliamperes is measured after a few minutes of operation, then the electrolytic condenser has excessive leakage and another one should be used in its place. Unless the condenser is completely shorted, the rheostat should be turned to the off position so as to get the true value of current through the condenser.

(*h*) Many servicemen test an electrolytic condenser by shunting it with an 0-1 megohm ohmmeter (an ohmmeter with a 45 battery is preferred). Connect the ohmmeter so the ohm indication increases, showing that the film is building up. As an average value the reading should exceed 1 megohm. You should check several good electrolytics to obtain an idea of what this value should be with your ohmmeter.

(*i*) Electrolytic condensers, it has been mentioned, have positive and negative terminals and if they are connected into a circuit incorrectly they will pass too much current. This may cause them to make a hissing or frying noise, and if kept up for any length of time, ruin the condenser, rectifier tube, and filter chokes.

(*j*) A voltage applied to a condenser higher than its rated working voltage will cause it to hiss and fry and eventually break down. This happens quite often, when the loudspeaker cable has not been connected to the chassis. Any defect in the power stage or loudspeaker that removes the load on the power pack, increases the rectified output voltage, will have the same effect.

(*k*) Electrolytic condensers that have not been used for a long time, especially in cold weather, may hiss and fry when voltage is applied to them due to the fact that they are improperly formed. Usually this will not last over a few minutes after which they will be in good condition. But if they hiss, watch the rectifier tube. If the space between the elements starts to turn blue shut the power on the receiver off at once. Use a new electrolytic.

(*l*) In checking an electrolytic condenser by the substitution method, listen to the receiver play so you can tell whether the new one makes an improvement in results.

15. TUNING OR ADJUSTING CONDENSERS. (*a*) *Variable condensers* are usually rated as to maximum capacity. Their minimum capacity and high frequency resistance are important factors but these factors are not easily checked by a serviceman. Always consider the maker, and when a replacement is required insist on an exact duplicate. In general a good variable condenser may be judged by its mechanical construction. The plates should be large gauge sheet aluminum, alignment of plates exact, and the frame of solid appearance. Sliding or pigtail connections should exist at each rotor section.

(*b*) Many service calls may be traced to defects in the tuning condensers. The plates of the condensers sometimes touch each other. They should be carefully bent so that this does not occur. Dust or dirt between the plates may be removed with a pipe cleaner. A metallic fuzz sometimes gets between the plates, causing shorts to occur at some points of the dial setting. A pipe cleaner will not remove this. It may be removed by burning it off by the application of a high voltage across the condenser plates. Unsolder the lead to the stator plate and apply the high voltage directly across the condenser, turning the tuning knob so that all shorts will be burned out. Dirt may be removed and leaks between plates may be eliminated by the same process. This voltage may be obtained from the high voltage winding of a power transformer, not the one in the set; and to protect the transformer a 100 watt lamp should be placed in series with the primary.

(*c*) The connections between the rotors of the tuning condensers and the chassis are very important. Should a poor connection occur, the ground will have to be through one of the other tuning condensers and this may result in feedback and consequent oscillation. When spring wiping contacts are used bend them to get a good contact and if necessary sandpaper all points of contact. Sometimes a pigtail (flexible) wire may be used to ground the rotors. If the wire cannot be readily soldered to the condenser shaft a small hole may be drilled in the shaft and a screw used to connect the wire and the shaft. Enough slack must be left so that the pigtail can wrap around the shaft when the condenser is turned.

(*d*) In some poorly designed receivers the condenser plates are so thin that they will vibrate. Naturally this change in capacity will cause very unstable reception. In most cases a new condenser gang is about the only remedy although some servicemen float the condenser on soft sponge rubber to reduce the vibrational pickup.

(*e*) If you find that it is impossible to tune a receiver over its entire range examine the tuning condensers as they may hit a wire or other stationary object which prevents them from turning.

(*f*) *Trimmer Condensers* sometimes short and they should be tested for continuity. Remember when testing any condenser to disconnect one of its leads otherwise you will obtain a reading through some object shunting it. If the mica in a trimmer condenser appears cracked it may be removed and a new piece installed.

(*g*) To check a section of a ganged condenser or a trimmer, unsolder the lead from one end of the condenser so the coil shunting it is disconnected, and check the condenser with an ohmmeter. No reading should be observed.

16. (*a*) **COILS, R.F. CHOKES AND A.F. TRANSFORMERS** are an important part of a radio receiver and naturally are used for their inductance. We will consider: *1*, the R.F. coils wound single layer on an insulating tube; *2*, the multi-layer coil used extensively in I. F. transformers, primary of R.F. transformers, secondaries of coils in midget receivers, and R.F. and I.F. choke coils; and *3*, the audio transformer.

(*b*) R.F. coils are fundamentally designed to have a definite inductance, a minimum amount of distributed capacity, and low high frequency resistance (or Q factor). The high frequency resistance cannot be judged from its D. C. resistance (measured with an ohmmeter) and is generally much greater. Audio transformers are designed for a definite frequency range, definite D.C. primary current, turn ratio and minimum distributed capacity, and maximum watt handling power. Tests for these properties are not made by the serviceman, unless a great deal of original designing is done.

(*c*) The usual tests are for continuity, opens, shorts, grounds and D.C. resistance of the windings. In the case of coils used in a tuning section the coils must match: have equal inductance and distributed capacity, best accomplished by using identically constructed coils.

(*d*) In connecting an R.F. or A.F. choke remember that they are so designed that the inside turn (nearest the core or form) is the ground or a low potential connection, the last outside turn is the high voltage (R.F. or A.F.) terminal. In connecting R.F. or A.F. transformers the inside turn of the primary (one nearest the core) is the plate connection; the outside primary turn, the +B connection. In transformers the outside turn of the secondary is the grid terminal, the inside turn (nearest the core) is the ground connection. In tracing the coils from the plate, to +B, to ground, to grid, a continuous winding, all in the same direction, should exist. Most servicemen merely reverse primary or secondary connections, and observe whether an improvement exists. In the case of split primary or secondaries, the center tap is ground, +B or − C, and the outer two terminals are the plate or grid connections.

(*e*) To test for continuity or winding resistance use an ohmmeter, the probes connected to the two terminals of the winding you wish to measure. Be governed by the values given on the circuit diagram. Shorts between a few turns are not easily detected by this test. Shorts in R.F. transformers can be judged by inability to line up the stage with another, broad tuning and lack of selectivity; in audio transformers no easy means of detecting a short between a few turns are possible. Of course, a replacement test will quickly show up any short; the action of the receiver will indicate its presence. Opens are easily detected by a continuity test. By unsoldering the terminals of a coil. choke or transformer, grounds or shorts to the frame or core are easily detected with an ohmmeter. Connect the ohmmeter to one terminal of each winding (the receiver leads unsoldered), and the core, or chassis of the device. No reading should be observed. Leaks are detected by employing a high range ohmmeter (at least 2 megohms).

(*f*) *Opens* occur because of poor soldering, corrosion at joints. and a physical tear; ***shorts*** are produced by high voltage arc overs, atmospheric conditions (moisture and fumes in the air), and tampering; *leaks* occur because of accumulation of dust and dirt plus moisture, breakdown of insulation: and ***change in inductance*** because the windings get loose, are crushed physically, or the shield has been disturbed.

(*g*) A physical inspection of coils is imperative. If the coil is moist be sure to bake it under a lamp. Go over joints and connections. Be sure the windings and shields are intact. Test for opens, shorts, leaks and resistance of windings.

(*h*) If an R.F. or I.F. coil is damaged beyond repair (one or two turns may safely be removed) use a new coil. Do not try to replace a secondary or a primary. Get a whole new part and an *exact* duplicate preferably made by the maker of the receiver you are servicing. If the new (or old) coil will not align with the others, either the other coils must be adjusted for turns, or a whole new set of coils procured and used.

17. POWER TRANSFORMERS AND IRON CORE CHOKES. (*a*) *Power Transformers* are designed to operate from a line of a definite frequency and voltage; to supply definite voltages from the secondaries when definite currents are drawn; and to handle a definite total ampere × volts —— apparent watts rating. *Iron Core Chokes* are designed to have a definite inductance (usually measured in henries) when a definite D.C. component flows through it. It must be able to handle this current with negligible temperature rise. The serviceman in making a replacement must assume that the new device is correct in these respects because reliable makers rate their devices correctly. Other than this the usual tests are for opens, shorts (continuity), resistance of windings and leakage. A number of special tests will now be considered.

(*b*) In testing a power transformer or iron core choke in the chassis with an ohmmeter make sure that there are no resistors or other parts capable of passing a D.C. current connected across it; otherwise the readings will be incorrect. When in doubt unsolder the connections, so the terminals of the device are free.

(*c*) A test should be made between the transformer taps or terminals and the core and shield of the transformer. No reading should be obtained. If the ohmmeter shows a reading, it indicates that the winding is grounded or leaky to the core or shield and the trouble should be repaired at once. No reading should be obtained when testing between any secondary winding and the primary winding. As the center tap on the secondary of the power transformer is usually grounded —unsolder the connection for a ground or leak test.

(*d*) Shorted turns in some cases can be checked with an ohmmeter, comparing the resistance you read with the value given in the circuit diagram. A short in the primary turns may increase the secondary voltage and overheat the transformer; a short in the secondary turns of a transformer will reduce the secondary voltage of the section shorted and overheat the device. The best test for a transformer or iron core choke is to connect it to a source of correct voltage and frequency (secondaries open in the case of transformers) and measure the A.C. primary or coil current. In the case of transformers the current should be less than .25 ampere; if more than that value a short exists. Even lower values should be indicated in checking a choke. Considerable experience is required to interpret the readings.

(*e*) Secondary filament windings on power transformers sometimes have center taps to which the grid returns are connected. If these taps are not exactly in the center of the winding, then A.C. hum is apt to be present. This trouble is seldom encountered in transformers manufactured by reliable companies. In such cases it is, of course, impractical to reconstruct the transformer. It is possible, however, to use small center-tapped resistances especially built for the purpose. The two ends of the resistance are connected directly across the filament taps on the transformer and the center tap of the resistance is used in place of the center tap on the winding, which is not used and should be disconnected. It is impossible to center tap the high voltage winding in this manner.

(*f*) Loose Laminations in a replacement part are usually due to faulty construction and the defective piece of apparatus should be returned to the manufacturer. In some cases the laminations can be tightened by tightening the bolts holding the apparatus together or by driving a small wooden wedge between the laminations.

18. SWITCHES. (*a*) The power off and on switch may become defective. This is easily indicated by the lack of light from the pilot lamp or the other tubes in the receiver. Of course, a careful check must be made to determine definitely whether or not the radio receiver obtains its power from the wall outlet. The power cord and plug, and fuses if used, must be in good condition. If the switch is defective (always open) then there will be no continuity when testing the plug cap terminals with an ohmmeter; if always closed it will be impossible to turn the set off. These conditions will occur with the switch in the closed or open position.

(*b*) The inductance switches used in all-wave sets may cause noise if they are dirty. Dirt will also cause certain bands on an all-wave receiver to be dead. Clean the contacts of the switches with a clean cloth (free of oil) using a little carbon tetrachloride (Carbona). This will remove all grease and dirt from the switch contacts.

(*c*) The rotating arms of all of the sections of an inductance switch must rotate when changed from one band position to another. Any switch arm failing to make contact should be repaired. Bend the switch arm into the proper position if it is damaged.

19. (*a*) **SHIELDING** in receivers is employed to prevent undesired coupling between circuits. Lack of shielding will result in oscillations and broad tuning. Not only lack of shielding will cause this but also poor or inefficient shielding. Dirty connections between shields and the chassis make them ineffective and you should be sure that the connections are tight and clean. A little sandpaper rubbed over the points of contact between the shield and chassis will eliminate this cause of trouble. Loose shielding will result in mechanical noises when set into vibration by sound waves from the speaker. Also, loose shielding will cause noises to arise in the receiver circuits and this noise will be heard from the loud speaker. Bending the shields so that they tightly grip their supports will prevent this. Be sure that the shields are in place, and not pushed out of line or to one side.

20. MECHANICAL TROUBLES. (*a*) Once the source of a mechanical trouble is located the repair is obvious. If a dial cord slips, the tension on the cord should be increased. The manner in which this should be done will be clear after an examination of the particular system in use. Perhaps a spring has slipped off its hook or a screw needs tightening.

(*b*) If a bearing is frozen (jammed) "3 in 1 oil" should be worked into the housing; if the bearing does not turn freely, remove it and rub it down with a fine sandpaper, return it and use a lubricant with a graphite base. The tuning condenser gang must turn easily, particularly where a rubber friction drive is used—oil bearings and if there are any tension screws at the end of the shaft, loosen them until the gang moves freely.

(*c*) Where the dial cord has broken it is necessary to install a new cord, which should be obtained from the manufacturer or his distributor. Oftentimes you will be able to obtain, on request, specific instructions on restringing the cord along with the new cord you order. It is possible to get along nicely without such instructions but then one must pay careful attention to the system, figuring out in one's mind just how the cord must go on if the system is to work properly. You may have to try two or three times before you get it just right.

(*d*) In any mechanical trouble, personal observation is the key to success. In radio receivers all mechanical systems have been made as simply as possible although hardly any two are alike.

(*e*) You must be the judge of when replacement of parts will be necessary. When new parts may be easily obtained and the originals seem badly worn, don't waste time trying to patch them up—put in new ones.

21. (*a*) **BATTERIES** are used extensively on receivers where socket power is not available. These battery receivers are to be found in camps, farms, rural and unwired homes. Then, too, there are obsolete battery operated receivers in homes where a modern all-electric receiver has not been installed. In all these cases, the batteries must be carefully inspected and tested, as they are a constant source of trouble.

(*b*) *"A" Batteries* furnish power to heat the tube filaments, and if they run down (voltage drops) they no longer serve their intended purpose.

(*c*) Storage Batteries generally consist of three 2 volt cells in series, a total of 6 volts. Checking the voltage of each cell is only an approximate means of testing the cell. A true voltage check should consist of loading the battery (the set turned on) and checking each cell for voltage at the start of the test run and 10 to 20 minutes later. The voltage should not be less than 1.9 volts per cell. A better and quicker test is to check the *specific gravity* of the electrolyte (liquid) in each cell, with a hydrometer. When the reading drops below 1.150 the battery should be recharged. The electrolyte in a fully charged cell should have a specific gravity of about 1.300. Connect the battery to a charger with the vents of each cell open. Charge until the electrolyte in each cell bubbles. Check the specific gravity of each cell, which should be about 1.300. If one cell shows a low density electrolyte, try charging this cell for a couple more hours and if the density of the electrolyte does not come up, have the cell repaired at a reliable battery repair station. If at the start of the charge, the liquid in any cell is low, add distilled water only, to about one-half inch above the plates.

(*d*) Confusion sometimes arises in determining the polarity of the terminals. The plus terminal may be marked +; or it may be painted red; or if you connect a D.C. voltmeter to the terminals of the battery so the meter needle reads up-scale, the + terminal of the voltmeter (always marked) connects to the + terminal of the battery. The latter is a good test for any D.C. source of power.

(*e*) All battery terminals should be kept clean and tight. Connections to storage batteries should be carefully watched as they corrode quite easily. If the terminals are corroded they can be cleaned by scrubbing vigorously with hot water, being careful not to let the water get into the cells of the battery. After the terminals are cleaned the connecting wires should be attached by means of battery clamps which also have been carefully scraped until they are clean and bright. A liberal application of vaseline applied over the storage battery terminals and connections will tend to eliminate corrosion.

(*f*) *Air Cells* are best tested with a voltmeter. To be sure that the battery will not be drained too much, use a high resistance voltmeter (any radio voltmeter will suffice). The voltage should not be below 2 volts. The best test is to check the battery voltage before and after a 10 minute test run. A radical change would be at least .1 volt. Then if the voltage is below 2 volts get a new air cell battery. Follow the instructions in filling it with water. and be sure that the cellophane on the breathing electrodes is taken off.

(*g*) *Dry "A" Cells* are extensively used for filament supply on modern 2 volt tube receivers. Two in series are required and sets of two all in parallel help to get greater life between battery changes. Dry cells are tested with an ammeter connected across the terminals. When new, about 35 amperes is normal. When the combination can no longer supply more than 2.5 volts. the cells should be discarded. A load test should be made. If the voltage drops rapidly while used. the life of the battery is exhausted. If a line variable resistor is used be sure to caution the customer not to reduce its value too often. A change of once a month is normal. Always replace the entire set of cells. for one bad cell will throw the load on the good ones.

(*h*) *"B" and "C" Batteries* must furnish current to the various electrodes of the tubes. Follow the markings on the cable tabs or the receiver instructions.

(i) "B" and "C" batteries should be replaced with new ones just as soon as the voltage has dropped 20 per cent. That is, any 45 volt battery should be replaced as soon as the voltmeter reading shows a voltage as low as 36 volts under load.

(*j*) It occasionally happens that a defective connection or a defective cell *inside* a battery will develop and cause trouble. The only remedy is to replace the entire battery with a new one.

(*k*) Reception frequently can be improved by placing a bypass condenser across the "B" and "C" batteries. Connect one terminal of a condenser having a value between .1 mfd. and 1 mfd. to minus B and the other terminal of the condenser to the highest voltage terminal of the "B" batteries—that is, 90, 135 or 180 volts as the case may be. The connection should be in the set if it is found that the condenser improves the results.

(*l*) It is actually more economical to use large "B" blocks instead of small capacity "B" batteries. The initial cost is greater, but the over-all cost is less.

22. VOLTAGE AND CURRENT MEASUREMENTS AS AN AID IN LOCATING THE DEFECT. (*a*) Voltage measurements afford a quick check on the voltage supply circuits but usually are of no use when a signal circuit defect exists. For example, an open coupling condenser or a shorted tuning condenser will have no effect on the operating voltages.

(*b*) You must be "on your toes" when making voltage measurements. The actual measurements are simple but the proper interpretation of the results is a more difficult matter. You must remember that the voltmeter is not only a measuring device but that it is also a resistor. Many a serviceman has been puzzled by the fact that on measuring the voltage across some part the set started to play. The part was burned out but the meter when connected across the part completed the circuit.

(*c*) For the experienced man as well as the beginner, good equipment is necessary if satisfactory results are to be obtained. The best outfit to own is a good high resistance multimeter which will enable you to measure currents, resistance values, and A.C. or D.C. voltages.

(*d*) Now suppose you have something with which to check voltages, whether it be a multimeter or the parts in your experimental outfits. The chassis is turned upside down and with the negative test probe from the meter on the cathode of one of the tubes touch the positive lead to the other electrode prongs one at a time. Write down your readings so they may be compared to those furnished by the manufacturer. If the grid return is made to the chassis a check from cathode to chassis will give the control grid voltage, otherwise a test must be made from the control grid to chassis. If the control grid bias voltage is correct, the plate current is in all probability of the right value. To measure the plate current the set is turned off, the lead to the plate disconnected and the milliammeter leads connected to it and the plate. This places the milliammeter in series with the plate and on turning on the set the plate current will gradually come up to normal if everything is all right. A socket plug in adapter simplifies current and voltage measurements.

(*e*) In checking the rectifier, a test with the D.C. voltmeter connected from the filament or cathode to chassis will check the general condition of the tube and power transformer high voltage winding. The power transformer may be checked by itself with an A.C. voltmeter. The high voltage winding has about 700 or 750 volts A.C. across it and the winding is center tapped in the case of full-wave rectifiers. Each half may be measured separately from a rectifier plate to the center tap which may or may not be directly grounded. The entire A.C. voltage is measured by connecting the A.C. voltmeter to both plates.

(*f*) In making measurements always use the highest range of the meter. This will protect the meter if the voltage is higher than normal and will show if a lower range may be used. Never use the milliammeter to measure voltage as this will burn out the meter. If the meter reads backwards, reverse the test probes. Use the A.C. range for A.C. measurements and the D.C. range for D.C. measurements.

(*g*) The internal resistance of your meter will affect the reading you obtain when testing voltages in high resistance circuits, such as plate and control grid circuits of resistance coupled systems. The lower the resistance of your meter the lower will be the measured voltage. The meters used by manufacturers when making up their voltage charts generally have a resistance of 1000 ohms per volt. A 1000 ohm per volt voltmeter will be satisfactory for you, although you may use a 2000 ohm per volt meter, if you wish.

(*h*) Remember that slight differences in line voltage will change your readings and that manufacturers' tolerances in resistor values will introduce another cause for variation from specified voltage values. As long as the measured values are within 20% of the specified values they are to be accepted as normal, if you use a 1000 ohm per volt meter. Where recommended voltage charts are not available, tube manufacturers' charts will give you *some* idea of what to expect although you must not follow them too closely. After you have done some service work you will know without charts whether the voltages are approximately correct.

(*i*) The following index is to help you interpret voltage and current readings. Study the index carefully:

COMMON CAUSES OF INCORRECT VOLTAGES AND CURRENTS

High Plate Potential

Insufficient load upon power pack due to weak tubes.
Open high current load in receiver.
Short circuited voltage reducing resistance.
High line voltage.
High grid bias voltage.
Incorrect tap upon power pack divider.
Open bleeder resistance between circuits.
Open bleeder resistance in divider.
Shorted filter choke or loud speaker field in power pack.

HIGH PLATE VOLTAGE ON ALL TUBES

(Output Tube Plate Current Low)

Excessive grid bias resistor (output stage).
Defective output tube or tubes.

LOW PLATE POTENTIAL

Excessive current drain upon power supply.
Open or leaky filter condenser.
Insufficient grid bias.
Shorted bleeder resistance.
Low line voltage.
Defective operation of line ballast, replace with a new one.
Leak through bypass condenser.
Shorted or defective section of voltage divider.
Defect in power transformer.
Defective rectifier.
Defective filter choke or loud speaker field.

LOW PLATE VOLTAGE ON ALL TUBES

(High Plate Current in Rectifier)

Defective filter condenser.
Short circuit in voltage divider system.
High resistance short in output tube plate circuit.
Resistance short in eliminator filter chokes.
Gassy tube in output system.

LOW PLATE VOLTAGE

(High Plate Current in Output Tube)

Shorted or grounded grid bias resistor.
Shorted or grounded grid bias resistor bypass condenser.
Ground connection to input push-pull secondary winding open.
Open grid bias resistance.
Open grid circuit.
Gassy output tube or tubes.
Shorted output tube.

NO PLATE VOLTAGE ON ALL TUBES

Shorted power transformer winding.
Shorted filter condenser.
Defective rectifier tube.
Open filter choke.
Open in − B circuit.
Ground in output tube plate circuit.
Open loud speaker field.

NO PLATE VOLTAGE UPON ONE TUBE AND REDUCED PLATE VOLTAGE UPON OTHER TUBES

Open R.F. choke in plate circuit which does not secure plate voltage.

Shorted bypass condenser.
Grounded plate circuit.
Shorted voltage divider bleeder section if it is the detector stage.
Grounded plate coupling unit in plate circuit.
Shorted plate element in tube.

NO PLATE VOLTAGE ON OUTPUT TUBES

(*Plate Voltage Available on Other Tubes*)
Open in plate circuit.
Open in output unit.
Open in − B connection to grid bias resistance.
Open in grid bias resistor.
Defective tone control.
Plate to chassis condenser broken down.

EXCESSIVE PLATE CURRENT

Gassy tube.
Insufficient grid bias.
Excessive plate voltage.
Excessive positive bias upon screen grid.
Open grid circuit.
Leaky or broken down grid coupling condenser.
Defective AVC system.

NO PLATE CURRENT

Open plate circuit.
No plate voltage.
Open filament circuit, cathode circuit.
Defective tube.
Very high negative bias.

INSUFFICIENT PLATE CURRENT

(*Normal or High Plate Voltages*)
Defective tube.
Low filament voltage.
High grid bias.
Low screen grid voltage.
Defective AVC system.

HIGH GRID BIAS

High plate current.
High value of bias resistance use correct value.
Defective bias resistance.
Defective bleeder resistor.
Defective condenser or resistor in grid return.

LOW GRID BIAS

Low plate current.
Shorted bias resistance or bypass condenser.
Defective resistance or incorrect value.
Measurement made incorrectly.

NO GRID BIAS

(*High Plate Current*)
Shorted grid bias bypass condenser.
Grounded cathode.
Grounded filament.
Open grid circuit.

LOW OR NO SCREEN VOLTAGE

Open variable control for screen grid voltage.
Open screen grid circuit.
Open resistance in screen grid circuit.
Broken down screen bypass condenser.

NO SCREEN VOLTAGE UPON ONE TUBE

(*Low Plate Voltage Upon Other Tubes*)
Grounded variable control.
Shorted screen grid bypass condenser.
Short in voltage divider across bleeder or screen grid control resistance.
Shorted screen grid in tube.

EXCESSIVE FILAMENT OR HEATER POTENTIAL

Incorrect adjustment of voltage reducing resistance.
High line voltage to power pack.
Insufficient load upon filament or heater winding; open filament circuit, or defective tubes.
Wrong tube; use correct tube.
Short circuit in power transformer primary.
Hi-lo switch in lo position.

INSUFFICIENT FILAMENT OR HEATER VOLTAGE

Too great load on heater or filament winding
Low line voltage.
Wrong tube in socket causing excessive current drain.
Incorrect line voltage reducing resistance.
Defective operation of ballast; replace.
Short circuit in transformer.
Short circuit in filament circuit.
Hi-lo switch in hi position.

C: GENERAL TROUBLES, CAUSE AND REMEDY

23. CUSTOMER'S OPINION—NATURAL EFFECTS (*a*) Of course, you want the customer's opinion of what is wrong—because your job is to service that complaint. But you must know when a complaint is just or unreasonable. If you find that the opinion is unreasonable, explain the situation as carefully as you can without offending the customer. Experience is an important factor in judging the performance of a receiver. Receivers are frequently weak in one or more ways. A receiver may be loud and clear but have poor selectivity; or it may be selective but poor in quality.

(*b*) If the receiver is of a reliable make (not necessarily the most advertised or the product of the largest manufacturers) and was not designed to sell for a low price, reasonable performance should be expected. But don't expect the receiver built three or four years ago to be as good as the one made recently. Improvements are constantly being made and each year the higher priced receivers are better all around.

(*c*) In general, the more tubes used in a receiver the better it should perform. Do not include AVC tubes, squelch tubes, automatic tone control tubes, tuning monitors, as they are merely aids to simple operation. A superheterodyne receiver is generally better than a tuned R. F. receiver. Selectivity and sensitivity are improved as more R.F. and I.F. stages are employed, and this should be used as a guide. Tone and volume is greatly governed by the size of the cabinet, type of power output tubes and cost of the receiver (including good workmanship and design, good material).

(*d*) When inexpensive receivers are encountered such as midget, universal, some D.C. receivers, too much should not be expected. These receivers were made to sell at a low cost and naturally only a limited performance may be expected. These receivers neither have sensitivity, selectivity, volume, nor fidelity comparable with a higher priced receiver. Here too, the number of tubes and the size of the cabinet are used roughly to judge their worth.

(*e*) Some of the shortcomings of an inexpensive receiver which cannot be readily changed are: Only local stations are strong, distant stations weak or absent (try a longer aerial); distorts on high volume (try adjusting loudspeaker if of the magnetic type and if voltages are correct nothing can be done); distorts on low volume (nothing can be done); only local station during the day (natural); tunes broad (natural).

(*f*) Customers expect too much from all-wave receivers. They must be told that only local and semi-local powerful broadcasts are reliable and free from noise. Foreign and distant shortwave reception is quite irregular, varying from day to day, hour to hour, and every minute. The same receiver will perform differently in various locations. An all-wave antenna should be used as it will generally give greater signal strength, but quite often only a reduction in noise will be obtained—in itself a very good reason for using one. Certain bands of the all-wave receiver work best during the day (ultra short-wave), while other bands work best at night. This is a natural condition. For more information on short-waves read section 25.

(*g*) Chance will have it that tubes burn out one after the other without any defect in the chassis. The whole set of tubes may be old and weak, and instead of replacing all at once, they are replaced as they burn out. Naturally they seem to require constant service. Tubes are guaranteed for 1000 hours, approximately one year, and no one should expect longer life. A chassis and power line voltage check will quickly tell if the frequent burning out is normal. If the line voltage fluctuates use a line ballast.

(*h*) Very sensitive receivers are naturally noisy except on local and powerful stations. Circuit and tube noises exist and cannot be remedied. The customer must be told to expect this on distant stations.

(*i*) Receivers with AVC will be noisy when tuned between stations, as the receiver is operating in its most sensitive condition. Receivers with squelch or automatic noise gates eliminate this trouble to a considerable extent.

24. NATURAL CONDITIONS WHICH ARE NOT DEFECTS. (*a*) A resistor is supposed to get hot, but it is only when it gets unusually hot that a defect is indicated. Of course, the position and use of the resistor that you question must be considered. A grid, or AVC, or plate resistor should not get hot; but a bleeder resistor or power pack voltage divider, or line voltage regulating resistor is supposed to get hot. Only when it gets so hot that it is red (O.K. for line ballast resistor), smokes, melts or chars surrounding parts is a defect indicated. Check with an ammeter to determine if the current through it is normal.

(*b*) Ballast tubes get hot, in fact they work because the resistance elements are working at high temperatures. The radio tubes get hot, even to the point where it is impossible to touch them. The rectifier and power tubes heat up the most. Only when the plates turn cherry red is a defect indicated. Check voltages and currents if in doubt.

(*c*) Certain tubes, especially the rectifier and power tubes, have a purple blue glow *at the glass envelope*. This is a natural condition and should not be confused with a blue glow in the space between the cathode and the plate which indicates a defective tube or its operation. In the case of rectifier tubes do not condemn mercury vapor tubes as defective. Usually you can see little balls or a film of mercury, on the glass. Glow in a mercury vapor tube is natural.

(*d*) Quite often radio men observe a spark when connecting the ground lead to the ground binding post of the receiver. This is natural in a receiver where a condenser is connected from the ungrounded supply line to the chassis. If you reverse the power line plug in the outlet the sparking will probably stop. You should insert the power plug so that the sparking is observed when the ground is connected. When this condenser is used and the ground is left off, touching the antenna or even the chassis may result in a shock. Connecting the ground will stop this.

(*e*) Some all-wave receivers tune broad on the broadcast band. A certain amount of broadness cannot be helped if the short-wave bands are to be designed to operate with minimum frequency drift (signal fading due to oscillator frequency shift). The I.F. stages are broadly band-passed so when the oscillator frequency shifts, amplification will still exist. A sacrifice of selectivity for better S-W results.

25. ALL-WAVE RECEIVING CONDITIONS. (*a*) It may appear very difficult to determine a natural from an unnatural short-wave receiving condition. However, the following discussion plus a little experience will greatly help:

(*b*) It will be necessary to classify radio receivers in two groups: *1*, the inexpensive; and *2*, the more expensive receivers. The inexpensive receivers do not have the sensitivity or the selectivity usually obtained from a more expensive receiver. Greater volume and less interference will be received from the expensive set. Consequently the inexpensive receiver will tune broadly, give weak signals in the day-time, give weaker signals at one end of dial, have dead spots, have fading due to lack of or inadequate AVC, have dead spots in one band of the all-wave receiver, dead spots in several bands of the all-wave receiver and lack of clear signals due to an inefficient antenna system.

(*c*) The receiver employing a short-wave converter may also be considered in the inexpensive class, as it is a make-shift assembly. On such an arrangement we may hear noises and yet no signals. This may be due to improper connections from the converter to the broadcast receiver. Check them. Is the antenna connected to the antenna posts of the converter? Is the broadcast receiver set to the correct dial position?

(*d*) The inability to get reception may be due to the wrong band setting or wrong time of day for the particular band. It is, therefore, important that you check the time when best reception can be expected and also when programs are actually on the air. Only those familiar with the general characteristics of the transmission and reception of short-wave signals can realize the full possibilities of the use of an all-wave receiver. Therefore, the following information regarding the nature and general characteristics of short waves will be helpful, especially to you and your customers interested in short-wave reception.

(*e*) It is interesting to know that there are four major short-wave broadcast bands. Each band has its own characteristics. For instance, the 19 meter band (16 megacycles) is best adapted for reception during daylight hours and will be rarely useful after nightfall. Furthermore, signals at distances of over 1500 miles from the receiver are heard best on this band.

(*f*) The 25 meter band (12 megacycles) works quite well during both day and night; however, only very distant stations, especially those located over 2000 miles away, can be heard after darkness. During the day signals approximately 1000 miles or more away will be heard.

(*g*) Just above the 25 meter band will be found a 31 meter (10 megacycles) broadcast band. This band has the general characteristics of the 25 meter band. However, very good reception of the distant stations is possible both day and night.

(*h*) Probably the most reliable short-wave band is the 49 meter band (6 megacycles). Very good daylight reception is obtained when the transmitter and receiver are but 300 miles apart, although very good distant reception is obtained when a large portion of the path taken by the signal lies in complete darkness.

(*i*) The reason for a difference in radio reception is explained as follows: Radio signals transmitted into the ether and on any wave length are known to divide into two parts, known as the *"ground"* and the *"sky"* waves. The former remain close to the earth's surface, thus providing reliable signals for short distances near the transmitter. The other wave, called the sky wave, is reflected back to earth at great distances from the transmitter. It is interesting to know that there is usually a point where the ground and sky waves exist together and the signal will distort, fade out and fade in again if the receiver is located here. Then there is an area following in which neither ground nor sky waves exist. This is known as a dead spot region, within which reception does not exist. The area or length of the dead spot region is commonly termed "skip distance," which varies with seasonal changes and with weather conditions and the time of day. Actually the reflecting layer for the sky wave changes its effective height, thus changing the angle of its route, giving a large variation in reception conditions. And it is known that reception may change radically in a very few minutes, especially in a region which borders on a dead area.

(*j*) The general characteristics of short waves must be considered in connection with frequency bands upon which reception is desired, as well as the time of the day. For instance, 6 P.M. is the best time in the eastern part of the United States to hear European broadcasting stations operating on high frequencies. Early afternoon broadcasts of European programs may be heard on frequencies above 25 meters.

(*k*) In order to check the operation of a radio receiver we should listen to a number of stations and if we receive only one station clearly in each band we know that the set is working properly and that the distortion, if any, is due to weather conditions or improper spacing between the transmitter and receiver. These conditions are, of course, beyond the control of the listener. These are natural conditions. The unnatural conditions can then be very easily weeded out from the natural. Such a case would be when an expensive receiver has poor sensitivity and broad tuning, as well as rapid fading.

26. PART INCORRECTLY CHOSEN OR REDUCED IN VALUE BY USE.

(*a*) A reliable make of receiver should generally give reception at least acceptable to the customer at the time of purchase. Otherwise the customer would not purchase it. Of course, it is not improbable that an incorrect value of a condenser, choke or resistor may have been used in the original design or that the value of some part will change after the receiver has been in use some time; yet the greatest chance of changing the characteristics of the receiver will come in making an improper replacement while servicing. A few examples will be helpful.

(*b*) When a decoupling condenser (connected from cathode to +B) is too small, regeneration and squeals may arise. For A.F. use .5 to 2 mfd., for R.F. use .1 to .25 mfd.

(*c*) If a bias resistor bypass condenser is too small, regeneration, degeneration, distortion or hum may be introduced. For A.F. use 2 to 8 mfd.; for R.F. use .1 to .25 mfd.

(*d*) If the condenser across a variable resistor is too small, the volume control will be noisy. Try a higher capacity value.

(*e*) Incorrect resistor value may result in improper electrode voltages. Even if the resistor used is according to the circuit diagram it is always safer to check voltages after a replacement, with a voltmeter.

(*f*) A resistor may be correct as far as ohmic value is concerned, but have inadequate heat dissipating properties. Its wattage rating is too low. If the resistor gets too hot, use one with a higher rating, or see that the air circulation is not blocked. If in doubt figure watts dissipated by the formula; watts equals volts dropped times current carried, or watts equals current times current times the resistance of the resistor. For under chassis use, select a resistor with about four times the power rating. For above chassis use, select one with about twice the power rating. High watts dissipation (50 watts and above) use resistors with equal watts rating and be sure there is a good circulation of air.

(*g*) The fixed condenser should have a working voltage at least equal to twice the voltage it is to be used on. There are two exceptions to this, solely for economical reasons. Filter condensers should be selected so their rating about equals the peak voltage and A.F. "C" bias resistor condensers should have at least the voltage rating of the terminals to which they connect. Whenever possible use as high a voltage rating as you can without running up the cost. For ordinary use accept nothing under 200 volts rating. Melting wax running from a condenser which is not near a hot spot, or is properly ventilated, indicates the necessity for a higher voltage condenser.

(*h*) Chokes, coils, transformers and variable condensers should be exact replacements, preferably of the same make.

(*i*) Substitute a new grid leak for the old one if you think it is defective. It is practically impossible to test grid leaks with any degree of accuracy. Try various grid leaks ranging in value from 2 to 6 megohms until you find the one giving strongest and clearest signals. If the set is used for distant reception, a high resistance leak gives best results. If for local or nearby stations, a low value resistance should be used.

(*j*) Always check the tubes in a receiver, as to proper type. It is not uncommon to find incorrect types used, for example, a 24 in place of a 51. Replacing a tube with the wrong filament voltage rating may cause it to burn out.

27. OUTSIDE INTERFERENCE (STATIC). (*a*) Noises originating outside the receiver can usually be determined by removing the aerial and ground wires. If the noise still persists, it is an indication that the noise originates IN the receiver or accessories (batteries, tubes, power unit or loose connections). Natural interference (static) presents itself as varying sounds, usually loud crackling or crashes. Static is a natural phenomenon, and up to the present time no means of successfully overcoming it has been devised.

(*b*) Static interference is much more noticeable during the hot, summer months and makes it impossible to receive distant stations with any degree of regularity. In fact, it is sometimes so bad that it is impossible to obtain satisfactory results, except possibly on the very strong local stations. Accumulations of static electricity on the aerial wires sometimes become so great as to severely shock a person touching the antenna system or antenna binding post of the receiver. Instances have been known when the charge is so great that the electricity will arc across to the antenna post to the receiver if a lead connection is broken.

(*c*) The ignition systems of automobiles and trucks passing along the road or street will cause static-like interference in shortwave reception. This is especially true in the 15 megacycle band. There is no remedy for this type of interference other than placing the antenna and lead-in as far as possible from the highway along which the automobiles pass.

(*d*) On some types of receivers it is natural to receive a large amount of static and other noises when tuning from one station to another, or when switching from one band to another in an all-wave receiver. The only remedy for this type of trouble is to turn down the volume control on the receiver before making the change.

28. STATION INTERFERENCE AND BROAD TUNING. (*a*) There is no receiver made with reasonable sensitivity, selectivity and fidelity which will not suffer from station interference. The designer recognized the fact that one good quality works to spoil another desirable feature and strikes a balance. It is your duty, to acquire, by experience, the ability to judge what performance should be expected from the receiver you are servicing.

(*b*) Before proclaiming that interference cannot be eliminated, check for broad tuning (see in this section "Judging Broad Tuning"). If the customer prefers selectivity to fidelity peak the tuning stages. If this does not reduce interference to a satisfactory amount, the only logical step to take is to install a wave trap. Contrary to the general opinion, any coil and condenser will not make a good wave trap. Use a good variable condenser of small size and a regular R.F. receiver transformer. The trap should be designed for the broadcast or the short-wave band in which interference is present.

(*c*) Connect the wave trap in series with the antenna lead wire, when the trap's coil and condenser are in parallel or has a primary winding; for all-wave antenna systems connect the coil and condenser in series and connect the trap across the two leads to the receiver. Tune the receiver to the station desired and adjust the wave trap to eliminate the undesired station. Retune the receiver for desired station and the trap for undesired station.

(*d*) The types of interference you will encounter are as follows:

(*e*) If the receiver is located too near a local broadcasting station, the station may be received over a wide range of the station selector scale. This is referred to as broad tuning. Assuming the receiver alignment is satisfactory, a wave trap should be used, tuned to the powerful local so stations to either side may be tuned in.

(*f*) Often the customer will complain that the local station can be tuned in with distant stations, but when a station is not tuned in, this station interference is not obtained. This difficulty is referred to as "cross-modulation" and is due to the fact that the local station is causing, usually the first tube to act as a detector, and not allowing the tuned stages following a chance to tune it out. Be sure to use variable mu screen grid or super R.F. pentode tubes if specified for the receiver, as these tubes help reduce cross modulation (also hum). A high C bias or low plate voltage on the first R.F. tube may produce this interference; check voltages with manufacturer's recommended values. Try a wave trap tuned to the local station riding in on distant broadcasts.

(*g*) If the local station radiates harmonics, interference will be obtained on higher frequencies. A 610 K.C. broadcast may be heard at 1220, 1830, 2440, etc. This is no fault of the receiver, and not a thing can be done to the receiver to eliminate these undesired signals. If you are sure that the station is radiating harmonics (check this fact on several receivers in various localities) call the station engineer. He will gladly make a check.

(*h*) In some supers a station having a frequency equal to the dial setting ***plus*** or ***minus*** twice the I.F. frequency may ride in on the desired signal. This is called image interference. A coil and condenser trap (both parts in series connected across the antenna and ground) tuned to the interfering signal will help eliminate this interference.

(*i*) Should you find that a local code or broadcast short-wave station interference on a lower frequency range of a receiver (for example, the broadcast band) tune the local out with a short-wave trap. The receiver is a superheterodyne and harmonics of its oscillator are beating with the frequency of the offending station.

(*j*) If long-wave code stations (above 550 meters) are interfering with reception of a superheterodyne receiver, the station is probably of the same frequency as that of the I.F. section. A long-wave wave trap may be inserted in the antenna lead-in. Use an I.F. transformer similar to the one in the receiver. Use only one coil and its condenser; open other circuits. You may also set the I.F. to a slightly higher or lower frequency. Realign the receiver completely. This may throw the station dial calibration off.

(*k*) It is worth remembering that many customers report that they hear the same station at different positions of the tuning dial. What they are really hearing is the same program coming from different stations. and have not bothered to check up that they are listening to a chain program.

(*l*) When we stop to realize that there are a few hundred stations on at the same time in the broadcast band, it is reasonable to expect some interference. First, several stations may be on the same frequency and a sensitive receiver, regardless of its selectivity will pick up both or several of the stations. Nothing can be done to eliminate this interference which is often recognized by one fading in while the other fades out, one after the other; or all coming at one time creating a hash of words or music; or a chopping up of the more powerful broadcast. On the other hand, if one station is off its assigned frequency by more than 50 c.p.s., a low pitch hum or squeal may be heard.

(*m*) If two stations are 10 k.c. apart as they should be and modulate a 5 k.c. sound, and the customer's receiver is band-passed to at least 10 k.c.—garbled reproduction is heard. Because it sounds so much like "monkey chatter" it is referred to by this expression. Nothing can be done with an ordinary receiver unless you wish to reduce fidelity by peaking the tuning systems. In a high fidelity receiver with variable band width, reduce or compress the band width of reception.

(*n*) In ***judging broad tuning*** do not estimate the number of divisions on the tuning dial over which the station may be received and then express an opinion. Figure out the actual number of kilocycles. Tuning is broad if on local stations the band width exceeds 30 kilocycles, on distance if it exceeds 20 kilocycles for powerful broadcasters, on distance if it exceeds 10 kilocycles for normal power radio stations. Sharp 10 kilocycle cut-off for all stations is ideal and making a receiver sharper than this value only tends to destroy tonal qualities. If in your opinion tuning is broad, and the receiver is capable of better selectivity, realign the tuning stages. See section 45, on Receiver Alignment. A 4 to 5 stage tuned R.F. receiver should give acceptable selectivity; a superheterodyne with one pre-selector stage and 2 I.F. transformers (tuned plate—tuned grid) should give satisfactory selectivity. Receivers with more tuned stages should be band-passed for higher fidelity. Receivers with less tuned stages should be peaked sharply. Receivers in which the detector is of the grid leak-grid condenser type are generally broader than if a bias type detector is used. A change-over may help.

29. ANTENNA SYSTEM TROUBLES. (*a*) *Short Aerial.* The aerial on any receiving set should have a length approximating that suggested by the manufacturer of the receiver. Generally speaking, for the broadcast band, an aerial 60 to 80 ft. long will give excellent results. Indoor aerials and light socket antennas never give the same results as good outdoor antennas. Such installations usually give good results on local or nearby stations, but are not of much value for distant reception. If possible, always use an outdoor straight-away.

(*b*) *Poor or High Resistance Joints.* The ends of all wires to be joined should be scraped clean and then soldered and taped. The ground wire should be connected by means of an approved ground clamp to the cold water pipe, or a pipe driven into the damp ground. Scrape the surface of the pipe under the clamp so as to form a good electrical connection. The ground wire should be soldered to the ground clamp. In all wave antennas a poor connection can exist at the coupling transformer, especially in the types having adjustments. Examine all taps, connections and switches carefully for loose, dirty or corroded connections.

(*c*) *Antennas that are too short* generally reduce volume and since some sets are more sensitive at one end of the dial than the other, this effect is more noticeable at the less sensitive end. In some cases, the aerial resonates at the end with good reception and falls off in efficiency at the other end of the band. A change in length, generally, an increase, is a remedy for this. Then, too, a short antenna may cause a receiver to oscillate; lengthening the straight-away helps.

(*d*) *When an antenna is too long,* the receiver may not be selective, the volume of local stations may be uncontrollable, or station interference may exist. Cut the length of the aerial to the size suggested by the manufacturer of the receiver or insert a condenser in series with the aerial. A small fixed condenser of approximately .0025 mfd. or .0001 mfd. is usually helpful. A variable condenser permits finer adjustment.

(*e*) An antenna system that is poorly designed and erected will not give the receiver a chance to show its ability. Be especially sure that an all-wave antenna is erected properly, following the antenna kit manufacturer's instructions carefully. Keep well away from trees, power lines, metal roofs, etc. Be sure that the antenna is correctly matched (coupled) to the set input. The types with adjustable or tapped transformers should be adjusted for maximum results. Be sure that the antenna is of a type that will work satisfactorily with the set.

(*f*) Keep antenna wires free from contact with other objects. Do not let the wire touch trees or sides of buildings. Use stand-off insulators to hold wires away from the building, and be sure to take the lead-in wire into the house through a porcelain tube or by way of an approved "lead-in strip" provided especially for that purpose. Remember, the better the antenna installation, the better the antenna insulation, the stronger and clearer will be the reception. It pays to take time to erect the antenna system in a workmanlike manner.

(*g*) Keep the *aerial* and lead-in wire pulled tight so it cannot *sway* excessively in the wind. By using an aerial spring or pulley and weight, the antenna may be kept tight. Avoid anchoring the antenna to objects like trees which sway with the wind.

(*h*) If you touch an *aerial* or its lead-in which is *touching a power line* you will get a shock. Aerials should be erected as far from them as possible. If the lead-in must come close to a power line, be sure that both are fastened so securely that no contact can be made. If the power line is loose, inform the power company; they will quickly rectify the defect. As a matter of course, you should keep the antenna system away from power and telephone lines; as this will minimize interference. It is advisable to install the aerial so that the wires are at right angles to any power lines and as far away as possible. Any power line passing through branches of trees should be thoroughly taped to prevent current leakage. This work can only be done by the power company. Whenever a large number of power and telephone wires are seen, always recommend a noise-reducing antenna, the straight-away in the noise free zone.

(*i*) Quite often you run across an installation where the receiver works equally well when the ground lead is disconnected. The *power line is a better ground* than the one used. The power line has a grounded side and is generally connected to the set chassis through a condenser; and by disconnecting the original ground, the power line then acts as the ground.

(*j*) A short, straight wire connected to the cold water pipe makes the most practical ground connection. Avoid the use of steam or gas pipes.

(*k*) An *arrester* having poor or corroded connections and leaks due to collections of dirt or soot will naturally cause noise. A shorted arrester will stop reception of distant stations. The arrester could be defective due to age or a lightning surge. The simplest test of this is to temporarily disconnect the suspected arrester or try a new one.

(*l*) *Select the Correct All-Wave Antenna.* There are many types of all-wave antennas, and there are certain types that will work satisfactorily only with receivers having definite input impedances for which they are designed. The older radio receivers may have low or high impedance inputs and special variable impedance transformers should be used so a correct match is possible. This should be considered before the purchase of the aerial. Types having variable impedances are on the market which can be made to work with most all-wave sets. An all-wave receiver requires an all-wave antenna for best results, and they should be properly connected to the receiver. Read the instructions with the antenna kit.

(*m*) *A Choke or Resistor Receiver Input* provides an untuned antenna input. Of course, no tuning action exists, thus permitting strong locals to "ride in" on weaker stations, an effect known as cross-modulation. A tuned input may be substituted or a wave trap used, adjusted to the offending local station.

(*n*) *Two receivers should not be used on the same antenna,* unless a system especially designed for this use is installed. Shocks can be obtained where two sets are connected to the same aerial. Noises, squeals and whistles often occur. Feedback takes place between the sets which are so coupled. Sets should be on separate ordinary aerials if they are to be used at the same time. However, if a shock is the only objection to the multiple use of an antenna, a small mica condenser should be placed in series with each lead-in, thus preventing shocks.

(*o*) *Testing an Antenna System.* A broadcast antenna should not be difficult to test. Disconnect the antenna and ground leads from the receiver. Connect an ohmmeter to ANT and GND receiver posts; a low ohm reading indicates normal continuity. Connect the ohmmeter to antenna and ground leads, set the ohmmeter to its highest range. The reading should be infinite resistance, showing no shorts or leaks. If a reading is obtained inspect the lead-in and antenna for poor insulation or possible shorts to conductors on the house, and disconnect and test the lightning arrester—no reading should be obtained. To check antenna lead wire for opens, connect one end to a metal gutter or pipe, test with the ohmmeter from the free end to the metal gutter or pipe. A low ohmic reading should be obtained for normal continuity.

(*p*) Checking an all-wave transmission line system calls for a little more deliberation. Disconnect the transmission line from the receiver transformer, and check the latter for continuity, just as you would any R.F. transformer. In general, continuity should exist between primary terminals and between secondary terminals. If in doubt, connect the transmission cable directly to ANT and GND receiver posts. If reception is now obtained, get a new transformer.

(*q*) To check the transmission cable, connect an ohmmeter to the ends disconnected from the transformer. If the antenna end starts with a transformer, the reading obtained should be low (resistance); if the antenna is a doublet with no transformer, a high resistance should be obtained. Due to breakdown of insulation in the cable, collection of soot and dirt, some reading will be observed in an installation that has been up some time. If it is less than 10,000 ohms, install a new cable, identical with the original. It is a good plan to disconnect the cable from the antenna coupler, if one is used and check the cable itself for leakage. Always check between the leads or shield to ground. No short or leak should exist.

(*r*) The antenna coupler is checked in the same manner as the receiver transformer. A schematic wiring diagram of the antenna system if followed will, of course, eliminate any guessing in the tests.

(*s*) If a poor connection is suspected, shake the antenna, lead wires, or cable when making an ohmmeter test.

30. POWER SUPPLY DEFECTS. (*a*) *Improper Line Power Supply.* Always be on the lookout for D.C. receivers in A.C. sections, as the receiver will not operate; and A.C. receivers in D.C. sections of a community as the line fuses will blow out. On the other hand, the receiver may begin to smoke due to excessive current of the improper type flowing through it and, the transformer may burn out. Universal receivers, however, will operate on either A.C. or D.C. In some Universal receivers it is necessary to throw a switch at the rear of the chassis to work it on A.C. or D.C., that is, to convert its operation. Also determine definitely the correct operating line voltage to be applied to the receiver if there is any question at all about the proper power supply.

(*b*) *High or Low Line Voltage.* The tubes in a radio receiver will go bad if the power supplied to them is above or below their specified working values, particularly if the voltage is above normal. It is therefore extremely important to check the line voltage.

(*c*) Low line voltage during the day time may cause weak signals to be received. On the other hand, we may experience broad tuning. High line voltage may cause squeals, howls or put-puts.

(*d*) Distorted or muffled signals may be reproduced if the line voltage is abnormally high or low. Again check the line voltage.

(*e*) When low or high voltage line supplies are suspected the first thing naturally to do, is to find out by an A.C. voltmeter test whether the voltage is above or below the recommended input for the receiver. If the receiver has any means of adjusting the primary of the power transformer to the line voltage (usually taps or a variable position fuse is provided), an adjustment is made. The taps or fuse positions are marked; set them to a position that is nearest to the line voltage. It is always safer to set the receiver for a high line voltage. If you set it to a low line voltage there is no immediate way of telling whether the line voltage will go up during the day. A line voltage check during the afternoon and early evening will give more definite information. Then set the power transformer primary for the highest voltage; or preferably install a line ballast. A ballast is always preferred when line voltage variation exists. When no receiver adjustment is provided and the line voltage stays constant but high, install a variable line regulator (variable resistor) although a ballast will work as well and insure against sudden line voltage rises. If a number of complaints of this nature are found in the same district, report the condition to the power company. In most cases the condition will be rectified. Don't expect the power company to build an entire feeder system; cooperate with them by using a line ballast.

(*f*) *No Power When Switch is Turned On.* The tubes in a radio receiver may not light for many reasons. However, a careful check should always be made of the power line voltage. A burned out house or receiver fuse, or an open in the power cord will make it impossible for the receiver to operate. Fuses in the receiver circuit should likewise be renewed if damaged accidentally.

(*g*) *A defective line switch* may cause the line fuse to blow whenever the receiver power plug is inserted into the wall outlet. When such condition occurs, install a new fuse and then proceed to test the continuity of the switch terminals with respect to the chassis and the power cord lead as well. With the receiver switch in the off position we should not have continuity between the prongs of the receiver power plug.

(*h*) *Reversed Power Plug.* When operating Universal A.C.-D.C. receivers as well as D.C. receivers from D.C. lines, it is extremely important that the line plug be inserted in the outlet with the proper polarity. Often times all tubes will light and yet no signals will be heard due to the fact that the line plug is reversed. Hum may exist in an A.C. receiver because of a reversed plug. These conditions may be easily corrected by merely removing the plug and inserting it again in reverse, thus reversing the polarity of the power supplied to the receiver.

(*i*) *Shock When Chassis is Touched.* Most of the inexpensive universal and D.C. sets have what is known as a hot chassis. That is, the chassis is above ground and usually a voltage equal to the line voltage is supplied to the receiver. When touching such a receiver chassis we may become shocked. If it is necessary to handle such a chassis with the line plug plugged in, wear a pair of rubber or dry canvas gloves. Be careful and do not touch the chassis with a ground wire or set the chassis on a sheet of metal which is grounded. The main line fuse may blow if you do!

(*j*) ***Filament Circuit Troubles.*** Whenever several tubes in a receiver do not light, look for a poorly soldered filament connection, or an open filament resistor, a poor socket prong, or a poor soldered joint at the tube prong. A break in a filament cord resistor may be found in some of the inexpensive Universal receivers. This condition will prevent the tubes from lighting. The resistor cord should be replaced if the break is found to be more than 6 inches from the ends of the cord.

(*k*) A short circuit between a filament circuit and a ground may cause hum in an A.C. receiver. This will usually be due to poor insulation or insufficient spacing between the leads carrying the filament supply.

(*l*) Distortion or muffled signals may be received by the application of excessive filament voltage or having a broken ground wire or lead. Check the filament voltage and also the ground to the filament circuit. Refer to the schematic wiring diagram of the receiver for exact connections.

(*m*) It is important to have the proper center tap to the filament source of the R.F. tubes in a high gain receiver in order to reduce resonant or tunable hum to the lowest value.

(*n*) Some receivers use fixed as well as variable midtap resistors. Hum will be heard if these are defective, when the receiver is A.C. operated. The resistance of the resistors may be checked by removing the connecting leads and using an ohmmeter. If the resistor is found to be open and should it be impossible to repair, then insert a new one.

31. DEFECTIVE FILTER SYSTEM. (*a*) A defective filter system of a radio receiver, regardless of the type, will cause serious trouble unless corrected at once. Naturally the defect will be in a choke coil or a filter condenser. A grounded filter choke coil, or a leaky or shorted filter condenser will throw an unusually large load on the rectifier tube and the power transformer. If the latter is adequately protected by a fuse, the set fuse will blow. If the fuse has too high a current rating the transformer may overheat and eventually break down; or the rectifier tube elements, particularly the plate will get red hot, emit gasses and a blue glow will arise between the elements; or the line ballast resistor will overheat and eventually burn out. A blue glow between elements is a definite indication of a filter defect, except in the case of a mercury vapor rectifier tube. Shut the power off at once and check chokes and condensers, as explained elsewhere in this reference text.

(*b*) Mercury vapor rectifier tubes oftentimes employ small radio frequency chokes at their plate lead terminals. When these chokes become defective due to improper installation, or are accidentally damaged, we may hear noise. This noise may be heard from the receiver chassis or loudspeaker.

(*c*) A filter choke or loudspeaker field which is shorted may cause hum, squeals, howls, and put-puts. This is due to the fact that there is insufficient reactance inserted in the circuit. A shorted radio frequency choke may also result in squeals.

(*d*) All receivers using a metal chassis generally have the chassis grounded. For this reason a careful inspection should be made to see that no piece of apparatus or bare wire is touching the chassis that is intended to carry power to points other than the chassis itself. This can be determined quite definitely by comparing all connections with a schematic wiring diagram and making continuity tests.

32. REGENERATION AND OSCILLATION. (*a*) *Regeneration* in a radio receiver is generally recognized by a swishing or rushing sound as you tune in a station; *oscillation* which is generally excessive regeneration makes itself known by squeals and howls, either with set tuned to any dial position or when tuning through a station. Oscillation is, of course, quite objectionable and must be removed, although some individuals may be willing to have regeneration if it is controllable. Oscillation in beat signal generators for signal finding is quite essential, and regeneration under control allows greater signal strength to be obtained. Regeneration is only objectionable if it distorts or muffles signals, or reduces the fidelity of reception.

(*b*) A check for internal and external squeals and howls or swishing should first be made. If any of these symptoms are heard when the station selector or receiver is not adjusted, some one in the neighborhood is producing the interference. Nothing can be done unless the offender is tracked down with a directional loop antenna receiver and that receiver corrected or the owner shown how to operate his receiver. All other conditions of interference are due to set defects or unbalance.

(*c*) Superheterodyne receivers often produce a squeal or howl when tuned, the harmonics of the I.F. or local generator beating with the incoming signal or some other signal passing through the preselector even when the signal itself is not audible. Lowering the oscillator grid bias or plate voltages, checking up on misplaced wires in the I.F. section often corrects this defect.

(*d*) Regeneration and oscillation is generally a radio frequency system defect. R.F. systems using triode tubes as amplifiers will oscillate unless suppressed or neutralized. Hence, when such a system is found which oscillates always reneutralize the receiver (see section 45 on Receiver Alignment) or check the grid suppression. They may be shorted. Usually grid suppressor resistors of large value may be required, but before this is done be sure that a defect is not causing an undue amount of feed back. For example: a grid lead may be too close to a plate lead. Try changing the position of the grid lead.

(*e*) R.F. systems using tetrode and pentode tubes when properly designed do not oscillate. Only a defect can produce undesirable feed back, as is often the case for systems with triode tubes. Whenever a defect exists which feeds the output into a previous stage or grid, regeneration will take place. Some of these possibilities are:

(*f*) Open or defective last filter condensers in the power pack. This is the common supply to all stages, and an open condenser will present a high resistance coupling, causing hum, regeneration and oscillation.

(*g*) An open grid bias condenser couples the plate to the grid often producing this interference.

(*h*) An open cathode to plate supply bypass condenser will allow R.F. signals from the plate to pass into the supply circuits and then to a grid circuit causing squeals and howls. An open in a cathode to — C terminal, or a short in the resistor to a plate or grid supply terminal will cause closer coupling through the supply system.

(*i*) Most servicemen usually track down a defective condenser by connecting two leads with probes to a 1 mfd. condenser and connecting the probes across various bypass, and filter condensers. If a defective condenser or its lead is open or poorly soldered (usually in its container) shunting the good condenser across it will stop the trouble. Install a new condenser of recommended size.

(*j*) Any high resistance connection may be a source of plate to grid feed back, and a good soldered connection should be made. Improper wiping contacts at the rotors of variable condensers, or their absence often result in regeneration and oscillation.

(*k*) Undesirable inductive coupling is, of course, a major source of feed-back. But all such possibilities are eliminated in the original design of the receiver. If the receiver is of reliable make, it is best to consider the other sources of trouble. If undesirable coupling is found it should be reduced (less turns) or eliminated entirely.

(*l*) A large number of possible defects are given in the index under "Squeals, Howls and Put-Puts." Study this part of the index if you have a job involving regeneration and oscillation.

33. (*a*) **MOTORBOATING** is a term describing the sound produced in some receivers, resembling the put-put-put of a single cylinder gas engine. It is in reality a low frequency oscillation produced by high common impedance in the plate circuit of the audio amplifier. However, any combination decoupling and filter system defect may result in motorboating.

(*b*) Defective tubes are to be suspected and new ones should be tried. Bypass and filter condensers should be checked for opens by shunting them with others. If an automatic volume control system is used, pay particular attention to the decoupling condensers —trying others. Check the connections between the rotors of the tuning condensers and the chassis. Sometimes, a 100,000 ohm resistor shunted across the signal input circuit of the first audio tube will prevent motorboating.

(*c*) Test for shorts between the primaries and secondaries of audio, R.F. and I.F. transformers. Open grid returns will result in a sound quite similar to motorboating and such circuits should be checked with an ohmmeter, using a circuit diagram as a guide.

(*d*) Push-pull and push-push stages may oscillate or motorboat. The simplest cure is to insert a 200 or 300 ohm resistor in series with each grid; and if this does not completely solve the trouble connect similar resistors in series with each plate; in each case, next to the socket terminals.

34. MECHANICAL FEED BACK. (*a*) Sound emitted from the loudspeaker is to a more or less degree, acoustically (through the air) or mechanically (through the cabinet and chassis), fed back to the signal circuits. This may result in a howl which rises from zero intensity to a loud amplitude. Naturally, such interference will not be tolerated by the customer. Recognizing the means of coupling indicates at once the solution of the trouble.

(*b*) Microphonic tubes are a common source of trouble. Tapping each tube with the receiver volume turned up and turned to a station will quickly identify the microphonic tube. Try the latter in a different position (where the same type tube is used) or replace with another tube.

(*c*) Another very common trouble is at the clamps which hold the chassis to the cabinet. In some receivers the machine floats on sponge rubber or springs. If they harden or lose their elasticity, microphonic noises arise. Adjust springs and replace hardened sponge rubber. Such machines are shipped with chassis temporarily bolted down. Before the machine is placed in operation free the chassis so it will float.

(*d*) If the felt rim on the loudspeaker has hardened or has been omitted or the loudspeaker is too tightly bolted to the baffle mechanical feed-back will be strong. Be sure the rim is used that it is soft and only moderately snug to the baffle board.

35. HUM. (*a*) When an appreciable amount of raw A.C. gets to the loudspeaker a low pitched hum will be heard. Theoretically, there is always some A.C. in the output, but for a receiver of good fidelity it should be one-millionth of the maximum output. As expense is involved in getting hum out of the output, only moderate and high-priced receivers will be found free of hum. Objectionable hum should never exist, in any receiver of reliable manufacture. Receivers with a small baffle have plenty of hum current in the loudspeaker but the hum is not reproduced by the loudspeaker due to the small baffle area. For high fidelity receivers hum output must be kept to a very low value, and the least power supply defect may result in hum.

(*b*) A procedure to identify and isolate the source of hum trouble is highly important. Hum is generally of three forms: *1*, hum existing at all times whether on or off a station, *general hum; 2*, hum existing only when set is tuned to a station, particularly a powerful station, called *tunable or resonant hum; 3, direct hum* coming from a part and not through the loudspeaker, called *mechanical hum.*

(*c*) General hum is easily identified. You will hear it coming from the loudspeaker soon after the power switch is turned on. A strong hum louder than the broadcasts that you can tune in indicates, as a rule, a total break down; a mild hum, not heard in a normal receiver of the same make, indicates inadequate filtering or some minor circuit disturbance.

(*d*) Tunable hum is generally produced by a defect which throws raw A.C. into the R.F. section causing some R.F. tube to be modulated by this interference. Before considering the receiver to be at fault, check for transmitter hum. A battery operated unmodulated oscillator is connected to the receiver input and the set tuned to this oscillator. A strong signal may be necessary. If hum is not tuned in, the station is radiating a hum. It will probably be removed in a few days by the station engineer. Signals entering the receiver via the power line may become modulated with A.C. Try two 0.1 mfd. 600 volt condensers across line, center tap grounded; if line filter is not used.

(*e*) When hum is heard and placing your ear next to the grill of the loudspeaker shows that it is not coming through the loudspeaker, you are reasonably sure that some part, usually laminations of an audio or power transformer or iron core choke are vibrating. Wedging the laminations or tightening the core bolts or rivets will help to reduce this trouble.

(*f*) In tracing hum first disconnect the aerial and ground and move the power supply cord around to be sure that induction from it does not exist. If the symptoms or experience do not indicate the probable cause (study the index on hum), isolating the stage where hum originates is a time saving procedure.

(*g*) Of course, tunable hum indicates a defect in the R.F. systems, and the index suggests locations and defects. Next if any hum adjusters are used they should be reset for minimum hum output. Unless you are familiar with the receiver you should refer to a circuit diagram, particularly one which gives the location of the various adjustments. If the receiver works normally except for too much hum output, a stage isolation test is made.

(*h*) For an isolation test use a head-set with a series 1 mfd. condenser. This is probably the most sensitive as well as the most practical hum indicator. The tests to be described should be tried on various receivers without abnormal hum, in order to acquaint yourself with the amount of hum that ordinarily is heard in a receiver which is in good shape. Check the input of the loudspeaker (plate to chassis or plate to plate of the last stage). If hum is heard and the loudspeaker has no hum bucking device, check the rectifier and filter system. Defective rectifier tubes, shorted or leaky filter condenser, shorted or grounded filter chokes may be causing the hum. A serious defect in the power pack may cause the rectifier tube to glow between elements, and this will be observed even before an isolation test is made.

(*i*) If the rectifier-filter delivers normal hum output (some will always be heard) isolate the stage it is entering. Connect the head set between plates and chassis (or cathode of each tube) or preferably in series with the plate (in which case the 1 mfd. condenser is omitted), starting from the loudspeaker and working towards the antenna-ground. When you pass through a stage of abnormal hum (equal to that received across the filter output) that section is allowing hum currents to pass from the power pack to the signal circuits. Poor connections, shorted isolating resistors from the supply terminal to the electrode or the electrode supply to cathode bypass condenser, defective or weak tubes, operating voltages and open circuits should be checked. Study the troubles peculiar to each section, as given in the index on hum.

(*j*) Quite often hum is accompanied by other defects; no volume, smoking parts, regeneration, oscillation, motorboating, etc. By isolating the primary defect and correcting the trouble, hum too will be eliminated. If inadequate filtering exists in the power supply system, replacing the condensers for others of less leakage, or adding more filter condensers (to increase the filter capacity) may eliminate the hum.

(*k*) Power pack filters with tuned circuits are often contributors to hum. If the choke and resonating condenser (a fixed condenser) are tested as normal, probably a shift in the air gap of the choke has thrown the circuit out of resonance. Try various small condensers in steps of .0001 mfd. across the choke. If this fails to tune out the hum adjust the choke's air gap. Loosen the laminations of the choke and insert various thicknesses of paper in the air gap. When least hum is heard clamp the lamination tightly.

(*l*) Some servicemen as a "make-shift" move the loudspeaker away from its baffle one or two inches. This will reduce low frequency response and hum as well.

36. EXTERNAL NOISE. (*a*) The test for external or internal noise is to disconnect the antenna and ground leads from the receiver, short ANT to GND, and listen for the original noise. Slap or shape the receiver chassis to check for loose connections. Now if the noise is not coming through the power line connection and no noise is heard we have definite proof that noise is coming from an external source.

(*b*) Most modern radio receivers have built in, a line noise filter. In some cases it is merely a condenser across the line input; in better receivers two condensers in series are connected to the line, the mid-condenser connection grounded; or in other receivers a shield is wound between the primary and secondary of the power transformer. The only sure way of determining whether a receiver has a line noise eliminator is to refer to a service circuit diagram. In your case it is wise to buy or build a portable line filter. Insert the line noise filter. If the antenna input is shorted and the insertion of the filter eliminates the noise, install a permanent line filter; if the filter does not eliminate the noise, the cause is internal; if after the filter has eliminated the noise, but restoring the antenna-ground connections bring back the noise the elimination procedure is as follows:

(*c*) In every case where external noise is experienced and a line filter does not help, *install a noise-reducing antenna.* There are many approved types on the market. Select one of reliable make, one which gives you good results and stick to it. Get the straight-away as far up in the air as you can, as far away from metal objects and power, telephone and trolley wires. Always run, if possible, the straight-away at right angles to lines. The length of transmission line is immaterial in a well designed noise-reducing antenna. Use an all-wave antenna for all-wave receivers.

(*d*) In 95 percent of the cases a well installed noise-reducing antenna will eliminate external noise. In the other cases, the offending device in the locality must be traced and noise filters installed, a subject studied in the regular course. A few hints will help.

(*e*) The power plugs connected to radio receivers are oftentimes connected to the power cord by means of small machine screws. When the cord is continually pulled in and out, we find that the screws become loose. Therefore, we will have a small break in the current or circuit, thus causing interference or external noise.

(*f*) Poor connections to electrical units within the house, such as fans, small motors, sewing machines and other electrically operated devices will cause external interference to be heard. Such conditions may be corrected by tracing all connections to lamps, and other power cord connections. Defective switches and power outlets cause interference and should be corrected or replaced.

(*g*) House line fuses may have been blown and replaced with tinfoil or a copper penny. Such fuses are loose and often will provide very poor contact. Poor contacts cause an arcing of the current and consequently, a radiation of interference. Install the proper fuse when such conditions are found.

(*h*) Line filters should be purchased, and for large electrical machines one designed particularly for the device used. A simple filter can be made by placing two 2 mfd. condensers in series across a line and grounding their midpoint. These condensers should have a working voltage of 600 volts. A short direct ground lead should be made from the midpoint between the two condensers.

37. SIGNAL CIRCUITS OVERLOADED. (*a*) Radio receivers can easily be fed with too much signal, which is in many cases no fault of the receiver. Each receiver is rated to handle a definite output without distortion and if this is exceeded by tuning to a local station or some other powerful broadcaster with the volume control wide open, distortion is inevitable. The customer must be instructed to reduce the output to a reasonable amount. Of course, there is some stage in the receiver which first shows signs of being overloaded, and if distortion at this point can be reduced the volume range of the receiver can be extended. Naturally, a receiver must first be correctly tuned, otherwise cutting of the side-band frequencies will cause distortion.

(*b*) Detectors very often overload. Before anything is done to this part of the circuit, check the tube in a tester or try several new tubes. Next check the tube's operating voltages. If the tube is defective the distortion will disappear, if the voltages are incorrect, the correction will be obvious by a stage voltage analysis. Grid leak—grid condenser detectors overload quickly on strong signals. Besides distortion, the detector may block stopping reception momentarily. If the customer prefers to listen to strong broadcasters, try leaks of lower ohmic values, about ½ to 1 megohms. This will reduce sensitivity. If the detector has an automatic C bias voltage drop, vary the cathode to —B resistor for best results; or, if readily done, increase the detector's plate voltage.

(*c*) Improper plate load filtering of R.F. current may cause distortion. Try a larger load filter bypass condenser, only large enough to keep R.F. out of the audio system, otherwise the tone of the output will be lowered to an apparent degree. Try a 10 to 30 millihenry R.F. choke in series with the plate load.

(*d*) Audio tubes are easily overloaded by too much signal. The tubes and voltages should be checked. With the exception of a push-pull (Class B) audio amplifiers, a plate milliammeter in the plate supply of each suspected stage should show no or very little current change. If the stage is fed with a signal above the value it was designed to handle (loudspeaker output high) a current change will be observed. This indicates the limit of the handling ability of the receivers. Although the output handling ability of tube may be increased by running up the plate and grid voltages, such a procedure is not recommended for normal service work.

(*e*) Loudspeakers are often overloaded or at least distortion comes from this point. Overloading is quickly spotted by the fact that rattles are mixed with false reproduction. The cone, the cone soft leather rim, or the spider may be weak or hardened. Replacement cones should be used after the voice coil or armature has been centralized and found not to cure distortion. If the voice coil hits against the stops on large signals, ask the customer to reduce the volume to a reasonable amount.

(*f*) The defective stage can be located by connecting a pair of 2000 ohm ear phones across the plate cathode of each tube working from the detector to the output. A 1 mfd. condenser should be in series with the phone. When distortion appears the immediate stage ahead of the connection is causing the trouble.

(*g*) Overloading in the R.F. section produces distortion, as well as hum modulation and cross modulation. Check: for correct type of tubes, the tubes themselves, and electrode voltages. A plate milliammeter check is often helpful. A pair of earphones in series with the plate of an R.F. tube should produce no or a minimum of audio signal; the current change with a signal tuned in should not be observed.

(*h*) It is worth recommending a shorter antenna (broadcast type only) if distortion due to overloading appears with broad tuning.

38. LOUDSPEAKER TROUBLES. (*a*) Loudspeaker *fields* which are suspected of being open or shorted may be checked with an ohmmeter. To test for a shorted field place the ohmmeter leads directly across the field coil. This will also enable you to check for an open in the field. A test from either of the field leads to its frame will enable you to show up a ground. In making the latter test have a wiring diagram handy as some fields are naturally grounded. When a field is open or shorted remove the field and take off the insulating paper. Sometimes the trouble is right on the surface of the coil and can be repaired. If repair is not possible purchase and install a new field.

(*b*) Lack of excitation on the field may be due to a defective rectifier or a filter condenser ahead of the field being broken down. If the field is open or shorted there will be no excitation. A quick check for this condition is to hold a metal (steel) screw-driver about a quarter of an inch away from the pole piece. It should be strongly attracted if the field is being properly excited.

(*c*) A frequent trouble encountered in dynamic loudspeakers is *opening* of the *voice coil.* Generally the flexible lead from the cone to the output transformer breaks. Usually resoldering this lead will complete the repair job. A partial open sometimes occurs and on strong signals when the cone moves quite a distance, distortion and partial intermittent reception will occur. Loose turns on the voice coil will cause a peculiar rattle which, once heard, can always be identified again. Remove the cone and coat the voice coil with a good loudspeaker cone cement, obtainable from the large radio supply firms, allowing it to dry thoroughly. This will hold the wire on the voice coil form.

(*d*) The voice coil sometimes becomes off centered and in such a case will rub against the pole pieces. You can check up on this by moving the cone in and out with your hand, pushing as nearly as possible on the center. If you feel the voice coil rubbing, loosen the screws holding the coil in place and move the cone around until no rubbing occurs. Then tighten the holding screws. A better way of doing this is to cut thin strips from a business card and insert these along side of the voice coil, between it and the pole pieces. This will center the voice coil and the holding screws may then be tightened and the strips removed. Iron filings in the pole pieces or openings of the loudspeaker are a frequent source of trouble. A pair of hand bellows is useful for removing them and it is seldom necessary to take off the cone to do this job.

(*e*) After being in use for several years a loudspeaker cone is liable to become stiff and the supporting ring may harden. It is advisable to install a new cone, as they are inexpensive. When a leather ring is used to hold the cone to the metal edge of the loudspeaker, "Neetsfoot" oil may be worked into the leather to soften it. When the spider looses its flexibility, replace with a new cone unit.

(*f*) Never operate a receiver with the loudspeaker disconnected. In the case of receivers using electrolytic condensers an overload on the first condenser will occur if the loudspeaker is not plugged in. If the condenser is of the wet variety, a hissing sound will be heard indicating that the condenser is breaking down.

(*g*) A.C. dynamic loudspeakers using dry disc rectifiers will in time emit considerable hum. If hum is heard when the receiver is turned off but the field excited you know that it is time to install a new rectifier unit.

(*h*) Defective loudspeaker cords, particularly on magnetic loudspeakers, are a source of trouble. They may be checked for continuity with an ohmmeter and if bad must be replaced. Do not neglect to shake and move the cords when making this test. An intermittent reading, of course, indicates a bad connection.

(*i*) Weak magnets in magnetic and permanent dynamic loudspeakers are a frequent source of trouble. In the latter case the loudspeaker must be replaced and in the former case you should try reversing the loudspeaker leads. If the loudspeaker is directly in the plate circuit of a tube, the polarity of the loudspeaker leads is important because current flowing through the loudspeaker windings in the wrong direction will tend to demagnetize the permanent magnet. The loudspeaker wire having the most red in it connects to plus B.

39. RESONANT EFFECTS IN CABINET AND ROOM. (*a*) Although there may be only a small amount of hum present at the output of a loudspeaker and this hum may be natural, it may be heard with sufficient intensity to cause a complaint from the customer. Resonant effects in the room or cabinet are often responsible. The hum is emitted from several different directions and on striking a hard surface may rebound and add to the hum at another point in the room. If a hum is heard only in particular spots in the room, experiment with the position of the cabinet. Drapes on the walls and a sufficiency of furniture in the room will usually eliminate hum. Placing a rug under the receiver is often helpful. In some cases, it may be advisable to bore holes in the bottom of the loudspeaker compartment or to line the inside of this compartment with some sound absorbing material such as celotex.

(*b*) Resonant effects in the room and cabinet will not only result in hum but also in noise. Loose parts in the cabinet may be caused to dance up and down under certain sounds from the loudspeaker giving rise to a rattling noise. To clear up the trouble, fasten the parts down so they cannot vibrate. Reflectors behind radiators are a common source of mechanical noise. Directing the loudspeaker away from such objects is the usual cure. Pictures and mirrors hung on the wall have also been known to vibrate when struck by certain sound frequencies.

(*c*) The more critical broadcast listener will complain that the receiver sounds too boomy, caused very often by cabinet resonance. Lining the loudspeaker compartment with celotex, sound absorbing wool, or heavy soft cloth helps. Keep the cabinet at least 2 to 3 inches away from the wall, and preferably in a corner—"katty-corner."

40. OSCILLATOR CIRCUIT TROUBLES. (*a*) When the oscillator circuit of a receiver is suspected of being defective, one of the simplest tests is to touch the ungrounded side of the oscillatory circuit with a moist finger. A click in the loudspeaker should result when the terminal is touched and also when the finger is removed; if only one click is heard, the tube is not oscillating. Another test is to tune in a station and pull out the oscillator tube. If the signal can still be heard, the oscillator tube is not functioning.

(*b*) When in doubt, try a new oscillator tube. Go over the connections in the oscillator circuit with a hot soldering iron as a high resistance connection will prevent the oscillator from functioning—possibly only over a section of its range. Test the continuity of the oscillator circuit and compare it with that of a schematic diagram of the receiver. All resistors should be tested for proper value and condensers should be checked for opens by trying new ones. Improper alignment of the oscillator stage will cause the set to be dead over a portion of the dial. This may also be caused, particularly in combination detector-oscillator stages, by excessive control grid voltages. You may try reducing the value of the bias resistor by about one-third of its present size.

(*c*) If the mica spacing in any of the oscillator trimmer adjustments appears to be split or dirty, try a new piece of mica. Do not neglect the fact that the plates of the tuning condensers may rub at some portion of the dial setting. If everything seems to be in good condition as far as you can determine, the installation of a new exact duplicate oscillator coil would be worth while.

(*d*) When adjusting the oscillator of a receiver, you may find at the very high frequency adjustment, two points at which a signal can be received. Use that adjustment which results in least capacity of the trimmer condenser. If you select the other position, the receiver will be dead at mid-scale. If the oscillator is equipped with a grid leak, it may be necessary to experiment with other values of resistors for best results.

41. A.V.C. TROUBLES. (*a*) When an A.V.C. trouble is indicated, you should, first of all, try new tubes in the A.V.C. stage and in the stages controlled by it. Then, the continuity of the circuit should be tested with an ohmmeter, using a wiring diagram of the receiver. Improper value resistors should be replaced with others of the right size and bypass and coupling condensers should be checked for opens by shunting them with others of about the same size and known to be in good condition.

(*b*) There are some peculiarities in A.V.C. receivers worth mentioning. When tuning from a strong station, the receiver sensitivity will be automatically increased. If you are in a noisy location the noise between stations may be terrific but it may cut down to nothing on strong signals. Where the A.V.C. tube serves only the purpose of automatically controlling the volume, you will oftentimes note an increase in volume when the A.V.C. tube is removed. This is quite natural and does not indicate a defect.

42. TUNING INDICATORS. (*a*) Whenever a tuning indicator is found, it is quite safe to assume that the receiver embodies automatic volume control (A.V.C.). Should no change in indication be observed first check the A.V.C. action. Tune through local and distant stations. Watch for elimination of blasting on locals, noise off station (if the receiver does not incorporate a squelch system) and reduction of fading. If the A.V.C. action is normal then the defect is definitely in the indicator.

(*b*) You should be able to tell when a reasonable correct action is taking place. The greatest indication is obtained on local or powerful stations. Distant stations and particularly those on the short wave band produce little change in indication when tuned in—perhaps only a "quiver"—because there is insufficient signal pick-up. When insufficient indication is obtained on local stations, and the receiver is otherwise normal, check antenna for grounds, or leaks, causing low pick-up. Try a longer aerial.

(*c*) The meter (needle indicator), the moving vane system (shadowgraph), the neon glow tube (glow indicator) may be defective. The moving vane instrument may be tested by applying a small C battery; the glow lamp checked by placing it in series with a 10,000 ohm resistor and connecting to a 110 volt A.C. or D.C. source. Or a new neon glow indicator may be tried. The shadowgraph or blinker type may not operate because the lamp is burned out, or not securely in the socket. After turning the lamp securely in the socket and no indication is observed, try a new lamp.

(*d*) There is always the possibility that the indicator is shorted. The moving vane unit should show continuity, a glow lamp no circuit resistance, when the proper test connections are made.

(*e*) Be sure the voltage supplied the neon indicator is correct. Usually an adjustment is provided. Try various positions and especially when a new neon indicator is used. It should be set so it barely lights on no signals.

(*f*) In the blinker system the three coil transformer and the input filter condenser often become defective. Check and replace if necessary. In replacing watch color code on leads for a proper reconnection.

(*g*) Remember, any defects in the A.V.C. system will affect the action of the visual indicator, so be sure to check the A.V.C. before blaming the indicator.

43. ASSOCIATED DEFECTS. (*a*) A part may be overheated, destroyed or made defective because some other associated part is defective. For example:

(*b*) A "C" bias resistor connected between the cathode of the tube and —B may become overheated, burn out, stop reception because the bypass condenser between +B and cathode is leaky or shorted. Even if the condenser is only leaky sufficient extra current will be bled to the bias resistor to send the C bias up to a value that will either distort or stop reception.

(c) A leaky coupling condenser between the plate and grid of two stages, will if the grid input has a high ohmic resistor destroy the tube. Current is bled from + B through the leaky coupling condenser, through the grid resistor. The grid is made positive, causing excessive distortion and eventually ruining the emission of the tube which becomes weak and useless. When such a stage is checked to have normal + B supply, high plate current and cathode to — B voltage, check for leaky coupling condenser.

(d) A rectifier tube becomes gassy emitting a blue glow between elements; or the plates get red hot due to an overload. The line fuse or ballast may burn out. The cause may be a shorted or leaky filter condenser, or a grounded filter choke, or a short in the load (signal circuits drawing too much current). Check D.C. drop across suspected parts or circuits.

(e) A socket or internal tube short between cathode and screen grid or plate, screen grid and control grid suppressor grid and plate, etc., may cause large current to flow in the associated circuits, destroying tubes, resistors, and even coils. A socket voltage analysis and comparison to the manufacturer's voltage table will reveal the defect.

(f) To check for abnormal current measure the voltage across the resistor through which the abnormal current is flowing. If higher than rated and the resistor itself is not shorted, high current is indicated. Or break the circuit, with an adapter if possible, and measure the current directly.

(g) *Moral:* When a defective part is located, be sure that some other defect did not cause the trouble. Always make sure of this fact or the trouble will reappear.

44. AUTO RADIO TROUBLES. (a) An automobile radio receiver may develop practically any trouble common to other radio receivers. Special conditions of use and special design of the power pack create troubles peculiar to auto radios. These will now be considered.

(b) *Vibrator Trouble.* The Vibrator B eliminator is a delicate instrument and must be operated without excessive sparking, otherwise continuous operation will burn the contacts. The burning of the contacts will cause improper operation of the unit. Adjusting screws may also become loose due to continuous vibration. Vibrators that do not have adjusting screws may be adjusted by bending the spring levers themselves to the proper spacing. Filing the contacts when they have become worn is sometimes desirable. This is especially necessary when the fuses in the vibrator leads blow continuously. Pitted or dirty vibrator points are therefore to be reconditioned by filing and proper spacing. Internal noise is oftentimes heard on an auto radio due to dirty contacts.

(c) Due to the continuous vibration within the vibrator unit itself, we may experience broken or loose connections. Such connections may cause the vibrator to be intermittent and also to produce excessive noise when the automobile is in movement.

(d) It is wise for the beginner and even a busy, experienced serviceman to replace defective vibrators with new ones. Fortunately these units are plug-in devices and therefore are quickly replaced. Use a recommended duplicate replacement unit.

(e) *Ignition Interference.* The following suggestions for the suppression of Ignition Noise Interference is given through the courtesy of the Galvin Manufacturing Company. These hints are given in the order of their importance, and if any have been overlooked on the job you service, make the necessary changes or additions.

1. Apply suppressors to spark plugs and distributor.

2. Apply generator condenser.

3. Reroute primary wire from coil to distributor, keeping it as far away as possible from high tension wires.

4. Connect dome-light filter to dome-light wire at point where it enters front corner post.

5. Shield high tension wire if coil is mounted on instrument panel.

6. Shield antenna lead-in wire from radio set to top of front corner post. Ground shield at both ends.

7. Shield primary wire from coil to distributor.

8. Connect a .002 to .006 mfd. high grade mica condenser directly across the primary breaker points of the distributor.

9. Bond (connect) the upper metal parts of the car body to one another and return a heavy copper bond (connector) from these points down to the bulkhead of the car. (This is usually necessary in cars using composite wood and metal body construction.)

10. Bond to bulkhead where necessary all control rods and pipes passing through the bulkhead.

11. Shield head of coil when mounted on instrument panel.

12. Cover floor boards of car with copper screening, bonded to car frame.

13. Adjust spark plug points to approximately .028 of an inch.

14. Clean and adjust primary distributor breaker points.

15. In cars having rubber motor mountings, connect heavy bond from grounded side of battery directly to frame of car.

16. Connect a .5 to 1 mfd. condenser from hot primary side of ignition coil to ground.

17. If ignition coil is mounted on driver's side of bulkhead, move it to the motor compartment side, using the same holes for mounting.

18. Clean ignition system wiring. Clean and brighten all connections. Replace any high tension wiring having imperfect insulation.

19. Ground metal sun visor and rain troughs if necessary.

20. Make sure hood of car is well grounded. Clean hold-down hasps on both sides.

21. Bond instrument panel and steering column to bulkhead.

22. When under-car aerial is used, connect a .5 mfd. condenser to tail and stop-light wires.

And special hints:

(*f*) *Static Noise.* Tail light, stop light, head light or horn wires sometimes pick up static charges from the tires and cause interference. To determine if these are at fault, drive the car from a dry pavement onto a wet one. If the wet pavement eliminates the noise, then the light wire should be shielded and the shield grounded. Noise is sometimes caused by the antenna being too close to body metal of car. Antenna should be checked for this condition whether the car manufacturer or an individual has installed it. There must be a space of at least 3 inches between the metal car body and the antenna. (Courtesy: Mallory.)

(*g*) *Wheel Brake Noise.* The front brakes sometimes accumulate static and cause interference due to a poor ground in the front wheels and a peculiarly constructed lining. If this condition is suspected, set the car in motion, then with the motor shut off and the clutch disengaged, apply the brakes. If the interference is eliminated then the front wheels are the cause. To overcome this condition, use graphite grease or insert grounding springs in the internal hub cups. In the case of external brakes, it is necessary to ground the brake bands to the chassis. (Courtesy: Mallory.)

(*h*) *Antenna Touching Car Frame.* The antenna in an auto radio must be carefully insulated from the frame. If allowed to touch, signals will be shorted out and noises introduced. The roof types must be carefully installed, at least 3 inches of space being between the aerial and any grounded metal. Be sure that the insulating bushings and washers are correctly used and in good condition in the under-car and bumper types of antennas.

(*i*) *Internal Auto Radio Noise.* Auto radios that reproduce noise with the antenna disconnected, may be experiencing interference due to dirty brushes on the generator which charges the battery. The brushes are usually dirty when excess oil has been applied to the generator commutator. In such cases, the cover over the generator brushes should be removed. Then, with the car idling, you should rub the commutator down with a canvas cloth dipped in carbon tetrachloride. Whenever the cloth becomes black you should move it along and try again. Eventually, the commutator of the generator will become shiny. Then you should add a very small quantity of vaseline thereby preventing oxidation. Incidentally, the brushes should be in good condition and held against the commutator by the springs provided. If the brushes are entirely too short to operate properly, they should be replaced. Sometimes it is necessary to apply very fine sandpaper in order to remove all of the carbonized surfaces of the commutator. When finishing such an operation, commutators should be covered with a thin coat of vaseline.

D: RECEIVER ALIGNMENT AND BALANCING

45. (*a*) In radio receivers there are two kinds of adjustments which you as a service man will be called upon to make. These are alignment (often called synchronizing) and neutralization (often called balancing). The first has to do with the tuning of circuits while the latter is a method used to prevent oscillations (squeals and howls).

(*b*) Sets having single tuning dials (the tuning condensers work on a common shaft) will be equipped with aligning or trimming condensers. Modern receivers using screen grid tubes employ no neutralizing condensers and therefore if such a set squeals or howls there are no adjustments to prevent this. The set has developed a defect. It is absolutely incorrect to try to stop howls and squeals by adjusting aligning condensers. (If 3 and 4 I.F. stages are employed and they are peaked when they should be band passed, the receiver may squeal. It is proper to band pass, adjust trimmers, only in this case.) This requires a close examination of every trimmer or padding condenser and its purpose.

(*c*) The following information is of a general nature. Exact details are given by the manufacturer for each of their receivers. Follow them. This subject is taken up in greater detail elsewhere in the course.

(*d*) *Neutralizing.* Bear in mind that not all sets using triode tubes have a neutralizing system. To check for neutralizing condensers first locate the aligning condensers (commonly called trimmers). These will be found on the tuning condenser gang frame. Then if there are any more similar condensers on the chassis they are probably there for neutralizing purposes. Check service diagram for a regeneration control. This should always be adjusted first.

(*e*) The method of adjustment is as follows: Open the filament circuit of the tube in the stage to be neutralized by slipping a soda water straw over one of the filament prongs—you can unsolder one of the filament leads if you wish—then tune to a station between 1000 and 1500 k.c. and turn volume all way on. Adjust the neutralizing condenser with an insulated screw driver for least signal output. The filament circuit is then closed and the same procedure carried out on the remaining neutrodyne stages.

(*f*) *Aligning T.R.F. Receivers.* To align a T.R.F. set, tune in a weak broadcast station at about 1400 k.c. Adjust the trimmers on the condenser gang for maximum signal output. For any other position, bend the end rotor plates in each condenser section. As many adjustments as there are segments in the split rotor plate should be made, one with each segment in full mesh with the stator. Start with the condenser set so the first segment meshes with the stator.

(*g*) *Aligning Superheterodyne Receivers.* To align a superheterodyne a service oscillator is really necessary. Connect the output of the oscillator, tuned to the I.F. of the set to the control grid of the first detector and the chassis. Turn back the attenuator (volume control) on the signal generator so that the signal can barely be heard. Adjust the I.F. trimmers for maximum output. An output meter is the best instrument with which to measure output level. Connecting a copper oxide rectifier type A.C. voltmeter, having a series condenser, to the plate and chasis or plate and plate of the output tubes will indicate output levels. If the receiver is an inexpensive one or has only two I.F. stages, the adjustments must be made very sharply. That is, adjusted for the greatest signal output.

(*h*) If the receiver has three or more I.F. transformers the stages should not be adjusted too sharply, as this may cause oscillation (squeals), circuit noise (rushing or hissing noise), or distort the signals. If in this case each I.F. transformer has been peaked each one should be band passed. On each transformer, tighten one adjustment slightly (one-quarter turn) and loosen the other slightly by the same amount. If the gain is too much, repeat the band pass adjustment for all the transformers.

(*i*) Connect the output of the oscillator to the aerial and ground posts of the set. Tune both the receiver station selector dial and the oscillator to 1400 k.c. Adjust the trimmers on the condenser gang for maximum output (the oscillator trimmer first) keeping the test oscillator attenuator set so the signal is always just audible or a low output meter reading is obtained. If the set oscillator is equipped with a low frequency padding condenser (will be shown in diagram by an adjustable condenser in series with oscillator tuning condenser and coil) tune receiver and test oscillator to 600 k.c. Tune set back and forth about 600 k.c. while you adjust the padder. You may hear the signal at more than one point. Adjust the low frequency padder at the point where signals are strongest.

(*j*) All-wave receivers have an I.F. amplifier to be adjusted as described above. They must be adjusted at the recommended I.F. They have tuning condenser trimmers and padding condensers for the broadcast band which are also adjusted as described above. For each short wave band covered by the receiver there will be a set of trimmers and padders. The trimmers are to be adjusted at the high frequency end of the band and the padder at the low frequency end of the band. Manufacturer's instructions which will give the location and purpose of the various adjustments should be obtained from the manufacturer or from his local distributor.

(*k*) *Antenna Compensator Condenser.* A few receivers have a special antenna compensating or trimmer condenser for adjusting the receiver to the antenna with which it is used. It is only necessary to tune in a broadcast station operating on a medium frequency (approximately 1000 k.c.) and then adjust this condenser for greatest volume. Instructions on making this adjustment are generally given in the operating instructions received with the radio receiver. After this adjustment is made it will not be necessary to change it unless a different antenna is used with the receiver.

(*l*) *Points to Remember.* Use an oscillator for aligning and neutralizing if you have one—otherwise use a broadcast signal. Don't try to neutralize if the set does not squeal. Don't try to align a superheterodyne without an oscillator. Always use an insulated screw driver for all of the above adjustments. In aligning an R.F., I.F., or Neutrodyne amplifier, the stage to be adjusted first does not matter greatly; however, in a super first adjust the I.F., then the trimmers, and finally the padders.

(*m*) Always align before you neutralize.

(*n*) Procure and follow when possible manufacturer's instructions especially for all-wave receivers.

THE VACUUM TUBE IN AUDIO FREQUENCY STAGES

15 FR

NATIONAL RADIO INSTITUTE

EST. 1914

WASHINGTON, D.C.

THE IMPORTANCE OF AUDIO AMPLIFICATION TODAY

This lesson on the "Triode as an Amplifier" is designed to do more than teach you how a vacuum tube amplifies—it is designed to serve as an introduction to the extremely important subject of audio amplification.

In the electrical and scientific world of today, reference is continually made to audio amplification. The fact of the matter is that the audio amplifier is the connecting link between Radio, Public Address Systems, Sound Pictures, and Line Telephony. I feel perfectly safe in saying that development engineers have spent more time on this subject than on any other in the past few years.

Without audio amplification, long distance telephone service would be impossible. A Public Address System is essentially nothing more than an audio amplifier. And an audio amplifier is an essential part of sound picture equipment.

Today there are many radio engineers who specialize in A.F. systems because of their many applications. The subject is an immense one—you will meet it again in the latter portion of your course. Master this lesson, and you will have no difficulties with those later lessons on audio and power amplification.

J. E. SMITH.

WASHINGTON, D. C.

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The Vacuum Tube in Audio Frequency Stages

THE FUNCTIONS OF AN ORDINARY TUNED RADIO FREQUENCY RECEIVER

A broadcast radio receiver is designed to receive signals from radio stations operating on frequencies between 550 and 1500 kilocycles. This is equivalent to stating that the wavelength, in meters, of these stations is between 200 and 550 meters.

To accomplish this, the radio receiver must serve at least three functions. *First,* it must be able to pick up the broadcast signals and amplify them sufficiently. This is the function of the radio frequency system which includes the antenna and ground and for efficient amplification, tuned radio frequency circuits are employed.

The radio frequency current is a modulated radio carrier, that is, it consists of a radio frequency component of definite "carrier" frequency and an audio frequency component.

Second, after sufficient radio frequency amplification has been obtained, a "detector" rectifies the modulated incoming "carrier" and separates the audio frequency from the radio frequency.

The *third* function of the radio receiver is to take this audio frequency in the detector circuit, which is ordinarily too weak to operate a loudspeaker, and amplify it sufficiently to work the speaker. This is the function of the Audio Frequency Amplifier of the radio receiver.

All this is illustrated in block fashion in Fig. 1. In this figure, "A" represents an aerial to "pick up" the broadcast R.F. signal, at some broadcast frequency between 550-1500 kc. This R.F. signal, which consists of an audio frequency component modulated on a "carrier" frequency, is amplified by efficient, tuned radio frequency circuits "B." After the audio frequency and radio frequency components have been separated by the rectifying properties of the detector "C," it is amplified by "D" sufficiently to operate a powerful dynamic speaker "E."

The voltage from the output of the detector is audio, but this voltage is so small and weak that if it were connected to a loudspeaker, it would be insufficient to operate it. You will remember from previous text books that the plate circuit of any tube contains an e.m.f., a plate load, and an actual load.

The purpose of an audio amplifier is to take this weak audio e.m.f. and to raise or amplify it so that it can operate a large load. This amplification is obtained by the use of vacuum tubes as audio amplifiers. Amplification is one of the greatest functions of vacuum tubes, and it is because extremely efficient vacuum tube amplifiers have been developed that fine quality radio reproduction is possible. To this is due also the success of the talking picture industry, centralized radio and public address systems, and wire line transmission.

USES FOR AUDIO AMPLIFICATION

Besides the use as an audio amplifier after the detector of a radio receiver, audio amplification plays an extremely important part in many other applications.

A few of the most important of these are as follows:

a.—Audio amplification for phonograph reproduction.

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One of the early successful uses of audio amplification is in conjunction with electrical pick-up reproduction from disc phonograph records. The voltage developed in the electrical pick-up is fed into an audio amplifier, which amplifies this voltage to work a powerful dynamic speaker.

b.—Audio amplification for electrical recording.

Phonograph reproduction was greatly improved by the electrical "cutting" of the disc records. This was only made possible by the use of a high quality audio amplifier after the microphone pick-up so that sufficient power was fed into the electrical recording device at the output of the amplifier to properly cut the record.

c.—Audio amplification for power amplifiers.

Power amplifiers are audio amplifiers requiring a high degree of audio amplification. These audio amplifiers require the use of several tubes, sometimes in special arrangements to handle tremendous audio power outputs. In many cases the audio amplification has to be sufficient to work several high power dynamic speakers.

Such uses are made of these power amplifiers in the talking picture industry. The audio frequency for these amplifiers is either taken from the output of an electrical pick-up or photoelectric cell, depending on whether the sound is from a phonograph record or a sound film track.

Power amplifiers are used where it is necessary to send out sound to large gatherings, such as for large auditoriums, stadia, and the like. Thus power audio amplification makes possible clear transmission of sound to accommodate a few hundred or many thousands, indoors or outdoors. In public address and centralized radio systems we find the most important applications of these types of power amplifiers. Generally a carbon or condenser microphone pick-up is used across the input of the power amplifier and the output of the microphone is amplified sufficiently to operate a high power load.

Audio amplification is just as important in transmission as in receiving. In transmitting systems audio amplification is

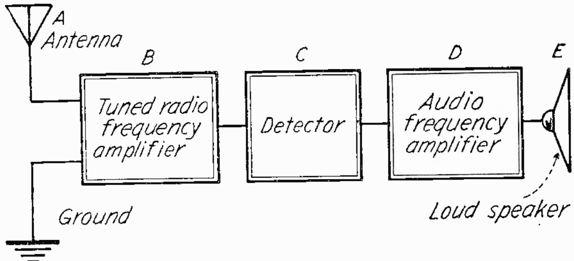


Fig. 1

employed to amplify the microphone output so that it can be modulated with the radio frequency output of any oscillator tube.

d.—Audio amplification in telephone and telegraph communication systems.

Telephone and telegraph communication lines constantly require amplifying means to make up for the attenuation or losses in the long transmission lines. Audio amplification, in the form of "repeaters," makes possible high quality telephonic communication and high speed telegraph transmission. In chain broadcasting, telephone wire lines are used to send the broadcast from one city to another on the chain. Proper frequency response over these wire lines is only made possible by correct audio amplification.

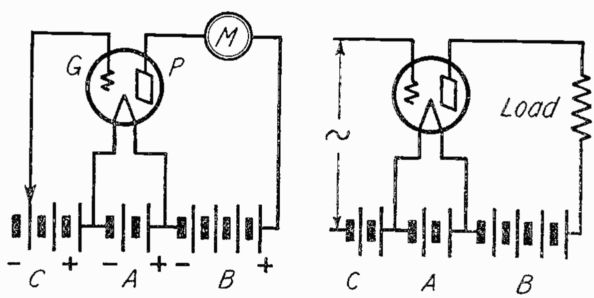
It is thus seen that audio amplification is used wherever amplification of audio currents is required. The study of the vacuum tube or "triode as an audio amplifier," is taken up first because audio frequency amplification is the simplest of all the three radio receiver functions, and is the sole function of most sound equipment. The fundamental study of audio amplification leads to a clear understanding of the more complicated tuned and untuned radio frequency and intermediate frequency amplifiers encountered in tuned R.F. and superheterodyne receivers.

WHAT CONSTITUTES AN AUDIO AMPLIFIER

4

The action of a vacuum tube or triode as an audio amplifier is best understood by the static plate current-grid voltage characteristic curve (E_g-I_p curve), as shown in Fig. 2c.

Figure 2a shows clearly how a normal plate current-grid voltage static characteristic curve is made. For a given plate voltage, the voltage on the grid G is varied over a considerable



(a) Fig. 2 (b)

range and for each different value of grid voltage the plate current is observed on a plate milliammeter M. The experimental data thus obtained is plotted in the form of a curve which will appear as shown in Fig. 2c. Such a curve is known as the plate current-grid voltage static characteristic curve of a vacuum tube and gives a complete picture of the effect of input grid voltage change on plate current change for a given plate voltage.

Assume now that an alternating voltage of amplitude P (see Fig. 2c) is applied across the grid and filament of the vacuum tube, as shown in Fig. 2b, and that the tube is made to operate on its plate current grid-voltage characteristic curve at point "A" of Fig. 2c, by using a suitable grid bias C battery. Because of the shape of the plate current-grid voltage characteristic curve, the plate current is made to change by the alternating grid input voltage in the form M. It is to be noticed that the change of plate current above the operating line A A_1 is exactly equal to the change of plate current below this line, and due to the shape of the characteristic curve, amplitude P_1 is considerably greater than the input amplitude P, showing that the plate output A.C. voltage, which is proportional to P_1, is considerably greater than the grid A.C. input voltage. The student should also notice that the operating point "A" is set at the mid-point of the straight portion of the curve and we say that the tube is made to operate over the straight portion of its E_g-I_p curve. This is one of the fundamental laws in using a vacuum tube as an amplifier, whether for A.F. or R.F. amplification; the amplifier tube must work on the straight portion of its characteristic curve. It will be shown later that when the

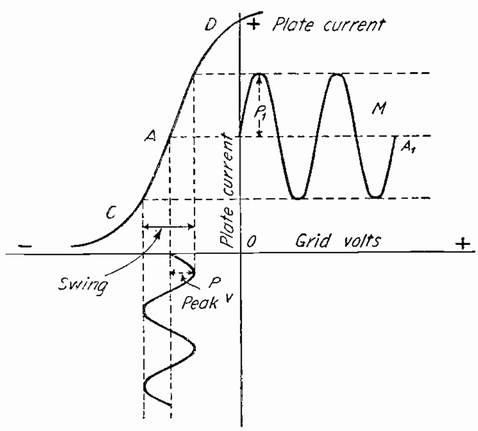


Fig. 2(c)

tube functions beyond the straight portion of the characteristic curve, distortion results.

From the above you will have a clear picture of how a vacuum tube can actually amplify a given signal. Remember that the signal voltage in the plate circuit of the vacuum tube is greater than the input impressed voltage in the grid circuit. After the tube has amplified this voltage, the signal is passed on to the next audio tube by means of some coupling device. This coupling is an audio device and may also amplify the signal.*

The combination of a tube amplifier and a coupling device raises the audio signal voltage to such a point that it can be made to operate a power tube. The audio power tube will be discussed in more detail later.

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6 *The only coupling device that amplifies is the step-up transformer, which is, however, used in most audio systems.

An audio amplifier tube and a coupling device constitute an "audio stage," and several audio stages, including the power
3 audio stage, make up an audio amplifier. Thus, the transformer coupled A.F. amplifier provides two means of amplification; one, the amplification of audio frequency through the tube itself, and two, the amplification of audio signal through the step-up transformer.

This multiplying action is clearly shown in Fig. 3. Here we have a two-stage audio amplifier which is used to operate a power tube. If the audio frequency tubes A and B amplify the signals eight times each, and the coupling devices T and T_1, four and three times respectively, the ratio of the output voltage E_1 to the input voltage E will be $8 \times 4 \times 8 \times 3$, or a ratio of 768. Such an A.F. amplifier, as shown, is called an audio voltage amplifier because we are interested in obtaining as large a *voltage* as possible to feed the grid of the power tube. On the other hand, *power* is required to operate a loudspeaker, that is, both current and voltage, which explains why the last tube in an audio amplifier is usually a power tube. It will be shown later how maximum voltage amplification is obtained in an audio amplifier of this type.

The important parts of an A.F. amplifier, other than the tube itself, are then in the system of coupling between the tubes. The important coupling methods used in audio amplifiers are:

a. Resistance.
b. Impedance.
c. Transformer.
d. Special Combinations.

These are not arranged in the order of their importance, but in the order of their simplicity of analysis, and will be taken up later in detail.

REQUIREMENTS OF AN AUDIO AMPLIFIER—DISTORTION

Good audio amplification is obtained when the amplified audio frequency is an exact duplicate of the original audio frequency.

Assuming that the input audio frequency is pure and undistorted, the amplification of this audio frequency through the tube and coupling device, must be such that it will not be distorted. Ordinarily the signal will not be distorted in the amplifier tube if the input grid voltage is kept small but referring to Fig. 2c again, it can be seen that if the input grid voltage is large, so that the plate current changes beyond curvatures C and D, the changes of plate current above A A_1 are different than those below A A_1, and distortion results. Such distortion is known as "tube distortion" and is caused by overloading of the tube.

Distortion often occurs in the coupling devices. An audio signal, as we have learned is made up of current having all kinds of frequencies, from 30 to 8000 cycles per second. For radio receivers the range need only be 60 to 5000 cycles per second. Each is of a definite intensity with respect to the other frequencies and not one must be altered, added to or removed. In the chapter on "Coupling Devices," you will learn that certain coupling devices discriminate between these frequencies, amplifying some too much, others not enough, either by improper design

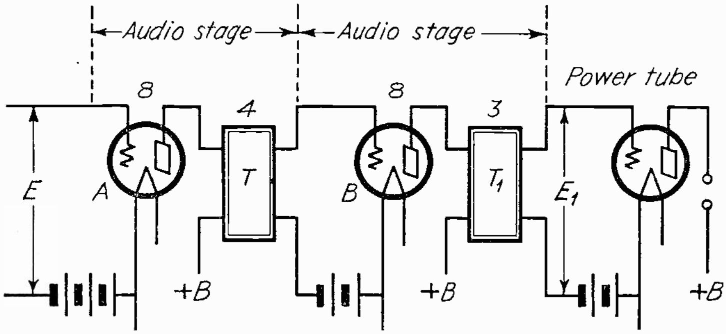


Fig. 3

of the coupling device or incorrect matching of the coupling device to the audio amplifier tube, which results in distortion.

The true requirement of an audio voltage amplifier is to amplify an audio signal without distortion, so that it will operate a power tube, and this power tube in turn will operate a large load, such as a dynamic speaker, in such a way that maximum power or maximum undistorted power output results.

Now we shall go on to see how maximum voltage amplification per audio stage is obtained.

VOLTAGE AMPLIFICATION—AMPLIFICATION CONSTANT (MU)

In Fig. 2c, it was graphically shown how small changes of input voltages result in large changes of current in the plate circuit, according to the characteristic of the plate current-grid voltage curve.

This phenomenon is due to a fundamental law that an A.C. grid voltage e_g applied across the grid and filament of an amplifier tube, appears as an A.C. plate voltage "Mu" times this grid voltage, that is μe_g. This factor "μ" (Mu) is known as the amplification constant or amplification factor of the tube and indicates the voltage amplification merit of an amplifier tube. It is ordinarily taken as a constant, its value depending solely upon the size and arrangement of elements. The exact value of the amplification factor is determined by the spacing between the elements, the size of grid wires, and the distance between grid and plate. Thus the amplification factor is not changed to any appreciable extent by changes in applied plate or grid voltages, except that at low plate voltages it may decrease very slightly. The amplification factor is a measure of the *maximum* voltage amplification obtainable from the tube alone.

The function of a triode when used as an amplifier, is to make available in the plate circuit a voltage of the same wave form as that impressed on the grid and as much larger as possible. The voltage developed across the plate load resistance depends on the Mu of the tube, the resistance of the plate load and internal resistance of the tube.

As shown in Fig 4 (a), the voltage impressed on the input circuit of a triode causes a change in the plate current flowing through the load Z, and the value of this load impedance determines the voltage developed across it, which voltage will be available for application to the input of the next tube.

The load, as shown in Fig. 4 (a) and (b), may be a resistance or an inductance. For simplicity, assume this load to be a pure resistance R. As noted above, an A.C. voltage e_g introduced in the input circuit of a tube is equivalent to a voltage μe_g introduced into the plate circuit, and this voltage causes an alternating current to flow in the plate circuit which will be equal to:

$$I_p = \frac{\mu e_g}{R_p + R} \quad \text{or} \quad e_g = \frac{I_p (R_p + R)}{\mu} \qquad (1)$$

where R_p is the internal plate resistance of the tube and R is a pure resistance load.

The voltage drop across R (e_p) is obviously:

$$e_p = I_p R \qquad (2)$$

From this we get the *actual* or *true voltage amplification* of the tube itself, which is the ratio of e_p to e_g; that is, the ratio of the alternating voltage produced across the plate load of the tube, to the alternating voltage impressed on the grid of the same tube.

$$\frac{e_p}{e_g} = \frac{I_p R}{I_p (R_p + R)} \mu = \frac{\mu R}{R_p + R} \qquad (3)$$

Equation (3) has been given because it shows clearly and simply that the *true voltage amplification* of a stage depends on the *mu* of the tube, the *internal plate resistance,* and the *plate load resistance.* Depending on these constants, the true voltage amplification e_p/e_g is always less than μ, and may be considerably below μ.

To show how the true voltage amplification e_p/e_g is dependent on μ, R_p and R, assume in equation (3) that μ is equal to 10, R_p is 10,000 ohms and R is also 10,000 ohms.

$$\frac{10 \times 10{,}000}{10{,}000 + 10{,}000} = \frac{100{,}000}{20{,}000} = 5$$

From this the true voltage amplification e_p/e_g is 5 or only 50% of the factor Mu, which was given as 10. Again, let us assume

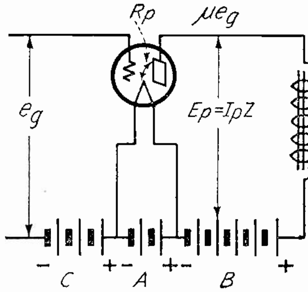


Fig. 4(a)

that μ and R_p are the same but the load resistance R is increased to 50,000 ohms.

$$\frac{10 \times 50{,}000}{10{,}000 + 50{,}000} = \frac{500{,}000}{60{,}000} = 8.3$$

In this case the true voltage amplification e_p/e_g is 8.3 or 83% of the factor Mu. These two examples illustrate that for a given amplification constant Mu and plate resistance R_p, for maximum true voltage amplification e_p/e_g, the load resistance R should be very large in comparison to the plate resistance R_p. This is shown graphically in Fig. 5a.

This curve shows clearly that in order to obtain the maximum true voltage amplification e_p/e_g, the load resistance R should be many times the plate resistance R_p. For practical purposes this load resistance should be about eight times the plate resistance. Figure 5a shows that the true voltage amplification of the tube is never equal to μ, and is always less, depending upon the value of the load.

Figure 5b is extremely interesting for it immediately shows that if an inductance is used instead of a resistor as the plate load, the reactance X_L does not have to be as great for the true voltage amplification e_p/e_g to approach Mu. When the reactance X_L is 20,000 ohms, twice the plate resistance R_p, which was assumed to be 10,000 ohms, e_p/e_g is nearly 90% of μ whereas, in Fig. 5a, when R was 20,000 ohms the true voltage amplification e_p/e_g is only about 63% of the Mu of the tube.

From this we might conclude that inductive reactance is a better plate load impedance for a voltage amplifier than a pure resistance. This is not true, for it will be seen later that both

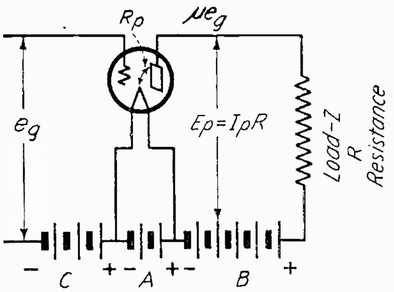


Fig. 4(b)

resistance and inductive loads play important parts in audio amplifiers, depending upon the particular use of the tube.

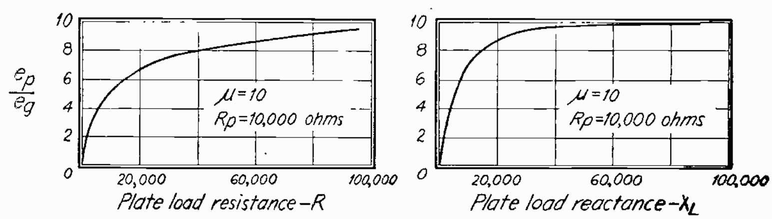
In a pure resistance load in the plate circuit of a voltage amplifier, the A.C. voltage developed across the resistance is simply the product of the current and resistance, *independent* of frequency. In other words, the load resistance R does not discriminate against or favor any audio frequency and the tube will amplify low frequencies equally as well as high frequencies, depending only on the tube constants. Pure load resistances are easy to obtain for a value many times the tube plate resistance for maximum voltage amplification. Since a resistance load does not discriminate between audio frequencies, "resistance coupling" provides a unique method for uniform audio amplification.

However, on account of the high value of resistance which has to be employed for maximum voltage amplification, a large plate voltage "B" has to be used. This can be appreciated by referring again to Fig. 4 (b). If the load resistance is 80,000 ohms and the D.C. plate current is only 1 milliampere, the IR voltage drop in the load resistance R is 80 volts, which voltage is taken away from the positive voltage on the plate of the tube.

In the case of an inductive load, since its value changes with frequency, the value of X_L for maximum true voltage amplifica-
5 tion must be chosen for the lowest frequency which is to be amplified.

The inductive reactance (X_L) of a circuit is expressed in ohms and is equal to the product of the self-inductance in henries, the frequency of the impressed voltage and the constant 2π, that is, $X_L = 2\pi f L$.

As an example, for the conditions given where Mu is 10, and R_p is 10,000 ohms, for X_L to be 20,000 ohms at 100 cycles to



(a) Fig. 5 (b)

obtain an e_p/e_g ratio which is 90% of Mu, the inductance of the load must be, from the formula, $X_L = 2\pi f L$:

$$L = \frac{X_L}{2\pi f} = \frac{20000}{6.28 \times 100} = 31.8 \text{ henries}$$

Most modern audio amplifiers can reproduce down to 50 c.p.s., in which case the plate inductance must have an impedance of 20,000 ohms at 50 c.p.s. Then, L, the inductance, must be 63.6 henries—that is, it must have twice the inductance required for 100 cycle cut-off.

Inductive plate loads are used where the plate resistance R_p is relatively small, or where good regulation is required for large A.C. amplitudes. An inductive plate load requires no extra plate voltage source, because very little voltage drop exists in the winding of the inductance coil.

An inductive load in the plate circuit, having a secondary winding coupled to it in step-up relation, increases the overall voltage amplification before feeding into the next tube. The advantage of this method, known as transformer coupling is explained under "Coupling Devices."

Voltage amplifier tube circuits are used to build up weak audio voltages to a value sufficient to operate the grid of a power tube. Such power tubes as types '71A, '45 and '50, for maximum recommended plate voltages, require grid voltage swings respectively equal to 40½, 50 and 84 volts. These high grid voltage swings* can be obtained only from voltage amplifier systems preceding the power tube. The voltage amplifier tubes and the coupling devices used determine the number of audio stages necessary to build up this required voltage swing.

COUPLING DEVICES AND SYSTEMS

It has been seen so far how a vacuum tube can be used to increase the voltage applied at its grid input, and how the true

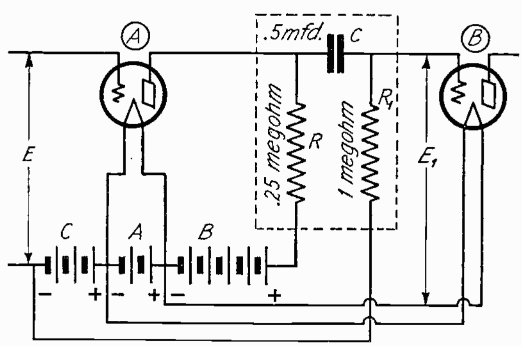


Fig. 6(a)

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voltage amplification depends on the Mu of the tube and the plate load. It was also shown that for a tube to be used as an efficient voltage audio amplifier, it was important that the value of the plate load be many times that of the internal plate resistance.

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*The term "grid swing" refers to the change of grid voltage from one peak value to the peak value in the opposite direction, if we do not consider any bias on the tube. Thus we may have a 50 volt grid swing, in which case the signal voltage rises to a maximum of 25 volts in a positive direction and drops to a maximum in the negative direction of 25 volts.

As the grid must ordinarily be kept from actually becoming positive, a 25 volt or larger bias should be used. Then the actual grid voltage would vary from 25 volts plus the bias voltage, to the bias voltage minus 25 volts. But still the grid swing is considered as being 50 volts, which is the same as saying that the peak voltage is 25^v (which of course is equal to a half **grid swing**).

In order to transfer the voltage built up in one tube to the input of another, suitable coupling means must be employed. A few of the most important of these coupling devices will now be considered.

The first to be taken up is "Resistance Coupling," examples of which are shown in Figs. 6 (a) and (b). In Fig. 6 (a), vacuum tubes A and B are coupled together by means of a resistance R. The voltage developed across this plate load resistance R is transferred to the input grid of tube B through condenser C, known as a coupling condenser. The capacity of this condenser should be large enough so that its capacitive reactance will not offer opposition to the lowest audio frequency. The purpose of this condenser is to keep the high positive plate potential from the

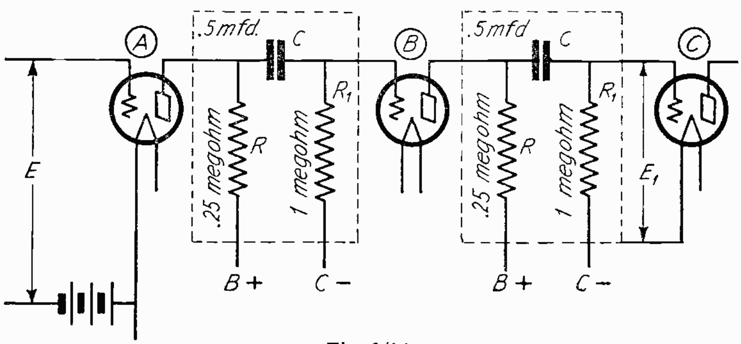


Fig. 6(b)

grid of the next tube. The leak resistance R_1 is necessary to maintain a definite negative bias or voltage on the grid of tube B, and the value of this resistance should be high enough so that it won't affect the amplification of the tube. In practice, the condenser C is about .5 microfarad and R_1 is about 1 megohm.

The value of the plate load resistance R is many times the internal plate resistance of the tube in order that maximum voltage amplification can be obtained. The only voltage amplification obtained from this circuit is due to the amplifying action of the tube. This means that the ratio of E_1 to E is the true voltage amplification of the audio amplifying tube A.

The two resistances R and R_1 and coupling condenser C enclosed in the dotted portion, compose the resistance coupling device. This device and tube B constitute a "resistance coupled audio stage." Two stages of resistance coupling are shown in Fig. 6b.

In these figures resistance coupling is shown with storage battery type tubes, in order that you can get a clear picture of how the proper grid and plate voltages are applied to the elements of the tube. The connections are identically the same for A.C. tubes, except that audio by-passing must be provided for.

Resistance coupling is used where absolutely uniform audio response is required. Very low frequencies, as low as 30 cycles, can be amplified with as much ease as high frequencies in the order of 4000 to 5000 cycles. Since the true voltage amplification is dependent on both the Mu of the tube and its plate load, special high Mu tubes have been developed which are splendid amplifiers for resistance coupled circuits. The old type '40 tube was specifically designed for this purpose.

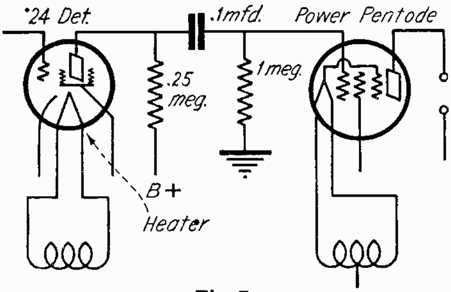


Fig. 7

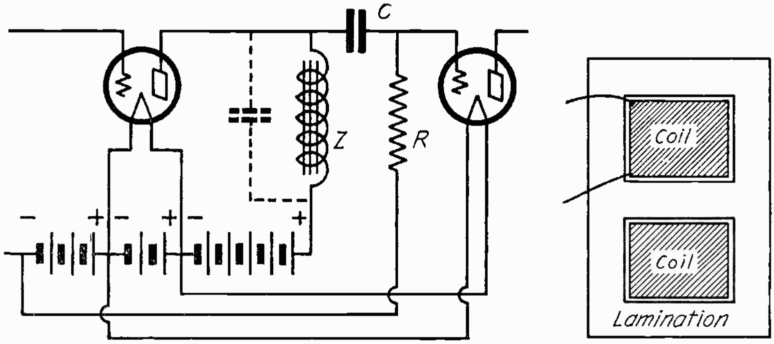
It is difficult to couple a device to a tube having a very high plate resistance so that its plate load will be high enough to obtain good voltage amplification, unless resistance coupling is employed. The modern '24 screen grid type tube is an example of this. It has a plate resistance of 400,000 ohms. Type '24 screen grid tubes are extremely efficient detectors, but when used as detectors it is necessary that they be resistance coupled to the audio system.

In the case of resistance coupling, the voltage drop across the resistor subtracts from the true voltage on the plate of the tube. In the older days when batteries were used exclusively, this was a serious objection to resistance coupling, because it was necessary at times to use D.C. voltages as high as several hundred volts. Of course in A.C. receivers such D.C. voltages are available.

Resistance coupling plays a very important part in modern commercial radio receivers. Due to the high sensitivity obtained in the radio frequency circuits, high audio gain is not required, and many circuits work their power tube directly from the output of the detector. For successful operation of the recent power Pentode requiring only a 16 volt grid swing, resistance coupling is used between the screen grid '24 detector and the single output tube, as shown in Fig. 7.

The trend of modern development is toward resistance coupling. This type of coupling will be particularly important in television reception. For good reception in television it will be necessary to obtain an audio response from 16 to 50,000 cycles, or even higher. Such a tremendous range can be handled only by resistance coupling.

Resistance coupling also has an economic advantage over all other types of coupling. The resistors used do not have to



(a) Fig. 8 (b)

carry much power, consequently they can be made very small and inexpensive. It is only important that they be noiseless* and that the resistance values remain constant.

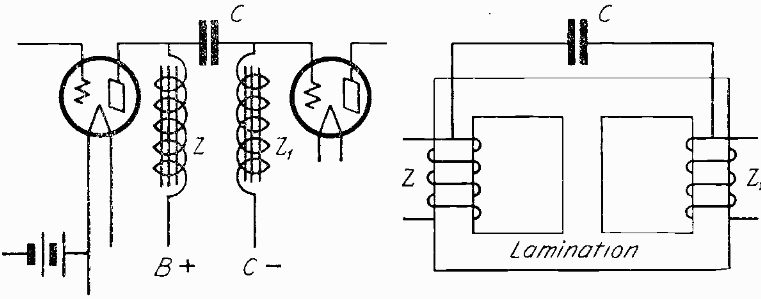
When the grid signal swing is so large that the amplitude of the plate current through the load resistance is excessive, the IR drop across the resistance causes a marked change in the operating plate voltage. This in turn will cause large changes in the supply voltage system and have its effect on other circuits. Therefore when the E_p change is excessive, the voltage regulation from the power supply is poor.

To overcome this poor regulation in a resistance coupled amplifier, the resistor is replaced by a large impedance connected as shown in Fig. 8. This is called impedance coupling. In this diagram Z is the impedance coupling, C the coupling condenser and R the leak resistance. The value of Z should be many times the value of the plate resistance. The plate load Z generally consists of many thousands of turns wound over an iron core, as

*Carbon and metallized resistors are apt to be noisy due to intermittent contacts within the resistance unit.

shown in Fig. 8b. It may have an inductance value of several hundred henries. Since the D.C. resistance of this coil, or impedance choke, is comparatively low, there is no appreciable voltage drop in the coil, resulting in good regulation. Due to the low resistance of the coil, only a comparatively small source of B voltage is required.

Since an impedance choke has inductance, it is affected by frequency. It must be large enough to offer considerable reactance to the lowest frequency it is called on to handle. This impedance must not only be designed for low frequency response, but it must be designed to have very little distributed capacity,* otherwise the high frequencies would be by-passed across the coil and would not reach the grid of the next tube. This distributed capacity of the coil is shown as a condenser in dotted lines in



(a) Fig. 9 (b)

Fig. 8a. Due to the distributed capacity of the windings of this choke, it can be expected that such a coupling will never be used in a television audio amplifier where good response at extremely high frequencies is required.

As in resistance coupling, there is no voltage amplification in the impedance coupling itself, all of the voltage amplification taking place in the tube. Impedance coupling is used in preference to resistance coupling where good regulation is required and where the source of D.C. plate voltage is limited.

A modification of the impedance coupling is the double impedance choke method of coupling, shown in Fig. 9a.

This type of coupling is claimed to have superior audio response with less distortion, especially at high sound levels. In such a system the two chokes are arranged as shown in Fig. 9b. By magnetic isolation and by the proper choice of capacity C a series resonance may be obtained to over-accentuate the low

* The capacity that exists between turns of wire in a coil.

frequencies to take care of deficiencies in the low frequency response of the loudspeaker.

We come now to one of the most effective and efficient types of coupling. This is "transformer coupling," an example of which is shown in Fig. 10.

With this arrangement, it is possible to increase the over-all amplification of the audio stage by a step-up voltage ratio in the

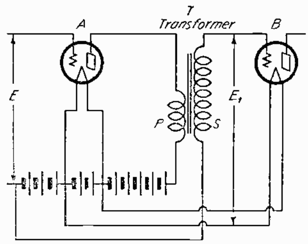


Fig. 10

transformer coupling itself. The primary winding P is the plate load for the voltage amplifying tube A and the voltage developed across P is transferred to the secondary winding S, which has more turns than the primary, by mutual induction. Therefore the voltage ratio of E_1 to E includes not only the voltage amplification of tube A, but also the amplification due to the step-up ratio in the coupling transformer T.

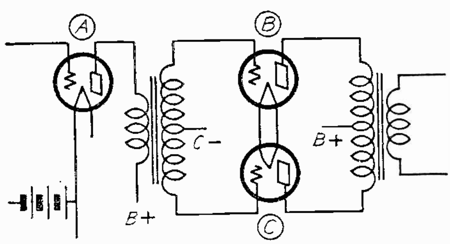


Fig. 11 (a)

As in an impedance coupling device, the low frequency response of a transformer coupling depends on the inductance of
9 the primary winding. The primary inductance of audio frequency transformers can be increased by using larger iron cores, or cores of improved alloy materials having high permeability; an increased number of primary turns. The step-up ratio which can be employed in an audio frequency transformer is limited by the uniform frequency range required. In a very high ratio audio

transformer, the audio response suffers at the low and high frequencies. The better types of audio transformers have turn ratios of about 3½ to 1 unless a very high grade, high permeability steel is used, in which case a ratio as high as 5 to 1 may be used successfully.

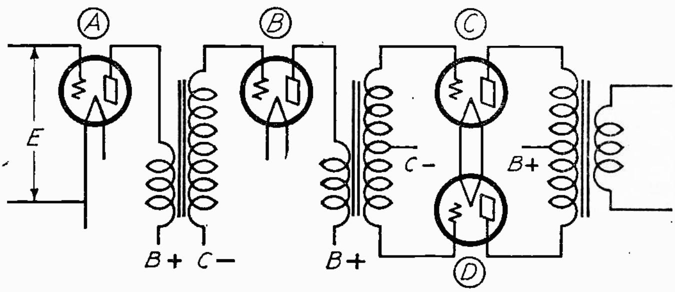


Fig. 11 (b)

When a transformer is used between two tubes, as shown in Fig. 10, it is called an "inter-stage audio transformer."

One of the finest examples of the use of inter-stage audio transformers is in the so-called "push-pull" arrangement, shown in Fig. 11 (a).

In Fig. 11a, the primary is connected to the plate of tube A, and the secondary is a center-tapped winding the ends of which

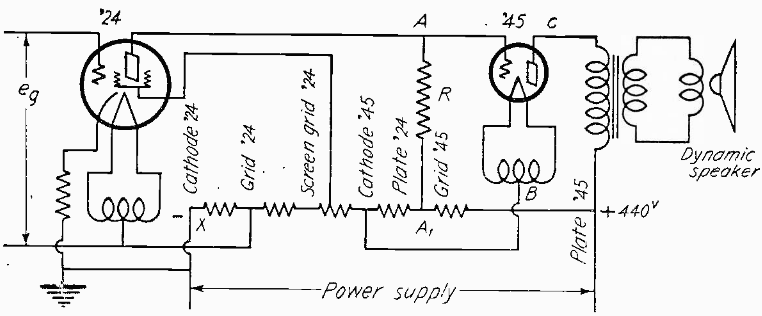


Fig. 12

are respectively connected to the grids of two push-pull tubes B and C. When an alternating current flows in the input circuit, one of the grids is positive when the other is negative, and *vice versa.* The plate current in one tube is increasing, therefore, while that in the other is decreasing. The output circuit is
10 connected in such a way that the resultant plate current is pro-

portional to the difference of the plate currents from the two tubes. The result of this is that any distorting components are balanced and eliminated. This arrangement is therefore very successfully used to operate power tubes in push-pull in order to obtain a very large undistorted power output.

Figure 11b shows two inter-stage audio transformers used, one as a single stage coupling and the other as a push-pull coupling.

A rather unique method of resistance coupling, usually called direct coupling, has been introduced by Loftin and White. It is schematically shown in Fig. 12. These inventors realized that the presence of inductance and capacity or both in a coupling device, discriminated between frequencies. Their arrangement does away with inductive and capacitive coupling, by using a resistance R only as the common coupling part.

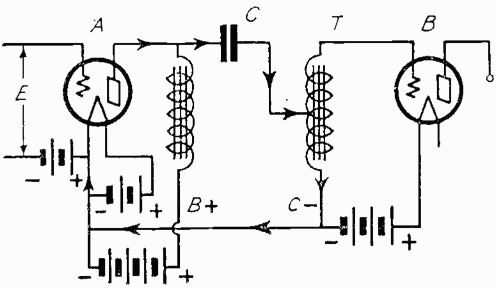


Fig. 13

This you will see places the plate voltage of the '24 tube on the grid of the '45, and the latter tube will not have the proper operating voltages. Realizing that it did not matter what voltage was applied to the grid of the '45 as long as it was at a potential equal to the "C" bias above its cathode, and the plate voltage of the '45 was above the cathode by an amount equal to the operating plate voltage, the inventors presented the circuit shown Fig. 12 as a workable solution. In this circuit the '24 plate and the '45 grid are at the same potential with respect to X (the cathode return of the '24 tube). But B the cathode of the '45 tube is positive by the amount of "C" bias with respect to the grid of the '45 tube, and the plate C is above B by the amount of required plate voltage. This arrangement requires a very high source of rectified voltage.

With a properly designed Loftin and White direct coupled amplifier system, an over-all voltage amplification equal to or better than the ordinary transformer coupling amplifier can be obtained.

Several miscellaneous coupling methods have been developed which are nothing more than modifications or refinements of the methods outlined above. One method is the Clough coupling shown in Fig. 13.

This type of coupling isolates the audio currents from the "B" supply source and the flow of these A.C. currents is shown by the arrows. By the proper choice of C and the inductance of T, resonance at, and accentuation of, certain audio frequencies may be obtained.

It is possible to employ several types of couplings in a single audio amplifier as shown in Fig. 14.

TABLE NO. 1

Type of Coupling	Expected Over-all Stage Amplification	Advantages	Disadvantages
Resistance	80%-90% Mu of tube.	Uniform response. Inexpensive.	High "B" source required. Poor regulation at high volume.
Impedance	80%-90% Mu of tube.	Uniform response. Low "B" source required. Fine regulation.	Expensive.
Transformer	80%-90% Mu of tube, times turn ratio.	High voltage amplification. Ease of push-pull arrangement.	Expensive. Limited frequency range.
Loftin-White	90% Mu of tube.	Less distortion at high sound levels.	Critical circuit design.

This is a schematic of an audio amplifier which was very popular at one time in radio receivers employing the '24 screen grid tube as a detector. "A" represents the '24 screen grid detector, coupled by resistance coupling to a '27 first audio tube, which is coupled by a push-pull transformer to a pair of push-pull power tubes.

The various methods of couplings used in audio amplifiers are summarized in table No. 1.

POWER AMPLIFICATION—POWER OUTPUT TUBES

The weak audio current from the plate of the detector tube is amplified sufficiently to operate the power tube by means of voltage amplification. Power tubes require relatively large voltage grid swings for their efficient operation. The larger the power tube generally the greater is the grid swing or plate voltage required to obtain the maximum power from the tube. As an example of this, one of the first power tubes used was the type '12A requiring approximately a 13.5 volt grid swing when used with a plate voltage of 180 volts to develop an output power of .30 watt, whereas the type '71A power tube required a 40.5 volt grid swing when used with a plate voltage of 180 volts, to develop an output power of .70 watt. It will be seen later what conditions are required to obtain best results from the more powerful output tubes such as the types '45, '50 and the Pentode.

The purpose of the audio amplifier then, between the plate of the detector and the grid of the power tube, is to develop by means of voltage amplification, a voltage swing great enough to operate the grid of the power tube.

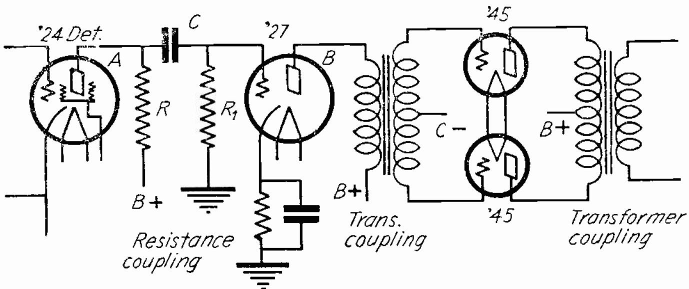


Fig. 14

In the case of the power tube, which is the last tube in a radio receiver, the voltage factor is not the important consideration. The usual load on the last amplifier tube is a loudspeaker, requiring a relatively large amount of power, so the important factor in a power tube is its power output.

One of the most interesting points in connection with radio tubes is the study of the conditions under which maximum *undistorted* power output can be obtained. In using the radio tube as a voltage amplifier, maximum amplification with minimum distortion is obtained when the load resistance is as high as practicable.

The load in the plate circuit of a power tube may be considered as a pure resistance, as shown in Fig. 15. A grid voltage e_g (rms)* applied to the grid results in a plate signal voltage mu times this, that is μe_g. The plate circuit then contains a plate

*Root mean square values are effective values of A.C.

voltage μe_g, the plate resistance and a plate load resistance. The main purpose of the power output tube is to feed the load with a maximum power (E $\times$ I). *Maximum* power across this load occurs when the plate load resistance R is made equal to the internal plate resistance R_p of the tube.* Here we are considering the tube only as a generator of power and we are not taking the question of distortion into consideration. But, of course, distortion is a factor of great importance.

In Fig. 16 is shown the relation between output power and plate load resistance. This curve was plotted for a power tube having an internal plate resistance of 2000 ohms and it will be observed that the maximum power occurs when the plate load resistance is equal to the internal plate resistance. This graph also shows that even when the plate load resistance is two or

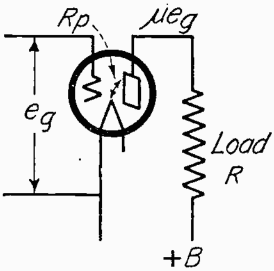


Fig. 15

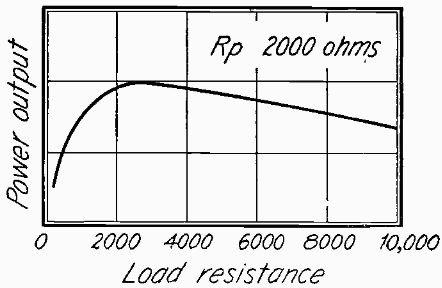


Fig. 16

three times the internal resistance of the tube, the power output is not appreciably affected, whereas a plate load resistance below the tube resistance materially reduces the maximum power output.

The method of obtaining the correct plate load to match the plate resistance of the tube is known as "impedance matching," and is of extreme importance wherever maximum power is to be considered. From the graph in Fig. 16, a mismatch of the load resistance two to four times above the plate resistance is not so bad, but a mismatch below the value of the tube resistance is quite serious.

In practice, *maximum power* output is not as important as *maximum undistorted power* output, for it is the undistorted power output which determines the fidelity of response in the dynamic speaker. When the grid voltage swing becomes too great, distortion appears in the plate current. At the point just before this distortion appears, maximum undistorted power

*A simple proof is shown on pages 28 and 29.

is obtained from the tube. This distortion is the result of the introduction of harmonic components in the output current wave form which were not present in the original signal wave form. The term "undistorted power output" is defined as "The amount of power obtained from a power tube whose grid swing is just large enough to result in 5% harmonic distortion." Five per cent is the permissible amount of distortion as it is practically unnoticeable in the speaker output.

For all ordinary power triodes such as '12A, '71A, '45 and '50, for maximum undistorted power output, the plate load resistance is usually about twice the internal resistance of the tube. However, for the power Pentode, due to its peculiar characteristics, maximum undistorted power output is *only* obtained when the plate load resistance is less than one-sixth the tube resistance. In all cases the recommended plate load should be used.

TABLE NO. 2

Type	Maximum Undistorted Power Output Milliwatts	Maximum Grid Voltage	Maximum Plate Voltage	Plate Resistance in Ohms	Recommended Plate Load in Ohms
'20	110	22.5	135	6300	6500
'31	150	22.5	135	4950	9000
'12A	260	13.5	180	5000	10,800
'71A	700	40.5	180	1950	3,900
'45	1600	50.0	250	1750	3,900
'50	4600	84.0	450	1800	4,350
'47	2700	16.5	250	60,000	7,000

It is necessary to have the proper value of "C" bias on the grid of a power tube to prevent distortion. Large grid swings, on the positive alternations, will cause the grid to become less negative (or more positive) than the cathode which would result in grid current flow. Any grid current flow reduces the grid-to-filament resistance of the tube on the positive swing only, making the load very uneven which, of course, results in distortion.

The following table gives the maximum undistorted power, recommended grid and plate voltage and required plate load resistance for the most important commercial power tubes.

Types '12A and '71A power tubes are employed where small power outputs are required, and the source of plate "B" supply is limited. Old types of storage battery and 110 volts D.C. supply receivers are typical examples of such tubes. Type '31 is a recent power tube developed for the new two volt battery receiver, and the '20 is for a dry cell receiver. When a large amount of power is required types '45 and '50 are used, the type '45 for home entertainment purposes, and the '50 type for power required for large gatherings, theaters, etc.

The power Pentode is an interesting development in power tube design. Most power tubes, such as the '45 and '50, require a relatively large grid swing in order to obtain sufficient power in the plate circuit. The power Pentode is a shielded grid power tube and a much greater power is developed in its plate circuit for a given grid swing than in ordinary power tubes. As shown in the above table, for 250 volts on the Pentode plate, and 16.5 volts negative grid, a maximum undistorted power output of 2.5 watts is obtained, whereas for the same plate voltage on the type '45 tube, a grid voltage of 50 volts is required to obtain a power output of only 1.6 watts. From this it can be seen that the audio gain before the output tube need not be nearly as great as when ordinary power tubes are used, and fewer stages of voltage amplification are necessary.

Power tubes in push-pull arrangement have for their sole purpose the giving of greater undistorted power output. It can be approximately stated that two power tubes in push-pull give about two to three times as much power output as a single power tube. The reason for this is that the even distortion harmonics are cancelled out. Two '45 tubes in push-pull are capable, if we assume the maximum factor three, of developing 4.8 maximum undistorted watts output, which is three times that developed by one tube, 1.6 watts.

Requirements for power output vary greatly with conditions. For home use, power output between .5 and 1.0 watt is ample for good volume. If used for dancing in the home 1.0-2.0 watts may be necessary. For small gatherings and entertainment in a small theatre 5.0-10.0 watts are sufficient, and for large gatherings and public address systems 25 to 50 watts are required. Radio receivers and power equipment are generally designed to have 100 to 200 per cent greater power output than is actually necessary, for reserve and for better quality reproduction.

Radio engineers and designers of radio receivers usually compute the maximum undistorted output of a power tube from a family of plate voltage-plate current static characteristic curves. The procedure they follow is rather complicated and as for all general purposes, tube manufacturers supply sufficient data in tabulated form, we shall not go into the use of E_p-I_p curves here.

The power rating of power tubes is in terms of maximum undistorted power output and the maximum plate and grid voltages recommended for the power tube are for this maximum undistorted power output. Any deviation from the recommended values will change the resistance requirements of the plate load. If higher or lower voltages are used in place of the recommended values, the undistorted power output will respectively increase or decrease.

Now you have seen that the triode as an audio amplifier can be used in two ways, as a voltage amplifier and as a power amplifier. Regardless of the type of plate load, whether it is a pure resistance or a reactance coil, certain load requirements must

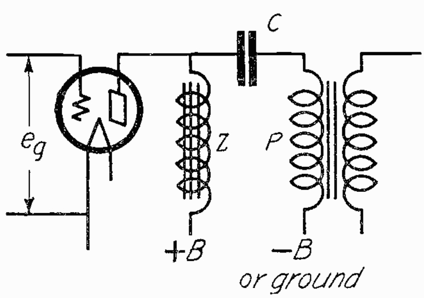


Fig. 17

be met in order that the vacuum tube may perform efficiently under these two conditions. The plate load on a voltage amplifier must be several times the internal plate resistance for maximum voltage amplification. Maximum power is obtained from a power amplifier when the plate load resistance is equal to the tube resistance, but maximum power is not as important as maximum *undistorted* power, which is obtained when the plate load resistance is twice or more the internal tube resistance.

TYPICAL AMPLIFIERS

The complete audio amplifier consists of voltage amplification audio stages and a power stage. The voltage amplification stages may be coupled by resistance, impedance, transformer, Loftin-White, or modifications of these. Each type of coupling has its own advantages and disadvantages and no fast rule can be set for the proper coupling to use. In general, where high audio gain is required with a minimum number of tubes, transformer coupling is recommended. The art of transformer design is so well known today that efficient uniform amplification over a frequency range of 30-6000 cycles can readily be obtained.

In push-pull arrangements transformer coupling is the only proper coupling to use. Some attempts have been made in commercial radio receivers to couple push-pull tubes by an impedance method, but such an arrangement is quite unsatisfactory as maximum undistorted output is reduced. Transformer coupling is almost universally used between the power stage and the loudspeaker. Whether in a single or push-pull arrangement this output transformer is used to feed the voice coil winding of a dynamic speaker.

Various uses are made of resistance and impedance couplings, depending upon conditions. Where audio gain is not im-

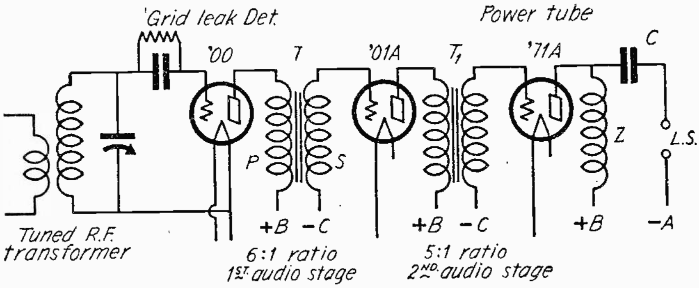


Fig. 18

portant and true uniform frequency range from 30-10,000 cycles is required, these types of coupling are used to good advantage. High mu or high plate resistance tubes are suitable tubes to use with resistance or impedance coupling. Impedance coupling may be used in various ways other than to provide the plate load impedance in a voltage amplifier tube. One important use is shown in conjunction with a transformer in Fig. 17.

Here the plate impedance Z is used to keep the signal current out of the B supply source. In some efficient audio transformers, especially those employing high permeability alloy laminations, the D.C. plate current passing through the primary winding is sometimes detrimental to efficient operation. An impedance Z is used instead of a pure resistance as the latter would necessitate the use of higher B voltages due to the voltage drop across the resistor. In the arrangement shown in Fig. 17, condenser C may be made to resonate with the primary inductance P at a low frequency so that the lower audio frequencies can be accentuated.

The history of audio frequency amplifier development is very interesting and tremendous strides have been made in the

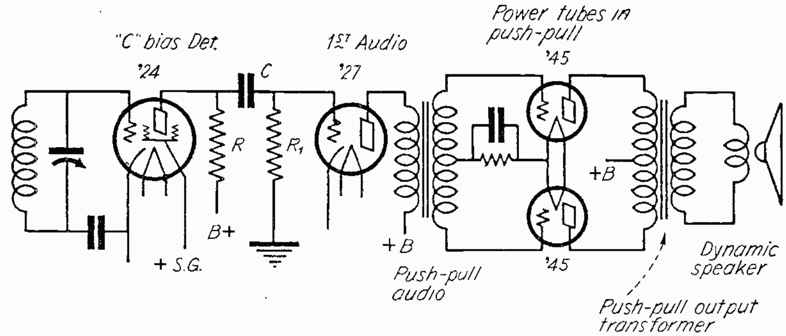


Fig. 19

past few years in successful designs of very efficient, high gain audio systems.

A few typical audio systems will now be given. In the first radio receivers the radio frequency systems were weak and the detector quite inefficient, requiring at least a two stage transformer coupled audio amplifier, as shown in Fig. 18. Trans-

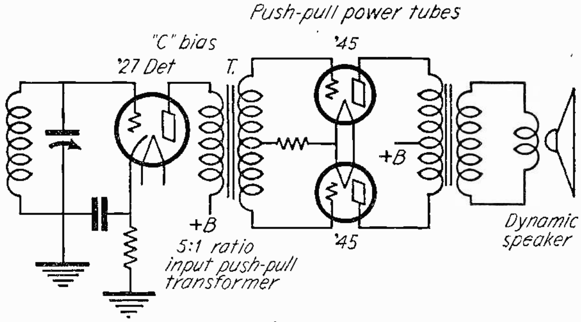


Fig. 20

formers T and T1 had a high step-up ratio and consequently the low frequency and high frequency response was not particularly good. An impedance coupling Z was used in the power stage to keep the high D.C. plate current from passing through the magnetic speaker L.S.

With the advent of the A.C. screen grid tubes, extremely sensitive tuned R.F. and superheterodyne receivers, and very efficient C bias detectors, less audio gain was required, and the system shown in Fig. 19 was used.

Resistance coupling is employed between the C bias screen grid detector and the first '27 type tube. From the output of the '27 tube a step-up push-pull transformer is used for the push-pull '45 tubes. In the output of the push-pull power tubes, an output step-down push-pull transformer is employed to feed the voice coil of the dynamic speaker. Low audio gain is an economical advantage as well designed audio transformers are expensive items in a radio receiver. Low audio gain also aids in the elimination of hum, as the filter supply does not have to be so efficient, and the component parts of the audio system are less subject to hum pick-up.

The most modern audio systems approach even greater efficiency by the use of a push-pull arrangement working directly out of a C bias detector, as shown in Fig. 20.

In this system the input push-pull transformer T has to be very carefully and efficiently designed. Generally a high permeability steel is used with a step-up ratio of 5 to 1 on each side. The only disadvantage in this system is the possibility of detector overloading which will result in distortion in the loudspeaker. This form of distortion is recognized by "double-hump" tuning, that is, a station can be tuned in at two adjacent points on the dial. In most audio systems in which the push-pull power tubes operate directly from the C bias detector, the maximum undistorted output that can be obtained is only slightly over 3 watts, due to the limitations of the C bias detector.

A SIMPLE EXPLANATION FOR THE NECESSITY OF MATCHING IMPEDANCES FOR MAXIMUM POWER OUTPUT

In this brief explanation we are going to assume that we have a 12 volt battery with a constant internal resistance of 1 ohm, feeding a variable resistor. Follow through the following calculations carefully and you will be able to see that maximum power output is obtained when the load resistance is 1 ohm—that is, the same as the battery resistance. The same calculations could be applied to impedance devices. If the load is .5 ohm:

$$I = \frac{E}{R} = \frac{12}{1 + .5} = \frac{12}{1.5} = 8 \text{ Amperes}$$

Voltage drop = 8 x .5 = 4
Power output = 4 x 8 = 32 watts

If the external resistance is changed to 1 ohm then we have:

$$I = \frac{E}{R} = \frac{12}{1 + 1} = \frac{12}{2} = 6 \text{ Amperes}$$

Voltage drop = 6 x 1 = 6
Power output = 6 x 6 = 36 watts

Again if the external resistance is changed to 2 ohms, then we have:

$$I = \frac{E}{R} = \frac{12}{1 + 2} = \frac{12}{3} = 4 \text{ Amperes}$$

Voltage drop = 4 x 2 = 8
Power output = 8 x 4 = 32 watts

TEST QUESTIONS

Be sure to number your Answer Sheet 15 FR.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and the best possible lesson service.

1. What is the purpose of an audio frequency amplifier in a radio receiver?

2. Name four other important applications of audio frequency amplifiers.

3. State three common coupling methods used in audio frequency amplifiers.

4. What complete picture is given to you by the static characteristic curve shown in Fig. 2c?

5. What is meant by the actual or true voltage amplification of a tube in a single stage?

6. Why is step-up transformer coupling preferred for use in voltage amplifiers?

7. Upon what *three* things does the true voltage amplification of a stage depend?

8. What relation should exist between the plate load resistance and the internal plate resistance of the tube, in order to obtain maximum voltage amplification using resistance coupling as shown in Fig. 6 (a) and (b)?

9. How can the primary inductance of an audio frequency transformer be increased?

10. What is the sole purpose of using power tubes in push-pull arrangement?

THE VACUUM TUBE IN RADIO FREQUENCY STAGES

16 FR

PIONEER HOME STUDY RADIO SCHOOL

NRI

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

BE SURE YOU WILL GAIN SUCCESS

Before you start work on this lesson, stop a moment and take stock of yourself. In fact you should do this frequently so you can keep a careful check on your progress and so that you can be sure you are doing the very best you can as preparation for your Radio Success.

In connection with this, let me give you a hint—every man has in him the germs of success—and the man who succeeds is the man who knows he is going to succeed and never lets anything persuade him otherwise.

Orisen Swett Marden says, "To be ambitious for wealth and yet always expecting to be poor, to be always doubting your ability to get what you long for, is like trying to reach East by traveling West. There is no philosophy that will help a man to succeed when he is always doubting his ability to do so, and thus attracting failure."

No matter how hard you may look for success, if your thought is saturated with the fear of failure it will kill your efforts, neutralize your endeavors and make success impossible.

Never doubt for a moment that you are going to succeed. Look forward to success with as much assurance as you look forward to the dawn of another day. Then work—with all that's in you—for that success.

J. E. SMITH.

NATIONAL RADIO INSTITUTE

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The Vacuum Tube In Radio Frequency Stages

THE MAIN PARTS OF A RECEIVER

As you have learned from previous text-books, there are three main divisions of a radio receiver. The tuned radio frequency amplifier *selects* the wave that is desired, and amplifies the signal after it has been selected, so that it is able to operate efficiently the second main division of the receiver, which is the *detector*.

The detector operates on the selected signal wave so that it is put into such a condition that it can actuate a reproducer such as a loudspeaker. Ordinarily, the signal, after passing through the detector, is too weak to operate a loudspeaker efficiently, so that it is necessary to incorporate in the radio receiver a third main part which is known as the audio frequency amplifier. The audio frequency amplifier strengthens the signals after detection, so that the sounds which emanate from the loudspeaker are strong enough to act on the ears of the listener without making it necessary for him to strain his ears to hear the program.

We may, therefore, list the various functions of a radio receiver as follows:

(1) It must *select* the desired signal wave from undesired waves.

(2) It must amplify, at radio frequencies, the signal wave, after selection.

(3) It must *rectify* (or detect) the selected signal wave.

(4) It must *amplify*, at audio frequencies, the detected signal.

(5) It must translate the rectified and amplified signal into sound.

Upon studying the various functions of a radio receiver carefully, it will be seen that there are some important qualities which a good radio receiver must have, and which must be carefully studied. Some of these qualities pertain to the radio frequency amplifier, some to the detector, and some to the audio frequency amplifier. They may be listed as follows:

Radio frequency amplifier.
(a) Selectivity.
(b) Radio frequency amplification.

Detector.
(a) Efficiency of rectification (detection).
(b) Audio frequency characteristic.

Audio frequency amplifier.
(a) Audio frequency amplification.
(b) Audio frequency characteristic.

Although we have included the subject of audio frequency characteristic in the above table this has been done only to make the table complete. The audio frequency characteristic of the detector and audio frequency amplifier determines the *fidelity* with which the receiver will reproduce a given sound impressed on the microphone at the broadcasting station. It will be studied in detail in later lessons of the course.

SENSITIVITY

The sensitivity of a radio receiver, which may be defined as the ability of a receiver to act upon a certain weak signal and render it sufficiently strong to operate a loudspeaker, depends upon the characteristics of all parts of the radio receiver. It depends upon:

(1) The radio frequency amplification.
(2) The efficiency of rectification (detection).
(3) The audio frequency amplification.
(4) The sensitiveness of the loudspeaker.

Unfortunately, there is a limit beyond which the detector cannot operate so that there is a certain maximum signal strength which we can obtain from the loudspeaker. However, we can so design the detector circuit that the maximum obtainable loudspeaker output is sufficient for most purposes. Therefore it is not necessary to consider the matter of overloading the detector when discussing the sensitivity of the receiver.

It is necessary, however, to be sure that fairly good volume is obtained from the loudspeaker. If we assume that we have a certain amount of amplification in the audio frequency amplifier, and a certain detector efficiency, we must amplify the signal in the R.F. amplifier so that it is fairly strong when it acts on the detector. The detector is least efficient when we need it the most. It responds weakly to a weak signal, and as the signal becomes stronger, the response of the detector becomes greater and greater. Suppose we impress on the detector a signal whose strength is 2, we will obtain a certain output from the detector. Now let us double the input signal to 4. The output of the detector is not doubled, but *quadrupled.* If we triple the input signal, the response is increased *nine-fold.* In other words, the detector is a *square-law* device; the output increases as the *square* of the input.

Looking at the problem the other way, suppose the input signal strength is reduced to half the original value; the response is then cut to one-fourth the original response. If the input signal is reduced to one-fourth, the response is cut to one-sixteenth. In other words, on account of the square-law characteristic of the detector the response decreases very rapidly as we tune our radio receiver to weaker and weaker signals. In order that we may enjoy the programs transmitted from distant stations whose signals are weak when they reach the receiving antenna, it is necessary to amplify these signals considerably before applying the signals to the input of the detector. This explains the need for an efficient radio frequency amplifier ahead of the detector, which will provide a much larger signal voltage at the detector than if no R.F. amplifier were used.

Suppose we did not have an R.F. amplifier and we tuned our detector to a certain strong local station. We would obtain a certain amount of sound out of the loudspeaker. Now, suppose we tuned the set to a signal which is only one-tenth as strong; by using a single stage of R.F. amplification ahead of the detector, whose amplification is, let us say 10, we would obtain the same amount of volume from the loudspeaker on the weaker signal that we originally obtained from the stronger signal without the R.F. stage. Suppose again we had two stages of R.F. amplification, each of which amplified 10 times. Then we could obtain the same volume from a signal which is one-hundredth (10×10) the strength of the signal originally applied to the detector.

SELECTIVITY

In addition to amplifying the R.F. signal, the tuned radio frequency amplifier has another function, which is about as important—it also selects. As a matter of fact, amplification and *selectivity* are so closely tied together, that we can hardly refer to one without having to keep in mind the other. The R.F. amplifier would not be required when the signals received are those coming from a near-by local station if it were only necessary to obtain a large volume-output from the loudspeaker. Excellent volume can be obtained on local reception with the antenna connected directly to the detector. However, if several powerful stations are broadcasting at the same time there will be no means of differentiating between these signals, and in general they will be all "hashed up" in the loudspeaker.

For this reason it is necessary that *selective circuits* be placed between the detector and the antenna circuit to which the radio receiver is connected. These tuned, or selective circuits are connected between the R.F. amplifier tubes in various ways. Regardless of the particular manner of connecting them, or of their particular design, provided the tuner is placed between R.F. tubes, it is a fact that the amount of selectivity obtained from these circuits is a measure of the amplification supplied by the several stages.

A single tuned circuit connected to the input of the detector is not sufficient to discriminate against all unwanted stations and pick out only the one desired station, because for the first reason there are so many stations, and for the second reason, some of the near-by stations are quite powerful. As you know, the range of frequency used by broadcasting stations is from 550 to 1500 kilocycles, and the stations are allotted frequencies 10 kilocycles apart. This means that there are $\frac{1500-550}{10}$ or 95 broadcasting channels. Now, if we have 100 divisions on our tuning dial and a straight line frequency condenser is used, there is practically one channel for each division on the dial. We can expect, therefore, that in some localities a great deal of interference will be encountered, especially in the middle west. For example, if a receiver located in Chicago should be tuned to a New York station (1000 miles to the east) at let us say, 50 on the dial, a station located at Denver (roughly, 1000 miles to the west) which is tuned in at 52 on the dial, would produce serious interference.

For these reasons, it is necessary to use more than a single tuned circuit connected ahead of the detector. By using a number of tuned circuits the receiver is made much more selective, and it becomes possible not only to separate distant stations only several divisions apart on the dial, but also to differentiate between powerful local stations perhaps 10 divisions apart on the dial. Local stations are allocated frequencies differing by at least 50 kilocycles by the Federal Radio Commission, in order to assist in separating the locals.

A tuned circuit is generally connected to a tube of the radio frequency amplifier in the manner shown in Fig. 1a. You will notice it is a series resonant circuit. There are usually four such tuned circuits and three R.F. amplifier tubes. One tuned circuit precedes each R.F. amplifier tube and one precedes the detector. The general arrangement is shown in Fig. 2, in which the various tuned circuits are numbered. The voltage connections have been omitted for simplicity. The R.F. amplifier tubes are T_1, T_2 and T_3. Preceding these are the tuned circuits, *1*, *2* and *3*. An additional tuned circuit is located ahead of the detector *D*, and is numbered *4*. Note that tuned circuit No. *1* is connected between the antenna and the first R.F. amplifier tube; this circuit is often called the antenna selector.

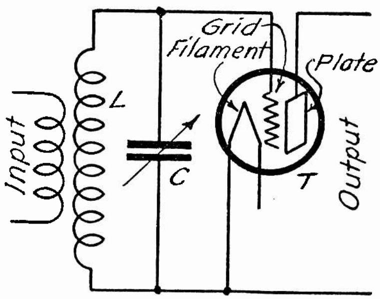


Fig. 1 (a)

It is usual practice to tune these circuits by varying the capacity of the condenser only; the four condensers are operated on a single shaft, so that all the tuning is accomplished by turning only one knob. Several years ago difficulty was found in making the four condensers "track," or tune exactly alike, so that in earlier receivers we often found a single tuning knob for each condenser. This made the process of tuning difficult, so as time went on, ways and means were found for designing the tuning systems as to permit them to be tuned by using one control knob.

FIDELITY

Earlier in this text, among various desired qualities in a radio receiver, we included the expression "audio frequency characteristic." This expression actually relates to the fidelity with which a radio receiver will reproduce sounds which enter into the microphone at the transmitting station. Although it is generally stated that the audio frequency amplifier is the predominating factor in determining the fidelity of reproduction of the radio receiver, the student must understand that this is only half the story. *The radio frequency amplifier is just as important as the audio frequency amplifier in determining the fidelity.* It can be stated very roughly that a poorly designed audio frequency amplifier results in a loss of low (bass) notes in the reproduction, whereas the selectivity of the R.F. amplifier causes a loss of high (treble) notes in reproduction. The reasons for these statements will be studied in detail later on, but it may be stated here that the more selective a receiver is, the poorer will be reproduction of the high notes.

SIDE-BANDS

A radio frequency carrier wave emitted from any broadcasting station consists of a radio frequency wave of constant (unchanging) frequency and amplitude (strength). When a performer speaks into the microphone, this carrier wave is *modulated;* that is, its amplitude is caused to vary, depending upon the strength and character of the spoken sounds.

The wave reaching the receiving antenna may be said to consist of a carrier wave of constant frequency together with "side" waves which differ in frequency from the carrier frequency by an amount equal to the frequency of the spoken sounds and having amplitudes which depend on the strength of the spoken sounds. In other words, if the carrier has a frequency of 1,000 kilocycles, and the sound directed into the microphone has a frequency of 1 kilocycle (1,000 cycles), the side band frequencies will be 1,001 and 999 kilocycles.* All three signals are relayed through the R.F. system and when passed through a detector, results in an audio signal of 1,000 cycles, and all three R.F. frequencies are shunted away from the A. F. system by a by-pass condenser. Any unequal amplification in the R. F. system will distort the final audio signal.

Now, suppose a 1,000 kc. carrier is modulated by a 5 kc. note. The side band frequencies would be 1,005 and 995 kilocycles. Since the radio receiver is tuned accurately to the carrier, i. e.,† 1,000 kilocycles, the frequencies 1,005 and 995 kilocycles would be "off tune." Consequently, we would not expect the receiver to respond as well to these frequencies as we would expect it to respond to the carrier frequency, to which it is accurately tuned,

* 1,000 plus 1 equals 1,001 and 1,000 minus 1 equals 999 kilocycles. † i. e., means, "that is".

any more than it should if carriers having these different frequencies, 1,005 and 995 kilocycles, were coming from entirely different stations.

It is clear, then, that the greater the modulation frequency the more "off tune" will this frequency be, and the poorer the response of the receiver. This is what is called *side-band cutting*. There is no side-band cutting at a modulation frequency of zero, because this is the carrier frequency, to which the set is accurately tuned. The cutting is worse the higher the modulation frequency; for example, a modulation frequency of 1,000 cycles produces side frequencies which differ from the carrier frequency by 1,000 cycles; a modulation frequency of 3,000 cycles produces side frequencies which differ by 3,000 cycles and so on. This loss of high audio frequencies is due to the selectivity of the R.F. amplifier and the greater the selectivity the worse will be cutting of side-bands and the loss of high audio frequencies in the loudspeaker reproduction.

Therefore, if the fidelity is to be good, the side bands must be fully reproduced. The radio-frequency amplifier must select the desired frequency and must amplify the carrier frequency with its side bands. The resonance characteristic must not be too sharp at the top or the side bands will be cut off. On the other hand, if the resonance characteristic is too broad, interference may be caused by the amplification of other frequencies.

THE R.F. AMPLIFIER

There are many different circuits for the radio frequency amplifier, but, as we have learned before, all these circuits are only variations in the methods of coupling one vacuum tube to the next tube. The R.F. amplifier usually includes three tuned circuits and the detector includes the fourth. In Fig. 1a we have one stage of the R.F. amplifier shown in detail. For simplicity the sources of e.m.f. have been omitted. However, it must be remembered that there is always a source of voltage supply for the plate, grid and filament circuits of the tube, without which the system cannot be expected to operate. There are various ways of connecting these sources of e.m.f., which we will discuss later on.

In Fig. 1a the signal voltage is impressed upon the input of the R.F. stage as shown at the left. This input coil may be connected either to the antenna and ground, if the tube shown is the first R.F. tube, or to the output of a preceding tube, if the tube shown is the second or third tube or the detector tube. The signal e.m.f. applied to the input coil of Fig. 1a induces a voltage in the tuned circuit which includes the coil L and the condenser C; this tuning circuit allows us to *tune* the system to the frequency of the signal voltage, and to *select* or separate the particular signal we want to listen to from other signals of different frequencies or wavelengths.

There is an important feature in connection with this circuit which must be emphasized at this point, and which you must always bear in mind. The secondary circuit in Fig. 1a, which includes the coil L and the condenser C, is a *series* resonant cir-

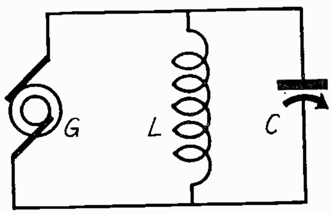


Fig. 1 (b)

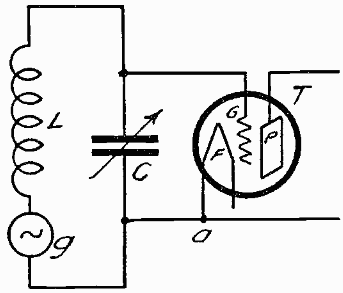


Fig. 1 (c)

cuit. At first glance it looks like a *parallel* resonant circuit, because the terminals of the condenser are connected to the terminals of the coil, and both pairs of terminals are connected to the input (grid and filament) of the tube. Actually, however, in determining whether a resonant circuit is parallel or series we must consider where the source of voltage is located.

If L and C were connected in parallel we should have the condition shown in Fig. 1b where G is an alternating current generator representing the signal voltage. In the transformer shown in Fig. 1a, in which the input coil is the primary and the coil L is the secondary, the voltage induced in the secondary is considered as in series with the secondary. For this reason we cannot consider that the generator is connected across the terminals of L, but in series with it. Therefore, we must represent the secondary circuit Fig. 1a by the circuit of Fig. 1c, in which the generator g is in series with the coil L. The circuit (Fig. 1c) of the generator, coil and condenser is therefore a series circuit. The voltage drop across the condenser C is impressed on the input terminals F and G of the tube T.

The circuit shown in Fig. 1a is the one which is used in almost all radio frequency amplifiers. The way in which two tubes are joined together by means of this R.F. transformer, or *resonance transformer*, as it is properly called, is shown in Fig. 3. The sources of e.m.f. for the filament and plate circuits, or "A" and "B" circuits, have again been omitted for simplicity. In studying the diagrams of radio frequency amplifiers, the main circuits to be considered are those which carry the radio frequency currents. For this reason it is more or less immaterial in what way the power-packs or the batteries are connected to

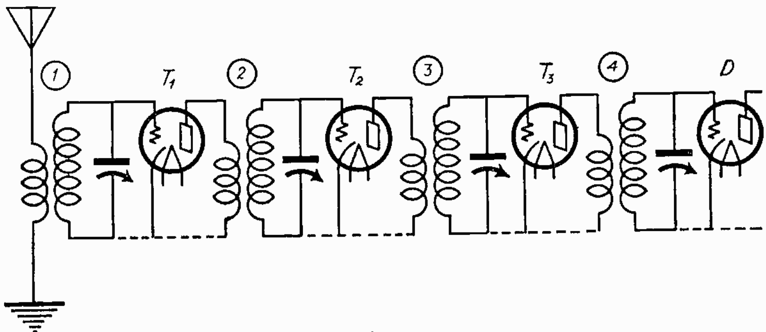


Fig. 2

the stages, provided the radio frequency circuits are kept complete and the radio frequency currents are prevented from getting out of these circuits.

BY-PASSING AND CHOKING

R.F. currents are kept in the proper circuits by means of by-pass condensers and chokes. Look at Fig. 4 (A) and (B). In this illustration are shown two radio frequency amplifier tubes. These R.F amplifiers are exactly the same in every respect as regards the circuits which carry the radio frequency currents. They differ only in the way in which the potentials are applied to the plates of the tubes.

In Figure 4A for instance, we have connected a "B" battery in series with the coil in the plate circuit with a by-pass condenser across the battery. Rectified and filtered alternating current from a power pack could just as well take the place of the battery. This condenser has a capacity of approximately 0.1

microfarad or more, so that the radio frequency currents in the plate circuit may pass through it with little opposition. In fact, the reactance is in most cases small enough to be disregarded for practical purposes. The radio frequency currents therefore pass around the plate circuit through the coil L and the condenser C, but do *not* pass through the "B" battery.

In the circuit of Fig. 4B we have the "B" battery connected in series with a *radio frequency choke coil,* marked Z, the two being connected directly to the plate and filament (cathode) of the tube. The radio frequency choke coil offers great opposition to the radio frequency currents which flow in the plate circuit of the tube, so that no radio frequency currents can flow through

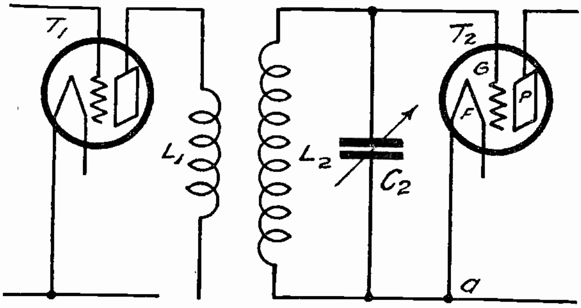


Fig. 3

it or through the "B" battery. They travel through the coil L and condenser C in the plate circuit.

So you see, as far as the radio frequency currents are concerned, the two circuits are exactly alike. In Fig 4A the by-pass condenser C is connected *across* the "B" battery for *by-passing* the radio frequency currents. In Fig. 4B the choke coil prevents the flow of radio frequency currents through the "B" battery. But in both cases the circuits traversed by the radio frequency currents are the same; also, both circuits have been arranged so that the positive terminals of the source of "B" voltage are connected to the plate of the tube. However, note that in Fig. 4B it has been necessary to place a *blocking* condenser in series with the primary coil L to prevent the "B" battery from shorting through coil L. The plate circuit of the radio frequency current must be continuous, that is, there must be no break in it.

Let us trace the circuit. Suppose we start out at the plate of the tube. Passing away from the plate we come to the coil L; next, passing through the condenser C we come to the cathode (filament) of the tube; then, through the tube itself, we come back to the plate, thus completing the circuit.

The question arises as to why we could not connect the lower end of the coil L directly to the cathode; the circuit would be complete for the R.F. currents. Surely, but it would also be complete for the "B" supply; the "B" battery would be short-circuited through the coil L and the coil would "burn up." So, the blocking condenser C in 4(B) is included to keep the direct current circuit open, and to keep the R.F. circuit closed simultaneously. The condenser C* should have a capacity of approximately .002 microfarad, so that little or no opposition is offered to the flow of radio frequency current.

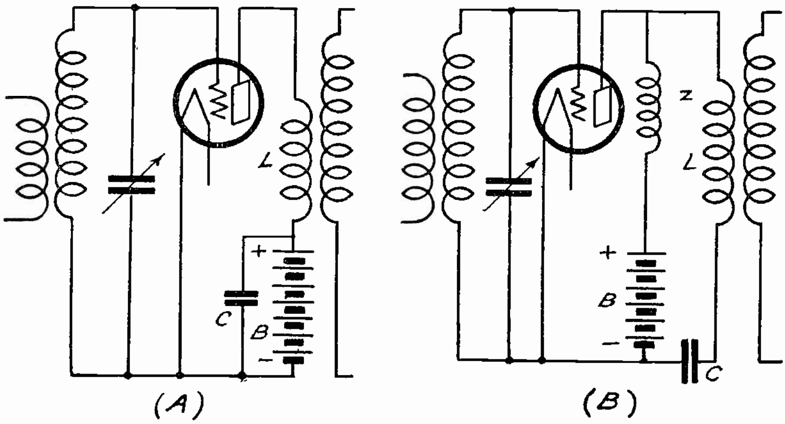


Fig. 4

In Fig. 5 we have shown the manner of applying the principles of by-passing and choking the R.F. circuits so as to prevent the radio frequency currents from leaving the proper circuits. Fig. 5A shows the series connection of the "B" supply. The primary windings of the two resonance transformers are both connected to the "B" supply, so that the "B" supply, primary winding and plate are in series for both tubes.

In order to prevent the radio frequency currents from leaving the plate circuits proper, and to prevent them from entering the "B" supply, the by-pass condensers C_1 and C_2 are connected from the low ends of the primary coils to the filaments (cathodes). However, if you will trace the circuit, you will see that these two condensers are really in parallel, so that they can be replaced by a single condenser C_3 whose capacity is at least equal

*The capacity C and the inductance L should not resonate in the tuning band, unless specifically intended in the receiver design.

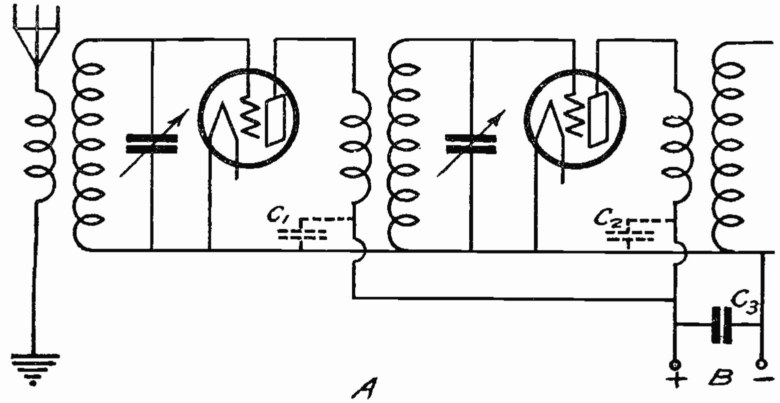
to the combined capacity of C_1 and C_2. As a matter of fact, great care must be taken in locating the common condenser C_3 so that the length of the wires from the first R.F. transformer to C_3 is not too great. As drawn in Fig. 5A the by-pass condenser C_3 is shown very close to the second transformer but quite a distance from the first. This means that the wire from the low end of the first transformer, being quite long, may have a lot of inductive reactance, which may oppose the R.F. currents in that wire and hinder them from passing to the condenser C_3 and thence to the filament.

As far as the R.F. circuits are concerned, the filament wiring is at ground potential. If the wire from the primary coil of the transformer has appreciable reactance, the low end of the first primary coil will have a potential which is higher than that of ground and there may be certain coupling effects between that wire and various parts of the circuits. This may result in an effect called *regeneration*, which interferes with the normal performance of the set in a manner which we shall study later on. For this reason the common condenser C_3 should be located so that the length of the wiring from each stage is as short as possible, and about the same in each stage. If this cannot be done it is better to use separate condensers in each stage, even though they are connected in parallel.

In Fig. 5B we have shown the shunt connection for the "B" supply. In each stage we have to use the blocking condenser mentioned in connection with Fig. 4B in order to prevent short-circuiting of the source of B voltage. C_1 and C_2 in Fig. 5B are the blocking condensers. In addition, we have to use in each stage the radio frequency choke coil, which is shown connected directly to the plate of each tube and to the "B" supply. The R.F. choke coils prevent the R.F. currents from entering the "B" supply circuit and the blocking condensers complete the plate circuits of the tubes for the R.F. currents, at the same time preventing short-circuiting of the "B" supply.

Which of the two methods of connecting the "B" supply is to be used in designing a radio receiver depends upon the conditions in the receiver and the amount of money the designer wants to spend. The series connection (Fig. 5A) is probably more used than the shunt connection (Fig. 5B), but the series connection has certain disadvantages as well as advantages. One disadvantage is that the by-pass condensers need to be large, about 0.1 microfarad, whereas in the shunt connection the (D.C.

current blocking) condenser is generally about .002 microfarad. An advantage with the shunt connection is that, if the choke coils are properly designed, there is less chance of having common coupling between the stages, or of having portions of the R.F. circuits with D.C. potentials higher than that of ground.*



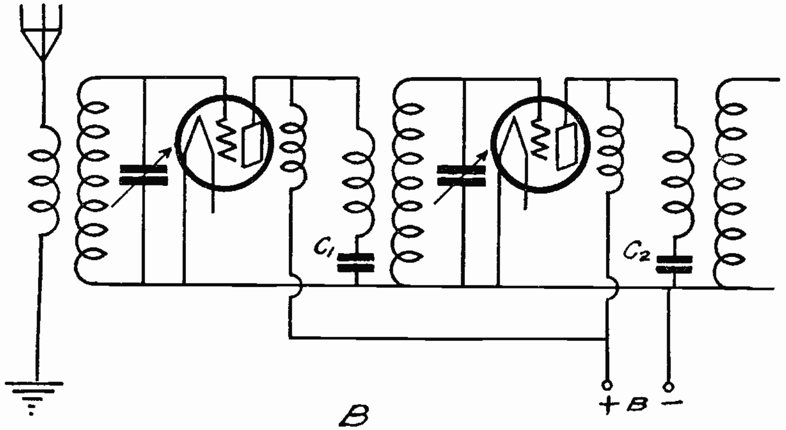


Fig. 5. A. shows a Two Stage R.F. Amplifier with Series Connection for "B" Supply. B. shows the Shunt Connection for "B" Supply.

TUBES USED IN R.F. AMPLIFIERS

All types of amplifier tubes have been used in R.F. amplifiers, but the ones which are used most frequently are the '30, '01A, '27, '22, '24, '35, '57 and '58 type. These are general purpose tubes, which differ mainly in the method of heating the filament. All of the above tubes of course have a "grid" and "plate." These

* In radio receivers the series feed method is universally used, while the shunt method is used often in R.F. circuits of transmitters.

elements are always connected to the resonance transformers in the same manner, no matter which type of tube is selected for the amplifier. This can readily be understood by comparing Figs. 6, 7, 8 and 9 with Fig. 4A. All of these stages are shown using the series connection of the "B supply." Figure 4A shows the connection used when "battery tubes" of the '01A, '99 and '30 types are employed. In speaking of "battery tubes" we

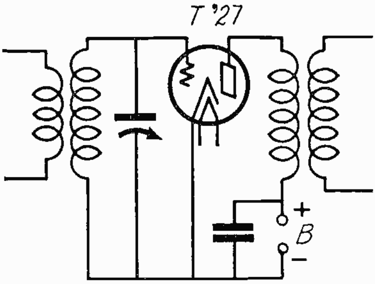


Fig. 6

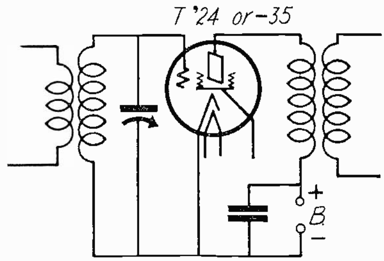


Fig. 7

mean those which will operate well only when using *direct current for heating the filament,* which of course is generally obtained from batteries. Alternating current cannot successfully be used for heating the filaments of these tubes because a very pronounced hum is produced.

The '27, '24, '35 or '26 types are used when only A.C. is available for heating the filament but these may also be used with

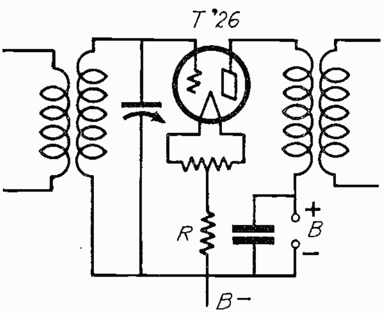


Fig. 8

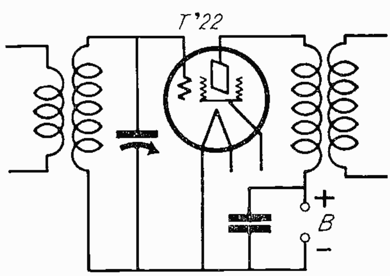


Fig. 9

D.C. if desired. The connections for these tubes are shown in Figs. 6, 7, and 8 in the order named. It will be noticed that the "cathode," of the '27 and '24 type tubes, forms the return connection of the grid and plate circuits; similarly the "filament" forms the return connection in the battery operated tubes. Figure 9 shows the connections for a '22 D.C. screen grid tube.

In Fig. 10 the complete circuit of an A.C. operated radio receiver is shown. This circuit includes three stages of R.F. amplification using '24 screen-grid tubes, a "C" bias detector of the '27 type, a '27 for the first A.F. amplifier stage, and two '45 tubes in push-pull in the power stage. Such a receiver is operated directly from the house lighting mains, generally 110 volts, 60 cycles. The power supplied to the heaters of the '24 and '27 tubes is "raw" A.C. and is supplied by a step-down transformer. This transformer steps down the A.C. voltage from 110 volts to 2.5 volts, which is required for these tubes. There are generally several heater windings in the power transformer as it is not

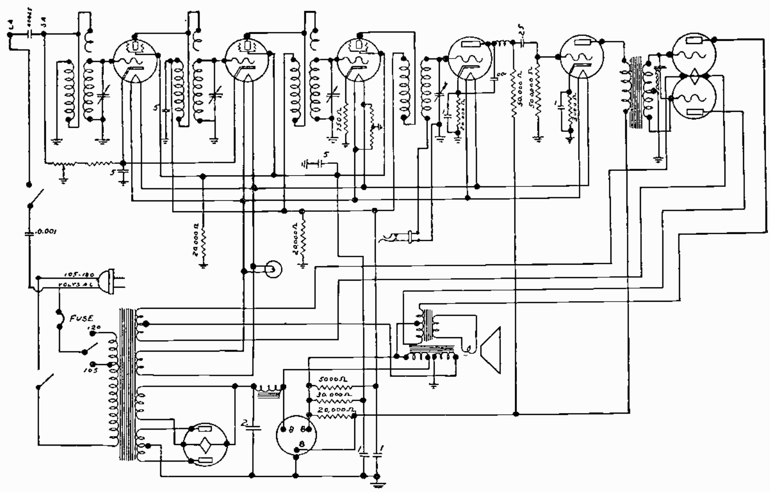


Fig. 10
Circuit Diagram of a Typical A.C. Operated Receiver.

always desirable to heat all the tubes from the same source. This is a matter of design. Generally the R.F. amplifiers, and the first A.F. tubes are heated by one winding, the detector is heated by another, and there is a third winding for heating the filaments of the power tubes.

Figure 11 shows the complete circuit of a battery operated receiver. The tubes used are as indicated on the diagram. It will be noticed that in this circuit, as in all battery operated receivers, the grid-return side of the secondary (or tuning) coil is connected to the filament, which, likewise, is generally connected to ground, through a by-pass condenser.

At this point we must indicate the difference in the connections used for the different types of tubes. There are in general two types of tubes—the filament type, and the heater type. In the filament type of tube, such as the '01A or the '30, the filament is the cathode; in the heater type of tube, the cathode is a metallic sleeve over the heater (filament). In heater type tubes all the circuit returns are made to the cathode.

Figure 12 shows the simple circuit of the filament type of tube. The point X in the circuit is the common point to which the grid-return is connected and to which the plate circuit is connected through the by-pass condenser C. Figure 13 shows the simple circuit connections for the heater type of tube. You will note that these are exactly the same as those shown in Fig. 12, except that the cathode K is used for the common element instead of one side of the filament. The heater terminals are

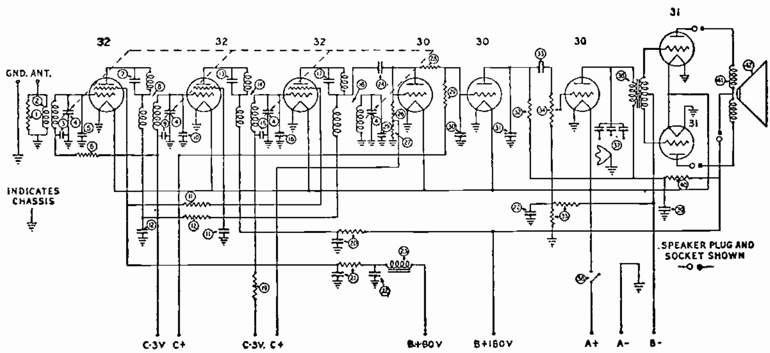


Fig. 11

Circuit Diagram of a Typical Modern Battery Operated Receiver.

shown at A. The leads from A go to the proper winding of the power transformer. H is the heater which serves only to heat the cathode K.

The tubes shown in Figs. 12 and 13 are three-electrode tubes. Some tubes, such as the '24 type (screen-grid) have four electrodes, the fourth one being the screen. The circuits for these tubes are very much the same as those shown in Figs. 12 and 13, except for the screen circuits. The connections are shown in Figs. 14 and 15. We have simply added the screens, connected to them the wires that go to the source of screen voltage, E_{sg}, and by-passed these wires to the cathode by means of the condensers C.

HUM

It is, of course, understood that no difficulties due to A.C. hum arise in battery operated receivers; the problem in A.C.

operated receivers, however, is quite serious, and as a matter of fact, it was the difficulty of solving this problem that caused such a long delay in the appearance on the market of the A.C. operated receivers. A very large part of the problem lies in the design of the apparatus supplying the voltages to the tubes. These voltages are provided by a power pack (which is connected

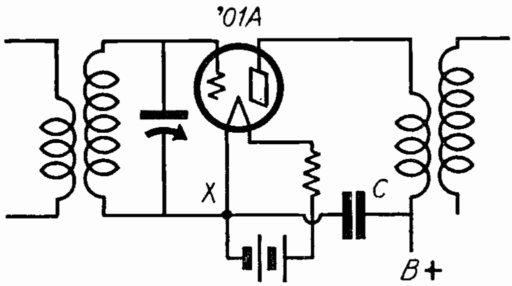


Fig. 12

to the A.C. supply, such as the house lighting mains). This has incorporated in it a rectifier of some kind, usually a tube rectifier to supply D.C. to the plate and grids of the tubes in the radio receiving set. The alternating current from the mains enters a power transformer which has several windings for supplying different values of A.C. and D.C. voltages, any ripples which

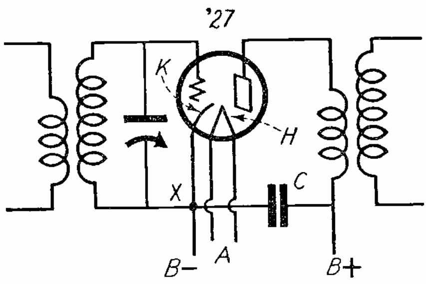


Fig. 13

might cause hum being smoothed out by the filter in the power pack as we have explained in previous text-books.

Hum problems were not solved merely by learning how to smooth out ripples. It was necessary to design tubes expressly for operation on alternating current. It was necessary to heat the filaments of the tubes with raw A.C. so this necessity led to the development of special tubes having what is known as a large "thermal lag."

The first A.C. tubes that were developed had thick ribbon filaments. A fairly large current was required to heat them and the tube was so designed that the filament retained its heat to such an extent that quick changes of current values in the filament did not cause very much of a change in temperature of the filament. This is the meaning of the expression "thermal lag." The change of temperature "lagged" behind the change of filament current; if the filament current decreased, the temperature would not be permitted to decrease very much before the current was able to increase again. Consequently, a fairly uniform temperature was obtained. This is the principle used in the '26 type of tube.

A further improvement was made in regard to hum prevention when the *equipotential cathode* type of tube was developed. This is the heater tube, of which the '27, '35 and '24 types are examples. In the heater type of tube, in place of the usual filament the electron emitting element, or cathode, is a metal sleeve slipped over a cylinder of insulating material. Inside the cylinder is placed the heater filament, the latter serving only to heat the cathode. Due to the relatively large mass of insulating material, it retains the heat to a considerable extent, thus producing considerable thermal lag.

This thermal lag, together with a properly designed filter in the power pack, helps to reduce the hum to a point where it is no longer annoying. However, there are various other methods in receiver design which must be used in order to reduce the hum to a point where it is no longer noticeable. For example, in A.C. tubes of the filament type it is necessary to connect the grid return to the center of the filament. Obviously, this cannot be physically done. It can be done electrically, however, by connecting the grid return to the mid-point of a center-tapped resistor connected across the filament terminals. Such an arrangement is shown in Fig. 8. Where it is desired to obtain the proper "C" bias without the aid of an additional source of voltage, it is only necessary to insert in the return connection, in the grid circuit, a resistance unit of the proper value.

The filament type tubes, such as the '26, are adapted to a standard four-prong base. The '27 tubes, however, are adapted to a five-prong base. The sockets usually have terminals marked as follows: G for grid, P for plate, H-H for the heater terminals to which is supplied the filament voltage, and C (cathode) to which is attached the return side of the secondary circuit of the tuner coil.

In many receivers the filament or heater leads of A.C. tubes are twisted together. This is done to prevent the alternating current which is flowing through the filament leads from acting

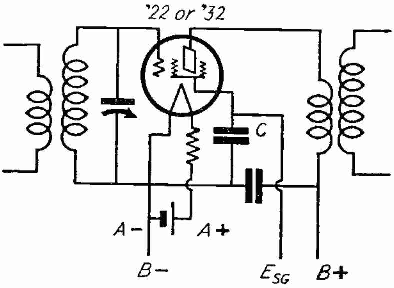


Fig. 14

magnetically on the coils or grid leads, thus producing hum. This effect may be prevented also by keeping the filament leads as far away from the other wires as possible and by shielding them.

Comparing the diagrams of Figs. 5 to 15 inclusive, the similarities of the amplifier connections can readily be observed and it is necessary only to see that the correct filament and plate

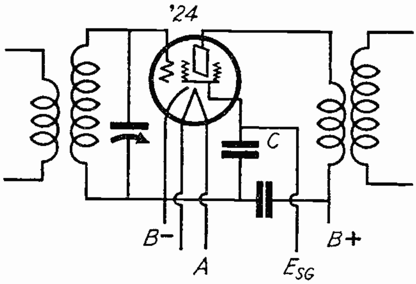


Fig. 15

voltages are applied to each tube, as recommended by the manufacturer of the tube, and of course adding grid bias voltage and screen grid voltage if the specifications call for them.

NEED FOR GRID BIAS VOLTAGE

The connections shown so far have not included a means for obtaining a voltage for biasing the grid circuit. One of the easiest and most common methods of obtaining the bias is to insert a resistance in series with the cathode or filament so there is a difference in voltage produced by the current of the plate circuit flowing through it, as shown by R in Figs. 16 and 17. The positive and negative polarities are indicated in the diagrams. The grid is connected, by way of the coil, to the negative end of this resistance R so that the grid is biased negatively with respect to the cathode (RULE; Current flows from the plate through the tube to the cathode to —B. Current always flows through a resistors from the + to — terminal).

TYPES OF R.F. COUPLING DEVICES

In the illustrations given so far we have shown two tubes coupled together by means of a *radio frequency transformer*, generally known as a *resonance transformer*. In nearly all cases at the present time the secondary winding of the resonance trans-

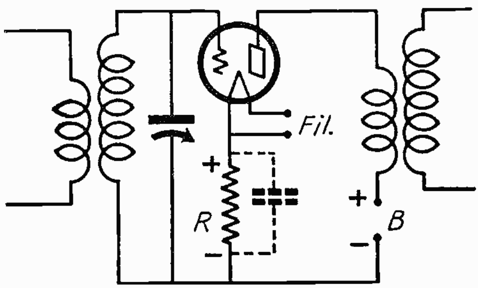


Fig. 16

former is tuned by means of a variable condenser. However, there are other ways of coupling two tubes together. The following types of coupling systems are used in R.F. amplifiers:

(a) Resonance transformer, the secondary of which is generally tuned.

(b) Impedance coupling, a special type of resonance transformer coupling, in which the resonance transformer takes the form of an auto-transformer. Choke coil coupling also falls in this class.

(c) Resistance coupling, which at present is generally limited to wavelengths above 1,000 meters (or the frequencies between 10 and 300 kilocycles per second).

You must remember that tuning may take place only in the radio frequency amplifier and in the detector stage. We cannot tune the audio frequency amplifier in order to obtain selectivity.

RESONANCE TRANSFORMER COUPLING

A resonance transformer consists, as we have seen, of two windings, a primary and a secondary winding. It does not, as a rule contain an iron core, but has simply air for the core. The general circuit of a resonance transformer is shown in Fig. 18. A signal voltage is applied to the input of the tube T_1, which is amplified by the first tube, and appears as a larger voltage v in the plate circuit of T_1. This establishes a current in the primary

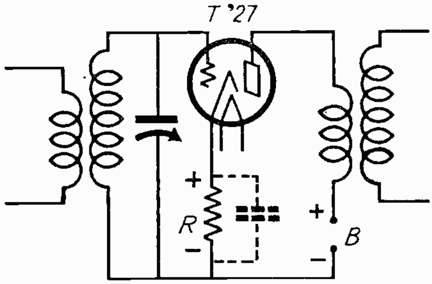


Fig. 17

L_1 of the resonance transformer, and a voltage is induced in the secondary circuit connected to T_2. As the current flows in the secondary it establishes a voltage across the terminals a and b of the condenser C_2 and it is this voltage which operates the second tube T_2.

We want the current in the secondary to be as great as possible, for this will make the voltage input to the second tube

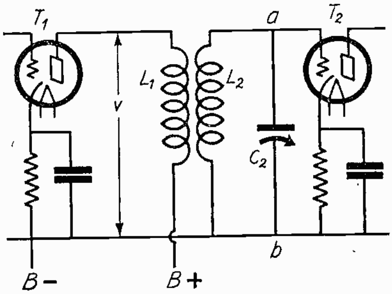


Fig. 18

(that is across a-b) large. In order to do this the secondary circuit is tuned to resonance by varying the capacity of the variable condenser C_2.

8

If we permit the voltage applied to L_1 and T_1 to remain constant, we can obtain a greater current in the secondary L_2C_2 (Fig. 18) by increasing the coupling between the primary

A 9x

and secondary coils, up to a certain point. The coupling can be increased by either bringing the coils closer together or by increasing the number of primary turns. However, by increasing the coupling we decrease the selectivity, due to the fact that the closer coupling permits more of the resistance in the primary circuit to be *reflected* into the secondary circuit. Therefore, as the coupling is made closer, we soon reach a point where the influence of the reflected resistance overbalances the improvement we expect due to the closer coupling, and current in the secondary circuit begins to decrease. In other words, there is an optimum coupling* between two circuits when there is the greatest amount of amplification. It is better, however, to keep the coupling less than the optimum, as this provides better selectivity than if the coupling is greater than the optimum.

A fair example of a resonance transformer, as generally used with '24 tubes, would be a single layer coil of No. 22 B & S gauge wire, having about 100 turns on a $1\frac{7}{8}$ inch tube as the secondary, the primary consisting of about 50 turns wound on a tube which will just slip into the other. These dimensions will vary considerably in different receivers, but they are given here to enable you to form an estimate as to the average size of such coils.

IMPEDANCE COUPLING

As in audio frequency amplifiers, there are many ways of coupling two tubes together in radio frequency amplifiers. A method of coupling that has often been used is shown in Fig. 19. In this diagram L is the plate coupling impedance, generally an untuned choke coil, of fairly high inductance. C_o is the coupling condenser, which must have a fairly small capacity, generally about 25 micro-microfarads or thereabouts. The tuned circuit consists of the coil L_2 and the condenser C_2. It is interesting to note that in this arrangement the tuned circuit is a true parallel resonant circuit because the signal voltage to which it is tuned does not originate in the coil L_2 but is supplied to it from another point in the circuit, across its terminals. This is in contrast with the previous cases where the voltage applied to the tuning circuit originated *within* the tuning coil itself.

The signal voltage delivered by the plate circuit of the first tube sets up a voltage across the choke coil in its plate circuit. This voltage is transferred by the coupling condenser C_o to the

* Optimum coupling is the degree of coupling with which there is maximum transfer of energy from one circuit to another.

terminals of the tuned circuit, which are also connected to the input of the second tube. The choke L is therefore used mainly as a means of supplying the constant "B" voltage to the first tube. A large amount of amplification can be obtained with this arrangement, but the selectivity which it provides is considerably less than that which the ordinary resonance transformer provides. This system has been tried many times, and works quite well, and is used with slight modifications.

Another form of impedance coupling is shown in Fig. 20. Here the tuned circuit is in the plate circuit of the first tube. C_o is the coupling condenser, as before; R is a grid-leak resistance, which may, if desired, be replaced by a radio frequency choke coil, although a grid leak is more often used. The inductance L and the tuning condenser C form a parallel resonant

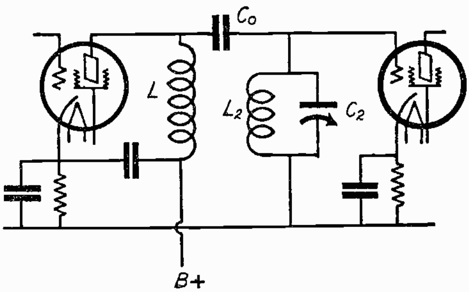


Fig. 19

circuit, which at resonance acts as an infinite impedance and prevents the signal from passing through. The voltage passed on to the next tube is therefore very large and unsuitable amplification is obtained. This system also provides poor selectivity.

The question of how much amplification is required in a radio receiver is a very important one from the standpoint of the designer, and certainly is a very interesting one from the viewpoint of the student. By knowing the answers to this question many other questions that arise in your mind will be cleared up. The main difficulty with answering this question is in determining where to start.

Perhaps the best place to start will be at the loudspeaker. We want to obtain a certain amount of volume out of the loudspeaker, and we may make the plausible assumption that all audio frequency amplifiers are more or less alike as regards the amount of amplification they furnish. It follows from this, then, that if we know how much of a signal we require at the detector to furnish a fair loudspeaker volume, and if we know the value of the signal at the antenna, we can easily calculate the required R.F. amplification.

We will take things slowly, to avoid confusion. As we have stated, all two-stage audio amplifiers furnish very nearly the same amount of amplification at about 1,000 cycles, because they are all built more or less alike. Measurements have shown that in order to obtain a power input to the loudspeaker of let us say, 50 milliwatts (0.050 watt), a signal voltage of about 0.2 of a volt is required at the input of a "C" bias detector when the carrier is modulated 30 per cent. This is a fair average condition.

Now let us consider the signal strength. Signal voltages at the antenna may be as small as five thousand microvolts (a microvolt is a millionth of a volt) for local stations, and much less than this for distant stations. However, it has been found that when the signal is less than about 20 microvolts (20/1,000,000ths of a volt) it is difficult to distinguish between the signal and static. Of course, the static varies considerably, but this is a fair value to settle on. Now, requiring a signal of 20 microvolts to be amplified to a signal of 0.2 volt requires an amplification of around 10,000 times. The voltage amplification between the antenna and first R.F. tube, that is, the step-up in the antenna selector, may have, at certain frequencies, a value of about 5. We require therefore in the R.F. stages an amplification of about 10,000/5 or 2,000 times. If we had three R.F. stages this means that we should have to have an amplification per stage of about 13 (the cube root of 2,000).

It is not difficult to obtain this amplification with screen grid tubes; in fact, in some cases we can design a screen grid set to have an amplification of 50 per stage. But the greater the amplification becomes the more difficulty we have with the tendency of the set to oscillate.

The amplification can be adjusted at will by making various changes in the circuit. For example, the amplification increases:

(a) With an increase of screen voltage (up to a certain maximum value).

(b) With an increase of coupling in the resonance transformer (up to a certain maximum value).

(c) With a decrease in the tuned circuit resistance.

(d) With a decrease of grid (negative) bias.

(e) With an increase of plate voltage (this is not very effective in the case of screen grid tubes).

The amplification also increases, as you may expect, as the number of stages is increased; that is, within the usual limits. If we use three stages that have individual amplifications of 25 per stage, the overall amplification will be 25 $\times$ 25 $\times$ 25 or 15,625.

As we mentioned earlier in this lesson, selectivity is very closely related to sensitivity. Everything that we do to increase the sensitivity also improves the selectivity. Therefore we can apply all the items given in the above list to improvements in selectivity, with one exception, i. e., increasing the coupling does not improve the selectivity, but rather, spoils it. However, small changes in the coupling generally have little effect on the selectivity. It is only the large changes that are noticeable.

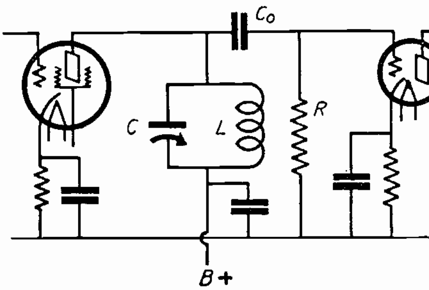


Fig. 20

INSTABILITY OF R.F. AMPLIFIERS

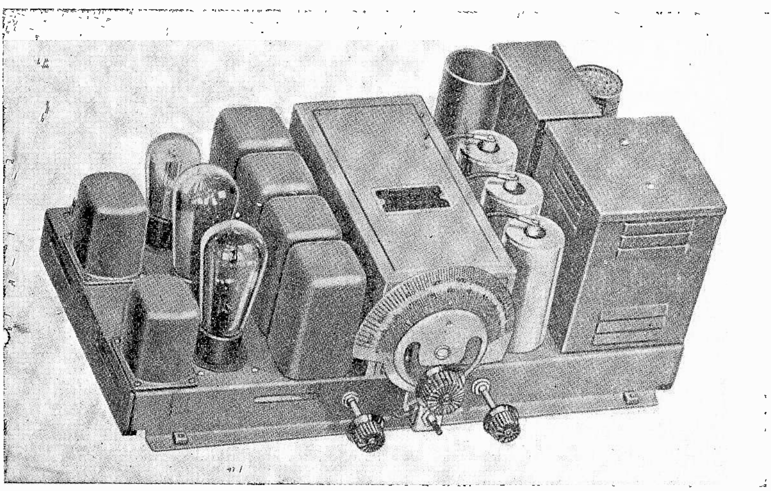
The matter of instability of R.F. amplifiers is a very important one and, a rather difficult one. In this lesson we shall treat the subject briefly because it will be discussed in detail in a later lesson. We have mentioned it several times before in this lesson, but before closing we must explain at greater length what is meant by instability.

Let us refer to Fig. 21, which shows an enlarged schematic view of a three-electrode tube. By means of broken lines we have indicated that between the grid and plate, the grid and cathode, and between the cathode and plate, we have, in effect, small condensers. This is because any pair of the elements may act as the plates of a condenser, which plates are separated by an insulating space or medium.

Now let us think what this means in a radio frequency amplifier. Suppose we have a signal voltage acting on the grid of the tube. The tube amplifies this voltage producing a greater voltage in its plate circuit. Now, the plate circuit is coupled to the grid by means of the capacity between the grid and plate, so it is clear that some of the voltage produced in the plate circuit can *feed back* into the grid circuit.

Under certain conditions this voltage can feed back in such a way as to reinforce the original signal applied to the grid. In other words, it can add itself to the original signal, making the latter *seem* as if it were actually stronger than it really is. This is *regeneration.*

This rarely occurs in a single tube, but where there are several tubes in cascade it happens very often. If the condition is quite bad it may actually lead to self-oscillation, and the receiver



Typical chassis of a screen grid T.R.F. receiver showing shielding. This is what the radiotrician or service man see when he removes the chassis from the cabinet.

will act as a weak transmitter. Let us see how that happens.

Let us suppose that the circuit connected to the input of the first tube has a certain amount of resistance. When a signal voltage is applied to this circuit there will be a certain amount of power lost in the form of heat in the wiring of the circuit. Now, let us suppose that we have a feed-back of power from, let us say, the third tube, which reinforces the signal applied to the first tube. Suppose also, the amount of power fed back to the first tuned circuit is exactly the same as the amount of power lost in the form of heat. Under this condition, because the power fed back is making up for all that is lost due to the resistance of the circuit, we have a condition which is equivalent to that in which the first tuned circuit has *zero resistance.*

Of course, such a thing is *physically* impossible, but the circuit *acts* that way, nevertheless. Its apparent resistance has been reduced to zero. A voltage applied to such a circuit therefore, would cause a current to flow that would continue of its own accord, and we would have established in the circuits a self-oscillating current. This current would have a frequency which is determined by the tuning adjustments of the circuit, and would interfere with the signal which it is desired to receive. It would "beat" with the signals, producing what is known as a "heterodyne" whistle, caused by the interference of the local oscillations in the receiver with the incoming signal.

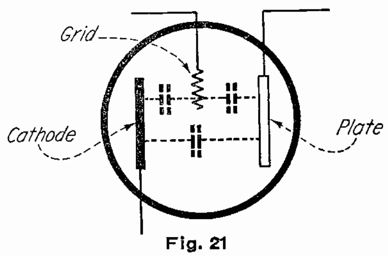


Fig. 21

There are several ways in which self-oscillation may be prevented, as follows:

(a) Keep the inductance in the plate circuits of the tubes small.

(b) Have the several stages well shielded individually, so that there is no magnetic or electrostatic coupling between stages other than in the resonance transformers.

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(c) Use tubes which have small capacity between the grid and plate.

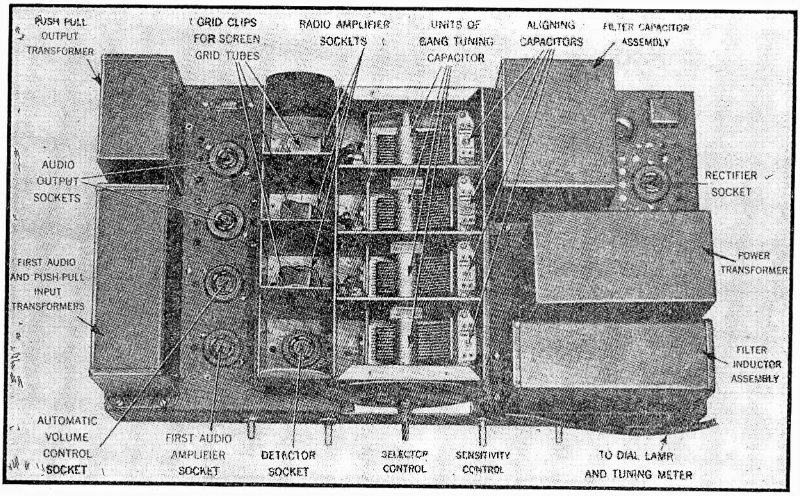
(d) Carefully shield or avoid wiring arrangements which permit coupling between stages.

(e) Carefully by-pass to ground or to cathode all wires passing out of the individual stage shields.

(f) Carefully choke (using R.F. chokes) all leads passing out of shields.

How far to go in any of these things is determined by the conditions existing in the receiver. Radio frequency choking is not always necessary. How small to keep the plate circuit inductance depends on the tubes which are used. Screen grid tubes were developed for the express reason that their grid to plate capacity is exceedingly small, so that there is but a slight amount of feed-back through the tube. Most of the feed-back occurring in screen grid sets occurs outside the tubes, and through coupling between wires and other parts of the circuit, and because of inadequate shielding.

Wiring arrangements that provide common couplings should be avoided, especially in connection with the location of by-pass condensers.



Top view of the chassis of another T.R.F. receiver with detector, screen grid tube and variable condenser covers removed for inspection. The R.F. coils, voltage divider resistor and the wiring of the apparatus is not shown as these are underneath the chassis. The apparatus used in this set is arranged a little different to the one shown on page 26.

Older R.F. amplifiers were handicapped by the large grid to plate capacities in the tubes, and accordingly had to be particularly designed to prevent or control self-oscillations. Many schemes were used for controlling it, but nearly all of these schemes involved the introduction of sufficient resistance in the tuning circuits to damp out the oscillations. There were several schemes, however, which were based on the principle of balancing out the feed-back rather than damping it out. Among these schemes were the Hazeltine Neutrodyne circuit, the Rice circuit, etc.

TEST QUESTIONS

Be sure to number your Answer Sheet 16 FR.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson.

In that way we shall be able to work together much more closely, you'll get more out of your course, and the best possible lesson service.

1. What is the purpose of a radio frequency amplifier ahead of the detector circuit?

2. Why are tuned circuits used in conjunction with the R.F. amplifier?

3. Draw a diagram of a 2-stage radio frequency amplifier, using either the shunt or series connection for "B" supply.

4. Let us say that a 600 kc. carrier is modulated with a 5 kc. (kilocycle) audio frequency. What are the side band frequencies?

5. What is the purpose of the condenser "C" in Fig. 4A?

6. Why are the filament or heater leads of an A.C. tube twisted together?

7. Name three coupling systems used in radio frequency amplifiers.

8. How is the secondary circuit of a tuned radio frequency transformer tuned to resonance?

9. (a) How can we increase the coupling between the primary and secondary circuit using radio frequency transformers? (b) What effect does increasing the coupling have on the selectivity of the receiver?

10. Name three ways R.F. self-oscillation can be prevented.

HOW A VACUUM TUBE ACTS AS A DETECTOR

17 FR-1

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

MAKE A GOOD JOB OF IT

I have just a word of advice to you in regard to this lesson, and if you follow it you will have no difficulty understanding and mastering it—READ IT SLOWLY.

There is a great deal of "meat" in this lesson and after you have read it slowly and carefully, two or even three times, you will have a clear picture in your mind of the processes of modulation and demodulation (detection). I might say here that detection is by no means the easiest thing in the world to understand, and when you have attained an understanding of the meaning of detection and the methods used to "detect" radio signals, you can be assured that you have really accomplished something.

From my own experience I know that while a man gets a great deal of satisfaction out of doing every job well, the greatest satisfaction comes from doing a difficult job well.

Besides studying the processes of modulation and demodulation, in this lesson you will learn about various associated processes, such as the methods used in making unmodulated waves audible, the principle of "beating" two frequencies, as in superheterodyne receivers, etc.

Mention is also made of the autodyne circuit. An examination of the circuit diagram shown in this text book will show you that it is practically the same as an ordinary regenerative circuit. The only real difference is in operation. The feed back circuit is made to oscillate at a slightly different frequency from that of the incoming carrier, resulting in a beat frequency. The use of autodyne circuits operated on the beat principle is confined to the reception of unmodulated or continuous waves. Operated with the feed back oscillations in resonance with the incoming carrier frequency, it acts as a simple regenerative receiver.

J. E. SMITH.

WASHINGTON, D.C.

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How A Vacuum Tube Acts As A Detector

INTRODUCTION

Every radio receiver has at least five distinct parts; a radio frequency amplifier, a detector, an audio amplifier, a source of power and a loudspeaker.

The detector may be either a crystal or vacuum tube, which furnishes a low frequency or audio frequency output which represents the modulation of the high frequency or radio frequency carrier current used at the input circuit.

At the transmitter we have someone talking into a microphone. The purpose of this instrument, the very first in the broadcasting chain, is to translate these voice waves into electric currents. Once transferred in this manner they can be transmitted across the room or across the country on a wire because a wire will carry electric currents. At the other end of the wire the currents are put into an amplifier and then into a loudspeaker where they are again made audible. In this case the wire is a *carrier;* it connects the transmitter with the receiver.

But a wire goes only to one place; and in a broadcasting system you want the voice and music waves to go to all places; they may even cross lakes and oceans where it would be impossible to run wires. What can be done?

In this case we must supply a carrier again, but a different kind of carrier. It must be an electric current, and of such a nature that when put into an antenna, something happens at the distant point. It must be a current that *radiates.* Now if we take an antenna and put into it the current coming from the microphone, we should find that such electric currents would not radiate. They could not be heard at the receiver no matter how near it was to the transmitter. If, however, we could continuously increase the frequency of these currents we should reach a point where the distant receiver would begin to pick up something. For example the *lowest* frequency used for radio purposes is about 15,000 cycles (20,000 meters wavelength). A 15,000 cycle sound wave is just about audible to some sensitive ears. It is too high a frequency for most people to hear.

At some of the very large trans-oceanic radio stations using antennas a mile in length, a radio current of 15,000 c. p. s. is used. However, the higher the carrier frequency the greater is the radiated signal, as amateurs found out when experimenting with short waves.

Therefore if we can use these high frequency electric currents to act as the carrier of our voice-frequency currents we can have a broadcasting system. The problem now is to make this carrier work for us.

Broadcast stations use carrier waves between 1500 and 550 kilocycles. This means that a station using, let us say, 1000 kilocycles, has an electric current generated in it which feeds the antenna. It is of exactly the same general nature as the 60 cycle current we use to light lamps, run motors, etc. This 1,000 kilocycle current will light a lamp or do any of the tasks the 60 cycle current will.

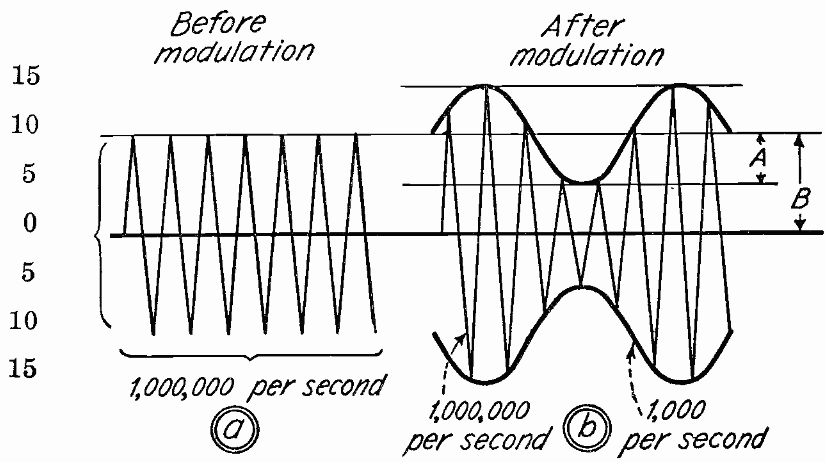
A 1000 kilocycle electric current can be represented as, in Fig. 1(a). 1,000,000 times a second the current rises from zero to a maximum value of, let us say, 10 amperes, decreases to zero, rises to 10 amperes flowing in the other direction and again falls to zero. If converted into sound it would be far above audibility. Suppose, however, we change the maximum values of this current—not its frequency, remember—1000 times a second, so that at some instants the maximum value of the current rises not to 10 amperes but to 15 amperes and at some other to 5 amperes instead of 10. Never mind how this is done at this time but just imagine how the new wave of current would look. It would look like Fig. 1(b). The 1000 kc. wave is now said to be *modulated.** If put into an antenna, the 1000 kc. frequency will act as a carrier for the 1000 cycle currents which can be picked up by a distant receiver, amplified, and then by the process of *demodulation* or *detection,* the 1000 cycle frequency can be separated from the carrier. After demodulation the 1,000 cycle signal can be amplified and made to operate a loudspeaker.

If instead of using a 1000 cycle note to modulate the transmitter carrier we talk into a microphone and use the output electric currents of this instrument to modulate the carrier, at the receiver we can get back the speaker's voice with its original tones and variations of power.

* This type of modulation, where the strength of a high frequency current is varied by a low frequency current, is called "amplitude modulation."

PROCESS OF MODULATION AND DEMODULATION

This process of modulation can be done in the following simple manner. The carrier currents are generated in a vacuum tube oscillator. The strength of the currents thus generated depends upon the plate voltage. (The frequency depends upon the values of capacity and inductance used.) Thus if we change the plate voltage at a certain rate, say 1000 times a second, we can change the maximum values of the individual cycles of carrier current. Or if our microphone currents are used to change the plate voltage of the oscillator, the amplitude of our carrier



A = *peak value of modulating current or voltage.*
B = *peak value of unmodulated current or voltage.*

$$\frac{A}{B} \times 100 = \textit{percentage of modulation.}^*$$

Fig. 1—A carrier signal before and after modulation. Note that modulation only changes the peak value of the wave, not its frequency.

current will change in accordance with these low frequency voice currents. This is exactly what may be done at the transmitter.

At the receiver this modulated carrier is received on an antenna, amplified at the carrier frequency, and demodulated, after which the carrier frequency is removed and only the audio frequencies are amplified and put into a loudspeaker.

The detector is the place where demodulation occurs; it is here that the low frequency signal is separated from the high frequency carrier.

* For example, if B is 80 volts and A is 40 volts, then the percentage of modulation is $\frac{40}{80} \times 100 = \frac{1}{2} \times 100 = 50\%$.

Usually the radio signal—the modulated carrier—is amplified before it is applied to the detector. This is the job of the radio frequency amplifier. Next we must use some device that will be affected by the modulation but not by the carrier frequency. It is much as though we had two sets of waves occurring at the same time in a pond of water. There may be waves occurring very frequently and also long rollers occurring less frequently. Thus the entire body of water can be seen to move up and down slowly in waves and on top of each of these surges and troughs will be many more rapid waves. We need some device which will bob up and down because of the slow waves, like a heavy float but not be bothered by the small waves, and then some other device which only the small waves can affect.

Suppose we have an amplifier tube characteristic like that in Fig. 2. This curve shows that the plate current would be about 8.0 milliamperes when the grid voltage E_g was –4, about 2 milliamperes when the grid voltage was –7 and nothing at all when the grid bias had been increased to –8 volts. Now suppose we have a carrier voltage of 2 volts peak value (unmodulated). This may be added to a fixed grid voltage of –3 furnished within our set by a "C" battery. Thus at some instants the actual grid voltage will be –3 (from the C battery) plus another negative 2 volts or 5 volts negative. At other instants it will be -3^v plus 2^v or –1 volt. The plate current will vary according to the curve *B* in Fig. 2.

Now suppose this carrier voltage is modulated by an audio peak voltage of 1.0 volt. This means at some instants the maximum carrier voltage will be $2 + 1$ or 3 volts and at other instants it will be 2-1 or 1 volt. Those values added to the steady C bias will cause the grid voltage to fluctuate between $-3 + 2 + 1$ or 0 and $-3 -2 -1$ or –6.

Remember that once in each radio frequency cycle the R.F. input has a zero value. It is the *maximum value* that changes with this 1.0 volt modulation. This modulated carrier voltage under these conditions will look like *C* in Fig. 2 and the plate current variations like *D* in this figure.

As long as the proper "C" bias voltage is chosen these variations in carrier voltage will be reproduced as current variations in the plate circuit. Flowing through some impedance in the plate circuit, they produce corresponding voltages across this impedance and in general these will be greater than the grid voltage variations, making the tube act as an amplifier.

Now consider a meter in the plate circuit of the tube in Fig. 2. If the steady grid voltage is –3, the plate current for this tube will be about 10 milliamperes. When the carrier voltage is added to the grid bias the plate current goes up and down in accordance with the grid voltage variations but because the positive and negative halves of each cycle of plate current exactly

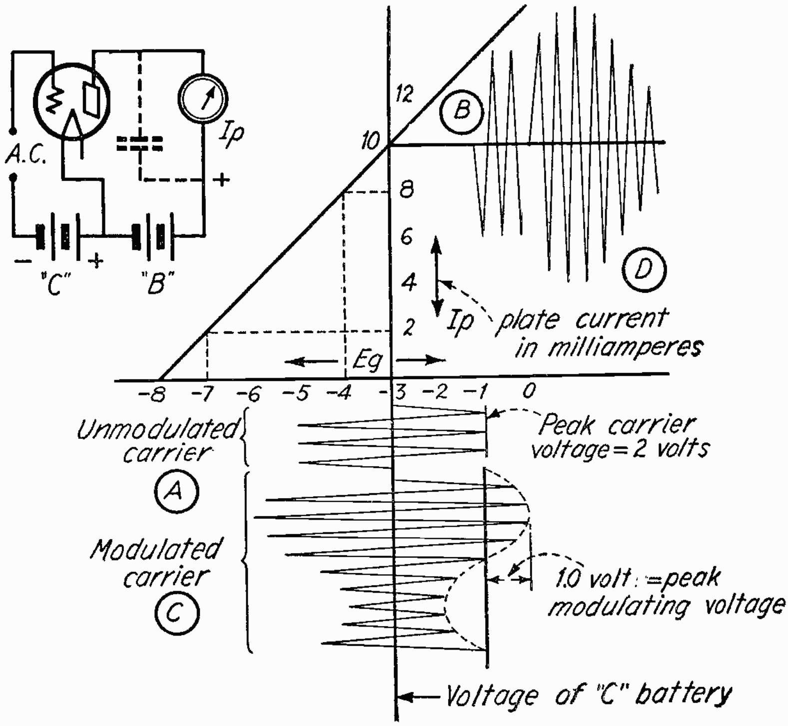


Fig. 2—Modulated and unmodulated carrier signals applied to an amplifier produces in the output a current wave exactly similar to the input voltage wave.

balance each other (because they are of opposite direction and of the same amplitude), the plate current meter will indicate no change. Even when this carrier is modulated there will be no change because the *average* value of the current has not changed. It is still 10 milliamperes.

Suppose, however, we make the "C" bias from the battery more negative so that it finally reaches the value at which no plate current flows, as at *A* in Fig. 3. Then suppose we add the carrier to this voltage and note what happens to the plate current. The negative halves of the cycles of grid voltage will not appear in the plate circuit as current variations because they only make the grid more negative and it already is so negative that no plate current flows (because of the steady bias from the battery).

From Fig. 3 we can see that when the carrier X is added to the bias voltage, during the positive half cycles some plate current flows. During negative half cycles no current flows. But the average of zero current and the various peak currents has a definite value; in other words there is some average positive value of plate current and a milliammeter will show it. Thus before the carrier voltage is applied, no current flows. After the carrier is added some current flows. The exact value will be somewhere between zero and the maximum.

If this carrier voltage is started and stopped with a telegraph key the milliammeter needle will jump up and down. Let us modulate the carrier not with a key, off and on completely, but with a very low audio note, say 5 cycles. Suppose this modulating voltage has a maximum value of 1.0 volt. Then the carrier will vary as Y in Fig. 3. The average value of the plate current will also vary up and down at a 5 cycle rate as shown in Fig. 3 at Y_1 and the needle of the meter will probably be able to follow such slow changes of current.

We have now detected or demodulated the carrier wave. The plate current meter indicates the audio output. The fact that passing through the milliammeter are also halves of cycles of very high frequency currents makes no difference in the milliammeter reading. It is this varying average value that counts, and if in place of the milliammeter we place a pair of headphones or an audio amplifier we will find that we have secured from a modulated R.F. wave the desired audio modulations.* Henceforth we can forget all about the radio frequency carrier. It may be prevented from flowing through the milliammeter by by-passing it with a small condenser, as shown by the dotted lines in the vacuum tube circuit in Fig. 2.

Such is the action taking place in a detector. All detectors are of this general nature. Some detect more, some less, some do so without distortion to the audio tones, some introduce appreciable distortion. Some detectors can handle a radio carrier voltage of only a few tenths of a volt, some can handle even as high as 50 volts. Some are "square law" detectors, others are "linear" detectors. These will be considered later.

* Of course, the modulating signal must have a frequency of about 30 c. p. s. if it is to be heard.

DETECTOR OPERATING POINTS

Detection takes place on any curved or non-linear characteristic indicated by a sharp bend in the E_g-I_p curve of a tube. Although never attained in practice, for ideal detection the curve would be a straight line above the zero-current point, for at this point there would be an abrupt change as in Fig. 3. It is about this theoretical point that detection occurs. Detection results in a change in the average value of the current. This average value varies at the frequency of modulation. When this average value

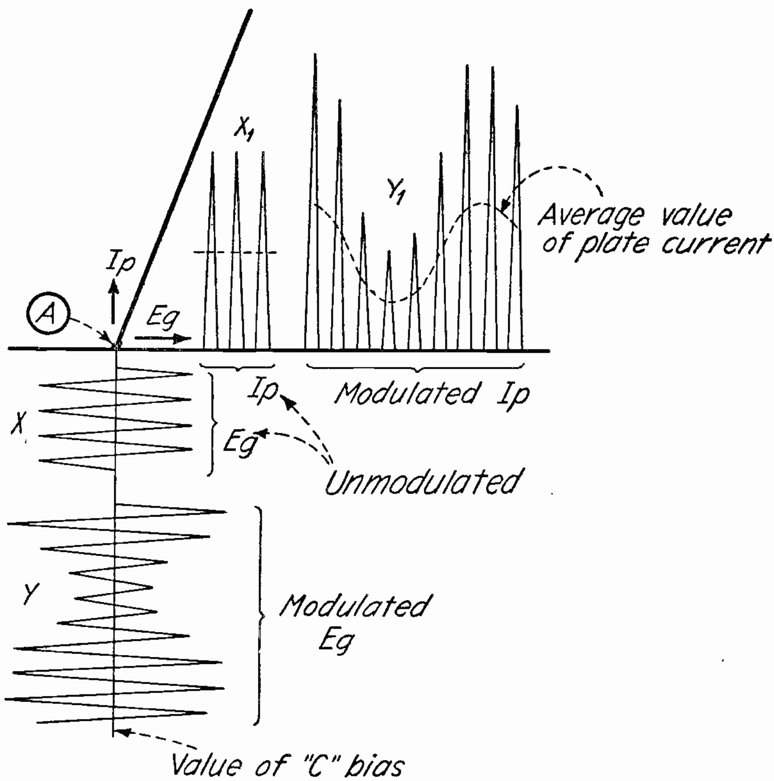


Fig. 3

changes, demodulation occurs. If the modulation is at a very low frequency a plate current meter will follow it and the needle will swing back and forth in accordance with the modulation. If, however, the modulation is at voice frequencies, the meter needle no longer can follow the individual notes, but a pair of headphones, or an audio amplifier, or a loudspeaker will indicate that they are there and are being separated from the carrier that brought them to the receiving station.

Now for detectors as we find them, the actual E_g-I_p characteristic of a vacuum tube with low plate voltage is more like the curve in Fig. 4 than like the curve in Fig. 3. The

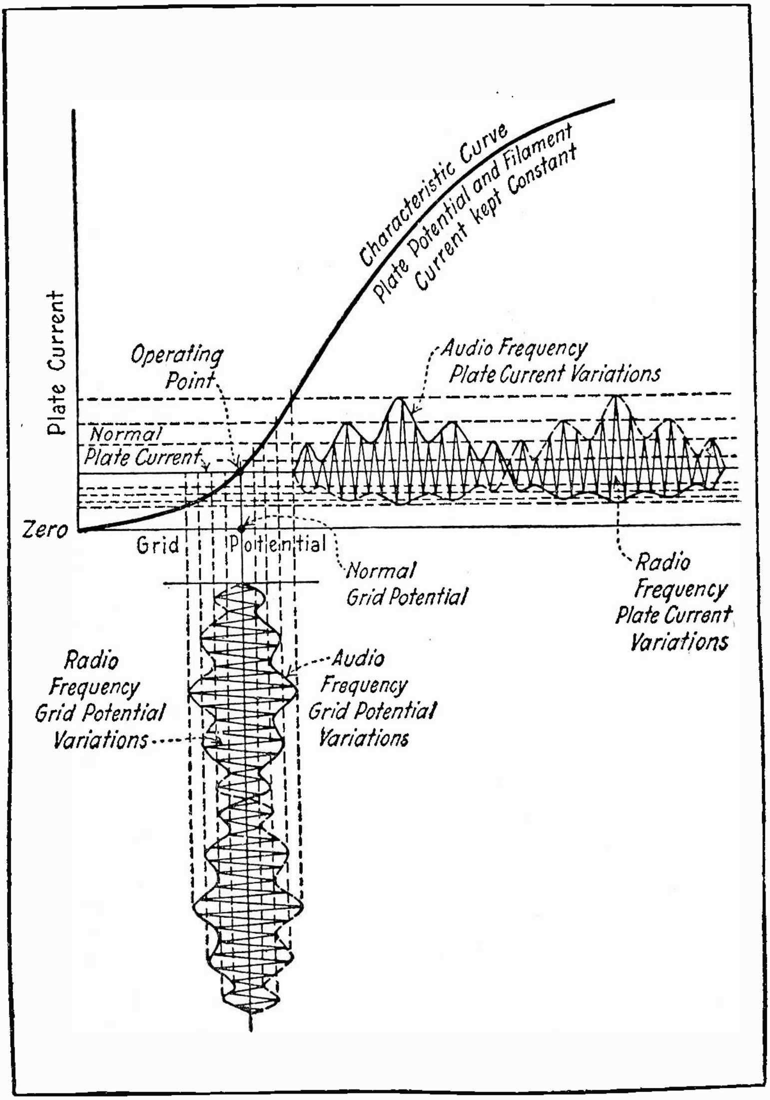


Fig. 4—Detection of sound modulated carrier signal.

operating point, set by the C bias, is at the point on the curve where the bend is greatest. For purposes of illustration the modulated carrier as it is impressed on the grid of the detector tube is plotted, along with the demodulated signal as it appears in the plate circuit of the detector.

A "C" biased vacuum tube works best as a detector when the "C" bias is set so the tube works at the sharp bend of the E_g-I_p characteristic curve. The more abrupt the bend the better is the detector action.

PERCENTAGE OF MODULATION

To get a complete insight into detection we must get clearly in mind what is meant by degree or percentage of modulation. Consider the R.F. current at the transmitter. We modulate it by causing the plate voltage of one of the transmitter R.F. tubes to vary at sound frequencies.* This tube is called the modulated amplifier. Each change in its plate voltage E_p will produce a

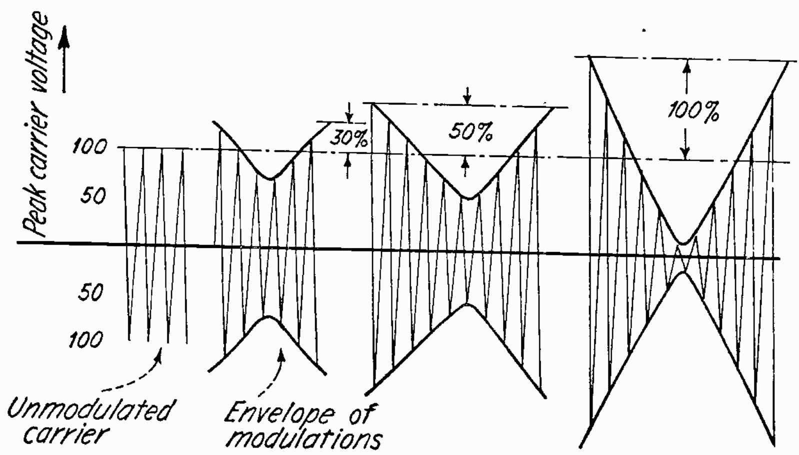


Fig. 5—Variations in degree or percentage of modulation.

corresponding change in R.F. current amplitude. If we make the plate voltage vary at sound frequencies, at some instants we shall have increased the R.F. value and at some other instants we shall have decreased it. Thus if the modulated amplifier plate voltage is 100, and we apply 100 audio volts (peak value) to it, on the negative half cycles of sound voltage the actual plate voltage will be reduced to zero. Then no plate current will flow and the tube will cease to produce any R.F. output. On the positive half cycles the total voltage on the modulated amplifier plate will be 200 volts, i. e., 100 applied and 100 added due to the positive audio peak. Under these conditions the R.F. voltage output will be double normal.

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* This method is preferred to the method of varying the voltage on the oscillator. It is the only method advisable in crystal controlled transmitters.

Usually we can apply as many audio peak volts as there are plate volts. Then we have completely modulated the R.F. amplifier, or, in other words, it is modulated 100%. If we apply only 30 peak volts to the above mentioned tube, it is 30% modulated and so on. In Fig. 5 is shown a carrier voltage modulated to various degrees. Thus an unmodulated carrier voltage of 100 when modulated 30% actually increases from 100 volts up to 100 plus 30% of 100 or 130 volts at times and decreases to 100 minus 30% of 100 or 70 volts at times. In other words, the variation in maximum carrier voltage due to 30% modulation is between 70 and 130 volts.

The drawings to the right in Fig. 5 show a carrier modulated at 50% and 100%. In Fig. 1 the formula $(A \times 100 \div B)$ is given for finding percentage of modulation.

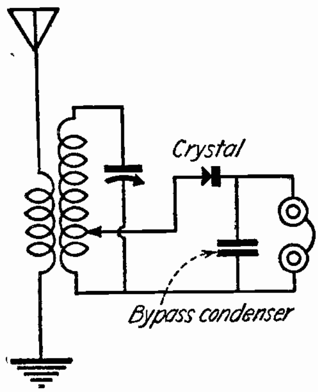

Fig. 6—Crystal detector receiving circuit.

PRACTICAL DETECTORS

Prior to the development of the vacuum tube, the crystal was employed exclusively for demodulation (detection). Today its field of use is limited to laboratory work. Such a detector when fed with an A.C. voltage allows current to flow in one direction but not in the other. From a technical point of view, the voltage-current characteristic of a crystal detector is like that shown in Fig. 3 but with rounded curvature at point (*A*).

A typical crystal receiving circuit is shown in Fig. 6. The tuned circuit consists of an R.F. transformer having a tuned secondary. Note that the crystal rectifier is connected between the low R.F. potential end of the secondary and a variable tap.

The latter is to control the rectifier output (volume) by controlling its input. A condenser across the headphone provides a low impedance path for the R.F. currents.

The use of a two element tube (diode) as a demodulator has been revived because of its ideal characteristics. Early in the history of Radio, special diode detectors were made, but today where this type of detector is used, it is the general practice to use a triode as a diode by connecting the grid and plate elements together as shown in Fig. 7. Although an insensitive device in comparison to our present standards, this tube is an ideal rectifier and is used extensively where a minimum of distortion is desired.

When a crystal or diode detector is properly connected in series with a voltage and the voltage is gradually increased, the current flowing at first is not proportional to the voltage. After

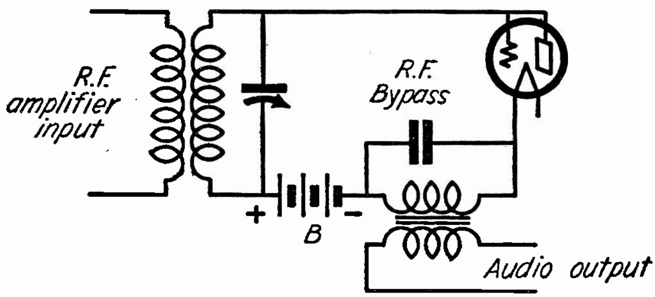

Fig. 7

a definite voltage is applied, the current starts to increase and thereafter the increase in current is proportional to the increase in voltage. It is for this reason that crystal detectors and diode tubes used as rectifiers require an initial positive bias before best detection is realized. In other words, a positive bias is required to cause the device to operate at the point of greatest curvature on its E_g-I_p characteristic.

A typical diode detector with the biasing voltage is shown in Fig. 7. In the case of 100% modulated signals, this bias voltage is necessary, but it may be dispensed with if low percentage modulated signals are to be detected.

Crystal and diode detectors are essentially rectifiers and do not contribute to the amplification of the signal, as does the three element tube when used as a detector. The latter will be considered shortly.

It was pointed out that the E_g-I_p characteristic of a triode has features that make it suitable for demodulation. The operating point of the tube is determined by its grid bias and if a circuit is arranged as shown in Fig. 8, the average plate current variations will follow the original sound variations. The controlling factor determining the action of the tube as a detector is its C bias.*

Note that there is a choke in the plate circuit of the detector to keep any R.F. current from circulating in the primary of the A.F. transformer and prevent it from being loaded up with R.F. current which serves no ultimate use. Furthermore, an R.F. by-pass condenser C_b is used as shown in Fig. 8 to supplement this R.F. elimination.

5 The triode with sufficient C bias to bring the operating point down on the lower bend near plate current cut-off is the usual

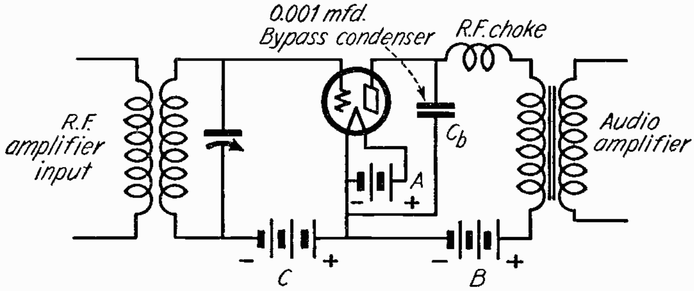

Fig. 8—Detector of the C-bias type.

type of detector in common use today. With sufficiently strong signals the positive half cycles of carrier voltage work up along the long straight portion of the characteristic, while the negative half cycles work down in the region where the plate current is zero. Thus when the detector tube has a carrier voltage applied to it, it draws more plate current than when a signal is not tuned in.

Any detector having a straight characteristic like that shown in Fig. 3 is a linear detector; and if its characteristic is curved like that shown in Fig. 4 it usually operates as a *square law* detector. A linear detector will deliver an audio signal proportional

* The grid leak-grid condenser triode demodulator will be taken up shortly.

to the R.F. signal fed to it; a square law detector will deliver an A.F. signal proportional to the square of the R.F. signal input. To explain what is meant, suppose we have a linear and square law detector, both fed with 2 volts R.F., and in both cases 10 volts A.F. is obtained. If the R.F. voltage is increased to 4 volts; that is the input is doubled, the linear detector supplies 2 x 10, or 20 volts A.F.; the square law detector supplies 2 x 2 (2 square) times 10 or 40 volts A.F. *A square law detector is not as good as a linear detector because it introduces considerable distortion on strong signals, and amplifies static excessively.* Incidentally a linear detector capable of handling large R.F. voltages without distortion is often referred to as a power detector. A tube operates as a square law or linear detector because of the hook-up, operating voltages used, and the strength of the R.F. signal fed to it.

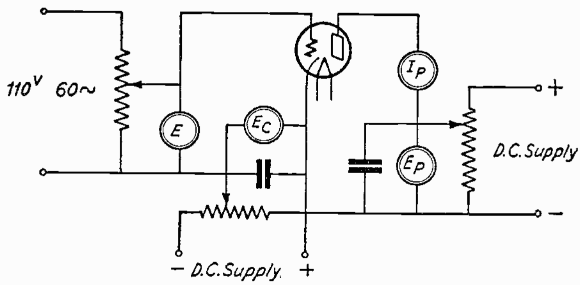

Fig. 9

Now that R.F. systems are capable of amplifying radio signals to reasonably large R.F. voltages, it is the universal practice to use only linear detectors in radio receivers. This assures us of good reproduction.

A TYPICAL "C" BIAS DETECTOR

In actual practice, the operating characteristic of a detector is obtained by actually setting up a detector circuit, applying the correct operating voltages and measuring the amount of rectified output for various conditions. Of course, such curves are for designers, but it is worth our while to understand them. Such a circuit is shown in Fig. 9 and it will be noticed that a 60 c.p.s. input source is used instead of an R.F. signal. Essentially there is no difference and it is much more easily dealt with. The general procedure in detector tests is to find its behavior for unmodulated carriers and deduce from this the action when the carrier is modulated.

Suppose we wish to test a '27 tube as a detector when a -18^{v} bias is used and determine how much plate voltage is required and what load should be used to give linear detection. A set-up as shown in Fig. 9 will be needed with -18^{v} as the bias. We would apply a definite A.C. voltage E to the grid input and vary E_p the plate voltage; the average plate current I_p (rectified current) will increase with E_p as shown in Fig. 10. Similar curves may be obtained by feeding the grid with different A.C. inputs. Note that no load is in the plate circuit. However, these curves will allow us to determine graphically the action with a plate load and thus determine the best load.

Suppose now that we consider a load in the plate circuit, let us say a 200,000 ohm resistor. Now, whenever any current flows, there will be a voltage drop. Suppose, for example, no plate current flows and we start with a plate voltage of 180 volts. If no current flows, there is no voltage drop along this resistance and the entire 180 volts will be impressed on the plate of the tube. Suppose, however, 0.9 ma. flows. Then the voltage drop along this resistance will be 0.0009 amperes times 200,000 ohms or 180 volts and no voltage will appear on the plate. The dotted line in Fig. 10 connects these two points, i. e., zero current (180 volts) and 0.9 ma. (0 volts). This is called the *load line.*

Now all possible current values for a C bias of –18 and a plate voltage of 180 and various A.C. carrier voltages may be found by noting where the various carrier voltage lines cross this straight line. For example, with 6 volts A.C. applied there would be about one-quarter milliampere, with 12 volts a little over one-half milliampere, and so on.

These currents are *rectified currents* produced by the tube acting as a rectifier. This means that no plate current flows, or very little, until an A.C. voltage is applied to the grid. This voltage is rectified and produces a flow of direct current in the plate circuit.

This direct current must go through the plate resistor producing there a voltage drop. This voltage subtracted from the plate voltage, 180 in this case, gives the voltage that actually is applied to the plate of the tube. For example, with no input signal applied, there is a D.C. current in the plate circuit of about 0.125 ma. This, flowing through 200,000 ohms produces across this resistor a drop in voltage of 25 volts.* This leaves 180 – 25 or 155 volts applied to the plate. Note that the intersection of the load line with the "$E = O$" line is about 155 volts (E_p). Now let us apply 12 volts carrier to the grid. The plate current is now about 0.57 ma. increasing the voltage drop across the resistor to 115 volts, leaving about 65 for the plate voltage. Note that the intersection of the load line with "$E = 12$" is at about 65 volts.

This change in voltage along the resistor, 115 – 25 or 90 volts, is produced by a carrier signal of 12 volts. It is a rectified

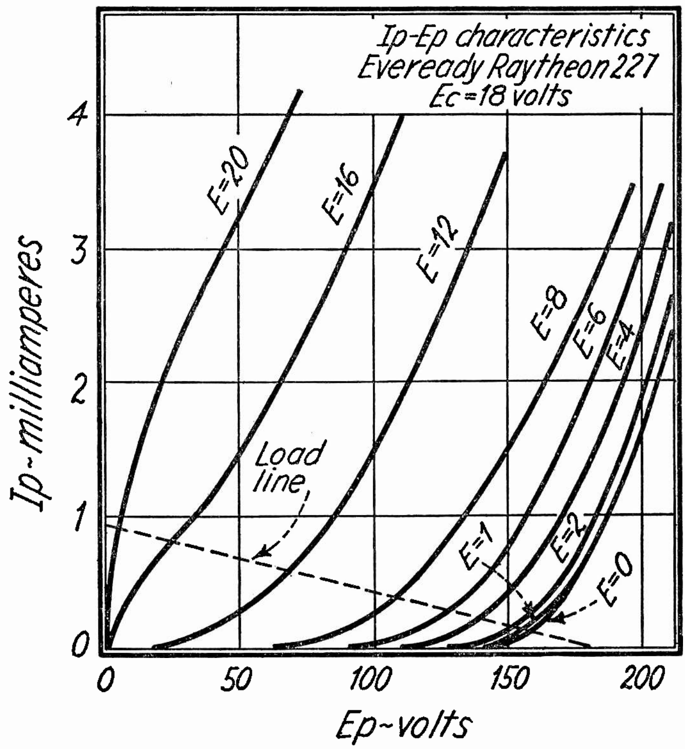

Fig. 10—Plate current (Ip) of detector controlled by plate voltage (Ep) and carrier input signal voltage (E).

voltage appearing across the plate resistor and is due to the introduction into the circuit of the carrier signal. A curve like that in Fig. 11 is obtained from Fig. 10 by getting the rectified voltage produced by various carrier voltages and plotting them.

Now any variations in the carrier voltage will produce corresponding variations in the rectified voltage across the load

* 0.125 ma. = .000125 amp. The drop is equal to I × R or .000125 × 200,000, which is 25 volts.

resistance. If, for example, the 12 volt carrier is modulated 30 per cent, the actual carrier voltage applied to the tube will vary between 12 – 4 and 12 + 4 or between 8 and 16 volts. This variation in carrier voltage will produce a variation in rectified plate voltage up and down from this value of 90 volts. Thus when the carrier is modulated, a steady voltage of 90 volts becomes at one instant 50 volts (when the carrier is 8 volts) and at another it becomes 130 volts (when the carrier is 16 volts).

And so in Fig. 11 the rectified voltage goes up to 130 from 90 and down to 50 from 90. This is equivalent to saying that across the plate circuit resistor there is a varying voltage of 40 peak volts. This is the result of demodulation or detection. Out of a modulated carrier we have secured a low frequency signal voltage which may be heard with a pair of headphones or applied to an amplifier finally to come from a loudspeaker. If a by-pass condenser is across the plate resistor, all the R.F. voltages that appear in the circuit will find an easy path to go through and will not be forced to flow through this resistor. This results in an increase in detection efficiency and prevents overloading the audio amplifier following the detector with unwanted voltages.

This varying voltage is the audio frequency voltage produced by the microphone currents at the transmitter. It is this voltage which feeds the audio amplifier and which is finally converted into sound by the loudspeaker.

DETECTOR INPUT-OUTPUT CURVES

Curves like those shown in Fig. 10 are valuable in that they help the designer to determine the correct load resistance and plate voltage for a detector. In general, a load is selected whose voltage drops are proportional to the input R.F. voltage. The exact procedure is more or less a trial and error method, that is, assuring reasonable loads and plotting the $E_{carrier}$ against $E_{rectified}$ as shown in Fig. 11. The load that gives the straightest line should be used. However, the curves shown in Fig. 11 may be checked directly with the set-up given in Fig. 9, using the estimated load, grid bias and plate voltage.

Once the $E_{carrier}$-$E_{rectified}$ voltage curve is obtained, it may be considered as the detector input-output curve, much in the same manner that an E_g-I_p curve is used to obtain the operating characteristics of a vacuum tube amplifier. From such curves, the modulated carrier signal may be analyzed as shown in Fig. 12. Here the operating point may be considered as the voltage amplitude of the carrier (10 volts in the figure). The variation in the carrier amplitude (the modulation) determines the effective audio signal. It is important to remember that these curves were obtained with an unmodulated A.C. signal and now the modulation effect is being considered. Note in Fig. 12, the absence of the carrier frequency in the output signal. This is removed by a choke and by-pass in the detector plate circuit.

Consider (as shown in Fig. 12) a carrier of 10 volts modulated 50%. The modulated signal E *carrier* at the input varies from 5 to 15 volts. The curve shows that the rectified output

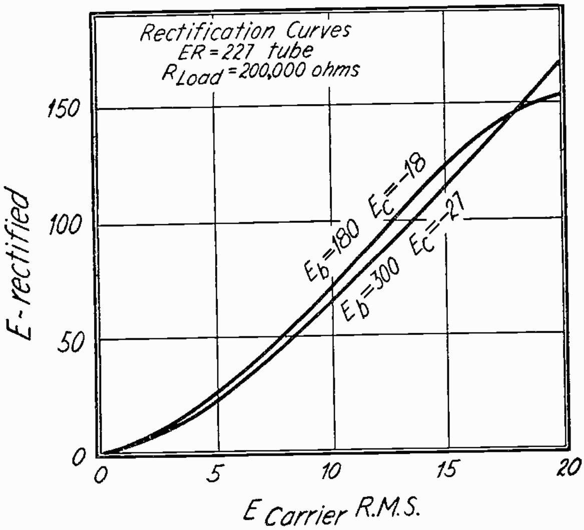

Fig. 11—Voltage measured across load resistance of detector as various carrier voltages are applied.

voltage varies from 35 to 125 volts—a difference of 90 volts. This may be considered as a fixed voltage (D.C.) of 80 volts plus an A.C. voltage whose peak value is 45 volts. The audio signal has a peak value of 45 volts or, in general, half the total swing. It should be clear that the greater the percentage of modulation, the greater will be the A.F. signal.

Going back to the actual E *carrier*. E *rectified* curves given in Fig. 11, we can see that for a carrier of 10 volts modulated 50%, the output signal will be a true reproduction of the input modulation. This is true because the action takes place over the straight portion of the curve. As we increase the percentage of modulation, the low bias-low plate voltage curve will not allow the signal to swing over the straight portion of the curve due to the bends at the lower and upper ends of the curve. Thus the output is distorted. However, when power detectors are used (high bias-high plate voltage detectors), a straighter (linear) detector curve is obtained and the high percentage modulated signal may be received with increased output and less distortion.

The analysis given in this section shows that for signals of normal intensity and with low percentage of modulation. the

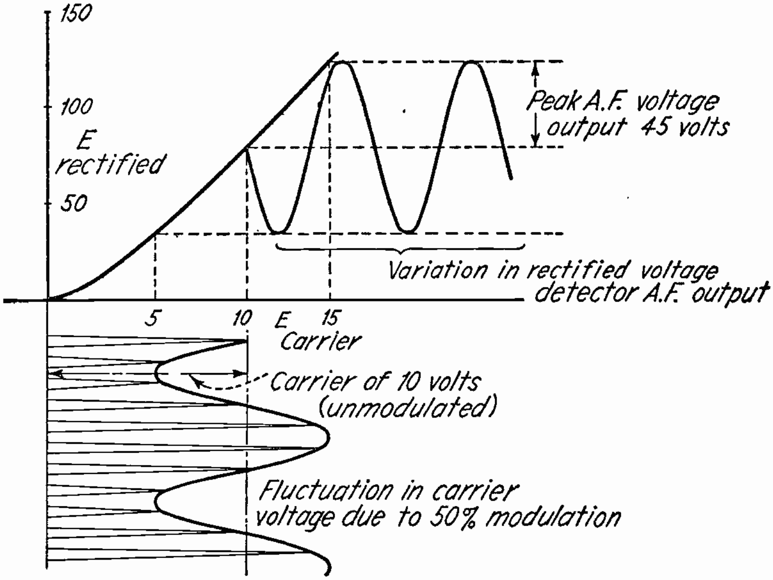

Fig. 12—How modulation of a carrier applied to a linear detector produce modulating frequency currents in the output.
NOTE.—Only half of the input modulated carrier is shown here to simplify the drawing.

average C bias detector will be satisfactory. But in modern broadcasting, a power detector is needed if 100% modulated, high intensity signals are to be demodulated.

AUTOMATIC BIAS

In modern A.C. operated receivers all biases for the various tubes are created by running the plate currents through resistors. These resistors are connected between the grid of the tube to be biased and the source of the electrons, either a filament or a cathode. Such a bias can be, and usually is, used for the detector as well as for the radio and audio amplifier tubes. In this case the rectified plate current of the tube is used to flow through a resistor, by-passed for A.C. currents, placed in the cathode and the voltage drop along this resistor is applied to the grid as a negative bias. (See Fig. 13.)

In this type of detector it is more difficult to analyze what is happening and how much because very little current flows in the plate circuit until some carrier signal is applied and when little plate current flows there is little bias. When the incoming signal causes the plate current to increase, the grid bias increases which in turn tends to keep the plate current down to a satisfactory value.

By experiment, however, a series of curves can be drawn which will explain the action of this type of detector.* In Fig. 14

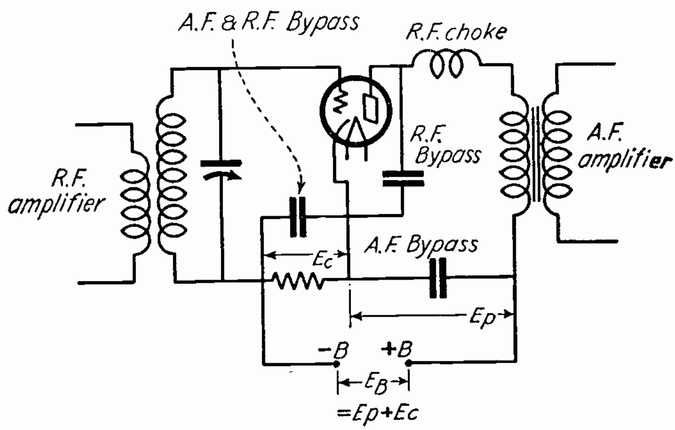

Fig. 13—Typical circuit diagram of an automatic or self-biased detector.

will be found some curves giving the result of such an experiment. They are exactly similar to those shown in Fig. 10 and the process of calculating how much audio output will be secured from a given carrier modulated to a given degree is exactly similar to the procedure just considered in detail.

In Fig. 13 note that the voltage required from the plate battery, or the power supply system, is the sum of the voltages required for the plate and for the grid bias. For example, if the plate should have 180 volts and the grid 27, the total voltage that must be supplied will be the sum of 207 volts assuming there is no loss in voltage (D.C.) across the load which may be a transformer primary with negligible D.C. resistance. This is because plate voltages are measured between cathode and the

*The action of any detector, whether grid leak and condenseer, screen grid, or two tubes in a full wave connection, may be analyzed in this way.

plate and grid voltages between grid and cathode (there will be no D.C. resistance in the input tuning coil to the detector and hence no voltage drop along it). This does not differ at all from the case of a battery operated '71A type tube where 180 volts are required from one battery—the B battery—for the plate circuit and 40.5 volts for the grid which comes from another battery—the C battery. The sum of the voltages required is 180 plus 40.5 or 220.5 volts.

In A.C. receivers the entire plate current of the tube flows through the C bias resistor to form the complete plate circuit.

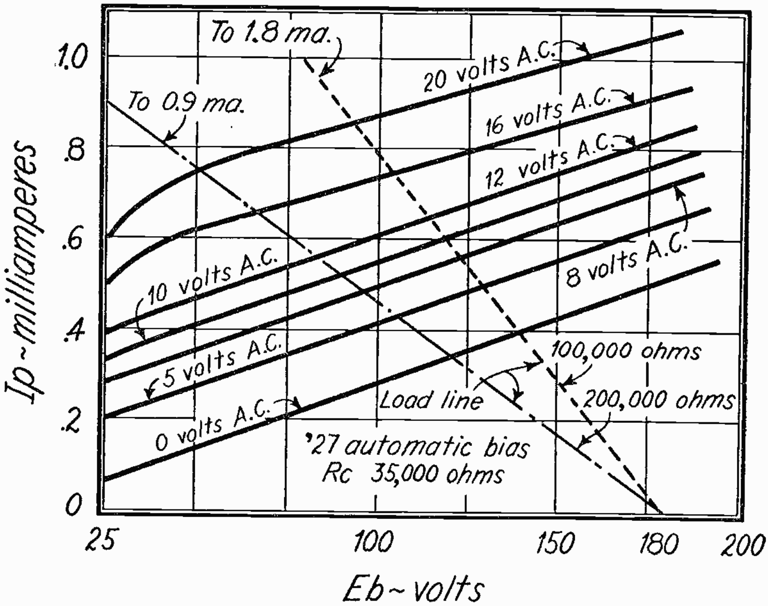

Fig. 14—Characteristics of a typical automatic bias detector of the '27 type.

The drop in voltage along this resistance is used to supply bias to the grid and must be made up by the plate voltage supply system.

A common value for the C bias resistor for a '27 power detector is about 35,000 ohms.

Such an overbiased tube has a high plate resistance and hence to get effective use of the audio voltages produced by detection, rather high load resistances or impedances must be used. The resistance, or impedance should be high to the lowest frequency to be received, say 50 cycles. The higher it is the greater percentage of the total audio volts produced will be use-fully applied to the amplifier. On the other hand if the resistance is too high, stray capacities across it will so reduce its impedance at high audio frequencies that the high frequencies will be lost. These stray capacities are made up of not only the wiring and the socket attached to the tube but the plate-filament capacity of the tube itself. With modern '27 type tubes 200,000 ohms is a reasonable plate circuit load.

If a transformer is used to couple the detector to the following audio amplifier it must be so adjusted in turns ratio that at the lowest reproduced frequency the input impedance is about 200,000 ohms. The transformer is so designed as to avoid capacity between turns, between leads, etc., otherwise the high frequencies will be lost.

Power detection is employed in all modern radio receivers built since the advent of screen grid tubes to prevent overload distortion when high percentage modulated signals are fed to the detector. It is a better system than the old "weak signal" detection using grid leak and condenser. It gives less distortion, is quieter, saves money because the high output level makes a very simple audio amplifier possible. And because more tubes can be used ahead of the detector (and hence fewer after it) considerably greater selectivity is possible (the more tubes amplifying at radio frequencies the greater the selectivity).

GRID LEAK AND CONDENSER DETECTION

Many sets in existence use grid leak and condenser detectors. They are usually followed by a two-stage audio amplifier and input to such detectors is of the order of one volt or less. Power detectors must have R.F. inputs of the order of one volt up to ten or twenty volts. The A.F. output of the grid condenser and leak type detector is about one-half volt when a weak signal is fed to it while that of the power detectors just described may be as high as 50 volts only when large R.F. signals are fed to the input. "C" bias detectors may have negligible output if the signals usually fed to the grid leak-condenser detectors were applied.

Bias detectors detect because there is some part of the plate current-grid voltage curve which is not straight, or they detect because they are so overbiased that they draw very little plate current at all on the negative half cycles of carrier voltage and draw a lot of current on the positive half cycles. *They detect*

upon a plate current-grid voltage tube characteristic. On the
7 *other hand a grid leak type of detector detects on a grid current-grid voltage tube characteristic.* In the grid leak type detector, detection takes place in the grid circuit and the resulting audio voltages are then amplified by the detector tube which acts also

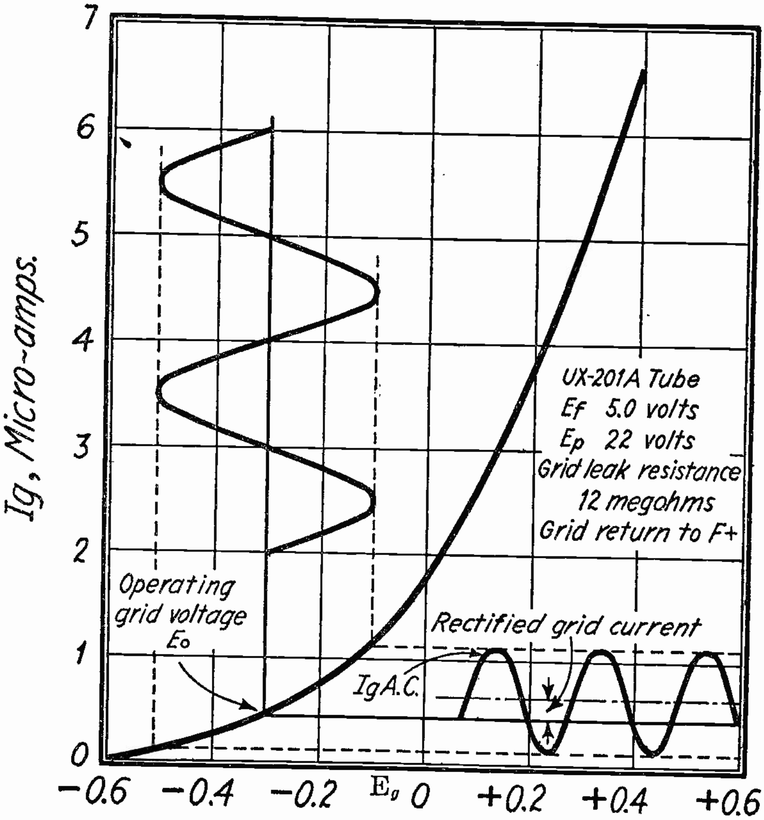

Fig. 15—Grid current-grid voltage characteristic of a tube showing how detection takes place in grid circuit.

as an audio amplifier. For this reason a given carrier voltage
8 will deliver more audio voltage out of a grid leak detector than will a C bias detector, if it is operated below the blocking point.

In a grid leak detector the process can be thought of as a detector—audio amplifier combination; in power detection where demodulation takes place in the plate circuit the process is a radio frequency amplifier-detector combination. In this case, however, there is very little amplification because the radio frequencies are by-passed out of the plate circuit load. Therefore the load impedance to radio frequency is very low and very low voltage at R.F. will be built up and hence the amplification at R.F. will be low.

In Fig. 15 is a typical E_g-I_g curve. It is a curved characteristic and is suitable for detection. The proper place upon this curve to secure maximum detection is fixed by the grid voltage. This grid voltage is determined by the voltage drop along the grid leak created by the rectified grid current flowing through it. For example, if 0.15 microampere of rectified grid current flows through a two megohm grid leak, as in Fig. 16, the grid will be 0.3 volt more negative than the end of the grid leak attached to the —B supply.

The purpose of the grid leak is to determine the grid voltage. Doubling the size of the grid leak increases to some extent the negative bias on the grid and for each tube and set of conditions there is a value of grid leak to give maximum detector action and hence maximum sensitivity.

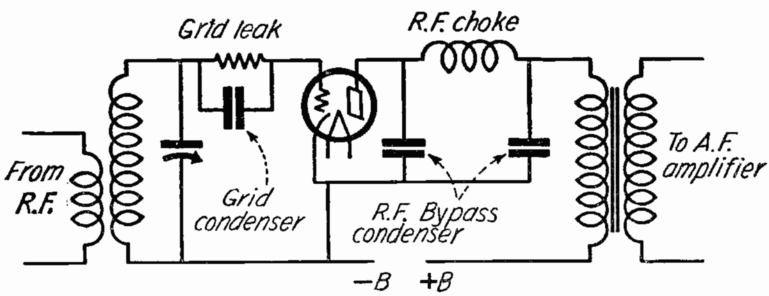

Fig. 16—Grid leak and condenser detector, which also acts as an audio amplifier.

Now if we impressed the carrier voltage on such a grid circuit there would be a very great loss in R.F. voltage across this leak resistance and hence very little of the carrier voltage would be applied to the grid-cathode circuit of the tube. This must be avoided and so we by-pass the grid leak with a condenser to by-pass the R.F. voltages and prevent loss in the R.F. input voltage. This is the purpose of the grid condenser.

The process of detection in such a detector differs but little from that occurring in a C bias detector. A carrier voltage is impressed on the curved characteristic of the grid circuit. Because of this curve the positive half cycles produce more change in grid current from its no-signal value than do the negative half cycles. Hence the average value of the grid current changes when the carrier is applied. If this grid current changes, flowing through the grid leak resistance a change in grid voltage results. This change in grid voltage produces a corresponding change in plate current.

Therefore these carrier voltage changes are changed into grid voltage variations and after amplification in the tube appear in the plate circuit as plate voltage variations (A.C. voltages). These variations occurring at the frequency of the modulating voltage at the transmitting station may be applied to the audio amplifier. Again a by-pass condenser is put across the audio amplifier to keep the R.F. voltage variations from loading it up with useless voltages.

It has been found that with average triode tubes the best value of grid leak is about two megohms and the best value of grid condenser is about 0.00025 mfd. These values have considerable effect upon the response of the detector to various audio frequency modulations. If the grid condenser is large it will by-pass some of the audio modulations and prevent them from being impressed upon the tube input. If the resistance is too high the higher audio frequencies will be partially lost because at such frequencies the relative impedance of the grid condenser, whatever its capacity value, becomes less in comparison with the leak resistance. If a very low value of resistance can be used, say 100,000 ohms, practically all frequencies will be detected equally, but such a low resistance will result in a low degree of sensitivity and selectivity.

The leak resistance can either be connected across the grid condenser or directly across the grid-filament path (as in Fig. 17 a and b, it doesn't matter as far as the detection action is concerned. But there are some circuits in which the bottom part of the input tuning coil of the detector needs to be connected to a high (D.C.) potential part of the circuit. If this voltage were applied to the grid it would ruin the detection action. Hence the condenser is used to keep this voltage off the grid as well as to by-pass the grid leak for R.F. voltages.

A grid leak and condenser detector tunes broader than a C bias detector circuit. The reason is as follows. Grid current flows in such a detector; it is because this current flows and is not directly proportional to voltage (i. e., has a *curved* characteristic) that detection takes place. If current flows there must be some definite resistance to the grid filament path which is the input to the tube. This is connected directly across the tuning circuit. Across this parallel circuit is the grid leak, also of definite resistance. Now the total resistance of two resistances connected in parallel is less than either of them alone. Hence the total resistance shunted across the tuned circuit is lower than that of either the tube input or the grid leak. It is of the order of one-half megohm or less.

On the other hand a highly selective tuned circuit must have a high impedance. Any resistances shunted across it decreases its selectivity, just as adding any resistance in series with it decreases selectivity. At the same time the voltage gain in the tuned circuit goes down. Hence no matter how good a tuning coil and variable condenser we use, bridged across it is this half-megohm which decreases its selectivity.

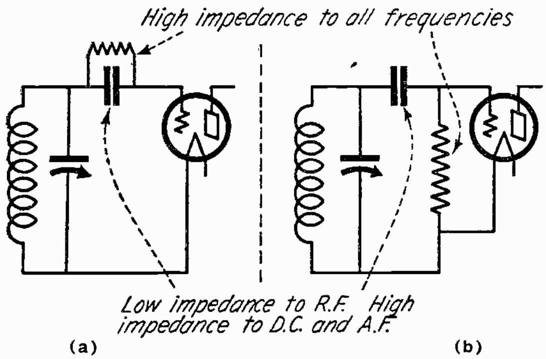

Fig. 17—Two methods of connecting the grid leak in a detector circuit.

Now consider a C bias detector. It operates with such a high bias, that practically no grid current flows. Hence the input resistance of the tubes is very high indeed, perhaps a hundred megohms. And there is no grid leak across the tuned circuit. Hence the selectivity and voltage gain of that circuit are as high as a low-loss coil and condenser will permit.

OSCILLATING DETECTOR

In all the cases of detection discussed so far we have had to deal with a high frequency current or voltage varying in peak value in accordance with modulation. This varying amplitude creates a change in the average value of the detector plate current in accordance with these modulations and this change in average plate current will affect a sensitive meter needle, if the modulations are very slow, or will build up a voltage across any impedance in the plate circuit and hence can be applied to an amplifier or can be heard by listening in with a pair of headphones.

Suppose, however, the amplitude of the incoming signals does not vary, or at most, varies in an abrupt fashion caused by the code transmitting operator keying his transmitter. Now the carrier stops and starts completely. This will cause an abrupt change in average value of plate current, and listening-in with a pair of headphones will disclose some severe clicks when this current change takes place. But between the time the key closes and the time it opens nothing will be heard in the phones. During this period the plate current is steady, at a greater value than when no carrier is coming in, but still not varying.

An operator could probably read these clicks as dots and dashes but it would be difficult. A better way would be to operate a sounder from them.

Suppose, however, the transmitting station were modulated at, let us say 1000 cycles. Now each time the key is closed the receiver operator would hear a dash or dot composed of this 1000-cycle signal. It would be easy to read. Such modulation is expensive. It requires considerable power to modulate a carrier. It is much simpler to furnish the modulations at the receiving station.

Suppose at the receiver we have an oscillator, generating a frequency nearly equal to that of this distant station. Let us put both of these signals into our detector. Sometimes these two signals will be in phase and will add together to produce a greater change in average plate current; sometimes they will be out of phase and will produce a smaller change in plate current. If the two carriers, one from the distant station, and one generated locally in an oscillator, differ in frequency by 1000 cycles, these increases and decreases of average plate current will take place 1000 times a second and the receiving operator would hear a 1000-cycle note.

This is the method of receiving an unmodulated carrier wave signal known as a "C.W." signal or continuous wave. It is called the *heterodyne* method. The two frequencies are said to beat with each other in exactly the same manner that two violin strings slightly different in pitch produce an audible beat or difference of tone when bowed. In this case, however, the ear can hear all three tones, those due to the individual strings and the third due to the difference between the two frequencies. In the C.W. case both the carriers are inaudible, because they are so high in frequency, and the method becomes one of making an inaudible signal audible by adding to it a locally generated signal, also inaudible.

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The superheterodyne operates according to this principle. The incoming modulated carrier frequency is combined with an unmodulated local oscillator frequency; this produces a beat frequency or an intermediate frequency of a predetermined number of kilocycles.

This beat frequency or intermediate frequency retains the modulations of the incoming carrier frequency, therefore it becomes the new carrier of the incoming modulations, and after amplification this intermediate frequency is impressed upon a detector which precedes the audio frequency amplifier.

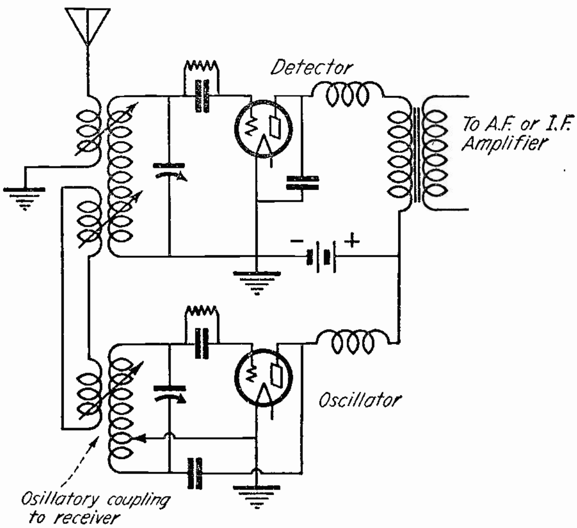

Fig. 18—A heterodyne detector. If the beat frequency is audible this circuit can be either a short or a long wave receiver. If inaudible it may be amplified again and detected to make it audible.

The strength of the signal created by this method depends upon the strength of both the incoming carrier and the local carrier. As a matter of fact, it is proportional to the sum of the two carrier intensities, and hence it is advisable to make the local oscillator capable of producing an output equal to the incoming carrier. Up to this point the stronger the local carrier the louder the resulting signal.

In Fig. 18 is shown a simple circuit of a short wave receiver. The C.W. signals are produced by the distant station;

the local carrier is produced in the oscillator which is merely a vacuum tube used in a special circuit, that is coupled to the input of the receiver so as to produce high-frequency alternating current. As a matter of fact, a neighboring receiver not coupled to the local receiver but which oscillates and thereby sets up in the ether a carrier wave can act in the manner of heterodyne reception. It is this process which causes an oscillating receiver to fill all other receivers in the neighborhood with squeals and howls. Here the beat frequency is produced by the oscillating receiver and the distant carrier differing slightly in frequency. The antenna system picks up both signals, and a beat results which is audible in the speaker as an annoying squeal.

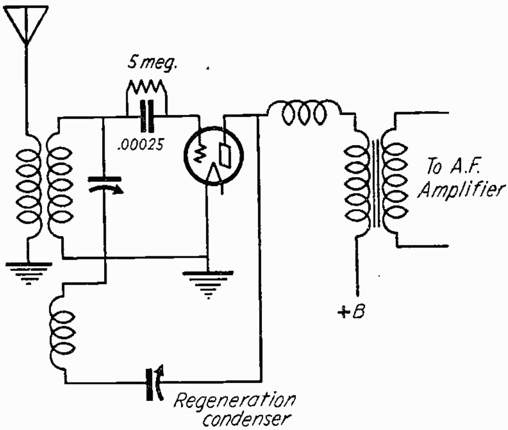

Fig. 19—An autodyne in which the beat frequency is produced in the detector itself.

In Fig. 19 is shown what is called an *autodyne* type of receiving circuit. Here the detector is tuned to the incoming signal, is permitted to oscillate and generate its own frequency. If it is exactly tuned to the incoming signal nothing will be heard in the headphones because no beat frequency is produced. But if it is slightly detuned, its frequency will differ from the distant station, and the operator will begin to hear the beat note which is numerically equal to the difference in frequency of the two carriers. Now when the distant operator keys his transmitter, the beat note comes and goes through the headphones and the operator can read the long and short periods of the beat notes as dots and dashes. The autodyne method of reception is a heterodyne in which local oscillations are produced in the detector itself. An additional tube used as an oscillator and a special circuit are not necessary with the autodyne receiver.

The autodyne method has this fault; because the detector is detuned from the incoming signals it does not have as great a voltage set up in it as it would if it were exactly tuned. Hence the average value of the plate current does not go through such wide variations and hence the headphones do not give off such a loud signal.

TEST QUESTIONS

Be sure to number your Answer Sheet 17 FR-1.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and the best possible lesson service.

1. What is the function of the detector in a receiving set?
2. On what part of a vacuum tube's E_g-I_p characteristic curve does the best detection take place?
3. Why is a square law detector not as good as a linear detector?
4. A modulating voltage as A in Fig. 1b is 20 volts peak and it is impressed on a 40 volt peak unmodulated carrier as B in Fig. 1b. What is the percentage of modulation?
5. What type of "C" bias detection would you expect to find in a modern receiver designed for high percentage modulated signals?
6. Draw a circuit diagram showing the connections of an automatic bias detector.
7. On what tube characteristic does the "C" bias detector detect?
8. What type of detector acts as an audio frequency amplifier in addition to its action as a detector?
9. In the grid leak-condenser type of detector what is the purpose of the grid condenser?
10. What method of detection would you use to make unmodulated carrier waves audible?

10 CIRCUIT DIAGRAMS EACH WITH TESTING INFORMATION

17 SS

SERVICE MANUAL

PIONEER HOME STUDY RADIO SCHOOL 1914

NRI

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

FOREWORD

This booklet is one of a series of service manuals which contain service sheets giving typical information on radio receivers. Each service sheet shows the circuit diagram in the usual symbolic form for that radio receiver. Many of the service sheets will contain such special service information as space will permit.

By studying each service sheet, you will gradually develop the ability to read any diagram or manufacturer's service manual and learn the usual methods of set adjustment. Enough typical receivers have been selected to give you quickly a good insight to the entire radio problem.

In reading a circuit diagram, learn to trace independently the power supply and the signal circuits. Then locate the special control circuits, such as the automatic volume controls, tuning indicators, manual volume controls, etc. Detailed information on power, supply, signal and control circuits, as well as set servicing, is given in the course, to which reference should be made.

J. E. SMITH.

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Service Sheet

Compiled Solely for Students and Graduates

NATIONAL RADIO INSTITUTE, WASHINGTON, D.C.

CROSS-INDEX
to
RCA Victor, General Electric, Westinghouse and Graybar Chassis
with corresponding RCA Victor of Canada, Canadian General
Electric Co., and Canadian Westinghouse Similar Chassis

RCA VICTOR	G. E.	West.	Graybar	RCA Victor Can.	C.G.E.	C. W. Co.
AVR-1,140,141,240	-	-	-	-	-	-
SW-2	JZ-30	-	-	SWA-102	JZ-30	-
R-4,R-6	J-70	WR-17	GT-7	-	-	-
R-5	T-12	WR-14	GB-4	-	-	-
R-5-D.C.	T-12-D	-	-	-	-	-
R-5-X	T-12-E	WR-14-CR	-	-	-	-
T-5	E-52	WR-9	-	-	-	-
R-6,R-4	J-75	-	GC-13	-	-	-
R-7	S-22,S-22X	WR-10	GB-8	R7,R78	S22,S22X	W801
R-7A	S-22 (2)	WR-10-A	GB-8-A	R7A,R8A,R9A,R104,R105	H77,S42A	W801
R-8,R12	J-80	WR-18	GT-8	R8,R10,R12	S-42	-
R-9	S-42	WR-12	-	-	-	W801
R-10	S-132	WR-15-A	GB-989	R10,R8,R12,R107	J85	-
R-11	K-62,K-82	WR-15	GB-9	R15	K62	-
R-12,R8	J-85	-	GC-14	R12,R8,R10	J85	-
RAD.16	-	-	GB-300	-	-	W16
RE-16	SZ-42-P	WR-13	-	RE37	H77	-
RE-16-A	-	WR-13-A	-	-	-	-
RAD.17	-	-	-	-	-	6AC-27/28
R-17-M	BX,K-41	WR-26-M	-	-	-	-
RE-18,RE-18A	KZ-62-P	-	-	RE41	-	-
R-18-W	K-40-A	-	-	-	-	-
RAD.18	-	-	GB-310	-	-	6AC-28/29
RAD.20	-	-	-	-	-	W55
RAD.21	B-1	-	-	-	-	-
RAD.22	B-2	-	-	-	-	-
R-21,R-22	-	-	-	R20R,R20,R109	-	-
R-22-S	L-50	-	-	-	-	-
R-22-W	L-51	-	-	-	-	-
RO-23	JZ-835	WR-16	-	RO112	-	W112
R-24	JZ-822,JZ826	-	-	-	-	-
R-24-A (47)	JZ-822-A	WR-24	-	-	-	-
R-24-A (2A5)	-	WR-24	-	-	-	-
R-27	K-40	WR-26	-	-	-	-
R-28	K-50	-	-	R28	K50	W53
R-28-P	K-50-P	-	-	R29,R31	K52,K53	W53
R-28-P (AtoG)	K-51-P	WR-27	-	-	-	W53
M-30	A-90	-	-	-	-	-
P-31	A-81	-	-	-	-	-
M-32	A-60	-	-	-	-	-
RAD.33	-	-	GB-311	-	-	6AC-28/29
M-34	B-40	WR-33	-	M-34	B-40	A-43
R-37	K-60	-	-	R-37	K-60	-
R-37-P,R-38-P	K-60-P	WR-28	-	-	-	-
R-38	K-65	-	-	-	-	-
R-38-P,R-37-P	K-65-P	-	-	-	-	-
RE-40	K-54	-	-	-	-	-
RE-40-P	K-54-P	WR-29	-	RE33	-	-
RAD.42	-	-	-	-	-	W61,W81,W71
R-43	S-42-B	-	-	R30	S42B	-
RAD.44,46	-	-	GB-500	-	-	-
RAD.46,44	-	-	GB-550	-	-	-
RAD.48	T-41	WR-4	GB-678	R15,RAD.48	T41	W71,W81,W61
R-50,R-55	H32	-	-	R20,R21	H32	-
RAD.51	-	-	GB-320	-	-	-
R51B,R53B	-	-	-	-	-	B103
R-55,R-50	H32	-	GB100	R20,R21	-	-
RAE-59	H72	-	-	RAE59	H72	-
RAD.60	-	-	GB-330	-	-	-
RAD.62	-	-	GB-340	-	-	-
RAD.66	-	-	GB-600	-	-	W89
R-70 & R-70-N	J-72	WR-21	-	R48	J72,J76	-
R-71,R-72	J-82,J-88	WR-19	-	R-50	J-82	W82

RCA Victor	G. E.	West.	Graybar	RCA Victor Can.	C. G. E.	C. W. Co.
R-71-B	-	B-83	-	R-6,R-67,R-68	JB83,JB87	B83
R-72,R-71	J-86	-	-	R52	J86	W82
R-73 (47)	J-83	WR-22	-	R-53	-	-
R-73 (2A5)	J-83-A	-	-		-	-
R-74,R-76,R-77	J-100,J-109	WR-20	-	R54,R56	J105	-
R-75 (47)	J-87	-	-	-	-	-
R-75 (2A5)	J-87-A	-	-	-	-	-
R-76,R-74,R-77	J-105	-	-	R56,R54	J105	-
R-77,R-74,R-76	J-107	-	-	-	J107	-
R-78	J-125	-	-	R22	J125	W122
R-78 (2)	J-125-A	-	-	R22A	J125A	W122A
RE-80	-	WR-23	-	RE80	-	-
RAD.80	H31	WR-5	GB-700	R-35,RAD.80	H-31	W101
RE-80-S	-	WR-25	-	-	-	-
RAD.82 & 82R	H51,H51R H91,H91R	WR6,WR6R WR8,WR8R	GB-770	R-39,RAD.82	H51	-
RAD.86 & 86R	H-71 & 71R	7R,WR7	GB-900	RE57,RAD.86	H71	-
RAE 84	-	-	-	RAE 84	-	-
RE-81	-	-	-	RE-81	-	-
R-90	K-106	-	-	90	K106	W103
R-90-P	K-106-P	-	-	-	-	W104
91-B	C-30	-	-	-	-	-
100,101	K-43	WR-32	-	-	-	W44
101,100	M-41	-	-	101	M41,M42	W44
102	M-40	-	-	-	-	-
M-105	C-41	WR-41	-	M105	C41	A44
M-107	C-60	-	-	-	-	-
110,111,115	K-52	-	-	-	K52	A53
111,110,115	K-53	WR-35	-	R31	K53,K59	-
112	L-52	WR-34	-	-	-	-
114	L-53	-	-	-	-	-
115,110,111	K-53-M	-	-	-	-	W53
M-116	B-52	WR-42	-	M-116	B52	-
118	M-51	WR-48	-	118	M51,M52	W254,W155
120	K-63	WR-36	-	-	K57	W53
121,122	K-64	WR-37	-	-	K64	W64
122,121	-	-	-	122	M69,M62	W634
M-123	C61	-	-	M-123	C61	-
124	M-63	-	-	-	-	-
126-B	C-62	-	-	126-B,223B	L6B,L6CB	B64
127	K-64-D	-	-	-	-	-
128	M-61	WR-46	-	128	M61	W165A
128-E	-	WR-50	-	-	-	-
135-B	C-70	WR-47	-	135-B	M7B	-
140,140E,141, 141E,240,AVR1	K-80	WR-30	-	140	K80,K85	W83AW
141,141E	K-80-X	WR-31	-	-	-	W83AW
142-B,241-B	B-81	-	-	R87	K8B	-
143	M-81	WR-45	-	143	M81	W84,W185X
210	K-55	-	-	-	-	-
211	M-56	-	-	211	M56	W254,W155
220,222	K-66	-	-	-	-	-
221	M-65	-	-	122,221	-	-
222,220	K-66-M	-	-	222	-	-
223	C-67	-	-	223-B,126B	L6CB	B634
224	M-67	-	-	224	M67	W165X
235-B	C-75	-	-	235-B	M7CB	B74,W185X
240,141,141E AVR-1,140	K-85	-	-	-	-	-
241-B,142-B	B-86	-	-	R88	K8CB	-
242	M-86	-	-	242	M86	W84
260	K-107	-	-	-	-	-
261	K-105	-	-	-	-	-
262	M-106	-	-	262	M106,M107	-
280	K-126	-	-	280	K-126	-
281	M-125	-	-	281	M125	W124
300	K-48	-	-	-	-	-
301	M-49	-	-	-	-	-
310	K-58	-	-	-	-	-
321	M-68	-	-	321	-	-
322	M-69	WR-49	-	-	-	-
330	K-78	-	-	R49	-	W73
331	K-79	-	-	331	K79	-
340	K-88	WR-38	-	340	-	-
340-E	K-88-X	WR-39	-	340-A	-	-
341	M-89	-	-	-	-	-
380	M-128	-	-	-	-	-
380 H.R.	M-128-R	-	-	-	-	-
381	M-129	-	-	381	-	-

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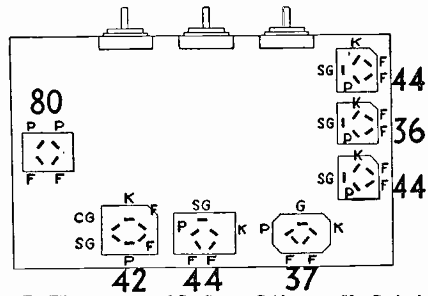
PHILCO MODEL 71 SERIES

The Philco Radio of the 71 series is a seven tube superheterodyne, employing the high efficiency 6.3 volt filament tubes, automatic volume control and pentode output. The chassis is made in two different types, one known as the 121 code, employing a single dynamic speaker, and the other known as the 221 code, employing twin dynamic speakers. These code numbers appear on the radio chassis as a part of the model number. Chassis of one code are not interchangeable with those of another. The intermediate frequency used in adjusting the superheterodyne circuit of the 71 series is 260 kilocycles. The power consumption of the various models is as follows:

Chassis	Volts	Cycles	Watts
71 -121	115	50-60	63
71 -221	115	50-60	80
71A-121	115	25-40	65
71A-221	115	25-40	85
71E-121	230	50-60	63
71E-221	230	50-60	80



F = Filament   SG = Screen Grid   K = Cathode
P = Plate   CG = Control Grid

Fig. 1—Tube Sockets

Table 1—Tube Socket Data*—A.C. Line Voltage 115 Volts

Tube Type	Tube Circuit	Filament Volts—F to F	Plate Volts—P to K	Screen Grid Volts—SG to K	Control Grid Volts—CG to K	Cathode Volts—K to F
44	R. F.	6.3	245	90	4.	20
36	Det. Osc.	6.3	235	90	2.3	20
44	I. F.	6.3	255	90	.2	20
37	Det. Rect.	6.3	0	.	..	15
44	Audio	6.3	50	50	.3	20
42	Output	6.3	250	260	.2	15
80	Rectifier	5.0	365/plate	..	..	..

*All of the above readings were taken from the under side of the chassis, using test prods and leads with a suitable A.C. voltmeter for filament voltages and a high resistance multi-range D.C. voltmeter for all other readings. Volume control at maximum and station selector turned to low frequency end.

Table 2—Power Transformer Data

Terminals	A.C. Volts	Circuit	Color
1–2	105 to 125	Primary	White
3–5	6.3	Filament	Black
6–7	5.0	Filament of 80	Light Blue
8–10	685	Plates of 80	Yellow
4	.....	Center Tap of 3–5	Black Yellow Tracer
9	. . .	Center Tap of 8–10	Yellow Green Tracer

Table 3—Resistor Data

No. on Figs. 4 & 5	Power (Watts)	Resistance (Ohms)	Color Body	Color Tip	Color Dot
52		185 & 245	Round	Tubular	
24	.5	1,000	Brown	Black	Red
57 58	.5	5,000	Green	Black	Red
48	(Twin	Speaker) 5,620	Round	Tubular	
1 54	.5	10,000	Brown	Black	Orange
59	3.	13,000	Brown	Orange	Orange
18	.5	15,000	Brown	Green	Orange
35	.5	25,000	Red	Green	Orange
35	5	(Twin Speaker) 51,000	Green	Brown	Orange
34	.5	70,000	Violet	Black	Orange
27	.5	99,000	White	White	Orange
37	.5	490,000	Yellow	White	Yellow
17 23 33	.5	1,000,000	Brown	Black	Green

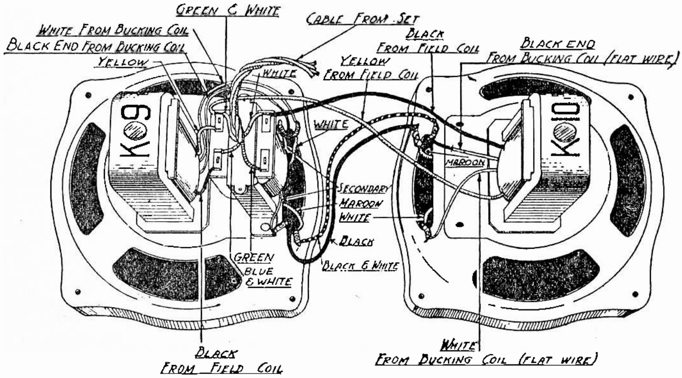


Fig. 2—Twin Speaker Connections—221 Code

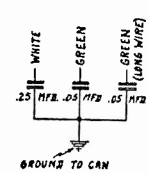
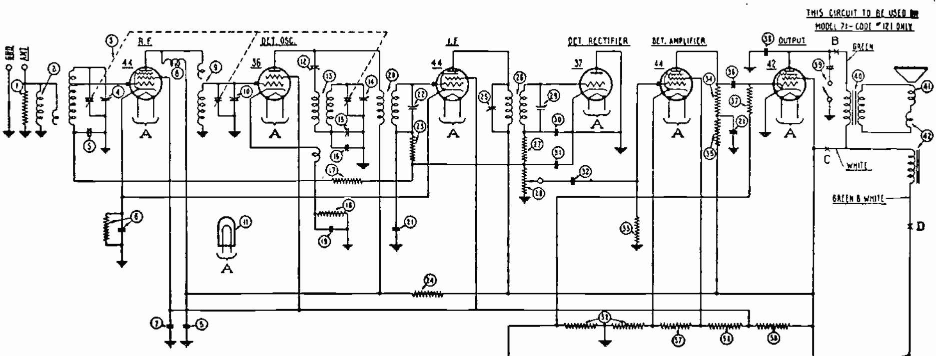
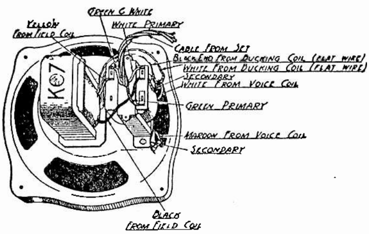


Fig. 3—Internal Connections Filter Condenser





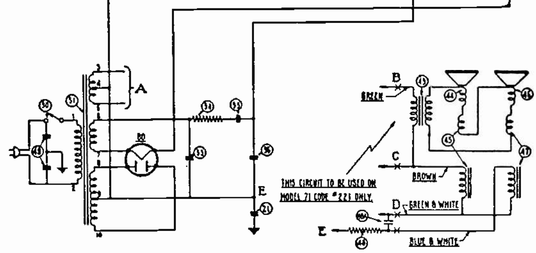


Fig. 6—Speaker Connections—121 Code **Fig. 4—Schematic Wiring Diagram**

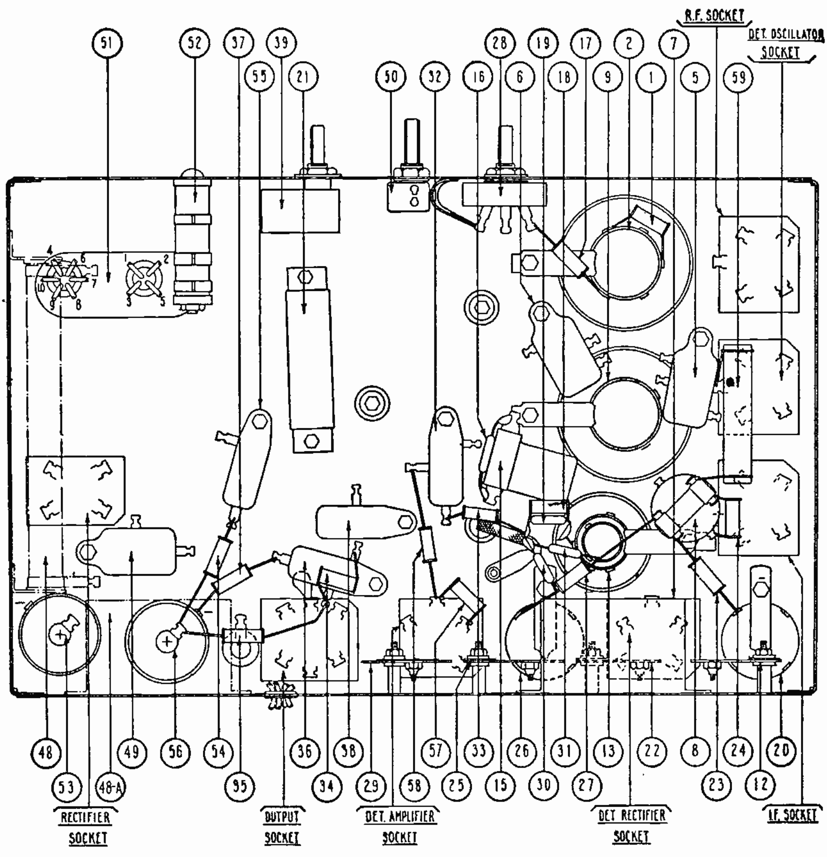


Fig. 5—Parts Diagram

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RCA Victor Radiolette R-5; Graybar Model 4 Graybarette; Westinghouse Model WR-14 and General Electric Model "G. E. T-12"

The RCA Victor Radiolette circuit is used also in the Graybar Model 4 Graybarette, the Westinghouse Model WR-14, and in the General Electric Model G.E. T-12, so that the information in this Service Sheet applies to all four receivers.

The receiver uses four Radiotrons, two UY-224, one UX-280, and one RCA-247 Power Output Pentode. Referring to Figure 1 and tracing a signal through the various stages we find the following action taking place.

The antenna and ground are connected to each side of a 20,000 ohm potentiometer. The moving contact of the potentiometer is connected to the primary of the first R.F. transformer through a .00013 MFD. condenser, the other side of the transformer being connected to ground. The action of the potentiometer, reducing the voltage applied to the grid of the first R.F. tube, constitutes that of a volume control. The secondary of the R.F. transformer is connected to the grid circuit of the R.F. Radiotron UY-224, which is tuned by one unit of the gang condenser. The plate circuit of this tube works into the primary coil of the 2nd R.F. transformer.

The detector is of the regenerative, grid bias type and its output is coupled by means of resistance coupling to the output Radiotron RCA-247. The regenerative feature of the detector is unusual in that it uses two regeneration coils. One of these resonates at a low frequency and improves the sensitivity at that end, while the other has but few turns and brings up the sensitivity at the high frequency end.

The output stage uses the RCA-247 Output Pentode which gives a high undistorted output—2.5 watts—together with a high gain in the stage.

The grid bias for this tube is obtained by using a portion of the drop across the reproducer field. Due to the fact that the plate current of the RCA-247 represents the greatest portion of the total plate current, using the drop across the field acts as a semi-self biasing arrangement.

Plate and grid supply to all tubes is supplied through the use of Radiotron UX-280. The filter is of the "brute force" type. The reproducer unit field coil functions as the reactor. One electrolytic 10 MFD. capacitor and one paper 2 MFD. capacitor act as filter capacitors.

Line-up Capacitor Adjustments

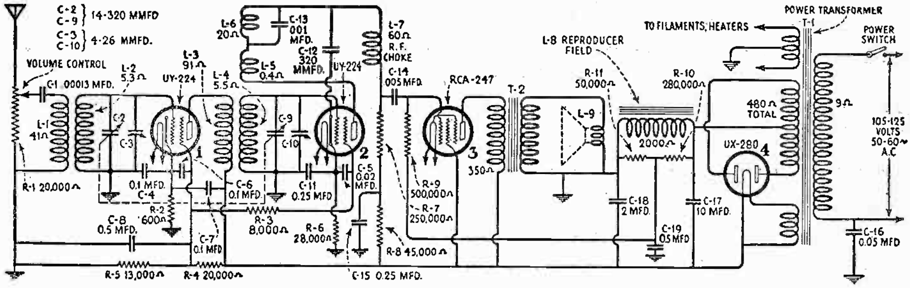
Two adjustable capacitors are provided for aligning the two tune circuits at the high frequency end of the scale. The following procedure may be used for making any readjustments that may be necessary.

A. Procure an oscillator giving a modulated signal at exactly 1400 K.C. Also procure a special socket wrench such as RCA Victor Stock No. 3007.

B. An output indicator is necessary. This may be a current squared thermogalvanometer connected to the secondary of the output transformer in place of the cone coil or other types of output indicators.

C. Turn the station selector until the knob reads exactly 0. Then remove the chassis from the cabinet, being careful not to disturb the setting of the dial. The gang condenser rotor plates should be fully meshed with the stator plates. If not, then the dial drum must be adjusted until such a condition exists. Replace the chassis in the cabinet.

D. Place the oscillator in operation at exactly 1400 K.C. and couple its output to the antenna lead. Set the dial scale at 85 and place the Radiolette in operation. Place a soft pad on the bench and turn the instrument on its side. Now with the special wrench, adjust each line-up capacitor until maximum output is obtained in the output meter. Be careful to adjust the volume control or oscillator output so that an excessive reading is not obtained. Go over each adjustment a second time to compensate for any interlocking of adjustments.



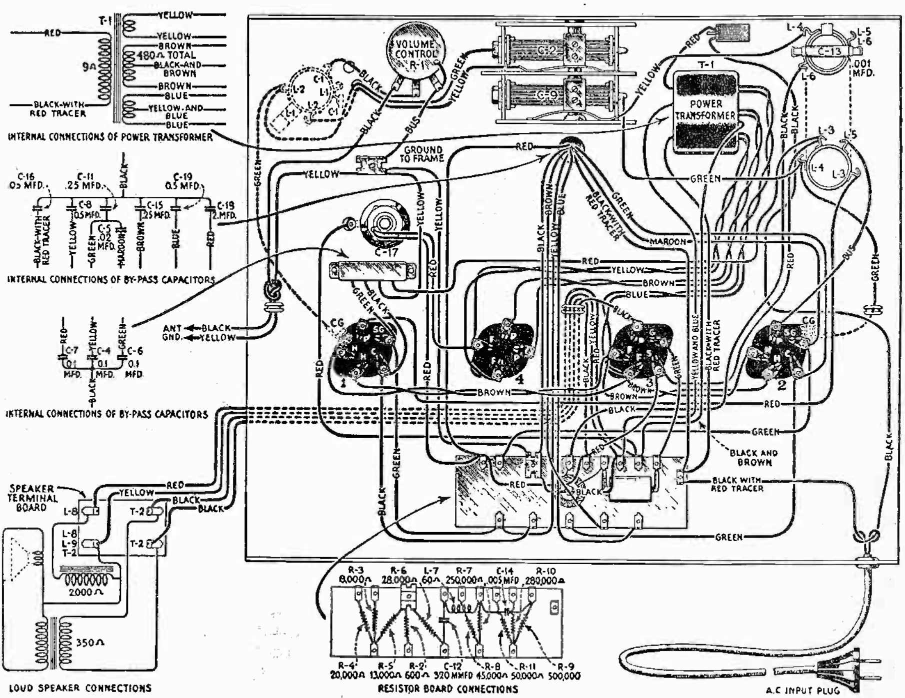
·*Figure 1—Schematic Circuit Diagram of Model R-5*

SOCKET VOLTAGE READINGS

110-VOLT LINE

These are readings obtained with the usual Set Analyzers and are not true readings of the voltages at which the Radiotrons operate.

Radiotron No.	Heater to Cathode Volts	Cathode or Filament to Control Grid Volts	Cathode or Filament to Screen Grid Volts	Cathode or Filament to Plate Volts	Plate Current M. A.	Heater Volts
1	3.0	3.0	85	225	4.0	2.2
2	7.0	7.0	65	100	0.25	2.2
3	——	2.0	225	215	30.0	2.2



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ATWATER KENT MODEL 66 RECEIVER

VOLTAGE READINGS

Use High Resistance D.C. Voltmeter (About 0-50-250-500) to Measure Plate and Grid Voltages. Use A.C. Voltmeter to Measure Filament Voltages.

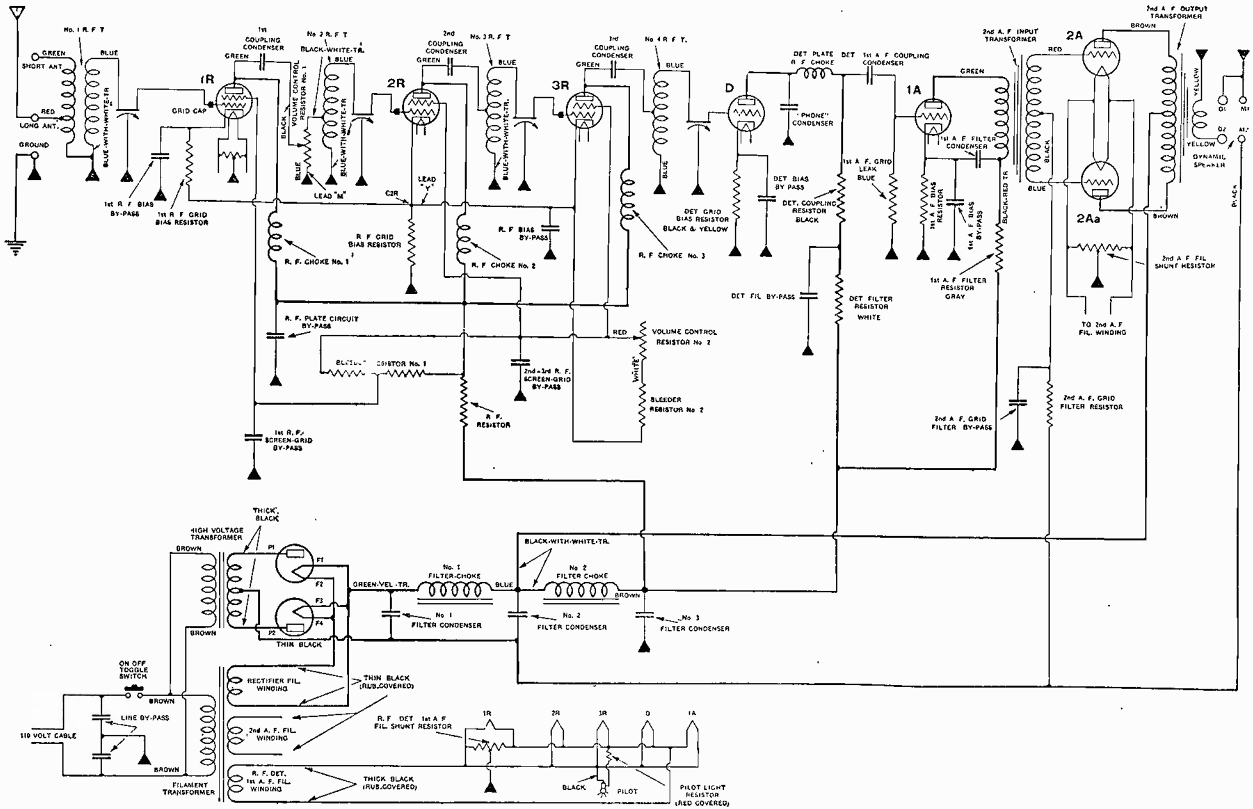
Tests Made With Set in Operation, All Tubes and Speaker-Plug in Sockets. Adjust Volume Control to Maximum. Make Tests in Order Listed.

	MEASURE ACROSS	Approx. Voltage 110 V. Line	120 V. Line	NO READING INDICATES‡
FILAMENT VOLTAGES	—F to +F Contacts on the detector, 1st A.F. and each R.F. Socket.	2.2	2.4	Open filament winding or connection.
	—F to +F on each 2nd A.F. Socket.	6.9	7.5	
	F1 to F2 on Rectifier Tube Socket.	6.9	7.5	
PLATE VOLTAGES	C1R to P1R.	158	173	Open high voltage winding, open filter choke, open R.F. resistor, open R.F.C. No. 1, open R.F. bias resistor or 1st R.F. bias resistor or open speaker field coil.
	C2R to P2R.	160	175	Open R.F.C. No. 2.
	C3R to P3R.	160	175	Open R.F.C. No. 3.
	CD to PD.	206	225	Open detector filter resistor, coupling resistor, R.F. choke, or det. bias resistor.
	C1A to P1A.	137	150	Open 1st A.F. filter resistor, primary of A.F. input transformer, or 1st A.F. bias resistor.
	—F2A to P2A.	412	450	Open primary of output transformer.
	—F2Aa to P2Aa.	412	450	
GRID VOLTAGES	C1R to G1R.	5.5	6	Open secondary No. 1 R.F.T.
	C2R to G2R.	2.8	3	Open secondary No. 2 R.F.T.
	C3R to G3R.	2.8	3	Open secondary No. 3 R.F.T.
	CD to GD.	23	25	Open secondary No. 4 R.F.T.
	C1A to G1A.*	2.8	3	Open 1st A.F. grid leak.
	—F2A to G2A.	78	85	Open secondary of input A.F. transformer, or open 2nd A. F. grid-filter resistor.
	—F2Aa to G2Aa.	78	85	
SCREEN VOLTAGES†	C1R to S1R.	110	120	Open No. 1 bleeder resistor.
	C2R to S2R.	78	85	Open No. 2 volume control.
	C3R to S3R.	78	85	

*This is the measured voltage, not the actual operating voltage.

‡Low plate, grid, or screen voltages may indicate a partially shorted by-pass condenser.

†High screen voltages may indicate an open No. 2 volume control or open No. 1 or 2 bleeder resistor.



Circuit of Model 66.

In some early Model 66, volume control resistor No. 1 is connected across the R.F. choke coil in the plate circuit of the 1st R.F. tube. The slider of this resistor is connected to a tap on No. 2 R.F.T. through a coupling condenser

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PHILCO RECEIVERS, SERIES 86 AND 82

Tube Socket Voltages

Primary Tap Switch Low	High	1st, 2d, 3d R. F. 1st A. F.			Detector		2d A. F.			Rectifier
A C Line Volts		F. V.	P. V.	G. V.	F. V.	P. V.	F. V.	P. V.	G. V.	F. V.
95		1.4	81	5.2	2.1	29	4.3	163	37.6	4.4
110		1.6	93	6.1	2.48	33	5.07	190	45.0	5.1
	110	1.3	79	5.0	2.0	28	4.2	160	36.0	4.3
	120	1.4	85	5.5	2.2	30	4.6	172	41.0	4.6
	135	1.6	94	6.2	2.5	33	5.2	193	46.1	5.3

D. C. Voltage Across Filter Condenser Block

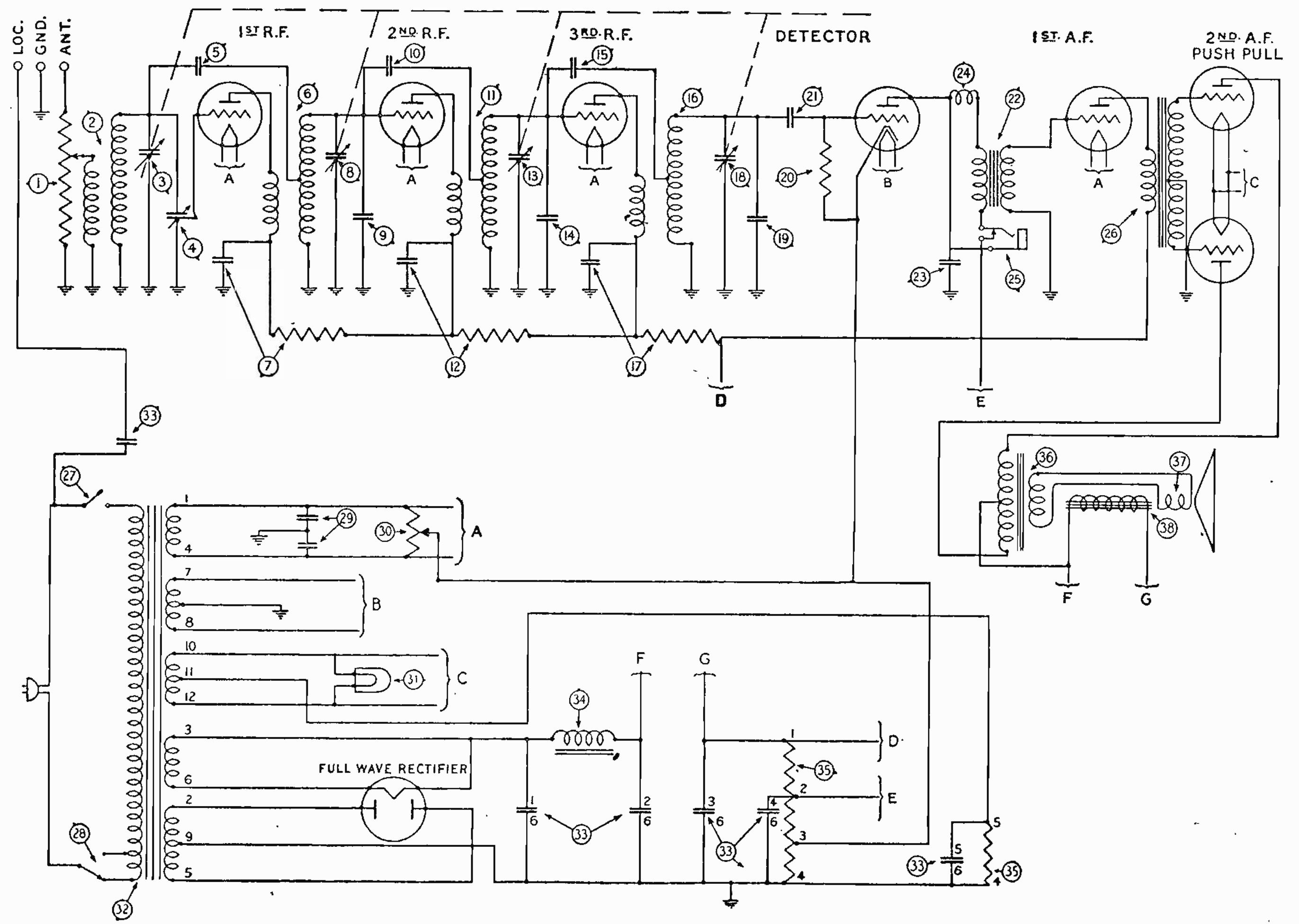
Terminals	D.C. Volts	Capacity	Circuit
1–6	252	2 Mfd.	1. to Rect. Fil. and (34)
2–6	220	4 Mfd.	2. to (34)
3–6	94	2 Mfd.	3. to 1 Terminal of (35)
4–6	40	1 Mfd.	4. to 2 Terminal of (35)
5–6	41	.1 Mfd.	5. to 11 Terminal of (32)
7–8	120 V.–A.C.	.015 Mfd.	6. to Ground
			7. to "LOC" Terminal
			8. to A.C. Cord and (27)

Voltage Across "B-C" Resistor

Terminals	Voltage Drop	Circuit
1–2	54	1 — 26 Tubes Plate Supply
2–3	40	2 — 27 Tube Plate Supply
3–4	5.5	3 — B–, 26, 27 Tubes
5–4	40.0	4 — Ground (Grid Potential)
		5 — B-71A Tubes

Power Transformer Voltages

Terminals	A.C. Volts	Secondary
2–5	560	A.C. supply to plate of Rectifier Tube
9		Center Tap
10–12	4.6	A.C. Filament of 71A Tubes
11		Center Tap
3–6	4.6	A.C. Filament Rectifier Tube
1–4	1.4	A.C. Filament 26 Tubes
7–8	2.2	A.C. Filament 27 Tube



LOC.
GND.
ANT.
1ST R.F.
2ND R.F.
3RD R.F.
DETECTOR
1ST A.F.
2ND A.F.
PUSH PULL
FULL WAVE RECTIFIER

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GRUNOW RADIO Receiver Models 670-671
Chassis Type 6-D

ALIGNMENT

1. Equipment

A—Test Oscillator

A modulated Oscillator capable of producing signals at 455 K. C., 600 K. C., 1400 K. C., 4500 K. C., 12 M. C. and 21 M. C. is necessary for alignment of the Type 6D Chassis.

B—Coupling Means

Coupling Condensers of 200 Mmf., .25 Mfd., and a 400 Ohm resistor should be used when coupling oscillator, to receiver during alignment as specified in following paragraphs.

2. Dial Setting

Turn dial knob until condensers are fully meshed. The dial pointer should be on the horizontal line of the dial.

3. I. F. Alignment

Connect signal lead of test Oscillator to grid of the 6A7 (1st Detector Tube) through .25 Mfd. Condenser.

A—Set Dial Pointer to 1400 K. C. and range switch on position "A." (Broadcast).

B—Place test Oscillator in operation at 455 K. C. Turn receiver volume control and tone control to maximum.

—Attenuate test Oscillator output to lowest value consistent with obtaining a readable indication on output meter.

D—Adjust five I. F. Trimmers, (A1, A2, A3, A4, A5), located on the I. F. transformers on top of the Chassis (2 Trimmers are on top of each transformer and the fifth is at the lower side of the 1st I. F. transformer) (this is the Bi-Selector I. F. stage), until maximum output is obtained. During alignment maintain as low a value of signal as will allow obtaining of accurate adjustment.

4. 4500 K. C. Alignment

A—Connect signal lead of test Oscillator through 200 Mmf. Condenser to Antenna binding post.

B—Connect the test Oscillator ground lead to the ground post of Chassis.

C—Turn Range Switch to range "B" and set Dial Pointer to 4500 K. C.

D—Align the following "B" range trimmers: Oscillator (A6), Detector (A7), Antenna (A8).

5. 1400 K. C. Alignment

A—Place test Oscillator in operation at 1400 K. C.

B—Turn Dial to 1400 K. C.

C—Turn Range Switch to range "A."

D—Adjust the following "A" range trimmers: Oscillator (A9), Detector (A10), Antenna (A11).

6. 600 K. C. Alignment

A—Place test Oscillator in operation at 600 K. C.

B—Tune in signal to maximum (this point does not have to be exactly at 600 K. C. setting).

C—Adjust the 600 K. C. Padding Condenser, (A12), in direction of signal increase. At same time rock the tuning condenser back and forth through resonance while adjusting Padding Condenser until maximum output is obtained.

7. 12 M. C. Alignment

A—Connect signal lead of test Oscillator through 400 ohm resistor to Antenna binding post of Chassis.

D—Set Range Switch to range "C."

E—Adjust the following "C" range trimmers: Oscillator (A13), Detector (A14), Antenna (A15).

F—When adjusting the Detector Trimmer (A14) on the "C" range it is necessary to rock the tuning condenser in a manner similar to that required when setting the 600 K. C. Padding Condenser.

G—When adjusting the Oscillator Trimmer on the "C" range with a 12 M. C. signal it will be noted that there are two settings at which the signal will be received. Use the higher frequency settings, that is, the setting at which the trimmer screw is farthest out. On the "A," "B," and "C" range the Oscillator operates at a higher frequency than the incoming signal, and consequently the trimmer capacity will be lower when adjustment is completed.

8. 21 M. C. Alignment

A—Set Range Switch on range "D."

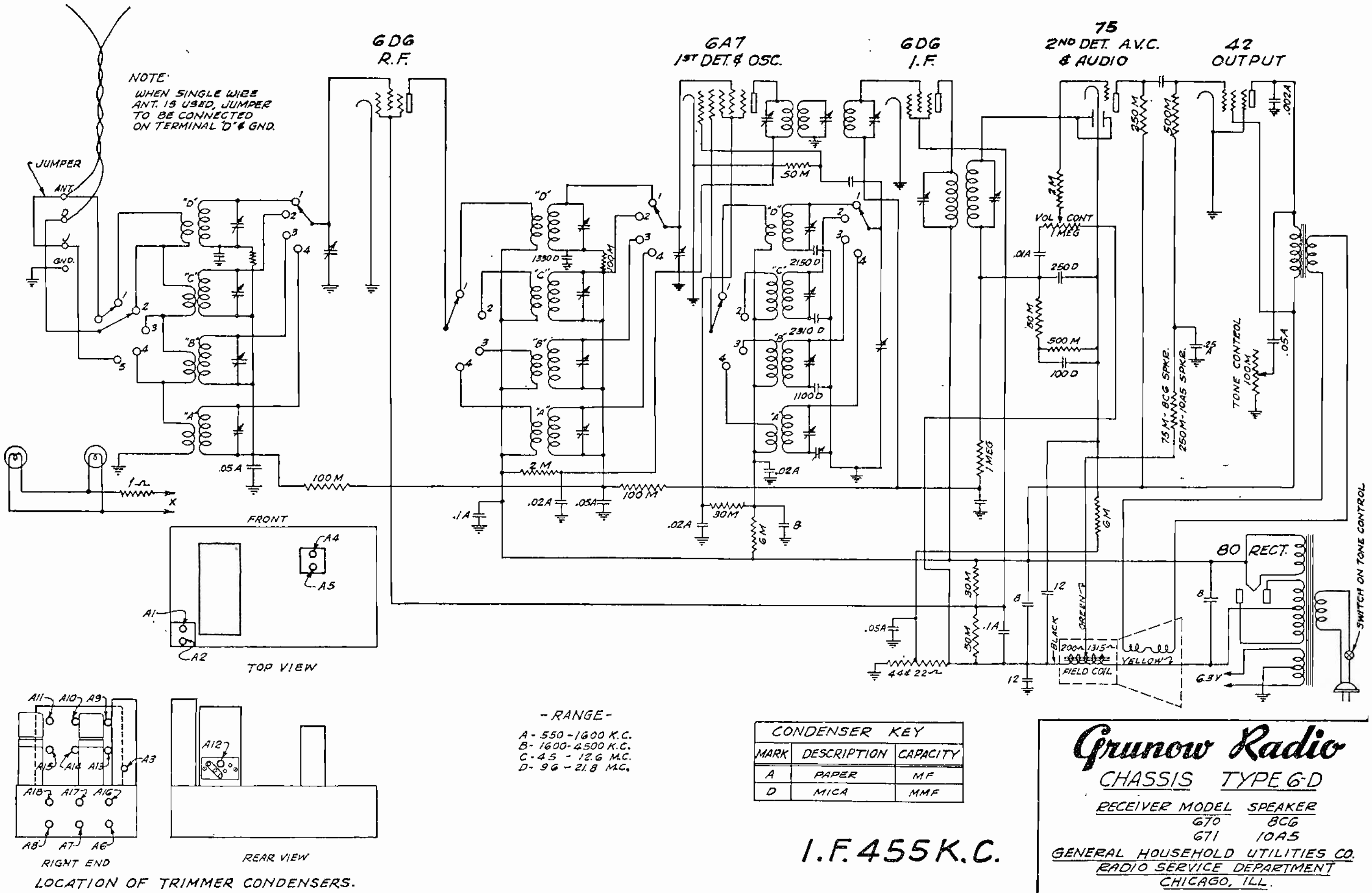
B—Place test Oscillator in operation at 21 M. C.

C—Turn Dial Pointer to 21 M. C.

D—Adjust the following "D" range trimmers: Oscillator (A16), Detector (A17), Antenna (A18).

E—When adjusting the Detector Trimmer (A17) on the "D" range it is necessary to rock the tuning condenser back and forth through resonance in the same manner as required when setting the 600 K. C. Padding Condenser.

F—When adjusting the Oscillator trimmer on the "D" range with a 21 M. C. signal it will be noted that there are two settings at which the signal will be received. Use the lower frequency setting, that is, the setting at which the trimmer screw is farthest in. On the "D" range the Oscillator operates at a lower frequency than the incoming signal, and consequently the trimmer capacity will be higher when adjustment is completed.



CONDENSER KEY		
MARK	DESCRIPTION	CAPACITY
A	PAPER	MF
D	MICA	MMF

I.F. 455 K.C.

Grunow Radio

CHASSIS TYPE 6-D

RECEIVER MODEL	SPEAKER
670	8C6
671	10A5

GENERAL HOUSEHOLD UTILITIES CO.
RADIO SERVICE DEPARTMENT
CHICAGO, ILL.

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VICTOR MODELS R-34, R-35, R-39, RE-57

Voltmeter Continuity Test of Electrola Parts

TEST	TERMINALS	APPROXIMATE Voltage (10 V. Scale)
Electric Pickup	On P. U. Connector Block	9.0 Volts
Record Volume Control	Two Ends	8.6 Volts
Input Transformer	1 and 2	9.0 Volts
	1 and 3	8.5 Volts
	1 and 4	4.4 Volts

Amplifier Terminal Strip
(CAUTION—High Voltage)

TEST ACROSS AMPLIFIER TERMINALS	VOLTAGE SUPPLY	NORMAL VOLTAGE
1 and 2	UY-224 and UY-227 Filament	2.4 Volts A.C.
3 and 7	UY-224 Plate	170 Volts D.C.
3 and 6	UY-227 Plate	65 Volts D.C.
3 and 8	Screen Grid	89 Volts D. C

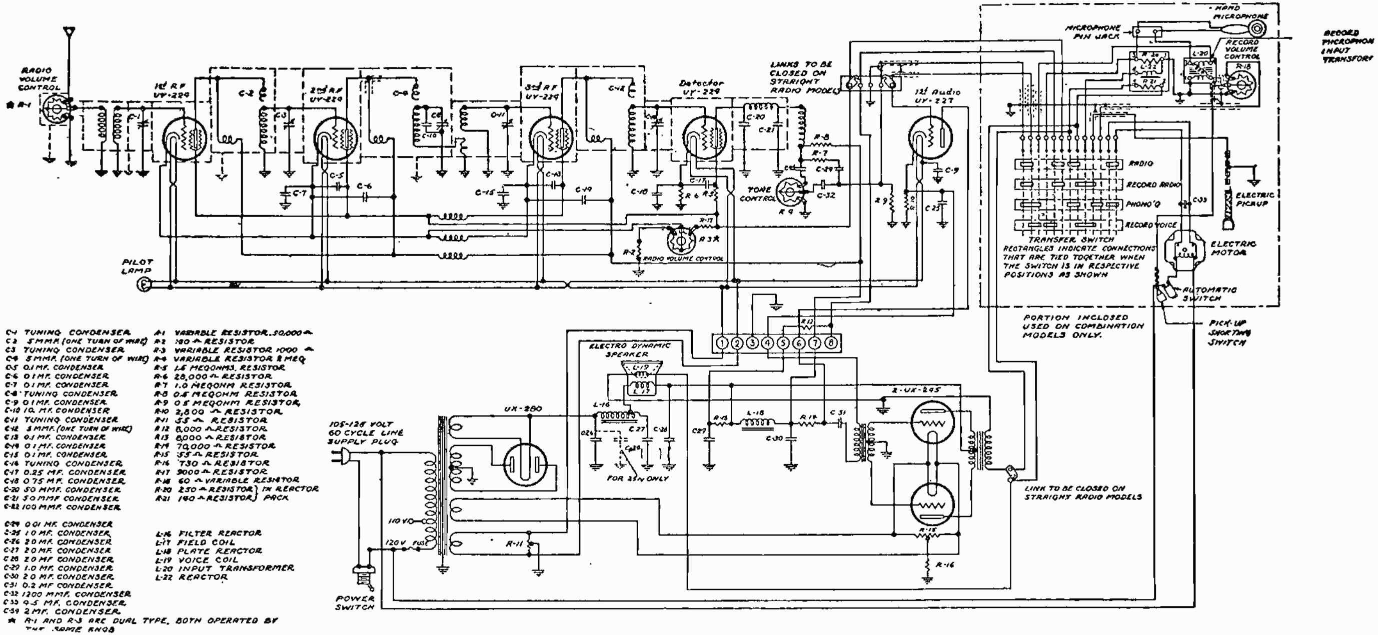
Radio Chassis Tube Socket Tests

TEST	SOCKET NUMBER	TUBE	NORMAL VOLTAGE	NORMAL CURRENT	LACK OF VOLTAGE OR ABNORMAL VOLTAGE INDICATES
Filament "A"	1 2 3 4 5	UY-224—1st R. F. UY-224—2nd R. F. UY-224—3rd R. F. UY-224—Detector UY-227—1st Audio	2.1 2.1 2.1 2.0 2.1		Open or shorted wire or contact in filament supply.
Plate "B"	1 2 3 4 5	Same as above	173 173 173 50* 67	3.1 3.1 3.1 .3 1.5	Open or grounded wire or contact in plate supply. Open plate coil short in any of the by-pass condensers Open or shorted resistor board Open in plate winding of any of the R. F. coils. Short between plate and grid section of R. F. coils. On detector, open or shorted plate filter open choke open .5 meg. resistor
Control Grid "C"	1 2 3 4 5	Same as above	3.1 3.1 3.1 1.5		Open or shorted wire or contact in grid voltage supply. Open or ungrounded R. F. coil, Open or shorted resistor on resistor board Open in control grid section of volume control. Any defect listed above which would cause an abnormal plate voltage would also cause an abnormal grid voltage. On UY-227 an open link in radio terminal strip (radio only) or open in wiring or poor contact in control switch (combination).
Screen Grid	1 2 3 4	Same as above	89 89 89 3.4		Open or shorted wire or contact in screen grid voltage supply. Open link in radio terminal strip (radio only) or open in wiring or poor contact in control switch (combination). Open in coil Any defect listed above which affects plate and control grid voltages will also affect the screen grid voltages.

*250 V Scale

Amplifier Tube Socket Tests

TEST	SOCKET	NORMAL VOLTAGE	LACK OF VOLTAGE OR ABNORMAL VOLTAGE INDICATES
Filament	UX-245 UX-245	2.25 2.25	Open or shorted wire or secondary winding in filament supply.
	UX-280	4.9	
Plate	UX-245 UX-245	222 222	Open or shorted wire in plate supply; open primary of output transformer 2, Fig. 3; open or shorted field or reactor coil; shorted condenser in con-denser bank
	UX-280	40 M. A.	Open or shorted wire in plate circuit. Open high voltage secondary of power transformer; any items listed above which affect UX-245 plate supply; any items which affect UY-224 plate supply.
Grid	UX-245 UX-245	37 37	Open or shorted wire in grid circuit; open secondary of interstage transformer; open or shorted grid bias resistor faulty ground in center tap of secondary interstage transformer or faulty ground in grid bias resistor



Schematic Wiring Diagram Victor Mico-Synchronous Radio, Models R-35, R-39, and RE-57.

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Airline, 32-Volt Direct Current

Superheterodyne Receiver Cat. No. 62-93

CAUTION

To avoid the danger of damage to the receiver and excessive current, the following facts should be understood:

The metal chassis is connected to one side of the line. In the 32-volt systems, either side of the line may be grounded. If the side of the line, not connected to the metal chassis, is grounded, and the metal chassis comes in contact with the external ground, the line will be short-circuited, resulting in an excessive current.

In any service work, therefore, on the 32 V. receiver, it is suggested that the chassis be kept on a wood or other insulated surface to avoid the above mentioned danger.

POLARITY OF POWER SUPPLY

There is a red mark on the plug. The prong of the plug at which the red mark is placed must be plugged into the positive side of the line. Use a receptacle on the 32-volt line, from which the plug will not have to be removed after it has once been correctly inserted.

If the polarity of the line is not known, it may be determined with a voltmeter. A meter having a 50-volt range or higher, may be used. If the pointer deflects correctly, the positive post of the meter is connected to the positive side of the line.

If there is no way to determine the polarity of the line, insert the plug both ways, leaving it in a few minutes each time. The receiver should operate with the plug in one way. If it does not, withdraw the plug.

ELIMINATING IGNITION AND GENERATOR NOISE

After the receiver is in working order, the following procedure must be followed in practically all cases, to eliminate ignition and generator noise caused by the charging plant. If the charging plant causes no noise, then of course, these steps do not have to be taken.

One spark plug suppressor must be placed on each spark plug of the engine. One spark plug for example would be required on a one-cylinder engine, and four must be used on a four-cylinder engine. To connect the spark plug suppressor, remove the wire from the top of the plug, put the suppressor on, and attach the wire to the other end of the suppressor.

The generator condenser consists of two .5 mfd. sections in one unit. The two sections have one side grounded to the metal case of the condenser. Mount the condenser on the frame of the charging plant. This will ground it. Then connect the two leads to the charging switch, one on each side of the line.

In some large installations, where the charging unit is on only two or three times a week, the above steps do not have to be taken, as interference is only caused when the generating plant is in operation.

CONDENSER ALIGNMENT

As the I. F. stages are fixed tuned, no I. F. alignment at the intermediate frequency of 175 K. C. is required.

First set the signal generator for a signal of exactly 1400 K.C. Connect the antenna lead from the signal generator to the antenna lead of the receiver, and the ground lead from the signal generator to the ground lead of the receiver. Set the dial pointer on the 1400 K.C. mark on the dial scale, and adjust the three trimmer condensers on the gang tuning condenser for maximum output, adjusting the oscillator trimmer, the one nearest the rear of set first.

As a rule no adjustment other than at 1400 K.C., as mentioned above, is required. If, after the receiver has been aligned at 1400 K.C., the sensitivity is still low at some portion of the band, adjust the signal generator to that setting and tune for maximum output with the station selector knob of the receiver. Then, without readjusting the trimmers, bend the slotted rotor plates on the front two sections of the gang, to obtain maximum output. Care should be taken not to bend these plates too far in an inward direction, as the condenser may short as a result.

After any adjustment of this nature, set the signal generator again for a signal of 1400 K.C., and check the adjustment of the tuning condenser trimmers at this frequency for maximum output.

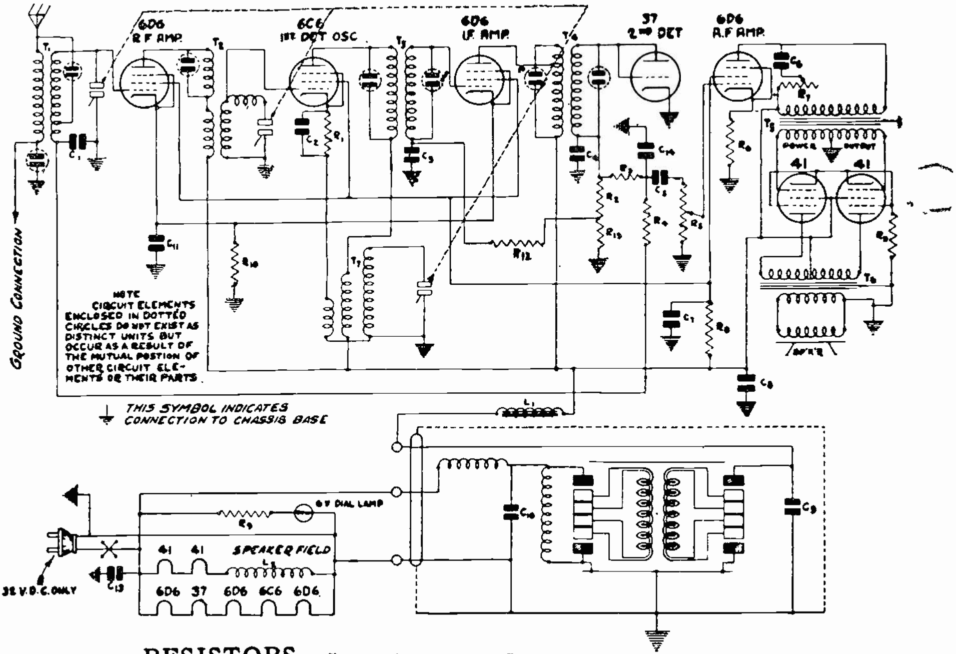

Fig. 1—Schematic Circuit Diagram.

RESISTORS

Code	Resistance	Type
R1	4,500 ohm	Carbon
R2	150,000 ohm	Carbon
R3	100,000 ohm	Carbon
R4	2 megohm	Carbon
R5	1 megohm	Volume Control
R6	1,000 ohm	Carbon
R7	40,000 ohm	Tone Control
R8	20,000 ohm	Carbon
R9	144 ohm	Armoured Wire Wound
R11	340 ohm	Armoured Wire Wound
R10	200 ohm	Carbon
R12	1 megohm	Carbon
R13	50,000 ohm	Carbon

CONDENSERS

Code	Capacity	Voltage	Type
C1	.050 mfd.	200 V.	Tubular
C2	.002 mfd.	600 V.	Tubular
C3	.050 mfd.	200 V.	Tubular
C4	250 mmf.	600 V.	Moulded
C5	.050 mfd.	200 V.	Tubular
C6	.050 mfd.	200 V.	Tubular
C7	1.50 mfd.	140 V.	Tubular
C8	8.00 mfd.	250 V.	Electrolytic
C11	.10 mfd.	400 V.	Tubular
C13	.50 mfd.	120 V.	Tubular
C14	250 mmf	600 V.	Moulded

VOLTAGES AT SOCKETS

Input 32 Volts, Antenna Shorted to Ground

Type of Tube	Function	Across Heater	Plate to Cathode	Screen to Cathode	Grid to Cathode	Normal Plate M.A.
6D6	R.F.	6.4	190	96	3.0(1)	7.5
6C6	1st D&O*	6.4	185	91	7.0(2)	1.6(2)
6D6	I.F.	6.4	190	96	3.0(1)	7.5
37	2nd Det.	6.4	0		0	0
6D6	1st A.F.	6.4	170	94	4.8(1)	5.0
41	Output	6.4	175	177	14.0	18.0

* Detector and Oscillator
(1) Cathode to ground
(2) Subject to variation with dial setting

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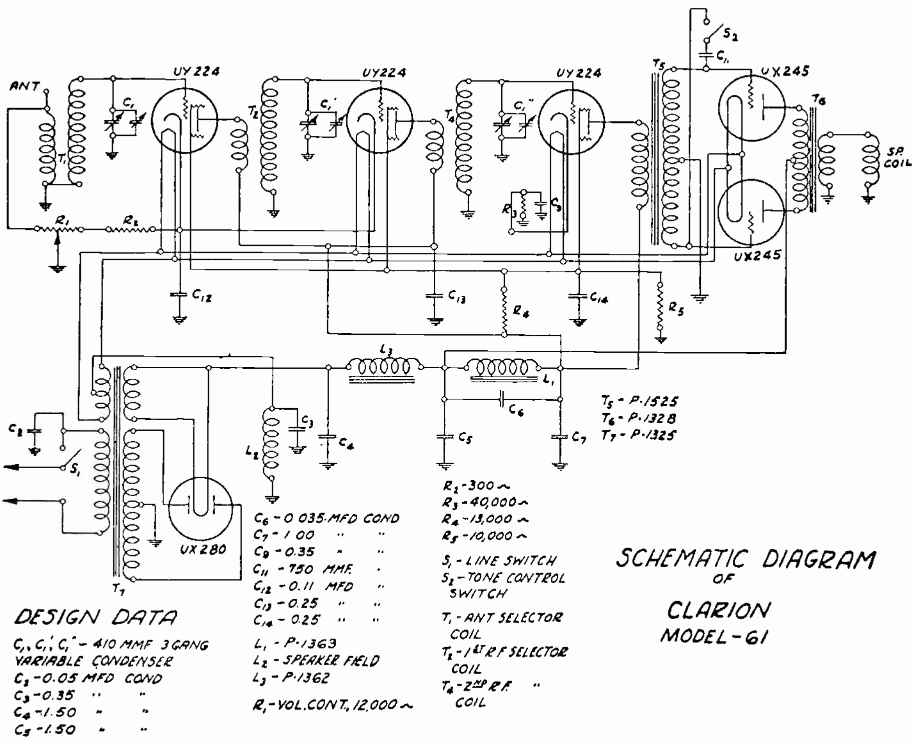
CLARION MODELS 61 and 70

Voltage Table of Clarion Model 61—Line Voltage 115 Volts

Position	Tube	Fil. Volts	Plate Volts	Grid Volts	Screen Grid Volts	Cathode Volts	Normal Plate M.A.
1st R.F.	224	2.40	260	3.2	100.0	50.0	4.3
2nd R.F.	224	2.35	260	3.2	100.0	50.0	4.3
Det.	224	2.40	260	8.0	100.0	42.0	0.200
A.F.	245	2.42	290	53.0			34.0
A.F.	245	2.43	290	53.0			34.0
Rect.	280	5.00					

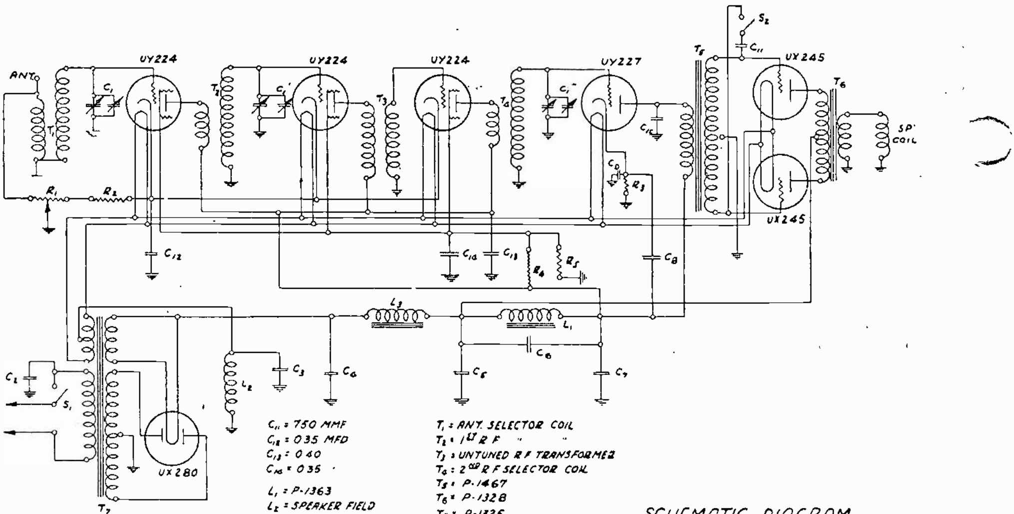
280 Fil. to Gnd.—320 Volts D.C. L1 & L2 Center tap to Gnd.—300 Volts D.C. End of Choke L2 to Gnd. 260 Volts D.C.



Voltage Table of Clarion Model 70—Line Voltage 115 Volts

Position	Tube	Fil. Volts	Plate Volts	Grid Volts	Screen Grid Volts	Cathode Volts	Normal Plate M.A.
1st R.F.	224	2.37	250	3.0	90	50.0	4.0
2nd R.F.	224	2.30	250	3.0	90	50.0	4.0
3rd R.F.	224	2.30	250	3.0	90	50.0	4.0
Det.	227	2.38	250	20.0		33.0	1.00
A.F.	245	2.42	290	53.0			34.0
A.F.	245	2.43	290	53.0			34.0
Rect.	280	5.00					

280 Fil. to Gnd.—320 Volts D.C. L1 & L2 Center tap to Gnd.—300 Volts D.C. End of Choke L2 to Gnd 250 Volts D.C.



SCHEMATIC DIAGRAM
OF
CLARION
MODEL 70

DESIGN DATA

C_1-C_1'-C_1'' = 410 MFD 3 GANG VARIABLE CONDENSER

C_2 = 0.05 MFD	C_6 = 0.035 MFD
C_3 = 0.35 "	C_7 = 1.0 "
C_4 = 1.50 "	C_8 = 0.05 "
C_5 = 1.50 "	C_9 = 0.35 "
	C_{10} = 750 MMF

C_{11} = 750 MMF
C_{12} = 0.35 MFD
C_{13} = 0.40
C_{14} = 0.35

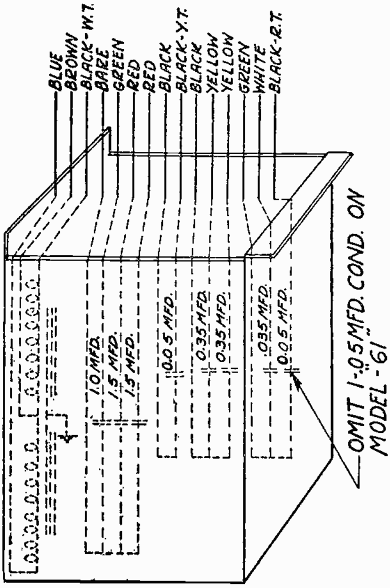
L_1 = P-1363
L_2 = SPEAKER FIELD
L_3 = P-1362

R_1 = VOL CONT, 12,000 Ω
R_2 = 200 Ω
R_3 = 20,000 Ω
R_4 = 13,000 Ω
R_5 = 10,000 Ω

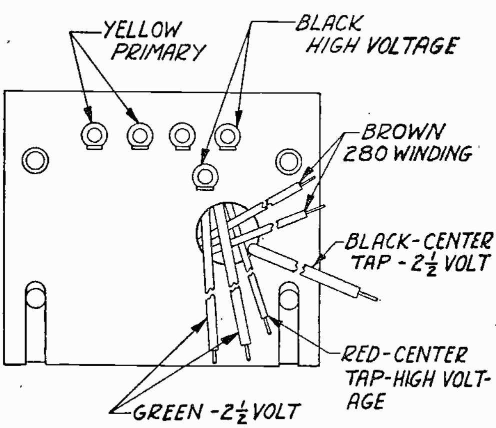
S_1 = LINE SWITCH
S_2 = TONE CONT SWITCH

T_1 = ANT. SELECTOR COIL
T_2 = 1ST R F " "
T_3 = UNTUNED R F TRANSFORMER
T_4 = 2ND R F SELECTOR COIL
T_5 = P-1467
T_6 = P-1328
T_7 = P-1325

MODEL "61" & "70"



60 CYCLE FILTER BLOCK



60 CYCLE POWER TRANSFORMER

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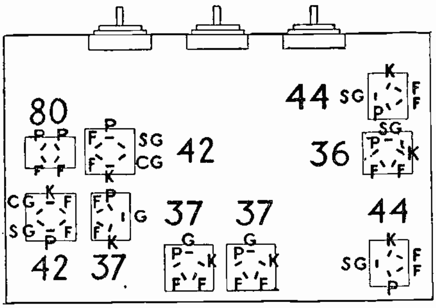
PHILCO MODEL 91 SERIES

The Philco Radio of the 91 series is a nine tube superheterodyne, employing the high efficiency 6.3 volt filament tubes, automatic volume control, shadow tuning, and push-pull pentode output. The chassis is made in two different types, one known as the 121 type, employing a single dynamic speaker and the other known as the 221 type, employing twin dynamic speakers. These type numbers appear on the radio chassis as a part of the model number. Chassis of one type are not interchangeable with those of another. The intermediate frequency used in adjusting the superheterodyne circuit of the 91 series is 260 kilocycles. The power consumption of the various models is as follows:

Model	Volts	Cycles	Watts
91-121	115	50-60	90
91-221	115	50-60	95
91A-121	115	25-40	92
91A-221	115	25-40	97
91E-121	230	50-60	90
91E-221	230	50-60	95



F = Filament   SG = Screen Grid   K = Cathode
P = Plate   CG = Control Grid

Fig. 1—Tube Sockets

Table 1—Tube Socket Data*—A.C. Line Voltage 115 Volts

Tube Type	Tube Circuit	Filament Volts	Plate Volts	Screen Grid Volts	Control Grid Volts	Cathode Volts
44	R.F.	6.3	200	50	.6	25
36	Det.—Osc.	6.3	250	80	10	10
44	I.F.	6.3	250	85	.2	5
37	Det.—Rect.	6.3	0	...	.2	2
37	Det.—Ampl.	6.3	60	...	.2	2
37	Audio	6.3	100	...	0	2
42	Output	6.3	240	250	15	15
42	Output	6.3	240	250	15	15
80	Rectifier	5.0	310/Plate	...	...	..

*All of the above readings were taken from the under side of the chassis, using test prods and leads with a suitable A.C. voltmeter for filament voltages and a multi-range D.C. voltmeter for all other readings. Volume control at maximum and station selector turned to low frequency end.

Table 2—Power Transformer Data

Terminals	A.C. Volts	Circuit	Color
1-2	105 to 125	Primary	White
3-5	6.3	Filament	Black
6-7	5.0	Filament 80	Blue
8-10	670	Plates of 80	Yellow
4	...	Center Tap of 3-5	Black Yellow Tracer
9	...	Center Tap of 8-10	Yellow Green Tracer

Table 3—Resistor Data

Nos. on Figs 4	Resistance (ohms)	Power (Watts)	Terminals	Color Body	Color Tip	Color Dot
46 Single Speaker	900	..	1-2	LONG	TUB	ULAR
	2700	..	2-3			
	95	.	3-4			
	205	..	4-5			
46a Twin Speaker	136	..	1-2	LONG	TUB	ULAR
	Blank	..	2-3			
	85	..	3-4			
	205	..	4-5			
14	1,000	.5	....	Brown	Black	Red
1	10,000	.5	. . .	Brown	Black	Orange
21	15,000	.5	....	Brown	Green	Orange
40 41	25,000	.5	....	Red	Green	Orange
41a	13,000	1.	....	Brown	Orange	Orange
32	99,000	.5	....	White	White	Orange
39	490,000	.5	....	Yellow	White	Yellow
43 3 38	1,000,000	.5	...	Brown	Black	Green
28	1,000,000	1.	....	Brown	Black	Green

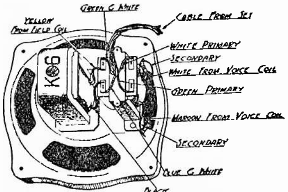


Fig. 2—Speaker Connections—121 Code

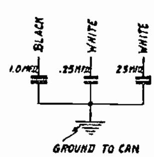
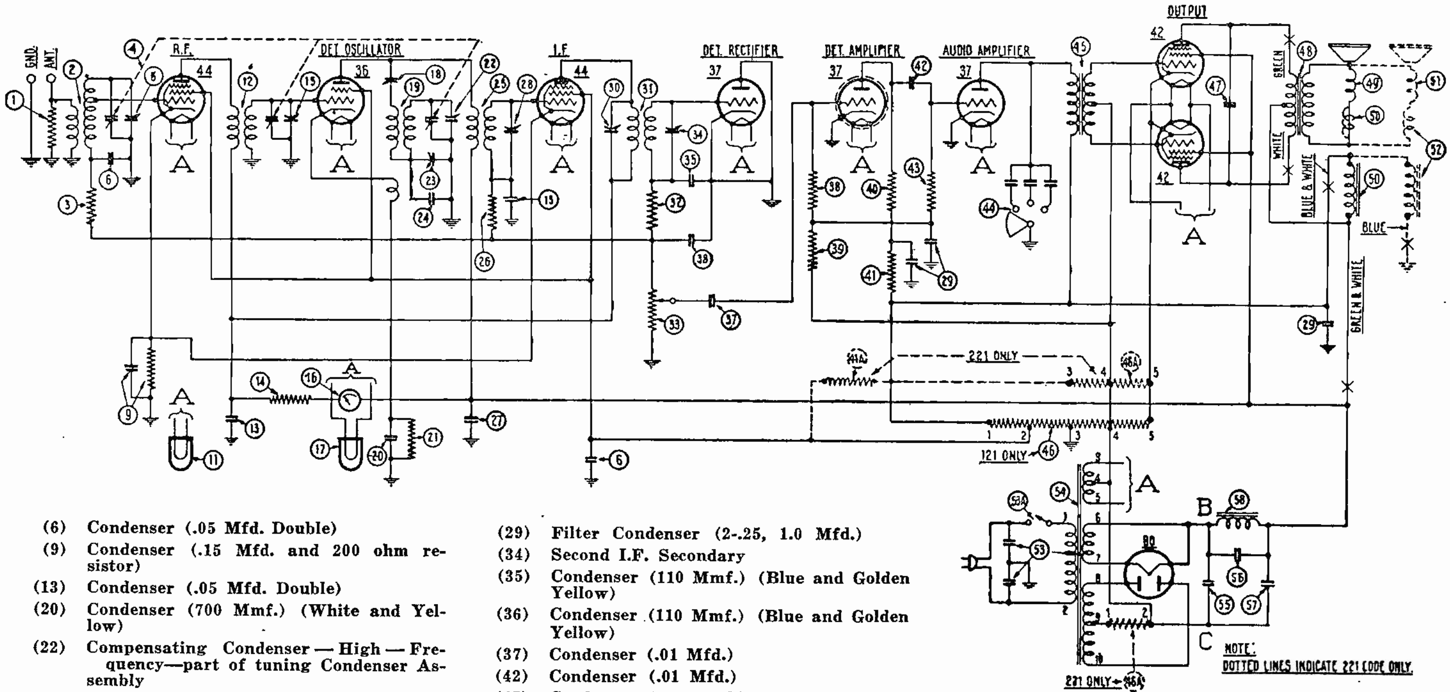


Fig. 3—Internal Connections Filter Condenser



(6)	Condenser (.05 Mfd. Double)	(29)	Filter Condenser (2-.25, 1.0 Mfd.)
(9)	Condenser (.15 Mfd. and 200 ohm resistor)	(34)	Second I.F. Secondary
(13)	Condenser (.05 Mfd. Double)	(35)	Condenser (110 Mmf.) (Blue and Golden Yellow)
(20)	Condenser (700 Mmf.) (White and Yellow)	(36)	Condenser (110 Mmf.) (Blue and Golden Yellow)
(22)	Compensating Condenser — High — Frequency—part of tuning Condenser Assembly	(37)	Condenser (.01 Mfd.)
(23)	Compensating Condenser — Low Frequency	(42)	Condenser (.01 Mfd.)
(24)	Condenser (410 Mmf.) (Yellow and Orange) Assembled with L. F. Condenser	(47)	Condenser (.001 Mfd.)
(27)	Condenser (.01 Mfd.)	(53)	Condenser (.015 Mfd. Double)
		(55)	Electrolytic Condenser (8 Mfd.)
		(56)	Condenser (.18 Mfd.)
		(57)	Electrolytic Condenser (8 Mfd.)

SCREEN GRID, VARIABLE MU AND PENTODE TUBES

18 FR-1

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YOUR HEALTH

In a previous talk we had, I hinted at the connection there is between a man's mental well-being and his physical well-being. This connection is a whole lot closer than people ordinarily care to realize.

If you eat something that you like but that doesn't like you, most likely in a few hours you will be feeling head-achy and out-of-sorts. Your outlook on life has suddenly become gloomy, your temper short, your mind more or less inactive.

Do you know the reason for blue Mondays? They are the result of too much food and too little exercise on Sunday and too little sleep Sunday night.

If you are afflicted with blue Mondays, you will notice that you do your best work on Wednesdays and Thursdays—it takes several days for your digestive system to become straightened out after the excesses of the previous week-end. On Thursday morning, let us say, you tackle your work with a clear mind, you find it easy to concentrate, your work is a pleasure, and the day slips by unnoticeably.

Then you say to yourself, "If only every day could be like this—I would be ever so much happier."

But every day can be like this, if you take the proper care of yourself. There are a few simple rules of health that everyone should follow—never overeat, chew your food thoroughly before swallowing, have your teeth properly cared for, take some exercise each day in the open air if it is only a brisk walk, keep your body clean inside and out, get enough sleep, don't worry and avoid excesses of all kinds.

Give your health the attention it deserves.

J. E. SMITH.

WASHINGTON, D. C.

[illegible]ed 1932, 1933, 1934,
1936 Edition

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Printed in U.S.A.

Screen Grid, Variable Mu and Pentode Tubes

THE PURPOSE OF THE SCREEN GRID

In a previous lesson the subject of internal tube capacity and its effects—regeneration and self-oscillation—was briefly mentioned in connection with triodes. You will remember we spoke about the capacity existing between the grid and plate of a triode. In other words, the grid and plate of the tube act as two plates of a small condenser. If we had a triode with absolutely no internal capacity, we could obtain the same effect by connecting a 6 micro-microfarad (.000006 mfd.) condenser across the grid and plate externally.

Through this capacity a certain amount of the A.C. signal voltage in the plate circuit of an amplifying tube can feed back to the grid where it combines with the incoming signal voltage. This in itself is not necessarily a disadvantage for it serves to increase the signal strength and so increases the apparent amplification. Practically all of the older broadcast receivers made use of the principle of regeneration to increase sensitivity, and for short wave reception, regeneration is almost essential.

But, as was also mentioned previously, excessive regeneration will cause the amplifier tube to oscillate and the desired signal is "killed." And so we can see that amplification is definitely limited, for when regeneration reaches a certain point the tube will oscillate.

It is largely because of this that the amplification factor (μ) of most triodes is not higher than 8 or 9.

Consider the circuit in Fig. 1. An incoming signal is impressed across the grid and cathode (filament) of the first tube. This signal is amplified and is passed on to another tube circuit.

Tube *A* will have a grid-to-plate capacity of about 6 micro-microfarads and part of the signal voltage in the plate circuit will feed back to the grid through this capacity. Thus the circuit will be a very efficient amplifier up to the point where self-oscillation sets in—that is, at the point where the feed-back voltage is larger than the signal input voltage.

Let us say that one-hundredth of the output gets back into the input through the grid-to-plate capacity. This adds to the signal voltage impressed on the grid and as the tube cannot discriminate between a new signal and an old one amplified by itself, it is reamplified and again appears in the output. Then one-hundredth of this new increased A.C. output feeds back, increasing the grid signal voltage still further. This process of feed-back and reamplification continues until the tube oscillates, unless some method of stabilization is used to prevent oscillation.

Of course, feed-back from the plate to the grid circuit can take place through any inductive or capacitive coupling between the two circuits. For example, if the field about the output transformer or coil can link with the field of the input transformer (grid coil), there will be inductive feed-back. This would be equivalent to the circuit shown in Fig. 2a where a tickler coil (shown in dotted lines) serves to feed back energy from the plate to the grid circuit.

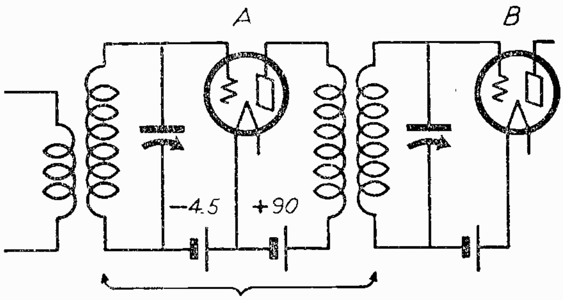


Fig. 1

In the same way, any capacity between wiring or metal parts will cause a feed-back. This would be equivalent to the circuit shown in Fig. 2b where a condenser is shown (in dotted lines) connected across the plate and grid of the tube.

In regenerative receivers the inductive method of feed-back is usually used in the detector circuit. Then the tickler is made variable or some other method of controlling regeneration is used.

However, in non-regenerative receivers and even in the R.F. stages of regenerative receivers, feed-back is undesirable and where triode tubes are used, special precautions are taken to prevent feed-back through the tube capacity, and to prevent any inductive or capacitive coupling between wiring and parts. Methods of neutralization and stabilization are employed (these will be taken up in later lessons), coils are spaced far apart and grid and plate circuit wires are kept away from each other.

Now getting back to the internal capacity of a triode—it should be clear that if we could reduce the capacity existing across the grid and plate, we could increase its amplifying prop-

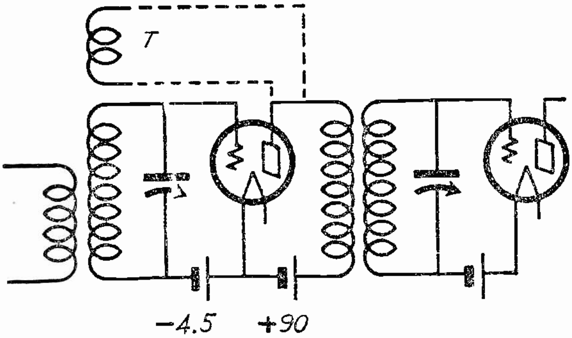


Fig. 2(a)

erties. The maximum amplification possible with a triode is 30—in the case of the '40 type tubes—but '40 tubes can only be used as A.F. amplifiers. They oscillate much too readily for use in R.F. stages. It was known for a long time that if this internal capacity could be eliminated, tubes could be constructed to have high amplification factors. The result of efforts to reduce

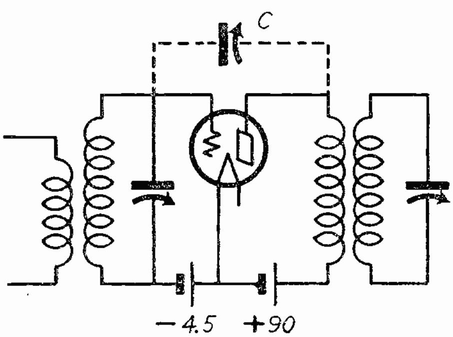


Fig. 2(b)

this internal capacity was the screen grid tube. And now that screen grid tubes are so well known and their operation is so clearly understood, it seems strange that the solution was not thought of long ago.

By a suitable arrangement of the elements of a tube it is possible to increase its amplification almost indefinitely but the inter-electrode capacity which would remain almost the same would become so much more effective in feeding back R.F. energy that a high mu triode could not be used for R.F. amplification. Any increase in the amplification factor of a tube will make it more susceptible to R.F. feed-back, i. e., while a type '01A tube requires 1/8 ($\mu = 8$) of the total A.C. plate voltage energy to sustain oscillation by feed-back, a type '40 tube requires only 1/30 ($\mu = 30$) of this.

Of course if 1 volt A.C. on an '01A grid will produce 8 volts A.C. in the plate circuit and its internal capacity is capable of feeding back 1 volt which will in turn build up another 8 volts A.C. in the plate circuit, oscillation will be sustained. If a type '40 tube (because its inter-electrode capacity is practically the same as an '01A) feeds back ⅛th its plate voltage, 1 volt applied

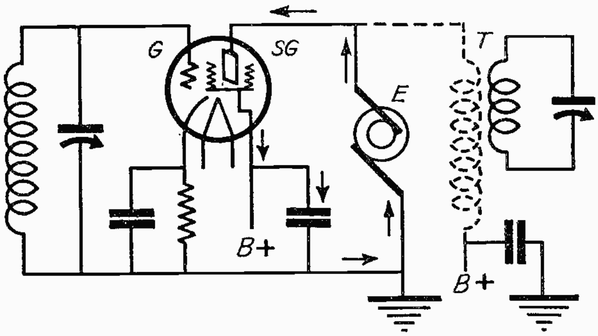


Fig. 3

to its grid will produce 30 volts in the plate circuit which will feed back 30 ÷ 8 or 3¾ volts. These 3¾ volts will produce 3¾ × 30 or 112½ volts A.C. in the plate circuit and the tube will oscillate very readily.

In the tetrode (the screen gride tube) the plate is shielded from the control grid by a screen (known as the screen grid). This screen therefore practically eliminates the grid-to-plate capacity in a tetrode. Thus there is extremely little feed-back through the tube and no possibility of oscillation to hamper the operation of the tube.

Now let us see how the shielding effect of the screen grid prevents feed-back from the plate to the grid circuit. Figure 3 shows a screen grid tube connected as an R.F. amplifier. However, in place of the primary of an output transformer, we have connected a small generator *E* which we are going to assume supplies an A.C. voltage corresponding to the feed-back voltage in a triode circuit. The arrows show what happens. The "feed-back" voltage goes through the plate to the screen grid, through a by-pass condenser to the ground.

But what about the grid circuit? Practically no feed-back voltage gets to the grid and what does get back is so little that

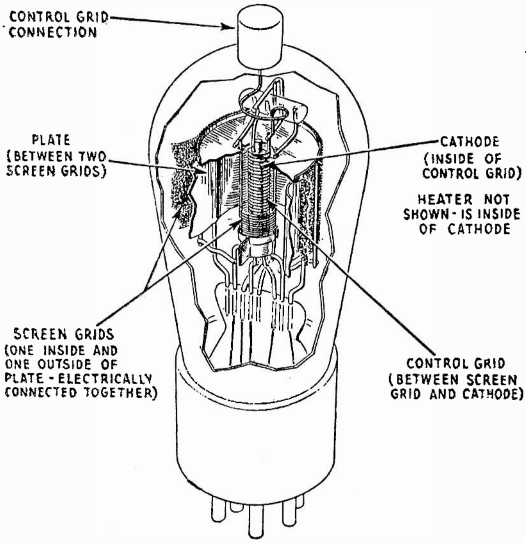


Fig. 4—Cross-sectional view showing the construction of an A.C. screen-grid vacuum tube.

it can usually be neglected. The grid-to-plate capacity of a tetrode (.006 $\mu\mu$f.) is one-thousandth that of a triode and it would take 1000 times as much feed-back to cause self-oscillation as in a triode.

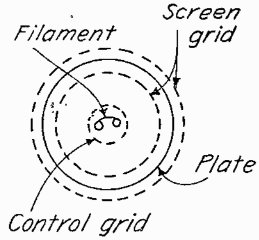


Fig. 5—Looking down into a screen grid tube showing how the elements are placed.

SCREEN GRID TUBE CONSTRUCTION

Figure 4 shows a cut-away view of an A.C. screen grid tetrode, from a study of which many of the constructional details can be learned. Figure 5 is a drawing of the elements, looking down on the tube, which shows the positions of the various electrodes.

In the very center is the filament which is nothing but a single, fine resistance wire threaded through a porcelain cylinder and turned back on itself. The cathode, not shown in Fig. 5, is a metal tube which is pressed onto the porcelain. Quite close to the cathode is the control grid, of rather coarse metal mesh. Then comes half of the screen grid—at a comparatively short distance from the control grid. Quite far away from this is the plate and then comes the other half of the screen grid. Thus the plate is practically surrounded by the screen grid. The internal half of the screen grid shields the plate from the control grid. The external half of the screen grid and the connecting disc shield the plate from the control grid connection to the cap of the tube.

The amplification factor of a screen grid tetrode used as an audio amplifier may be as high as 1000. Used as an R.F. amplifier it is about 400. This is a considerably greater amplification factor than any triode has. One of the reasons why the greater mu is possible has already been mentioned—the practical elimination of grid-to-plate capacity. The real explanation of the very high mu is that the grid in a tetrode is very close to the cathode and comparatively far away from the plate, a factor which makes for large amplification. There is also another reason for this high amplification factor which requires a bit more explanation.

When an electron leaves the cathode, it shoots toward the plate. But just as soon as the cathode loses one negative charge, it is less negative (more positive) by that amount. It can be seen then that if a great number of electrons leave the cathode, it may be quite positive—not with respect to the plate of course, but with respect to the stream of electrons that are on their way to the plate. What happens? Those electrons that are quite close to the cathode will be attracted back to the cathode, just about as much as they are attracted to the plate, which, while more positive, is farther away. Not knowing which way to go they congregate in the space between the cathode and plate in a sort of cloud. This negative cloud then tends to retard other electrons on their way from the cathode to the plate.

The effect of these electrons that don't know where to go is called the *space charge*. Very frequently the name is extended to apply to the cloud of electrons itself. Because of the space charge, not all the electrons emitted from the cathode get to the plate, and the grid which is between the cathode and the plate cannot control the electron flow as it could if this space charge of "loafer" electrons did not exist.

In the screen grid tube provisions are made to get the "loafer" electrons moving. The method used is simple—a positive charge is placed on the screen grid—usually 1/3 to 1/2 of the D.C. plate voltage. Then the electrons emitted from the cathode will be very strongly attracted to the screen grid. They feel the effect of both the plate and the screen grid which is closer to the cathode than the plate. Most of the electrons, however, do not flow through the screen grid circuit—they fly directly through the openings in the screen, to the plate. Thus the screen grid acts as a sort of "puller," helping the electrons over to the plate. It puts the "loafer" electrons to work.

The result is a steady stream of electrons from the cathode to the plate—the grid can control *all* the electrons emitted—and we obtain maximum amplification.

3 It must be remembered however, that while the screen is at a relatively high D.C. potential—it is at ground potential as far as radio frequency currents are concerned—the screen grid being connected to ground through an R.F. by-pass condenser. In this respect (as far as R.F. is concerned) it is at the same potential as the cathode, for it, too, is grounded. It is very important that you understand the distinction between D.C. potential and R.F. potential. The screen is usually operated at a D.C. potential of 1/3 to 1/2 of the potential of the plate in order to overcome the effect of the space charge. It is at ground R.F. potential to prevent grid-to-plate capacity and regenerative feed-back.

If it were not for the space charge effect resulting in low amplification and tube inefficiency the screen would require no D.C. voltage and could be connected directly to the cathode. It would be just as effective in reducing inter-electrode capacity without a D.C. potential. But by placing on the screen a rather high D.C. potential and at the same time by-passing it to ground we make it serve two purposes—eliminating tube capacity and space charge effects.

Very obviously, since tube manufacturers have gone to so great trouble to build a tube which has negligible grid-to-plate capacity, precautions must be taken to prevent feed-back from the plate circuit to the grid circuit through circuit wiring and between parts. It is for this reason that shielding is so essential in screen grid circuits. To prevent coupling between circuit connections, leads are made as short as possible. Coils are placed in metal shielding cans. The screen grid tubes themselves are covered with metallic shields and in many circuits even the gang condenser is placed in a metal box to prevent undesired coupling.

What would happen if there were some plate-to-grid coupling? In a screen grid receiver with three stages of screen grid R.F. amplification, the voltage amplification may be about 30,000 times. Thus the least part of the R.F. voltage in the output of the last tube which gets back into the input of the first tube will reappear in the output amplifier 30,000 times. Clearly the expense and care that manufacturers go to in order to shield all the parts in a screen grid stage is justifiable.

SCREEN GRID TUBE PERFORMANCE

By this time you should be quite accustomed to getting an insight into the performance of a device from a study of its characteristic curve. In considering the performance of screen grid tubes we are going to start out with a study of the plate voltage-plate current (E_p-I_p) characteristic curves of one type of tube.

In Fig. 6 you will find a family of static E_p-I_p characteristic curves for the UY-224 screen grid tube. Notice that there are five E_p-I_p curves, taken for various grid bias voltages. The sixth curve which looks very much like one of the others but reversed, ($I_{C2}\ E_{C1} = -1.5$), is the curve of screen grid current, taken with 1½ negative volts on the control grid and at various plate voltages.

Now let's see what these curves tell us. Forget about the screen grid current curve for the moment. The other curves show us that when the plate voltage is lower than the screen grid voltage (less than 75^v), electrons will actually flow from the plate to the screen grid (indicated by the portions of the curves below the zero current line) and that this electron flow may be as high as 1 milliampere. As the plate voltage is increased, however, plate current increases very rapidly up to a point where the plate voltage is about 15 volts higher than the screen grid voltage. And any increases in plate voltage beyond 90^v result in rather small increases in plate current.

The explanation of electron flow from plate to screen grid is interesting. Let us say an electron is emitted from the cathode with sufficient force to carry it past the control grid. Here it encounters the positive field produced by the screen. But the attraction of the screen is so great that the electron gains sufficient speed to go right through the meshes of the screen. If there is a very low positive voltage on the plate, let us say 5 volts, immediately the electron gets past the screen it will feel a mild attraction to the plate and a stronger attraction back to the screen. Which way it will go is a question. From our curve, and this time considering the screen grid current curve along with the others, we might say that out of five electrons, four go back to the screen and one goes on to the plate.

But what happens if the plate is, let us say, 35 volts positive —with no bias on the grid? Now there is a greater attraction

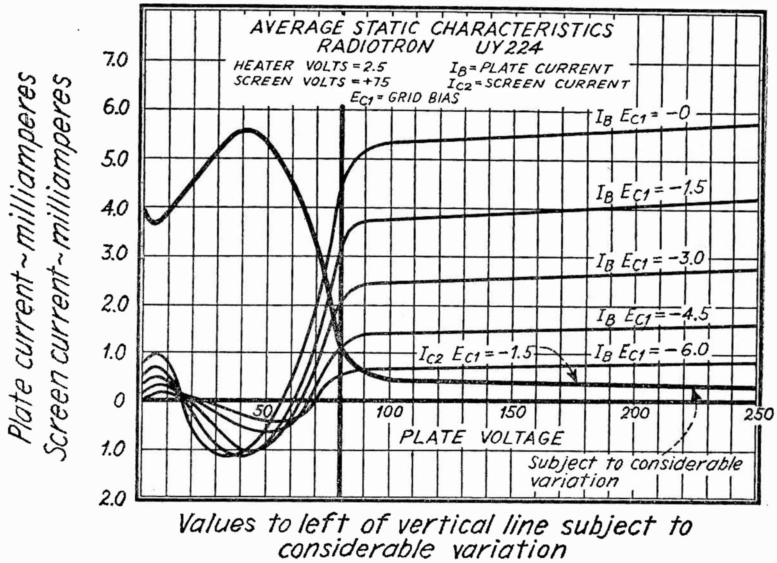


Fig. 6—Plate voltage-plate current characteristics of a screen grid tube. It is worth remembering that the sum of the plate and screen grid current is a constant value for a given screen grid and control grid voltage. The total is the cathode current.

to the plate and the electrons that pass through the screen grid strike the plate with greater velocity. As the electrons bombard the plate, they may bounce back—they may even knock other electrons off the plate. As the screen grid is more positive than the plate, the chances are that instead of returning to the plate they will move back to the screen grid—and we have considerable screen grid current flow. In effect then, the plate acts as a second cathode as it emits electrons. For this reason we call this current flow "secondary emission" current. From the curves we can see that with 45 volts on the plate and 75 volts on

4

the screen we have a screen grid current flow of 5½ ma. and a plate current flow, *in the negative direction* of about 1 ma.

The electrons that return to the screen grid from the plate are the result of "secondary emission." However, when the screen grid tube is supplied with the proper operating voltages there is very little secondary emission and almost all of the screen grid current that flows is due to those electrons which strike against the metal of the screen grid and do not pass through the openings.

As the plate voltage is increased there is less and less screen grid current flow. In practice it is usually considered negligible.

As far as the effect of grid bias is concerned, these curves show us that as the bias is increased the average plate current values decrease, which is as it should be. In practice the screen grid tube is operated with a negative bias of 1½ volts.

So much for the E_p-I_p characteristics of a tetrode tube. Now there are other characteristics to be considered such as the plate impedance of the tube, the mutual conductance and the amplification factor. The last of these has already been mentioned—the mu of a tetrode used as an R.F. amplifier is 400. The μ varies somewhat with the screen grid voltage.

Due to the construction of the tetrode, with the plate much farther away from the cathode than in a triode, the plate impedance is extremely high, about 400,000 ohms. The mutual conductance of the tetrode is about 1000 micromhos (.001 mho).

As you learned in a previous lesson, the amplification factor of a tube is equal to the mutual conductance multiplied by the plate impedance. If g_m is .001 and r_p is 400,000, "mu" will be 400 as previously stated.

But the actual voltage amplification obtained from an R.F. stage depends on the plate load impedance. For maximum obtainable voltage amplification the plate load impedance should be from 6 to 8 times the tube impedance. This would mean that to take advantage of about 90% of the mu of the screen grid tube we would have to use a 3 megohm load impedance in the plate circuit.

In an R.F. amplifier where transformer or inductive coupling must be used, it is impossible to build up a plate load impedance of much more than 100,000 ohms. In practice the total inductive reactance in the plate circuit of a screen grid R.F. amplifier may be considerably less than 100,000 ohms. Consequently the actual voltage amplification of a screen grid R.F.

stage will be much less than the mu of the tube, possibly about 50 to 80% at the most. Then only one-half to four-fifths of the mu of the tube is realized. Even considering this, however, the R.F. amplification of a screen grid stage is about ten times that of an ordinary stage of R.F. amplification using a triode tube.

From this discussion of the performance characteristics of a screen grid tube, it might seem that we could make one screen grid stage of R.F. amplification do the work of three or four triode stages. And yet in screen grid receivers we find as many R.F. stages as in receivers which use triodes as R.F. amplifiers.

If all the radio frequency stages had to do was to amplify, we could use a single screen grid tube instead of three or four triodes. But the R.F. section must not only amplify, it must

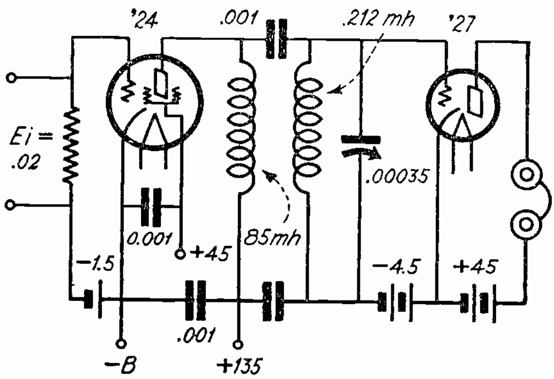


Fig. 7—A stage of screen grid R.F. working into a triode C bias detector.

select the signals. Let us see what would happen if we had only one stage of screen grid amplification before the detector as in Fig. 7. We will get very loud signals from local stations but selectivity will seem very poor. Actually the selectivity may be better than if a single triode were connected in a similar circuit, but the apparent selectivity is much less. Why?

Refer to the lower curve in Fig. 8 which is the resonance curve of a triode. Notice that signals 10 kc. off the resonant frequency will not be amplified and selectivity is apparently very good. But let us say the amplification of a screen grid tube is 10 times that of a triode and its response curve is as represented by the upper curve. In this case all signals 20 kilocycles off the resonant frequency will be amplified and selectivity is apparently decreased.

This is the reason why just as many tuned circuits are necessary in a screen grid receiver as in a receiver using triode tubes in the tuning stages. A good selectivity characteristic is absolutely essential in modern receivers. The chief advantage in the use of screen grid tubes in the R.F. section is the increased sensitivity. With the use of screen grid tubes, weak signals can be brought in full volume—signals that would be unheard if triodes were used. Or if we are not interested in distant stations or

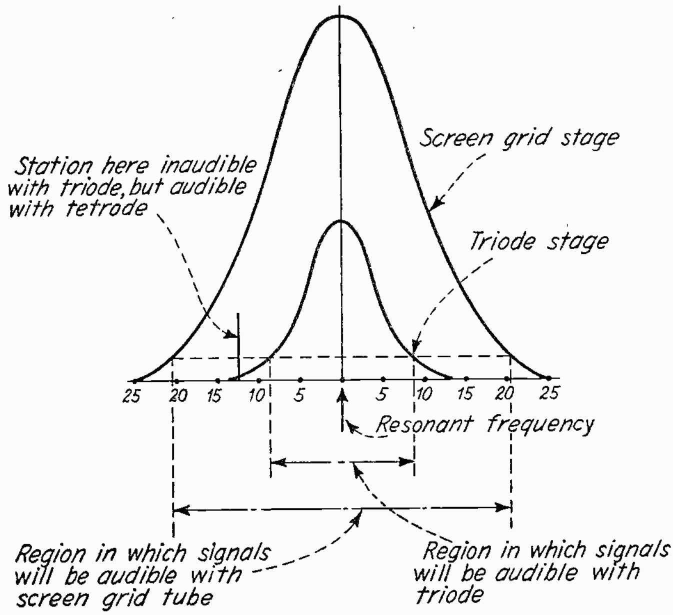


Fig. 8—Graph illustrating how increasing the gain of a single stage seems to decrease the selectivity.

large volumes, we can use a much smaller antenna with a screen grid receiver and eliminate a great deal of noise and interference.

In midget receivers where a great deal of amplification must be crowded into a small space, one screen grid R.F. tube is actually made to do the work of several triodes. That is the set is so designed that one screen grid tube provides all the R.F. amplification necessary, and selectivity is provided for by the use of a band-pass tuner ahead of the R.F. tube. In full sized receivers, even though band-pass tuning is provided for, there are several stages of screen grid R.F. amplification, for maximum sensitivity.

COUPLING SYSTEMS USED IN SCREEN GRID AMPLIFIERS

In R.F. systems consisting of several screen grid tube stages, the individual tubes are coupled together either by transformers or by choke coils and condensers. Most receivers of the tuned radio frequency type use from two to four screen grid stages before the detector which may be a triode or a tetrode. Superheterodynes have one or two screen grid amplifiers working at the carrier frequency, and two to three screen grid stages for intermediate frequency amplification. Following the intermediate frequency amplifier is a triode or tetrode second detector after which comes the audio amplifier.

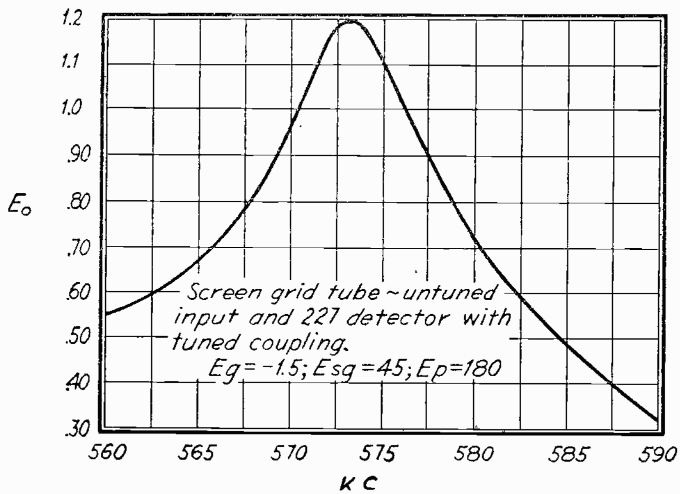


Fig. 9

Transformer coupling is generally preferred to choke coil coupling because of simplicity of wiring and construction, greater economy and somewhat greater amplification and selectivity.

Figure 9 shows a typical selectivity and gain curve for a stage of screen grid R.F. amplification. This characteristic is obtained by feeding an R.F. voltage of variable frequency to the stage and measuring the output by means of a vacuum tube voltmeter, which is nothing more than a detector stage with a milliammeter in the plate circuit. In this case a type '27 tube was used in the V.T.V.M. as indicated in the figure, and the input voltage was kept to 0.02 volt. It will be noted that the voltage gain at 10 kc. off resonance is about one-half that at resonance. In other words there is not much selectivity.

If two stages were used, at 10 kc. off resonance the signal would drop to about one-fourth the value of the signal at resonance, and the selectivity would be doubled.

The actual voltage gain in this stage is the output voltage (1.2 volts) at resonance, divided by the input voltage (.02 volt) or about 60 times. If transformer coupling were used, somewhat greater amplification would result. In practice, transformers almost always are used. Another advantage in the use of transformer coupling is that there is less possibility of hum voltages in one tube getting back to the grid of the previous tube.

VOLTAGE GAIN CALCULATIONS

It has already been mentioned that the actual voltage amplification which can be obtained from a vacuum tube depends upon the mutual conductance of the tube and the resistance of the plate load. The larger this resistance, the greater is the amplification for a given mutual conductance. But the plate load on an R. F. amplifier is a coil, usually the primary of a coupling transformer. Thus the amount of amplification the tube can supply is largely dependent on the A.C. resistance of the plate coil.

In practice it is impossible to obtain coils for use in screen grid tube stages that have a high enough impedance and yet have so little distributed capacity that the signal will not be shorted out. For this reason the gain of an R.F. screen grid stage is rarely over 40 to 80 times. In actual screen grid receivers, the voltage gain per stage is between 30 and 50 where several stages are used and in midget receivers where only one or two R.F. stages are used and a great deal of amplification must be obtained from a single stage, the gain may be as high as 60 or 80 per stage.

In the intermediate frequency amplifier of a superheterodyne receiver we can get the screen grid tube to work at much higher efficiency. In some cases the gain per stage is as high as 300 at 175 kc., although gains as large as this are not usual. The reason for this is that an intermediate frequency amplifier is designed to resonate at a single frequency and its band width need be only 10 kc. It has no moving parts, it can be carefully shielded at the factory, it has no large parts that are more or less exposed (which might serve as couplings between adjacent stages). Therefore, a high impedance load can be placed in the plate circuit and a much larger portion of the mu of the tube utilized.

Suppose a load impedance at 175 kc. (the intermediate frequency) is made equal to the resistance of the tube. The actual voltage amplification of the tube will be about 200, that is, one-half the mu of the tube. However, any increase in load impedance above this amount will not result in a proportional increase in voltage amplification. Remember that if the plate load impedance is 6 to 8 times the internal resistance of the tube, the voltage amplification will be only about 90% of the mu of the tube.

Now let us stop a moment and review the requirements that must be fulfilled by a good vacuum tube amplifier. In the radio frequency section we naturally want maximum amplification. If we use triode tubes which have a comparatively low internal resistance, we can easily make the plate load several times as large as the tube resistance and obtain almost the entire mu of the tube. But as the mu of an ordinary triode is only 8 or 9, even maximum amplification will not be very large.

On the other hand when we use screen grid tubes that have a very high internal impedance, it is impossible to have a plate load many times this value, so we use as large a plate impedance as we can and leave it up to the high amplification factor of the tube to provide the needed amplification. Even with a comparatively low plate load resistance, a voltage amplification of 30 to 50 is obtained.

In the I.F. amplifier the difference between the screen grid tube and the ordinary triode is much more pronounced. Even if we used '40 tubes, the maximum voltage gain per tube would be less than 30. But when screen grid tubes are used as I. F. amplifiers, the gain per tube may be as high as 300, as previously mentioned.

THE SCREEN GRID TUBE AS AN AUDIO AMPLIFIER

While the screen grid tube is essentially an R.F. amplifier, it can be made to amplify at audio frequencies as has been made evident by the development of the Loftin-White circuit.

The screen grid tube used in a conventional audio system is not very satisfactory. Let us see why. The effect of the plate load resistance on voltage amplification has been stressed in this lesson. When used as an audio amplifier, the screen grid tube should feed into a plate load of about 250,000 ohms. Then the voltage drop across this resistor will reduce the voltage on the plate of the tube considerably and amplification falls off.

The Loftin-White circuit is a rather successful attempt to make use of the screen grid tube as an audio amplifier. It is a so-called "direct coupled" amplifier because there is no condenser between the plate of one tube and the grid of the following tube as in a resistance coupled amplifier. The basic circuit is shown in Fig. 10. The plate of one tube is connected directly to the grid of the following tube. The resistor R_c is the plate supply resistor and provides the load impedance. The sum of the volt-

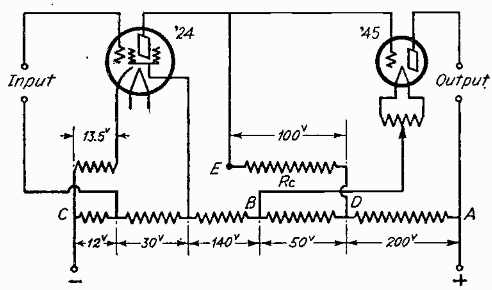


Fig. 10—Circuit showing direct coupled audio amplifier.

ages necessary for the two plate circuits and the two grid biases must be supplied to the terminals of the resistors between *A* and *C*. If *A* is the positive end, then as we progress toward *B* the voltage becomes more and more negative. Thus at *B* the voltage may be 250 volts negative with respect to *A*. This means that the '45 tube plate is 250 volts positive with respect to point *B* and the '45 filament. Point *E* is 50 volts negative with respect to *B* and so the grid has a negative bias of –50^v. The C bias of the '24 tube is –13.5 + 12 or –1.5 volts, and the plate voltage with respect to the cathode is 30 + 140 + 50 — 100 less the C bias of 1.5 volts or 118.5 volts.

It is obvious that a very high supply voltage is required, which is usually considered a disadvantage. The chief advantage of this system is that no distortion can be introduced into the signal by the coupling—which is nothing but a short heavy "jumper" wire with practically no inductance.

THE SCREEN GRID TUBE AS A SPACE CHARGE AMPLIFIER

Some few fairly successful attempts have been made to use present types of screen grid tubes as space charge audio amplifiers. When operated as a space charge amplifier a positive D.C. potential is put on the control grid of the tube and the screen grid is made to act as the control grid—that is, the input is fed directly to the screen grid instead of to the control grid.

Then the positive potential on the inner grid tends to overcome the effect of space charge and the electrons emitted from the cathode are speeded up on their way to the plate. The screen grid which is now the control grid regulates the number of electrons that actually reach the plate in accordance with the signal voltages impressed on it.

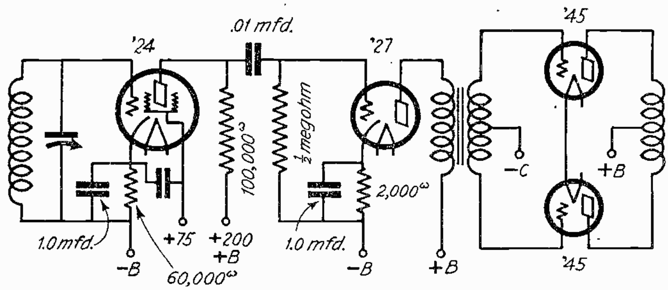


Fig. 11—Circuit of a screen grid detector working into a push pull power stage through an intermediate amplifier.

Operating a screen grid tube in this manner changes its characteristics considerably. The internal impedance is naturally made smaller and so is the mu—the theoretical maximum amplification obtainable—because the control grid is now much closer to the plate.

In practice it has been found that a '22 type tube used as a space charge amplifier will have a plate impedance of about 125,000 ohms and an amplification factor of approximately 100. Of course the amount of actual amplification that can be obtained is dependent on the A.C. resistance in the plate circuit.

The space charge amplifier has the advantage that it can take a weak audio signal and amplify it considerably, but it also has the disadvantage that amplification falls off above 2000 cycles due to the capacity between the plate and the screen grid, so that while low frequency response is good, high frequency response is rather poor.

It may be that special tubes will be developed for use as space charge amplifiers which will not have the disadvantage of poor high frequency response. The main difficulty with the present screen grid tube used in this manner is that the spacing of the elements does not permit uniform audio response.

THE SCREEN GRID TUBE AS A DETECTOR

In many modern receivers the screen grid tube is used as a detector feeding into a '27 tube which in turn feeds into a push-pull amplifier using '45 tubes, through a transformer coupling.

TABLE NO. 1

Type 224			*Type 222*			*Type 232*		
Ep	Esg	Eg	Ep	Esg	Eg	Ep	Esg	Eg
180	25	–2.5	135	22.5	–4.5	135	45	–3.0
"	35	–3.5	"	45	–9.0	"	67.5	–5.0
"	45	–4.5	"	55	–11.0	"	90	–8.0
"	55	–5.5	"	67.5	–13.5			
"	65	–6.5	"	75	–15.0			
"	75	–7.5						
250	90	–9.0						

Ep = plate voltage.
Esg = screen grid voltage.
Eg = C bias voltage.

The usual value of plate voltage on the screen grid detector is 180 with a C bias of –7.5. The plate load impedance is usually about 100,000 ohms. See Fig. 11.

This system will do about the same amount of work as a '27 tube with a C bias of –20 volts and 180 volts on the plate, or a C bias of –30 with 250 volts on the plate (see Fig. 12).

To deliver a large enough voltage swing to load up the push-pull '45's, a '27 detector would require from 20 to 30 peak volts on its grid. On the other hand, the screen grid detector will load up the '45's through an intermediate '27 stage with only 7 peak volts on its grid. This increase in gain is obtained at the cost of an additional '27 tube between the detector and the push-pull stage but it eliminates some R.F. amplification before the detector.

The screen grid tube, like the triode, is universally used as a

C bias detector in modern broadcast receivers. Only in amateur sets or in special cases is the grid leak and condenser detector used.

In Table No. 1 various operating voltages for the different types of screen grid tubes when used as detectors, are given.

THE POWER PENTODE

While a screen grid tube is an extremely efficient R.F. amplifier and detector, and a fairly good audio amplifier it cannot be used as a power output tube. Let us see why. Suppose a signal voltage causes the control grid of the tube to swing from 3 volts positive to 3 volts negative. This voltage swing is amplified 75 times by the tube so that the signal voltage in the plate circuit swings from 225 volts positive to 225 volts negative. If

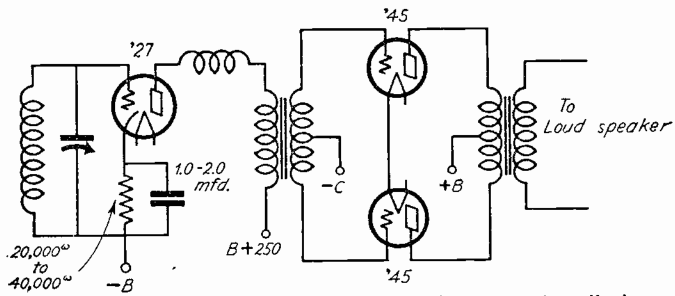


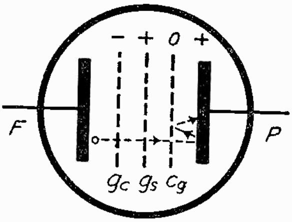
Fig. 12—Circuit of a '27 detector working into a push pull stage.

the applied plate voltage is 250, it can readily be seen that when the signal voltage is –225, the total plate voltage will be only 25 volts. When the instantaneous plate voltage is 25, there will be considerable secondary emission—that is, a considerable flow of electrons from the plate to the screen grid resulting in distortion.

In addition to this the plate load impedance on a screen grid tube should be extremely high. Therefore the power output obtainable from a screen grid output tube would be very low.

Triode output tubes are very satisfactory but their amplification factors are low—3.5 for a '45 tube. Therefore designing engineers set out to design a tube that would incorporate the advantages of the screen grid tube (high amplification factor) and still be capable of supplying a large undistorted power output. The result was the A.F. pentode.

This pentode has an additional grid, which is connected to the cathode (and so is at ground potential), between the plate and the grid which corresponds to the screen grid of a screen grid tube. This cathode grid as it is called prevents secondary emission electrons leaving the plate from getting to the screen grid as this cathode grid is highly negative with respect to the plate. Any electrons that leave the plate are instantly attracted



gc = control grid   gs = screen grid
Cg = cathode grid

Fig. 13—Illustration showing how the three grids of a pentode tube are arranged.

back to it. Due to the practical elimination of secondary emission effect, the distortion due to secondary emission is eliminated.

In addition to this the power pentode tube is so designed that undistorted power output is obtained when the tube feeds into

TABLE NO. 2

American A.F. Pentode Tubes

	Tube Types 247	238	233
Filament voltage ...	2.5 volts	6.3 volts	2.0 volts
Filament current...	1.75 amperes	0.3 amperes	0.26 amperes
Plate voltage	250	180	135
Screen voltage.....	250	180	135
Grid voltage.......	–16.5	— 18	–13.5
Plate current.......	31 ma.	14 ma.	14.5 ma.
Screen current.....	6.0 ma.	2.4 ma.	3 ma.
Plate resistance....	60,000 ohms	115,000 ohms	50,000 ohms
Mutual conductance.	2,500 micromhos	1,050 μ mhos	1,450 μ mhos
Amplification factor	150	120	70
Load resistance....	7000 ohms	11,600 ohms	7,000 ohms
Power output	2.7 watts	1.0 watts	.700 watts

a plate load impedance which rarely exceeds ¼ the internal impedance of the tube.* Thus the load impedance for maximum undistorted output for 247 or 233 need be only about 7000 ohms.

In an audio tube the matter of internal capacity is relatively unimportant as the capacity would have to be very large to per-

* Table No. 2 shows for modern tubes a load of 1/7 to 1/9 of the plate resistance gives maximum power output with minimum distortion.

mit audio feed-back. Therefore there is no shielding grid on the outside of the plate, and the grid which corresponds to the inner half of a screen grid in a screen grid tube serves merely to overcome space charge effects. It is kept at a potential equal to the potential of the plate.

8 Because the A.F. pentode has a large power output and a high amplification factor (as compared with power triodes) it is a very sensitive power tube. Pentodes now on the American market deliver about the same maximum undistorted power output as a triode operated with the same plate voltage, but require

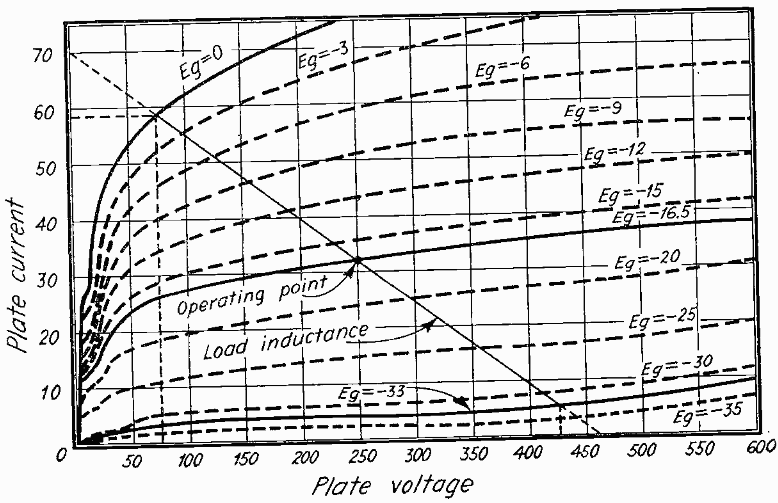


Fig. 14—Plate current characteristics of a modern power pentode.

only ¼ as much grid A.C. voltage because of their high amplification constant. See Table No. 2 for operating characteristics.

Many receivers now on the market employ pentode tubes in the output—in some receivers you will find two pentodes in push-pull—and in many cases, the detector feeds directly into the output stage.

The pentode is an especially valuable development for use in midget receivers where space is at a premium and it is necessary to use as few A.F. stages as possible. In some of the more recent midget receivers the detector feeds directly into a single pentode (without any intermediate A.F. stage) which provides all the audio amplification and power output needed for the operation of the loudspeaker.

THE PROPER LOAD RESISTANCE FOR AN A. F. PENTODE

It has been mentioned that for maximum undistorted output a pentode should work into a load resistance less than ¼ that of the tube resistance. Now we are going to see how a radio engineer would go about determining the exact load impedance which should be used.

First he will get a family of plate voltage-plate current curves like those shown in Fig. 14. Then he will locate on the graph, the operating point set by a definite grid bias and plate voltage. In our calculations we are considering a 250 volt plate voltage and a grid bias of –16.5 volts.

It is clear that the grid can swing just 16.5 volts either side of the bias value without becoming positive and for minimum distortion there must be the same change in plate current for a

TABLE NO. 3

Load Resistance Ohms	*Second Harmonic %*	*Third Harmonic %*	*Watts Output*
4,000	3.9	3.8	2.15
6,000	1.7	5.4	2.60
8,000	1.7	6.7	2.8
10,000	5.5	8.0	2.77
12,000	10.9	9.0	2.62
16.000	17.8	9.3	2.40

16.5 volt negative swing as for a 16.5 volt positive swing. If we draw a straight line through the operating point that will cut both the $E_g = zero$ and the $E_g = -33$ volt lines in such a way that both halves of the line are equal, this line will represent the correct impedance. Now all we have to do is to find the numerical value of this load impedance.

We know that load impedance is equal to the A.C. plate voltage divided by the A.C. plate current component ($E_p \div I_p$). We extend our straight line to the edges of the graph. As you will see from Fig. 14, the line now cuts the plate voltage line at about 465 volts and the plate current line at about 71 ma. Dividing 465 by .071 we get approximately 6500 ohms which is approximately 1/9 the internal resistance of the tube.

What would happen if a higher resistance were used and the portion of the line below the operating point would be longer than that above the operating point? For a given signal voltage there would be a greater increase in plate voltage on the negative half cycle than a decrease in plate voltage for the positive half cycle and distortion would result.

In Table No. 3 you will find data on distortion in relation to various values of load resistance as well as relation between power output and load resistance. It can be seen from this table that of the load resistances considered, 6000 ohms would give the maximum undistorted output.

It will be noted that the power output is fairly constant irrespective of the load resistance, which is not at all like the relation between these two factors in a triode circuit. When a triode is used as a power output tube and the impedance of the loudspeaker varies considerably, the power fed to the speaker will vary proportionately. However, in a pentode circuit, the impedance of the speaker may vary appreciably without affecting output power very much.

VARIABLE MU TUBES

The screen grid tube was designed for one purpose—to deliver a large voltage from a small one. When it is called upon to handle a large voltage, it tries but fails. The tube is not designed for that purpose; it has a steep plate current curve so that a large voltage soon drives the plate current to zero. On the other hand a low mu tube is designed to perform another job, it takes a fairly high input voltage and delivers considerable *power* (not a large voltage) from it. It can handle a large signal, but it does not amplify voltage much.

Now consider a modern broadcast receiver, using screen grid tubes, in the vicinity of powerful broadcasting stations. Very strong voltages are induced in the antenna by waves from these nearby powerful stations. To reduce the volume to a comfortable level the control grid bias of the screen grid tubes is increased, thereby decreasing the mutual conductance and the amplification of each stage. But in increasing the C bias we approach the zero current or cut-off point. Then on the first tube, particularly, these strong signals force the plate current to go toward zero at times causing it to act as a detector of unwanted signals. These audio signals modulate on the carrier of the station that is tuned in and the result is "cross-modulation," which "rides into" the rest of the receiver on the desired carrier and finally reaches the loudspeaker, either as a signal in which the true tones are distorted or even in gasps or crashes of bits of music.

If, on the other hand, a low mu tube is used in the first stage, it can handle considerable input voltage because its grid bias can be increased to many volts before plate current cut-off occurs. (See Fig. 15.) But a low mu tube will not produce much amplification. And there is the dilemma. The hi-mu tube, such as the screen grid tube, produces the desired amplification but

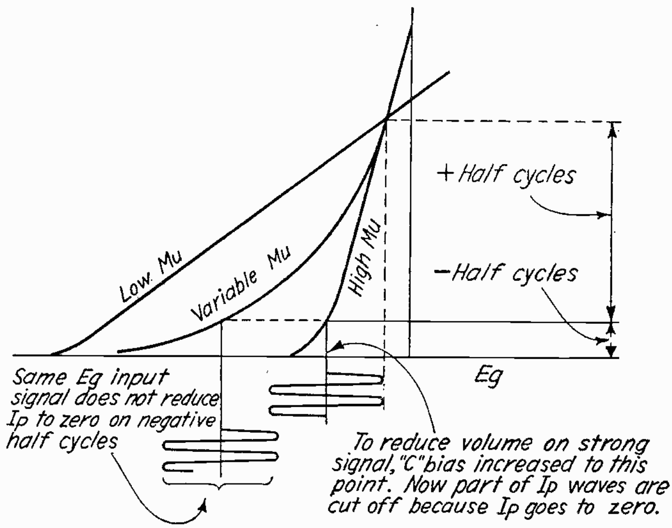


Fig. 15—Comparison of characteristics of high mu tube, low mu tube and variable mu tube. Note the gradual slope and wider grid voltage range of the variable mu tube.

also distorts (modulation distortion*) on strong signals. The low mu tube will handle the strong signals but produces little or no amplification.

The most common method of eliminating cross-modulation without decreased selectivity is the use of an R.F. band-pass selector before the first R.F. tube. The selectivity of this R.F. band-pass is such that only the desired carrier is impressed on the first tube.

The idea occurred to the inventors of the variable mu tube to get around these difficulties in the following manner. The trouble with the screen grid tube is that its plate current goes to zero with large C biases. Let us shunt this tube with a low mu tube so that some plate current still flows even when the C

* This type of distortion is due to unequal amplification of the signal because the tube is worked over the curved portion of its Eg-Ip characteristic.

bias is so increased that the screen grid tube no longer passes plate current. Then current cut-off does not occur, and the volume control can be worked right down to the point where the local signal has the desired level.

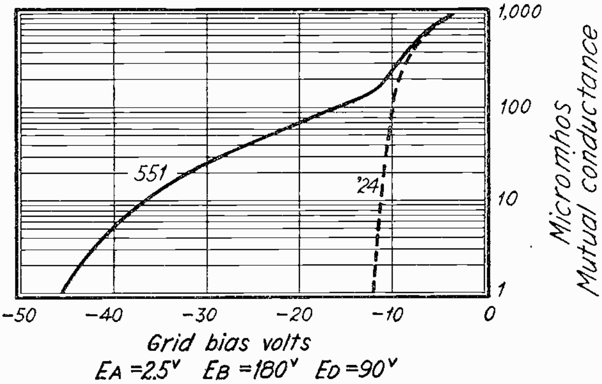


Fig. 16—Comparison of mutual conductance of variable mu and screen grid tube. Notice how much longer the variable mu tube continues to show mutual conductance.

Such a scheme worked. But it took two tubes to do the work of one. The next step was to put two grids in the same tube, one grid being coarse like that of a low mu tube and the other fine like that of a high mu tube. At high C biases, corresponding to reduced volume control, the high mu tube ceases to pass current but the low mu part of the tube continues to pass current.

From the E_g-I_p curve of a variable mu tube in Fig. 15 it can be seen that the slope of the curve is different at various operating points. The operating points are determined in practice, by the C bias setting. Of course the difference in slope means a dif-

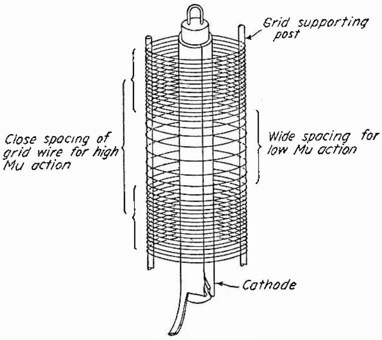


Fig. 17

ference in mutual conductance (g_m) so that the mutual conductance is directly controlled by the grid bias and this control is obtained by the introduction of a variable resistance in the cathode to ground lead of the tube.

The variations in g_m with grid bias are shown in Fig. 16 with corresponding variations for the '24 type tube plotted in the same graph for purposes of comparison. Notice that the g_m of the variable mu tube varies over a considerable range of bias whereas the g_m characteristic of the '24 tube cuts off sharply.

With increased negative bias the g_m decreases, that is, the amplification of the tube goes down. Therefore at a low negative bias, the tube acts as a high mu tube and at a high negative bias, the tube acts as a low mu tube.

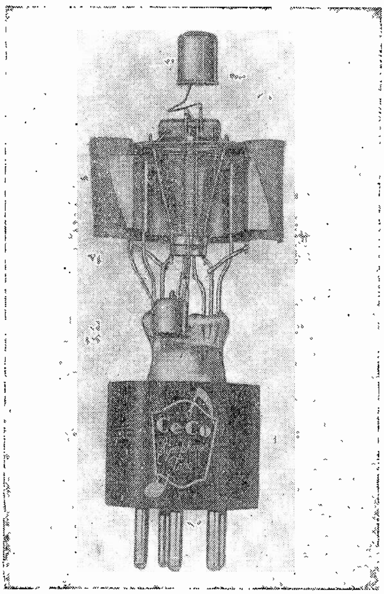


Fig. 18—Exploded view of a variable mu tube.

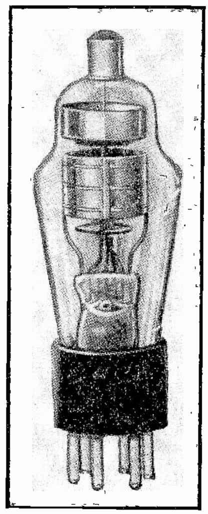


Fig. 18a—A.C. R.F. Pentode with a 6 prong base.

Because the E_g-I_p characteristic of a variable mu tube is long
9 and does not cut off sharply, the two types of distortion, that is, cross-modulation or modulation distortion, is less than in ordinary receivers using screen grid tubes.

The variable action of the tube can best be explained from the physical construction of the control grid. See Fig. 17. When
10 there is a low bias on the grid, the controlling effect of the grid on the electron stream is small. As the bias is increased, the grid offers greater opposition to the electron stream but this opposition is concentrated at those portions of the grid where the wires are close together. Electrons still find it possible to get through the grid at the points where the wires are spaced

farther apart—even though the potential is the same at all points on the grid. As a result, at high C biases or when large negative voltages are impressed on the grid, some plate current still flows.

Another construction is shown in Fig. 18 where the grid is closer to the plate at one end than at another. The closer it is to the plate, the lower the mu.

The variable mu tube eliminates the need for local-distance switches and for preselecting to eliminate cross-modulation. This effects a considerable economy and simplicity of operation. The types '35 and '51 variable mu tubes will handle about 25 times the input voltage, without trouble, as a '24 tube. It is only necessary to provide the proper range of grid bias, which is not difficult. (See Figs. 19a and 19b.) The tubes cannot be introduced into receivers not engineered for them and still retain the full advantages of the newer tubes.

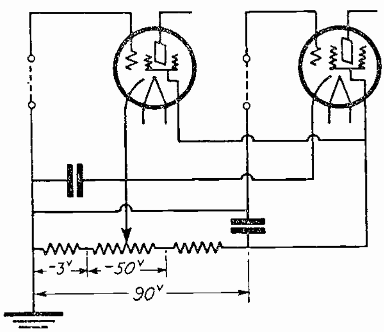


Fig. 19(a)

R.F. PENTODES

If the screen grid tube is designed with a third grid placed between the plate and screen grid and connected to the cathode, a tube with characteristics like the variable mu tube will be obtained. In fact, its ability to reduce modulation distortion will be even greater than that of the variable mu tube.

An electron, upon leaving the filament or cathode, is attracted to the plate of the tube. Its velocity at the plate is so high that secondary emission takes place. The electron cannot be drawn to the screen grid because of the pentode grid and as the plate is at a higher potential than the pentode grid, the knocked off electrons are attracted back to the plate where they belong. Thus the dip shown in Fig. 6 between 0 and 50 volts on the plate is eliminated and a regular, smooth characteristic is obtained.

The E_g-I_p characteristic becomes long drawn out as shown for the variable mu tube in Fig. 15, thus making the R.F. pentode act like a variable mu tube. The same type of C bias volume control is required.

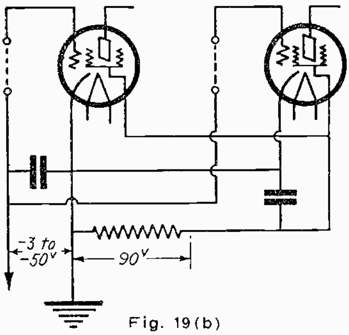


Fig. 19(b)

Table No. 4 gives the characteristics of the four types of R.F. pentodes now in use. The '39 tube is the automobile receiver tube, the '34 is a companion tube to the 2 volt filament series, and the '58 is a special pentode that is now superseding the '35 and '51 type tubes. Its third grid (the suppressor or

TABLE NO. 4

	'34	'39	'58	'57
Filament volts	2.0	6.3	2.5	2.5
Filament amperes	0.06	0.3	1.0	1.0
Plate volts	135	135	250	250
Control grid volts (minimum)	-3	-3	-3	-3
Control grid volts (maximum)	-22.5	-40	-50	-7
Screen grid volts	67.5	90	100	100
Amplification factor (maximum)	360	530	1280	1500
Plate resistance—megohms	0.6	.54	.8	1.5
Mutual conductance—micromhos	600	980	1600	1225
Plate current MA	2.8	4.4	8.2	2.0
Screen current MA	1.0	1.2	3.0	1.0
Socket	UX	UY	Six prong.	Six prong.

cathode grid) is not connected to the cathode internally but is brought out to the sixth prong.

The '57 type pentode has none of the characteristics of the variable mu tube, in which it differs from the other R.F. pentodes. It is similar to the '58 tube in appearance and construction but it is intended to supersede the '24 detector and voltage amplifier. Note that its C bias is —3 volts and that plate current cuts off at —7 volts. Think of it as a screen grid tube with good characteristics.

TEST QUESTIONS

Be sure to number your Answer Sheet 18 FR-1.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and the best possible lesson service.

1. Explain briefly how the tetrode (screen grid tube) practically eliminates grid to plate capacity.

2. Why is complete shielding of tubes and stages essential in a screen grid receiver?

3. How is the screen grid kept at ground R.F. potential?

4. What is "secondary emission" in a screen grid tube?

5. Why is the actual voltage amplification of a stage of R.F. amplification using a screen grid tube much less than the mu of the tube?

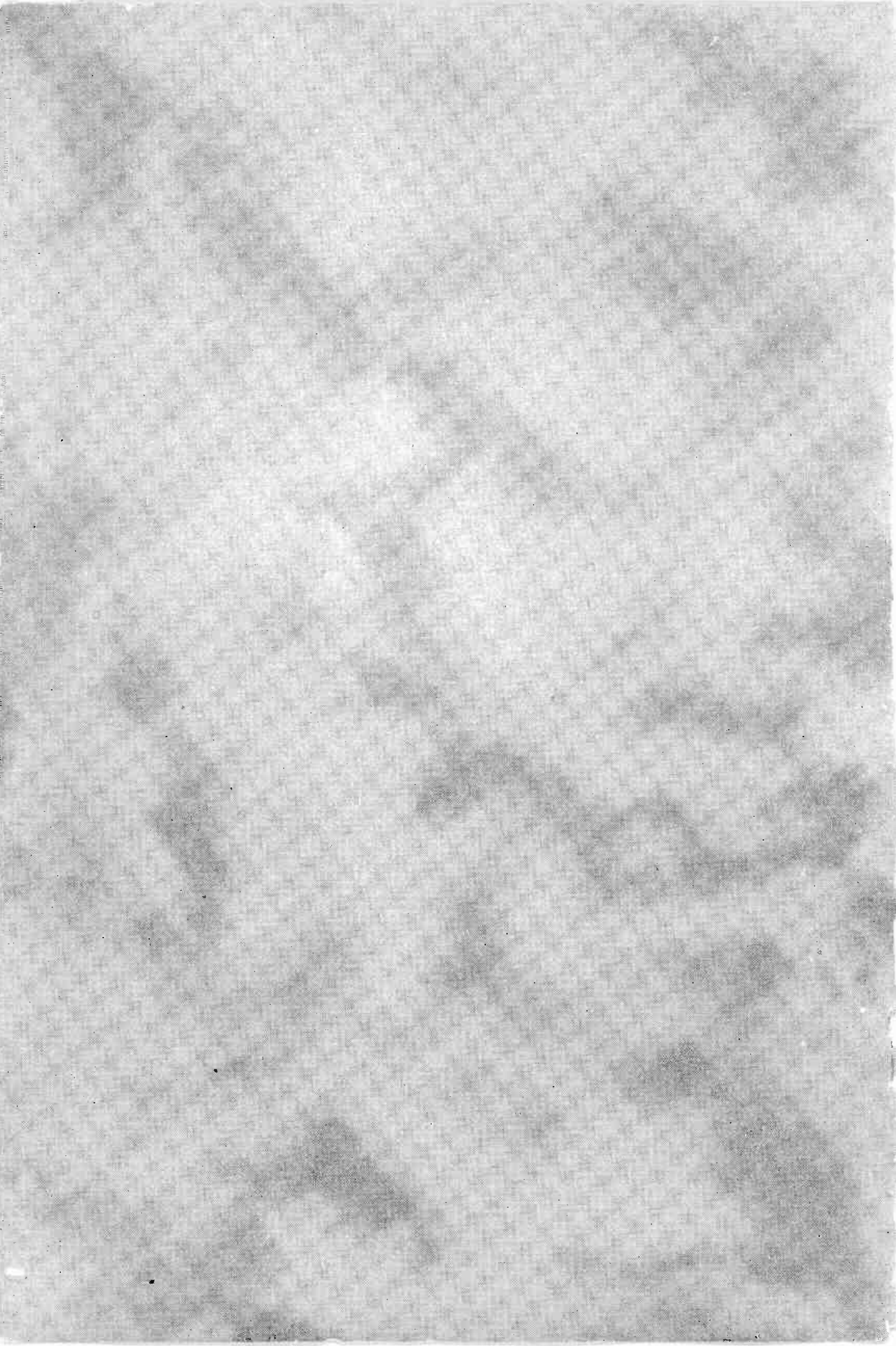
6. How are the secondary emission electrons from the plate, prevented from getting to the screen grid in the pentode?

7. How should the plate load impedance compare with the internal impedance of a power pentode?

8. Why does the use of a power pentode make unnecessary an intermediate audio amplifier stage?

9. What two types of distortion that are common in ordinary screen grid receivers are overcome by the use of variable mu tubes?

10. What is the difference in the amplification factor of a variable mu tube at a high negative bias and at a low negative bias?



PRACTICAL R.F. CIRCUITS AND METHODS OF CONTROLLING VOLUME

19 FR-1

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

THE MIDDLE COURSE

The old Romans had a phrase that was frequently on their lips. Translated into English, it was, "moderation in all things."

Most of us have been taught, from early childhood on, the necessity for moderation in eating and drinking. But the fact that moderation in all things is essential to happiness is largely overlooked.

Take for example the simple matter of opinions. You have certain ideas about things—certain opinions. If you can see only your own opinions—if you won't alter your opinions, even though your reason tells you you are wrong, you are opinionated. And opinionated people don't get along very well with other people—and for this reason are often unhappy.

On the other hand you may yield your ideas to another's too readily. Then you are weak-kneed—and also unhappy.

But if you can give and take—if you are open to reason, if you steer a middle course, you will be liked, people will be comfortable in your company. As a consequence you will enjoy your association with others and you will have learned one of the first rules of happiness.

The same idea of moderation should guide you in everything. In your dress be neat but not foppish. In your association with people be courteous but not fawning or affectedly polite. Be sympathetic but not sentimental. Be self-confident but don't be led into difficult situations by overconfidence. Don't believe everything you hear but don't think that everything you are told is false.

Let "moderation in all things" be one of the guiding principles of your life.

J. E. SMITH.

WASHINGTON, D. C.

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Practical R. F. Circuits and Methods of Controlling Volume

ANTENNA CIRCUITS

Up to this point in the course we have been chiefly concerned with the various actions that take place in a Radio receiver, as individual actions. We have made a detailed study of resistances, inductances, and condensers. We have learned that circuits can be coupled by capacity, resistance, inductance or mutual induction. We understand resonance, the theory, use and construction of vacuum tubes, wave filters, power transformers, A. B. C. supplies. We know how detection is accomplished and how audio frequency variations are converted into sound waves. Now we are ready to assemble our knowledge and in our study of complete Radio circuits we shall tie up all we know and thus take a big step forward toward our Radio goal.

The function of a Radio receiver is to collect, from the ether, the Radio waves which carry with them the message or entertainment sent out by the transmitting station. The ideal receiver, the aim of all Radio engineers, should intercept this signal, amplify the radio frequency current without cutting side bands and without allowing adjacent frequencies to interfere; the detector should separate the audio signal from the carrier wave without distortion. A perfect audio system should amplify the rectified signal and step-up its intensity so that it is strong enough to operate a loudspeaker. No distortion should be allowed in the speaker, it should not produce any audible vibrations of its own.

This ideal receiver has not yet been built in spite of many claims of perfection and near-perfection. And yet, year after year, our busy Radio engineers are coming closer to it.

Of course, we cannot start our study of circuits with the receivers of most advanced design. As always, the only proper way to learn anything is by following the steps of its development.

It was not many years ago that the crystal receiver was the last word in Radio. In fact, the crystal receivers of those days were more reliable than the vacuum tube sets. Today the crystal receiver is practically obsolete. But still, a brief study of a crystal circuit will teach us a great deal about circuits in general.

Figure 1 shows, in diagram form, a crystal circuit. It is this circuit that was used when crystal sets were at the height of their popularity. It consists of three circuits coupled together A-C_1-L_1-G form one circuit—a series circuit. Although mechanically simple, electrically this circuit is about the most difficult to understand thoroughly.

The aerial A and the ground form a condenser having a capacity of usually .00025 mfd. The aerial can be considered as one plate of a condenser and the ground as the other plate. Besides this, the aerial itself acts as an inductance. Accordingly, we have in the aerial circuit, considering only the antenna and the ground, antenna capacity (C_a) and antenna inductance (L_a). Figure 2 shows how capacity exists between the aerial and

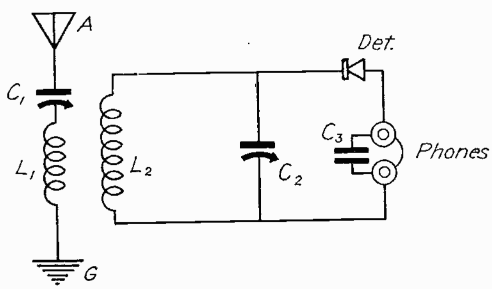


Figure 1

ground, and shows that the aerial wire is equivalent to a large number of small inductances in series (L_a).

The circuit in Fig. 1 has a variable condenser C_1 and an inductance coil L_1 in the antenna system. By means of C_1 the aerial system can be tuned to the desired frequency.

Thus there are two capacities in this antenna circuit, C_a, C_1 and two inductances L_a and L_1, all of which determine the frequency to which the circuit will resonate; but only C_1 is variable. Figure 2a shows a circuit containing these electrical properties and 2b&c show its equivalent—the two inductances add; the capacity of C_a is considered with the capacity C_1—the total value being the capacity of the fixed condenser plus the varying value of the variable condenser, thus $\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_a}$.

As you know, the electromagnetic wave which carries Radio signals, striking an antenna which is so tuned that it is in resonance with the waves, causes an electric current to flow in the antenna. The Radio wave may be considered to be in two parts—the "electro" part and the "magnetic" part. The first is an electrostatic field like the field existing between the plates of a charged condenser. The second is a magnetic field like the field between the primary and the secondary of a transformer which is carrying current. Both fields travel outward from the transmitting antenna, in all directions, at a speed of 300,000,000 meters per second.

These two fields exist together in Radio and both accomplish practically the same thing in the receiving antenna, but in different ways. The magnetic field induces current flow as it cuts the

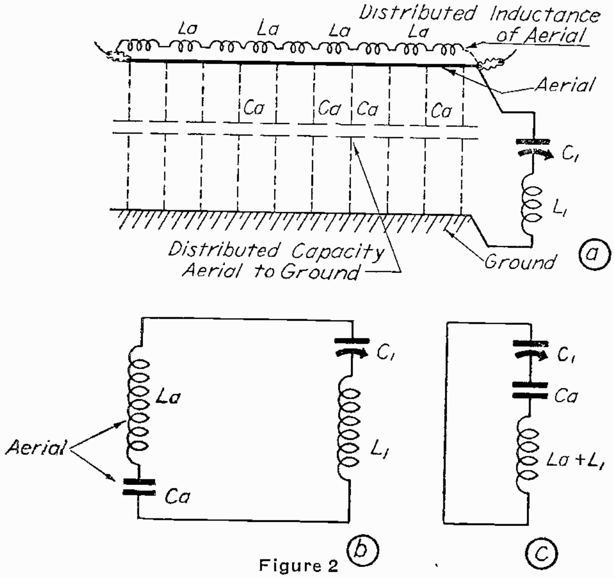


Figure 2

aerial wire or wires, the electrostatic field charges the condenser, of which the aerial is one-half and the ground the other. Theoretically, either field would produce the same result—actually, however, the one does not exist without the other in Radio waves.

By tuning, we mean putting a circuit in resonance with the frequency on which the desired station is transmitting. Suppose we want to tune in a station broadcasting on a frequency of 300 kilocycles. Let us say that at maximum value of C_1, the circuit would respond to a frequency of 250 kilocycles. With the full capacity of C_1 in the circuit, no voltage would be induced in the antenna by the 300-kilocycle waves. But by decreasing the value of C_1 the 300-kc. signals will be gradually tuned in. By further decreasing C_1 beyond the point of resonance, the 300-kc. current in the antenna will again be reduced to zero.

The antenna circuit, because it is the first circuit, is called the *primary circuit.* Adjusting the primary circuit for maximum signal current of a certain frequency is *antenna tuning* and is of great importance in crystal receivers.

For sharp tuning, the aerial should be of stranded, flexible wire, 50 to 75 feet long, as high in the air as possible. The best possible ground should be used. Good aerials and good ground connections made possible a number of records for distance with crystal sets.

This does not apply only to crystal sets—it applies to every set, late or old. The better the aerial system, the more satisfactory the reception, every time.

Now let us assume that the variable condenser C_1 (in Fig. 1) has been tuned for maximum R.F. current at a frequency of 300 kc. By mutual induction between L_1 and L_2, a voltage is induced in coil L_2, the secondary. L_2 and C_2 form another resonant circuit and if C_2 is tuned so that its circuit is at resonance with the incoming signal, the maximum current will flow. L_1 and L_2 usually are the primary and secondary of a step-up transformer so that a comparatively large voltage will be induced in L_2. If L_1 consisted of 15 turns of wire and L_2 of 60 turns, the voltage step-up would be 4, that is, the voltage in L_2 would be 4 times the voltage in L_1. In actual practice, however, the step-up would be less than 4 due to magnetic flux leakage.

So far the Radio signal has passed through two tuned circuits and in doing so should have separated itself from possible interfering waves—these should have been tuned out. But if L_1 and L_2 are coupled closely, any interfering waves will be stepped-up and passed along together with the signal current. For this reason, L_1 and L_2 are usually separated from each other. Then the coupling is "loose" and while loose coupling means a lower signal strength passed along, it means greater selectivity, it makes the tuning-out of unwanted frequencies easier.

The type of coupling naturally affects the point of resonance. Changing L_1 and L_2 in our circuit which is tuned to 300 kc. from close to loose coupling, would necessitate a readjustment of C_1 and C_2.

The voltage in L_2 and across the capacity C_2 is modulated radio frequency voltage, just as it was in the aerial circuit. It is the carrier current modulated by the voice or music sound vibrations. We say that the voice current is *impressed* on the carrier current which is a radio frequency current. Now it is necessary to separate the voice current from the R.F. or carrier current and to do this a rectifier is needed.

Rectification is accomplished in the circuit in Fig. 1, by means of a crystal rectifier in series with a pair of earphones. The crystal separates the voice current from the carrier current and only the voice current flows through the phones.

Figure 3a represents the original modulated e.m.f. as it exists across condenser C_2. The effect of the crystal is to cut off the lower portion, allowing only the part above the zero line AB to flow through the phones. What passes through the phones then is a pulsating direct current of a high frequency. See Fig. 3b for the curve of this current.

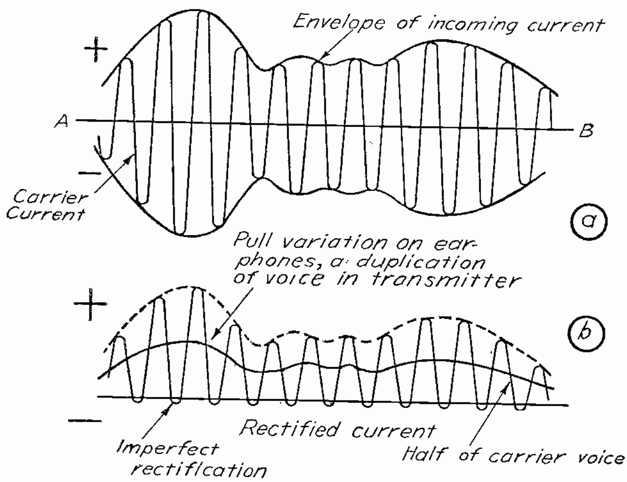


Figure 3

But phones are made to respond to voice frequencies only—they can't follow the up-and-down movements of the high frequencies. Their diaphragms move in and out only to the extent of the changes in current amplitude. They follow these changes in a manner shown by the solid line in Fig. 3b, which, as you see, represents the average distances between the top and bottom peaks.

Some of the R.F. current may get through the crystal unrectified. If allowed to go through the phones it would cause distortion. For this reason a fixed condenser C_3 is connected across the phones. C_3 provides a path for these unrectified R.F. currents to flow over, taking them out of the phone circuit thus reducing distortion due to incomplete rectification. This is called *by-passing*. You will learn more about by-pass condensers later on in this lesson.

There were as many modifications of crystal receivers as there are of electric receivers today. A few are shown in Fig. 4. The simplest possible receiver is shown in Fig. 4a. The aerial and ground form the only resonant circuit and its resistance is so great that it is tremendously "broad." The signals are rectified in passing to the ground and only the audio currents flow through the phones. Obviously, this receiver could be used only near one very powerful broadcast station.

Figure 4b shows a circuit from which the antenna variable condenser has been eliminated. Approximate antenna tuning is obtained by varying the inductance which is tapped, either with a tap switch as shown in 4c or by a slider as used in rheostats.

None of these circuits has any means of volume control. The fact is, there is very little need for controlling the volume as maximum volume is not very loud. When necessary, volume was controlled by tuning off resonance with any of the tuning adjustments.

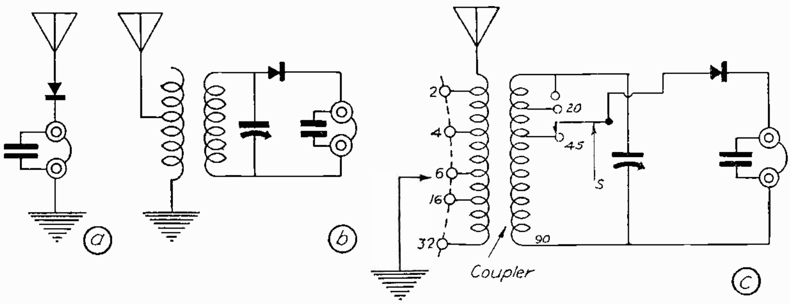


Figure 4

By tapping the secondary as in 4c, three degrees of loudness are possible. Volume is least when the selector switch S is on the 45-turn tap. A coupler like the one in 4c can easily be made by winding 32 turns of No. 28 double cotton covered wire, tapped as shown, for the primary, and by winding 90 turns of the same wire, properly tapped, for the secondary. The tubing on which the windings are placed should be about 2 inches in diameter. The primary and the secondary should be separated by about ¼ to ⅜ of an inch. Single layer winding only should be used. Tap 2 should be farthest away from the secondary.

Although crystal receivers are practically out-of-date at the present time, a study of them is very valuable and will help you to understand the various actions in a receiver, particularly tuning, which is a matter of tremendous importance.

The use of crystals as detectors (rectifiers) has by no means been discontinued. Crystals have some advantages as detectors —crystal reception has remarkable clarity and fidelity. Many experimenters today are using crystal detection along with vacuum tube amplification and claim that crystal detection "can't be beat" for clarity and fidelity of signals.

The circuit diagram in Fig. 5 shows how an audio amplifier may be added to a crystal circuit for loudspeaker reception. A first audio using a UX-199 tube and a stage of power amplification using a UX-120 tube will operate a sensitive speaker with sufficient volume and surprising clarity. Volume control can be had either by tuning off resonance at C_1 or C_2 or by means of rheostat R.

C_1 and C_2 are not ganged. Single dial control is not practical for these circuits as everything depends on very careful tuning.

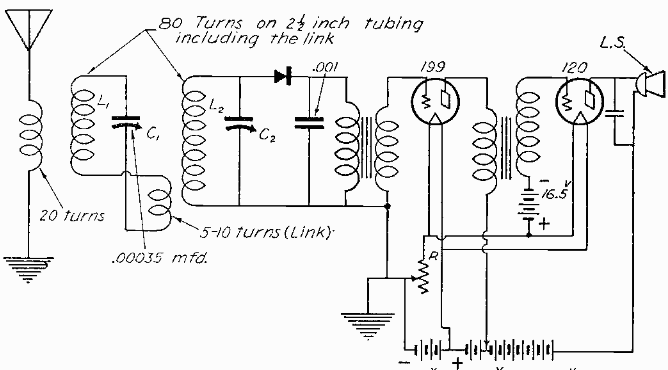


Figure 5

This is the circuit that many experimenters still "swear by." Some introduce regeneration (which we shall study next) with surprisingly good results.

Before leaving the study of crystal receivers, go over carefully the tuning system. Note that there are two tuned circuits controlled by C_1 and C_2—that the two circuits are coupled by a 5 to 10 turn "link."

This link can teach us a very important fact and that is, that things should not be despised because they are out of date. It is often said that there is nothing new under the sun, that everything called new is something old "dressed up" or in another form. This 5 to 10 turn link which was the latest thing in crystal receivers some years ago is coming back strong in the latest screen grid receivers.

This arrangement is now called "band pass tuning" and coupling between filter stages is accomplished by means of mutual induction. The fewer the turns in the link, the sharper the tuning and the better the selectivity.

Radio frequency amplification is usually impractical in the case of crystal receivers, although one stage is sometimes successfully used. The difficulty is that crystals do not hold up when called on to handle strong signal currents.

REGENERATIVE RECEIVERS

Detection by means of vacuum tubes is by no means a new thing to you. And you have learned that the grid-leak method is very sensitive to weak signals.

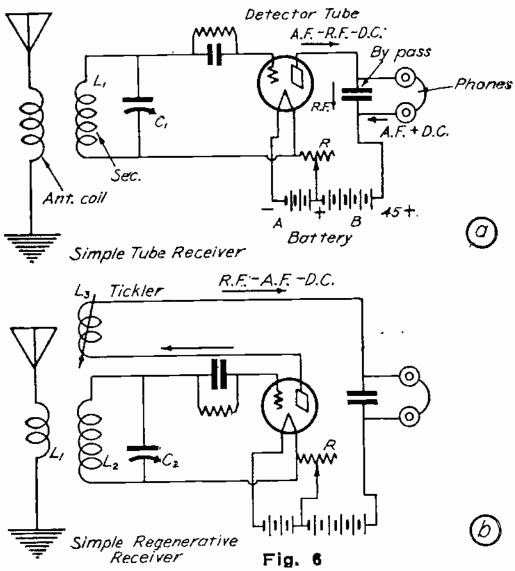


Fig. 6

Figure 6a is the diagram of a circuit using grid-leak detection, that was the last word in Radio receivers just a few years ago. The tuning system is practically the same as in the crystal receiver—and from a strictly engineering point of view, not much different from those of the present day. Of course, only broad tuning is possible in the antenna circuit. This circuit is loose-coupled to the only tuning system, L_1 and C_1. A vacuum tube detector takes the place of the crystal detector and critical adjustment for sensitive detection is made possible by rheostat R and by varying the voltage for the B supply.

As a Radio-Trician you know that a grid-leak detector is equivalent to a stage of detection and a stage of audio amplification. Detection is imperfect, however, in this arrangement and some R.F. current gets into the plate circuit. The by-pass prevents this stray R.F. from getting into the phones.

This receiver is much superior to the *diode* tube receiver in Fig. 7. The *diode* tube acts as a rectifier only—no audio amplification is possible with it.

It is interesting to know that the diode tube, invented by Dr. Fleming, the English father of modern Radio, is as old as crystal detectors. And curiously enough the diode tube has reappeared just recently as a detector and has been used in B and C supply devices for some time.

Audio frequency stages may be added to either of the above *simple circuits* by any of the means you learned in previous lessons. Many old commercial receivers used these circuits to-

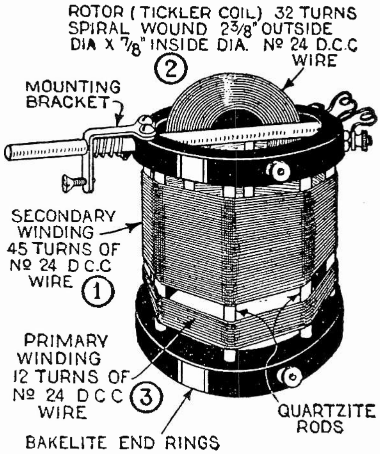
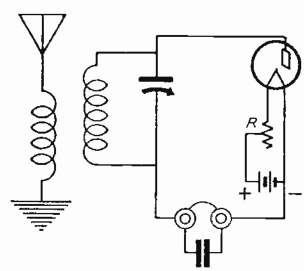


Fig. 6c—Three Circuit Tuner.



Diode Tube Receiver
Figure 7

gether with sufficient audio amplification to operate loudspeakers.

Now let us go back to the circuit in 6b for a moment. It is exactly like the simple tube receiver except that 6b has coil L_3 in the circuit. This coil is called the "tickler" coil.

It should be understood that the current flowing in the plate circuit of a detector tube is a combination of audio frequency (A.F.) current, direct current (D.C.) and a small amount of unrectified radio frequency (R.F.) current. The R.F. current is undesirable and of no use whatever in circuit 6a. But knowing that any change in grid voltage (the voltage across L_1) is amplified by the detector and the audio action of the detector tube, Armstrong devised a scheme whereby the R.F. in the plate circuit was returned to coil L_2 by mutual induction between L_2 and L_3. A "feed-back" of this kind is very critical so the mutual induction must be variable. See Fig. 6b.

Inductances L_1, L_2, and L_3 form a tuning coil unit. A modern coil, called a three-circuit tuner is shown in Fig. 6c. The three circuits that are brought together in this coil are: the aerial circuit, the resonant circuit L_2-C_2 and the feed-back plate circuit.

The use of this system makes possible the building up of very weak signals and the sensitivity of the receiver is greatly improved. This re-enforcement of the incoming signal by feeding some of the plate energy back to the grid is called *regeneration.* In a regenerative circuit, the tube acts as an R.F. amplifier,

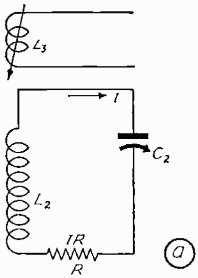


Fig. 8a

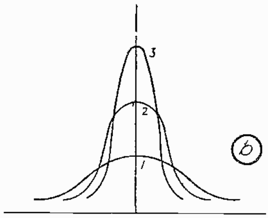


Fig. 8b

a detector and an A.F. amplifier. A receiver of this sort, with two stages of amplification is very satisfactory and thousands of them are still in use.

Now you might ask, "Why not increase regeneration indefinitely and by increasing the amount of the feed-back, increase selectivity and volume?" Here is the reason: the grid-feeding circuit is the resonant circuit L_2-C_2 which has an appreciable resistance R. Curve 1, Fig. 8b, is the resonance curve of the circuit without regeneration. When regeneration is added to the circuit and the additional alternating e.m.f. is fed into the circuit, the IR drop* is gradually balanced out and the resonance curve becomes higher and higher. As more feed-back grid voltage is applied, the plate current goes up and the receiver becomes more sensitive.

But the grid voltage has been amplified by regeneration to such an extent that instead of swinging from (a) to (b), (Fig.

* Due to the R.F. resistance of the coil.

8c) the swing extends from A to B, and includes the more horizontal portions of the grid voltage—plate current curve. At this point, any further increase in grid voltage due to increased feed-back does not increase the plate current. In fact, beyond this point the D.C. current would disappear from the plate circuit and in its place would be an A.C. current oscillating at a frequency determined by L_2-C_2. This is illustrated in Figs. 8c, 8d, 8e.

So you can see that the amount of feed-back permissible is limited by the characteristics of the tube used.

For satisfactory operation, the tickler circuit must be made to feed back at very nearly the same frequency as the incoming signal. The adjustment is very critical and careful adjustment of the tickler coil is required.

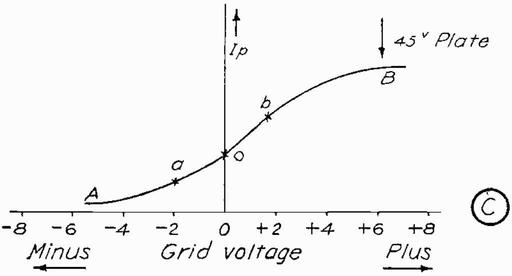


Fig. 8c

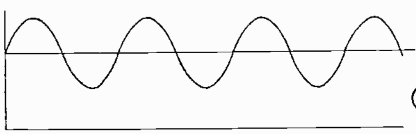


Plate current regeneration

Fig. 8d

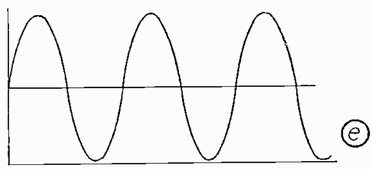


Plate current oscillation

Fig. 8e

What happens if the circuit is tuned to a frequency slightly off the signal frequency? In the grid circuit there are several currents, the signal current, the feed-back part of the oscillating plate current and the combination of the two. Suppose the first two currents are of slightly different frequencies as 9(a) and 9(b). They are alternately in phase and out of phase with each other. When in phase they add—when out of phase they subtract. When exactly out of phase, if the currents are equal, they will wipe each other out. These two currents having slightly different frequencies combine to form a current of a frequency near that of the signal frequency, but having amplitudes (crests or humps) all its own, as a, b and c in Fig. 9(c). The number of crests or humps is equal to the difference in frequencies between the two 9(a) and 9(b). In this case the difference in number of amplitudes, "crests" would be 15 — 12 = 3 crests.

Now if we say that the incoming signal frequency is 300,000 cycles per second and if circuit L_2-C_2 is considered as being slightly off resonance, tuned to 300,500 cycles, the two frequencies will combine due to the feed-back properties of the circuit and in the resultant current there will appear 500 humps per second. This combined current in going from the grid to the plate, will be rectified as a modulated carrier current and will result in a shrill 500 cycle whistle or "squeal."

If L_2-C_2 is tuned to 310,000 cycles, the squeal will be a 10,000 cycle note, as 310,000 — 300,000 = 10,000.

The note resulting from the combination of two slightly different frequencies is called a "beat" note. Various beat notes are formed while L_2-C_2 is being tuned—and they appear in the

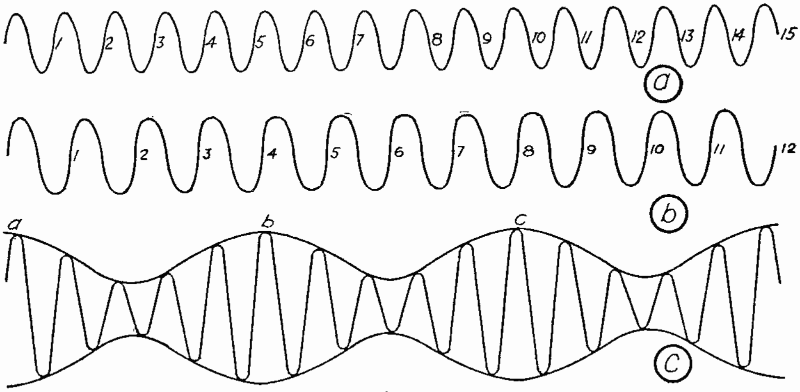


Fig. 9

speaker or phones as whistles—first shrill, then low, then shrill, as the resonant condition of the circuit is changed.

This phenomenon of beats is a serious problem in modern receivers. You will learn much more about beat frequencies in another lesson.

If the L_2-C_2 frequencies were exactly the same as the frequency of the incoming signal, no beat note would be heard, but as said before, it is very difficult to accomplish exact matching of frequencies. Sometimes oscillation makes its presence known by a thud or a click followed by a hiss. Touching the grid terminal of the tube may cause the squeal to appear.

Distortion in the speaker due to beat oscillation is only part of the story. This beat frequency present in the regenerative circuit, turns it into a miniature transmitter and nearby receivers will get the modulated carrier wave and will amplify the resulting squeal or whistle. For this reason, regenerative receivers should be operated very carefully and the regenerative circuit be kept below the oscillating point. Because of the care required in operation, regenerative receivers are passing out of use for broadcast reception. But they are by no means forgotten—their popularity for short-wave work is growing. We shall study regenerative receivers again when we take up S.W. (short wave) receivers.

Several ways of eliminating re-radiation (action as a transmitter) in regenerative circuits have been found. The most outstanding method is that used in the Browning-Drake circuit. A stage of special radio frequency is connected ahead of the regenerative circuit, first to increase sensitivity and second to prevent re-radiation. This stage must not regenerate or oscillate and the method used to prevent this is called neutralization. C_n connected to center tap S in Fig. 10a is the neutralizing

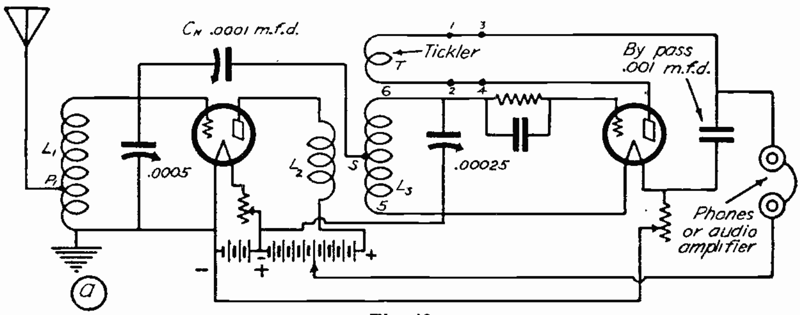


Fig. 10a

agency. The theory of neutralization must be left until later, but Figs. 10a and 10b show all hook-up details.

In order to have regeneration in any of these circuits, the R.F. current from the plate must pass through the tickler coil in such a way that the voltage induced in L_3 will aid the signal voltage already present. It must be in phase with the signal voltage. In practice, if regeneration is not accomplished when the current is flowing through the tickler in one direction, reverse the tickler coil or reverse its connections (change them so that 1, in Fig. 10a, makes contact with 4 and 2 makes contact with 3).

The by-pass condenser (.001 mfd.) is needed in this circuit to provide a low impedance path for the R.F. currents which otherwise would have to flow through the high impedance of the phones.

Figure 10c shows the action of the tickler in graph form.

T can be rotated from zero position (horizontal) to 90° (vertical). Amplification does not begin until the 30° position. Oscillation begins at 63°.

FIXED AND TUNED R. F. RECEIVERS

Modern broadcasting makes heavy demands on receivers. There are over 600 stations on the air and every one of them wants the maximum power allowable. Although every set buyer would like to have a sensitive receiver, the chances are that he will pass up a highly sensitive receiver for one that is selective, capable of tuning out even powerful, nearby stations.

Absolutely silent operation is very desirable. It goes without saying that the modern receiver must never squeal or howl. For this reason, regenerative circuits, no matter how well provided with anti-radiating devices, are no longer popular.

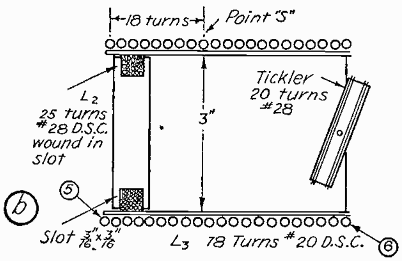


Fig. 10b

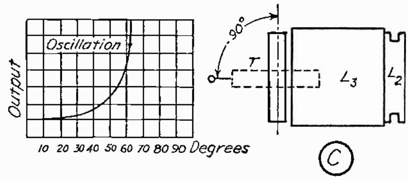


Fig. 10c

Now refer to Fig. 11a. It shows part of the circuit diagram of one of the first radio frequency sets, and one that is still used. Many sets of this type are sold today in a slightly modernized form. Figure 11a shows only the R.F. section and detector, the audio stages have been omitted for the sake of simplicity.

T_1, T_2, T_3 are the R.F. transformers. They are connected together just as audio amplifiers would be and form a system just as stable as an A.F. system would be. These transformers are of the type first successfully designed by Radio engineers—permitting amplification at frequencies of 1500 to 550 kilocycles. They are still in use today, especially in portable receivers.

Oscillation is prevented by keeping the B voltage down. This is accomplished by means of the variable high resistance R (0-250,000 ohms). The amplification curve of this type of transformer is given in Fig. 11c. The minimum amplification factor is 15 per stage. Our R.F. system then has an amplification factor of $15 \times 15 \times 15 = 3375$ for the R.F. system. This is reduced somewhat by the filtering stages in the tuning arrangement.

This R.F. system is called *fixed* R.F. It is preceded by cascade tuning which is a remarkable development. It is an elabo-

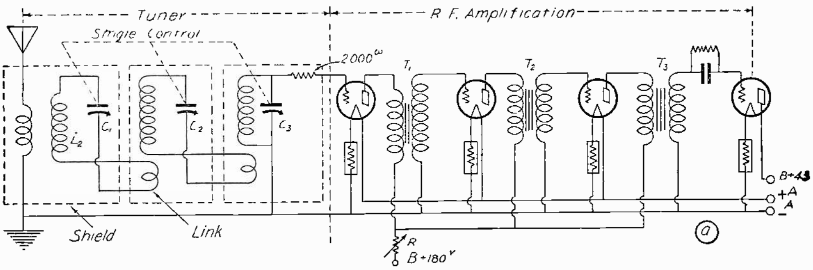


Fig. 11a

ration of the tuning circuit shown in Fig. 5. You remember when we were studying Fig. 5, it was mentioned that the same idea was used in modern receivers.

The antenna inductance, coil L_2 and variable condenser C_1 form a single stage of filtering. The only connection (coupling) between this stage and the next stage is through the link as shown. Modern practice demands that they be placed in a copper or aluminum case (shielding).

Although older sets had three dials (control knobs), three dials on a set today would make it unsalable. So in modern machines, the variable condensers are ganged together—all mounted on the same shaft or belted together, so that one dial operates all of them. Of course, the condensers in this sort of an arrangement must be identical, exactly alike in every way and the ganging adjustment must be very accurate.

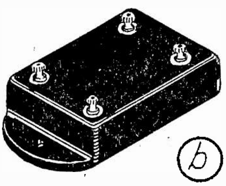


Fig.11—Fixed R.F. Transformer.

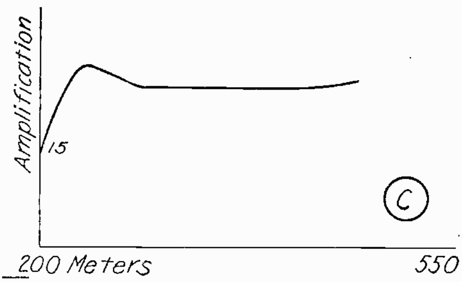


Fig. 11c

It is on the quality and design of the variable condensers and inductances that selectivity depends. The expert Radio-Trician inspects these parts of a receiver he is servicing first of all. Inductances must be perfectly matched, too, over the entire tuning range just as the variable condensers must be. The coils should be kept dry and rigid.

Equipped with a modern audio system and with a perfect loudspeaker, receivers of this type are being sold today at high prices. If made carefully and of good materials, these receivers will span the continent. Manufacturers who feature quantity production do not use these circuits primarily because T_1, T_2, T_3 are not absolutely necessary—they can be eliminated by the use of another circuit. But with slight modifications, this circuit, as shown, has been used in a number of portable receivers.

At this point let me caution you again not to be hasty and condemn these circuits on the ground that they are not exactly the ones in use today. We are building up our knowledge gradually, which is the proper way. And now with the use of A.B.C. power units, and with the circuits adapted for screen grid tubes, and other refinements, modern circuits may look quite different from those we have been studying, but fundamentally they are the same.

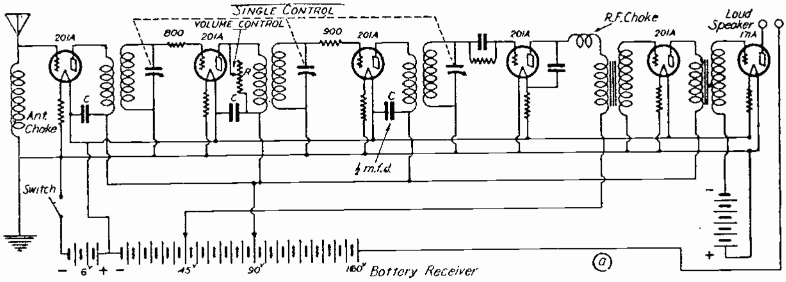


Fig. 12a

Tuned R.F. amplification is used in quite a number of Radio receivers at the present time.

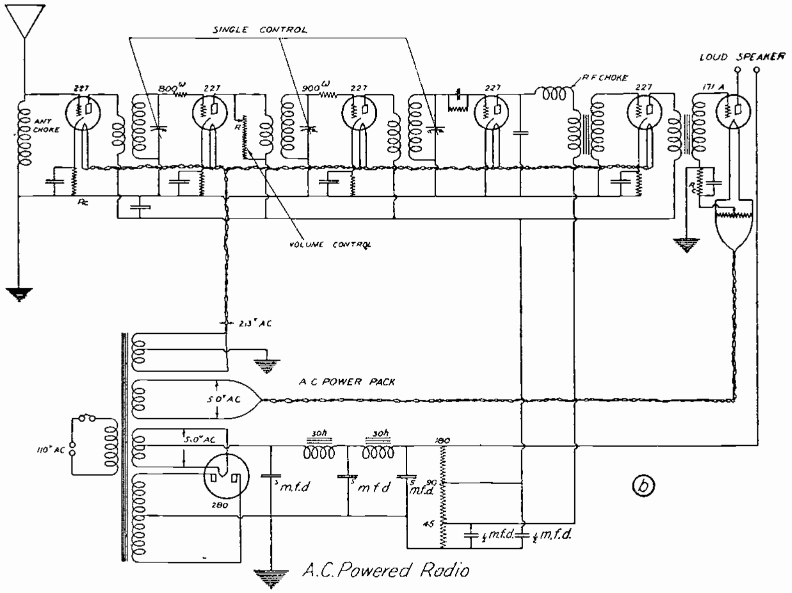
Each vacuum tube stage has a double function; first, that of R.F. amplification; second, that of tuning. The tube action (regeneration) may even counteract some of the results of error in design and an R.F. stage may work in spite of the mistakes of the designer.

A battery receiver that was popular a few years ago is shown in Fig. 12a. The same set designed for A.C. operation is shown in Fig. 12b. 12a can be converted to 12b without altering any of its coils or mechanical arrangements, merely by changing the tube sockets so that A.C. tubes can be used, and by replacing the batteries with an A-B-C power supply. So with 12c which is the same circuit using D.C. socket power.

The battery receiver derives its power from a storage battery as the "A" supply and four blocks of B batteries as the

"B" supply. The 171-A tube is grid biased by means of a small 45-volt C battery. The batteries are usually placed in a single container for convenience. Bias for the radio frequency and first audio tubes is obtained by connecting the grid return of the tuned circuit directly to the ground potential; that is, A –. Thus, by inserting a fixed or automatic resistance in the filament lead to control the current heating the filament, a proper bias may be had.

The A.C. socket-powered receiver (Fig. 12b) has a radio frequency and audio frequency system identical with those of the battery receiver. Not one item of mechanical set-up of the radio



A.C. Powered Radio

Fig. 12b

frequency system is different. Only the A.B.C. supply is different and A.C. tubes are used instead of D.C. tubes. Also, proper connections are made to the supply unit. We have already studied A.C. supply systems and here is our first introduction to their actual use in Radio receivers. The filaments of the '27 tubes are in parallel and the cords are twisted so as to prevent stray magnetic fields. The 171-A power output tube filament has a separate secondary feeder in the power supply. Heater type tubes are used universally in modern Radio receivers and are, therefore, shown in this particular arrangement. The cathode is now the grid return and is independent of the filament, although the heater center is connected to ground for hum elimination.

The C bias is obtained by means of a C bias resistance (R_c) which will vary in value, depending upon whether the tube is a radio frequency amplifier, an audio amplifier or a power tube. This resistance and the plate current determine the bias voltage as has already been explained.

Again, in 12c, the same radio frequency system is shown, connected for operation from D.C. electric power sockets. The coils, the variable condensers, in fact, everything that constitutes the radio frequency, detector and audio frequency systems remains the same as in 12a and 12b—only the tubes and the power supply are changed. In this particular instance, it has been found most desirable to use 112-A tubes throughout the system so that the tubes will not respond to the slight ripples that are present in a D.C. socket supply.

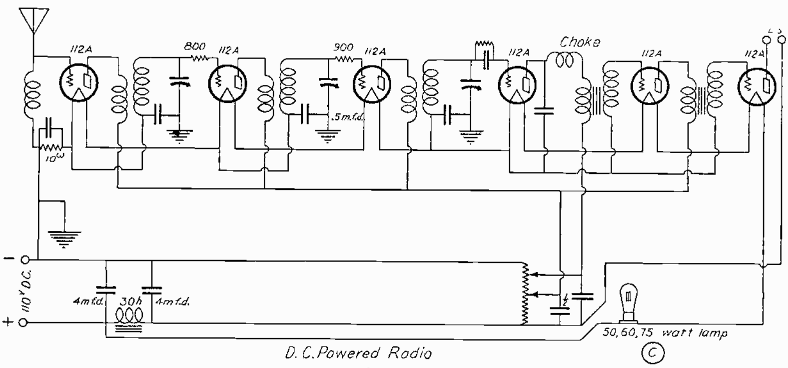


Fig. 12c

All '12-A tube filaments are connected in series and in series with an ordinary electric lamp so as to reduce the 110-volts to approximately 30 volts, the amount required by these tubes in series. A power rheostat or power resistor of the screw plug type may be used instead of the lamp. Notice that the variable condensers are not connected directly to their respective resonant inductances but through by-pass condensers, and their rotors are connected to the ground. This particular arrangement allows the three condensers to be ganged together as is required in modern receivers. The grid return of each tuned R. F. circuit, instead of being brought back to its own A– terminal, is brought back to the preceding A– terminal and in that way places a grid bias of five volts on each tube. The initial tube grid bias is obtained through the 10^{ω} grid bias resistor.

Engineers in talking about radio frequency development, design and problems, disregard generally the fact that a set may be operated by batteries or D.C., or A.C. electric power supply. The problem of supply doesn't enter into the design of a good Radio receiver as far as sensitivity, selectivity or tone fidelity is concerned. It has considerable to do, however, with the economy of operation and the salability of the product and is, of course, an important phase of Radio engineering. A.C. tubes compare with D.C. tubes just as oil furnaces compare with coal furnaces—the effects are the same, only the type of fuel is different and the method by which the fuel is fed.

Let us see what modern R.F. design has added to these circuits. In the antenna circuit, there is a choke coil of approximately 85 millihenries instead of an R.F. coil with its secondary tuned by a variable condenser. (See Fig. 12d.) The antenna and ground now act alone as a resonant circuit because of the distributed capacity and inductance in the circuit. This circuit has high resistance and tunes broadly from 1500 to 500 kilocycles. Many receivers use special antenna chokes designed to make the antenna circuit resonate at 550 meters.

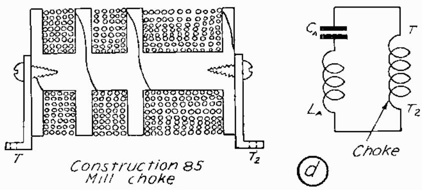


Fig. 12d

The usefulness of this choke should be apparent. The tuning is removed from the antenna and is independent of the size of the antenna. Of course, there are some disadvantages—first, sensitivity is lost, and second, if this type receiver is used near a powerful local station, this station will have a tendency to "ride-in" along with weaker stations at other points on the tuning dial. Many Radio designers are willing to overlook these disadvantages, but the latter is of such importance to us as Radio-Tricians that we are going to consider it later in detail.

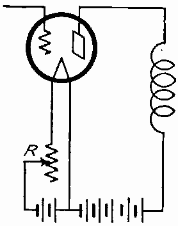
Regeneration is suppressed by grid resistances as shown. Normally, a non-inductive resistance of 600-1000 ohms is sufficient. This is often called a *grid losser* system.

Volume control is obtained by a 0-5000 variable resistance usually placed across the middle R.F. stage as indicated. When the resistance is near zero, the R.F. current coming from the plate of the second R.F. tube will not enter the primary and no signal will be heard in the speaker. As more resistance is allowed in this *volume control* rheostat, the R.F. current divides between it and the primary of the R.F. coil, allowing the signal to go through. This kind of volume control also has the advantage of controlling regeneration. It is widely used as it does not affect selectivity.

A Radio receiver without a volume output control is like a ship without a rudder. No commercial set has been built without one. Volume control is invariably obtained in the R.F. stages. If the R.F. were not controlled, the tubes in these stages might be overloaded and then, regardless of volume, if controlled elsewhere, the output would be distorted.

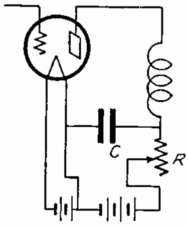
Radio-Tricians are frequently called on to correct the method of control. For this reason, the eight common methods of volume control are given in Fig. 13a to h.

In Fig. 13a, a rheostat is placed in the R.F. filament line. This method was used in battery sets and is not very good be-



(a) By means of rheostat in r.f. filament

Fig. 13a



(b) By means of 0-250,000 ω resistance in plate of r.f.

Fig. 13b

cause of possible distortion and reduced selectivity. Method (d) could be used in place of this. It is not advisable to control volume in audio systems by this method (a) because of the distortion that results. Filaments in A.C. and D.C. sets should be operated at normal, constant voltage.

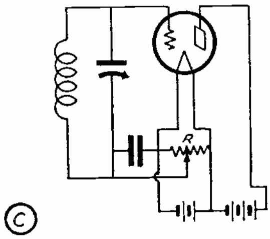
Many of the older sets use a 0-250,000 ohm variable resistance (13b) in the plate circuit of the R.F. tube. The effect is to introduce a large plate resistance and reduce the plate voltage. The amplification of the stage is thus reduced. The by-pass condenser (.5 mfd.) is very important. This method (b) is satisfactory for D.C. sets but not for A.C. sets. The R.F. stage tends to act as a detector and powerful signals will be muffled.

In method (c) a potentiometer of 400-500 ohms is used to control the C bias of an R.F. tube. Although this method controls the volume very satisfactorily, it introduces resistance into the grid circuit and so affects selectivity. Method (d) is much better.

A 0-5000 variable resistance is connected across the primary of one of the R.F. transformers. This method is very popular because it can be used with either A.C. or D.C. receivers.

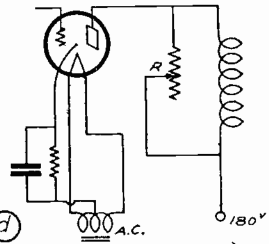
Method (e) is also widely used. An 0-2000 ohm resistance is connected across the antenna and the ground. It is often used without the antenna choke. This serves to cut down the signal energy right at the point it enters the receiver, and therefore is of real value especially when receiving strong local signals.

Method (f) is sometimes used as a volume control in the audio system, when amplifying phonograph music where no R.F.



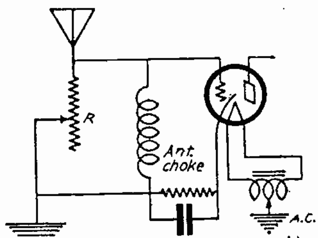
By means of 400ω potentiometer in grid return of r.f. tube

Fig. 13c



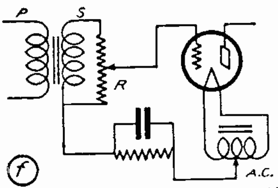
By means of 0-5,000ω resistance across primary of r.f. transformer

Fig. 13d



(e) *By means of a 0-2,000ω resistance across aerial and ground*

Fig. 13e



By means of a 0-500,000ω potentiometer placed across secondary of audio transformer

Fig. 13f

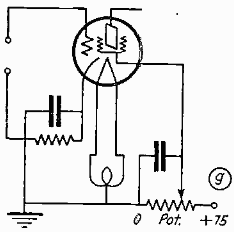
amplifier is employed. An 0-500,000 ohm potentiometer is placed across the secondary of an audio transformer.

Methods (f) and (d) are often used together. When this is done, a twin variable resistance unit is mounted on a single shaft. The two resistances are insulated from each other. In this way, the hum which is usually present in the detector and first audio stages can be reduced simultaneously with the volume.

Method (f) has been tried alone, across the secondary of an R.F. transformer. This was not satisfactory, however, because the resistance affects selectivity and upsets the matching of the variable condensers.

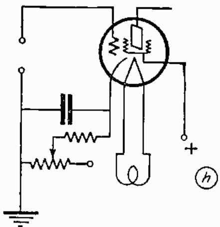
When screen grid tubes were first used, volume control was obtained by inserting a potentiometer between the B– and the 75-volt terminals (method g). The variable center connection of the potentiometer was connected to the screen grid. Although this method was effective, it had one serious fault—it reduced the "C" bias on the R.F. tubes, resulting in modulation or cross-talk. In other words, it allowed the grid bias to become so low that one of the R.F. tubes functioned as a detector.

With the advent of the variable mu tube the variable grid bias method is used as shown in Fig. 13h. In any tube, if the C bias is increased the plate current goes down and with it the mutual conductance of the tube. A reduction in mutual conductance results in less amplification. It is important that the bias never be reduced beyond a minimum amount and for this reason



By means of a potentiometer which increases screen grid voltage from 0 to 75 volts

Fig. 13g



Variable control grid bias method

Fig. 13h

a fixed resistor is placed in series with the variable resistor. This method may be used with any tube and is highly recommended.

Two typical volume controls as used in various modern receivers are shown in Fig. 14. The resistance wound type (14a) is very substantial, and if the "tapers" obtainable are suitable it is advisable to use this type in repair work even though they are slightly more costly than other types. They will carry a fairly heavy plate current.

The carbon deposit type consists of a flexible fiber strip, ⅜" wide and 3" long, covered with a solution that has soft carbon mixed in it. By varying the thickness of the solution over its length, a uniform or tapered resistance can be secured. Years of research have greatly improved this flexible volume control, by improved methods of applying secret compounded solutions and by the use of roller bearings.

A resistance curve that is uniform is shown in Fig. 14c, curve a. Curves b, c, and d are said to taper and a resistance unit that has resistance of this kind is called a "tapered" resistance. Curve c has a particularly quick "take-off" while

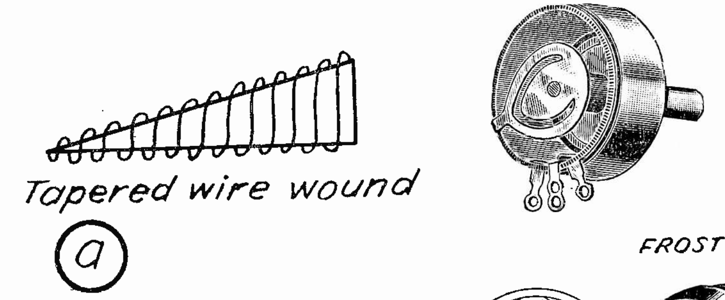


Fig. 14a

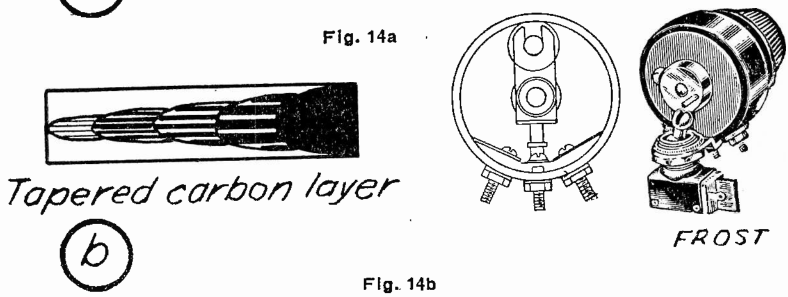


Fig. 14b

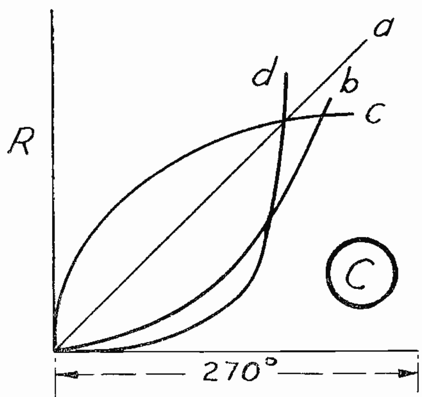


Fig. 14c

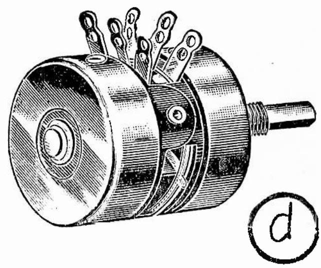


Fig. 14d

curves b and d have slow "take-offs." If the terminals of a volume control resistance are reversed, the effect of the taper is destroyed. This must be watched out for in repair work.

Figure 14b illustrates a single control rheostat, ganged with an approved underwriter's A.C. line switch.

Figure 14d shows a double control resistance permitting the control of two variable portions of a circuit simultaneously.

BY-PASS CONDENSERS AND R. F. CHOKES

In the fundamental radio frequency circuits we were working with, we noted the use of by-pass condensers and choke coils.

You know that the plate circuit of any tube has flowing in it D.C. current, audio signal current and possibly R.F. current. A detector plate circuit contains all three. In all these circuits which carry several different currents at once, means must be provided for separating the various currents and keeping them in circuits of their own.

A grid bias detector has these three currents in its plate circuit—the direct current from the power supply; the audio current from the rectifying action of the tube; and some R.F. due to incomplete rectification.

The plate of the tube is connected to the primary of an audio transformer. The signal is passed on through this transformer for amplification. It is important that nothing else but the audio signal be passed through the transformer. And for this reason, no R.F. currents must be allowed in the audio system.

But these small R. F. currents are in the plate circuit—how can they be kept out of the primary of the transformer? By "choking" them out. That is, by placing an R.F. choke coil (L_1 in Fig. 15a) in the plate circuit.

But the audio signal is also A.C. and it is needed in the audio system. Will this be choked out, too? A little but not much and whatever amount is choked out may be made up in the audio amplifier system.

Now that we have separated this unwanted R.F. from the plate current, what are we going to do with it? It must have a place to go. This is where the by-pass condenser takes it and by-passes it to the ground.

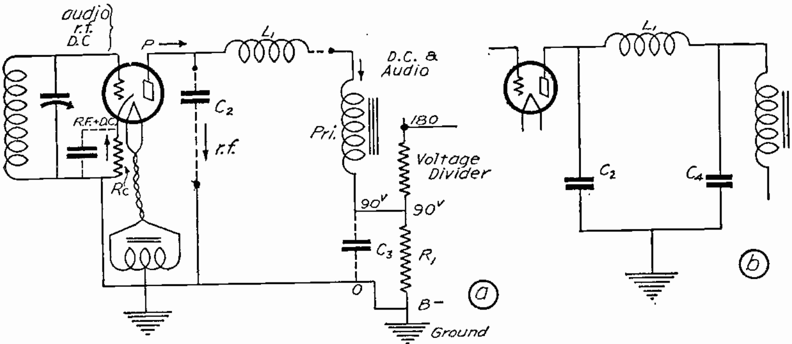
The size of the condenser used to by-pass R.F. currents is very important. If made too large, the audio current will be able to pass through and there will be no signal current at all for the audio system to amplify. Usually, condensers between .0005 and .002 mfd. are suitable for by-passing. Note that the condenser is always placed between P, the plate and B– or the ground.

In order to keep the cost of receivers down, some designers omit choke L_1 and depend on the action of C_2 to get rid of stray R.F. If a choke is introduced into one of these circuits, there may be no perceptible difference in the reception possible. But good practice demands that chokes be used with by-pass condensers in quality receivers.

In some recent sets, a double by-pass is used. This is illustrated in Fig. 15b. In this case L_1 can be considerably smaller and the action is very similar to that of a band-pass filter.

Now let's look for a moment at the current in the primary of the audio transformer. It is composed of direct current and the audio signal current. The direct current can flow only through the circuit L_1, Pri, and R_1, to the ground as condenser C_3, no matter how large, or how small, will not allow direct current to flow through it, unless leaky (defective).

The audio current is an A.C. current and may go through either R_1 or C_3. R_1 is a resistance of about 4000 ohms, and if the current were allowed to pass through it, the value of the current



-27 Detector-grid bias detection

Fig. 15a* Fig. 15b

would be considerably reduced. C_3 provides a low resistance path. Assuming that the audio frequency is about 2000 cycles, a .5 mfd. condenser will cut the resistance to 159 ohms. The plate current is then well choked and by-passed.

Defective chokes and by-pass condensers make tone reproduction weak and "mushy." Watch out for them in your Radio work.

There is still one point to be considered in connection with the circuit in Fig. 15a—the "C" bias.

* The arrows merely indicate the existence of a D.C., A.F., and R.F. current. However, the arrows show the direction of electron flow for D.C. current, the actual current would flow in an opposite direction. A.F. and R.F. current will alternately flow in both directions.

Resistance R_c carries the same three currents that are flowing through the wire at point P. To function as a "C" bias, it needs only direct plate current. But as a resistance in both the plate and grid circuits, it offers resistance to the A.F. and R.F. currents in its circuit. This is undesirable as it would cut down the signal strength, and as A.F. and R.F. currents are not needed for "C" bias, they are by-passed through a condenser, which is made large (½ mfd.) to handle the A.F. and so will by-pass the R.F. simultaneously.

It is necessary that you become familiar with modern methods of by-passing and choking as used in the latest receivers. A few basic methods are shown in 15a, 16a and 16b.

There are some very important rules regarding by-passing and choking which you should learn and remember.

1. To exclude an A.C. frequency use a choke.
2. Where a choke is used, a by-pass must also be used to provide a path for the excluded currents.

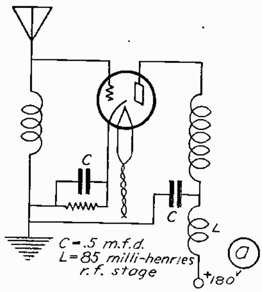


Fig. 16a—R.F. Stage.

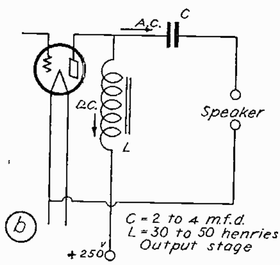


Fig. 16b—Output Stage.

3. A capacity allows a high frequency current to pass—an inductance blocks the passage of R.F. currents.
4. If a resistance or an inductance offers resistance to an A.C. current that should be kept at maximum value, always by-pass by means of a condenser. Use a large condenser if both A.F. and R.F. are to be by-passed; use a small condenser if only R.F. is to be by-passed.

CROSS MODULATION

It has been pointed out that broad aerial tuning presents a difficult problem in Radio. Broad tuning always is present in an untuned antenna system and is easily detected by the reception of powerful local signals at any position of the dial where a weaker station may be tuned in. The strong station is said to "ride in" on the weaker station.

Figure 17 (a, b, c) shows the three standard methods of absorbing energy from the antenna-ground system without tuning. Method 17b may also be used as a volume control provided there is not a trace of regeneration in the R.F. system.

The curve in Fig. 18 is a curve of the grid voltage plotted against plate current. A negative grid bias of 1½ volts (using a UY-224 tube) is normal for an R.F. amplifier, and the position A represents the operating point on the curve. A signal current of 100 micro-volts enters the R.F. tube and the grid voltage

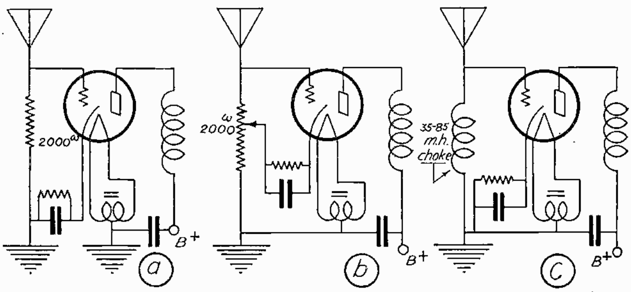


Fig. 17a Fig. 17b Fig. 17c

swings from A to B, back to A and then from A to C. This is on the straight portion of the E_g-I_p curve and the tube behaves as a good R.F. amplifier.

Now we are receiving a signal from a distant station. But a local station is broadcasting, and because the antenna is broadly tuned, the first R.F. tube amplifies this local signal regardless of its frequency, even though the other R.F. stages are tuned to the frequency of the distant station. This signal is strong enough to make the grid of the first tube swing from X to Y (in Fig. 18),

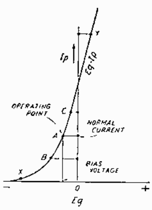


Fig. 18

let us say a swing of 300 micro-volts. This is beyond the straight portion of the E_g-I_p curve and plate rectification takes place, just as in a detector tube.

The local signal appears in the plate of the first R.F. tube as an audio signal and combines with the carrier of the distant station in the grid of the second R.F. tube, forming a modulated current carrying both the distant and the local signals. This is what is meant by "cross modulation." The other R.F. stages amplify this combination, the detector rectifies and gives the audio system two signals to amplify. Accordingly both are heard in the speaker and we have "cross-talk."

The prevention of "cross-modulation" is primarily a matter of receiver design. Before the advent of the variable mu tube it was the practice to have the first R.F. tube preceded by a highly selective antenna coupler as shown in Fig. 19. Or a band-pass filter stage was used before the first R.F. tube. Thus the undesired local signal is filtered out before it has a chance to overload the first R.F. tube. In other cases, the '27 tube was used in the first R.F. because this tube would handle a larger grid swing without making it act as a detector to the local strong signal.

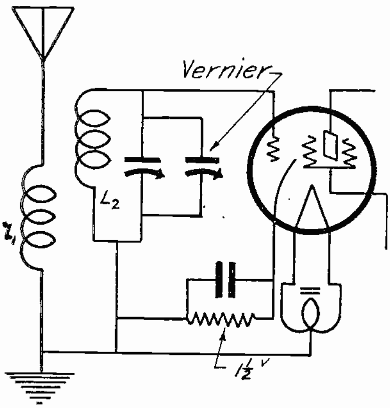


Fig. 19

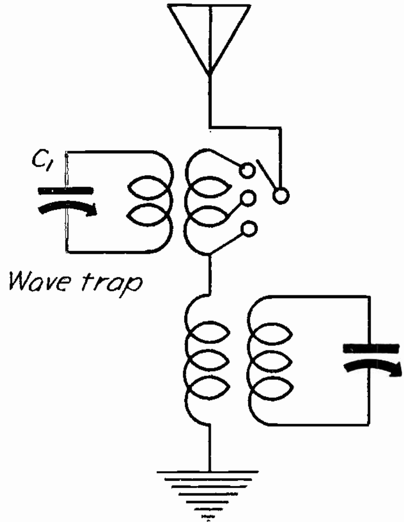


Fig. 20

Now that the variable mu and R.F. pentode tubes are used extensively as R.F. amplifiers, the need for band-pass filters ahead of the first tube has been eliminated. Their E_g-I_p characteristics are long and show limited curvature so that even strong off-resonance signals that might get to the first R.F. tube will not cause that tube to act as a detector and cross-modulate.

A wave trap as shown in Fig. 20 is often used where there is only one offending local. This consists of an R.F. transformer having a variable primary with taps at about 6-10-16 turns, a secondary tightly coupled, which will resonate over the complete 1500-550 kc. scale when used with an .00035 mfd. variable condenser. To use a wave trap follow this procedure: tune in the powerful local station on the receiver and then tune C_1 of the wave trap very carefully until the local station is practically tuned out. Then the weaker stations may be tuned in without any danger of "cross-talk." Greater "trapping-out" may be effected by the use of the 10 or 16 turn tap on the primary of the wave trap than with the use of the 6 turn tap. Several wave traps may be used in series and then each one acts individually.

A wave trap may also be employed for eliminating interfering signals from stations either local or distant, that spread on the dial, and whether "cross-talk" is present or not.

TEST QUESTIONS

Be sure to number your Answer Sheet 19 FR-1.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and the best possible lesson service.

1. What combination of currents are present in the plate circuit of a detector tube?
2. When oscillation takes place in the detector tube, what happens to the D.C. plate current?
3. Suppose an incoming signal frequency of 650 kilocycles is being received with a regenerative receiver but the L and C in the grid circuit of its detector tube is tuned to 654 kilocycles. What will be the frequency of the regenerative whistle or squeal?
4. Explain briefly the difference between a battery powered receiver; an A.C. powered receiver; a D.C. powered receiver.
5. Should a regenerative receiver be operated in an oscillating condition?
6. Why is the volume of a radio receiver usually controlled in the R.F. system rather than in the audio system in modern sets?
7. In Fig. 15-a what two devices are used to keep R.F. currents out of the primary coil of the A.F. transformer?
8. What tube action takes place in the first R.F. when "cross-modulation" is present in a receiver?
9. Draw a symbol diagram of a tuned antenna circuit. Explain each symbol.
10. What is the advantage of using a wave trap?

HOW RADIO PROGRAMS ARE SENT FROM THE STUDIO TO YOUR HOME

2FR-3

PIONEER HOME STUDY RADIO SCHOOL

NRI

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EST. 1914
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Marshall Field, famous American merchant, once said:

"If you put money into a business, it will bring you returns. But if you put it into developing your brain it will pay you bigger returns than any other investment on earth."

Was he right? Let's see. Suppose you invested $100 at 6% interest, compounded annually. It would be twelve years before your money doubled—amounted to $200.

Now you are investing approximately $100 in your Radio training. If you do as well as many N.R.I. students do, you'll make $5 to $10 a week in your spare time while you are still studying. Let's say you average $5 a week or $260 a year. In one year your investment will have returned 260%.

And you aren't yet ready for the real money in Radio. When you graduate and go into Radio full time, either working for some one else or in business for yourself, the returns should be much larger.

Let's be conservative, however, and say that you increase your salary only $10 a week. At the end of one year your investment will have earned an additional 520%. That's real profit. In twelve years at the $10-a-week rate, your $100 investment instead of returning a $100 profit such as it would at 6% compound interest, will have brought you $6,240.

It's amazing, isn't it, what an investment in knowledge can do. Keep that in mind. Make your spare minutes count. Study diligently, and regularly.

J. E. SMITH.

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How Radio Programs Are Sent From the Studio to Your Home

INTRODUCTION

Indeed, it is very interesting to take a trip through a radio broadcasting station; watch the performers; see the studio, monitor and radio transmitter operators at their assigned posts; inspect the spic-and-span equipment; and watch a program go off like clockwork. This about satisfies the ordinary radio enthusiast. But as a Radio-Trician you naturally want to know the *whys and the hows* of radio broadcasting. Therefore, I am sure you will be interested in following me on this technical explanation of "how radio programs are sent from the studio to your home."

First we will follow a sound broadcast, originating at the microphone, all the way through the loudspeaker in your home. Then I will show what basic changes are necessary to send a television broadcast.

Naturally, at this early point in your course I must omit the details which will be given in following lessons. From *this* lesson, all I want you to get is a very general idea of how radio broadcasting and reception is made possible. I have many facts to present, so read slowly. You will find it worth while to spend a week or two on this lesson. In fact, I suggest that you first read this book from beginning to the end; then start over, mastering the facts in every four or five pages before you go on to the following pages.

STARTING WITH SOUND

We know that when some one talks or sings, he creates *sound* which is picked up by our ears. This is so natural a happening (or phenomena) that we rarely give it a moment's thought. Yet to us as radio men, this phenomena is very important, for in ordinary radio broadcasting we convey *sound,* from the studio or some place where an interesting event is going on—right through a radio communication system (the transmitter, space and the receiver) to the listener's ears. A vast radio system bringing within "earshot" an event or a performance that interests us.

What is *sound?* Sound is a *vibration* of the air surrounding us. When we talk, sing or shout, the *vibrating* vocal cords in our throats make the air in our mouths *vibrate.* We use our vocal cords and our mouths to change the *characteristic* of the vibration. You and I, through years of experience, do this automatically. But perhaps you have seen a baby just learning how to talk, try various mouth positions in an attempt to get definite desired sounds—trying to change the *characteristic* of the vibrations of his vocal cords.

Sound usually travels in all directions. Air, as you now know, is nothing more than oxygen, nitrogen, water and other materials in a gaseous state. The human talking apparatus, or musical instruments are *vibrating* devices which set the air particles in motion, and since the air exists all around, the air particles originally set into vibration push and pull those next to them, *transmitting* the vibration in all directions. We say a *sound wave* is created.

You, of course, know that the performer in the studio talks into a microphone; or the microphone is placed so it will pick up the sound

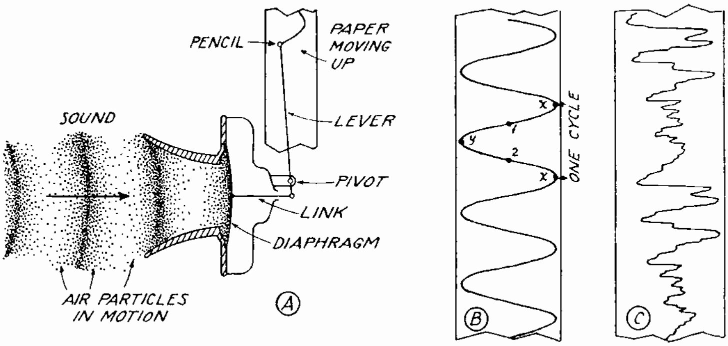


FIG. 1

that is to be broadcast. In the studio the microphone replaces our ears, interrupting and reproducing the sounds that are to be transmitted. The microphone must be placed in the path of the sound wave.

When a *sound wave* strikes an object, it naturally causes the object to vibrate; and if the object is flexible or light in weight, it will follow the vibration, just as if it were an air particle. Every *microphone* has a part that is primarily used to respond to the air vibration, and in most cases it is a round thin disc. In one common microphone, a dura-aluminum disc about three inches in diameter and one-thousandth of an inch thick is used; in another microphone a ribbon about one-eighth of an inch wide, three inches long and one-thousandth of an inch thick is used. So light are these two parts that should you place either one on a table, you could easily blow it off.

To better understand how the microphone works, suppose we were to "rig up" the special mechanism shown in Fig. *1A*. The part marked *diaphragm* is a round disc, just like those used in a microphone, and to its center a link mechanism is connected, so when the *diaphragm* moves the link mechanism and the pencil moves sidewise. The pencil writes its movement on a paper tape moving past it with a uniform speed. Now, when a sound *impinges* (or strikes) the *diaphragm,* the diaphragm *vibrates* or moves, causing a wavy line to be written on the paper tape. With this crude apparatus we may analyze the *characteristic* of a sound wave.

If a tuning fork (such as piano tuners use) was employed to create the sound, or we were to whistle a single note, this device would trace a wavy form, like the one shown in Fig. *1B;* if a man were to say "ah" as the letter "a" is pronounced in the word "father," the wavy form traced would be as shown in Fig. *1C.* But if a child or a woman were to say "ah" the wavy form would not be exactly like the one shown, although similar. What I am anxious to have you grasp is

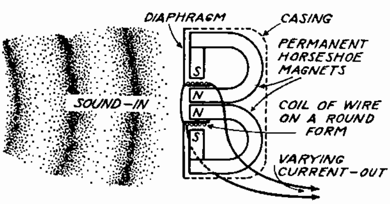


FIG. 2A

FIG. 2B

A spherical shaped inductor microphone. The internal construction is similar to Fig. *2A.* The round form and flat top cap permits sound pickup from all directions.

the fact that *sounds* are *vibrations* in air, and their *characteristics* vary with *who* or *what* produces them.

In radio sound broadcasting, the prime purpose is to send the original sound to your home, through the medium of the *transmitter* and the *receiver*—all with the least change in the characteristic of the sound. To be sure, we do not convey the original sound, for the original exists only ahead of the microphone and a duplicate is created by the loudspeaker. In the radio system the *sound* exists as a *varying electric current* or a *varying radio wave,* which has the *characteristics* of the original sound. From this simple statement you immediately guess that the purpose of the microphone is to convert (or change) a *sound* variation to an *electric current variation.* X2

HOW THE MICROPHONE CHANGES SOUND TO A VARYING ELECTRIC CURRENT

Figure *2A* shows the working mechanism of a widely used microphone; this one is called an *inductor* or *moving coil dynamic* microphone. To be sure, it is only one of the many types used. Figure *2B* shows one of them in use in a studio. This microphone works because of a very simple principle. Observe that a small coil of wire is attached to a very thin diaphragm. Insulated copper wire, ever so thin, almost the size of a human hair, is wound on a very thin bakelite tube about one-half inch in diameter, to make the entire moving system extremely light. When the *diaphragm* is set into *vibration* by sound created by a voice or musical instrument, the coil naturally moves. Since the coil is placed between the poles of horseshoe-shaped magnets, an *electromotive force* is developed (or produced) in the coil winding. Technicians say a *voltage* has been *induced.*

The basic electrical phenomena which takes place is important enough to remember. When, as shown in Fig. *3,* a wire moves through and across a magnetic field (that is, what is visualized as magnetic lines of force) electrons in the wire tend to pile up at one terminal and leave the other terminal. The result is an electron generator. When the motion of the wire is in *one direction* across the magnetic lines of force, each terminal will have a definite polarity (+ or —), and when the wire moves in the *other direction* the polarity of the terminals will change. If the position of the diaphragm varies, the induced voltage (that is its strength or intensity) will vary. If we were to take a picture of the voltage, it would look just like the original sound wave.

By means of the microphone we convert (or change) a *sound vibration* into a *mechanical vibration*—which in turn is changed into a *voltage vibration.* It has been given an *electrical characteristic* in place of a *sound characteristic.* In this process the energy has been greatly reduced, so we end up with a weak voltage which varies just like the original sound. It must be made stronger; and, thanks to the invention of the radio or vacuum tube, this is quite possible.

THE RADIO TUBE AS AN AMPLIFIER

The vacuum tube which *amplifies* (increases the strength of) the electrical characteristic (voltage vibration) of the sound, may be many feet away from the microphone. In fact, it is in the control room near the studio. It is the purpose of this tube * to build up the varying voltage, henceforth to be called the *audio signal;* audio having the same meaning as sound intelligence, *signal* meaning the energy we wish to convey.

* As you will shortly learn, several vacuum tubes are used in the control room to amplify the sound signal. Now we are considering the first amplifying tube.

Now I am going to "put the cart before the horse" and tell you how the audio signal is amplified, before I tell you how it gets to the radio tube. Simple amplifying tubes are shown in Figs. *4A* to *4C*. Figure *4A* is a cut-away view of a glass enclosed tube. It has in its center a small one-sixteenth inch diameter metal sleeve through which a hairpin shaped resistance wire, called the *filament,* is placed. To be sure, the filament is insulated from the sleeve. An electron generator is connected to the two filament terminals, and enough current flows through it to make the resistance wire (filament) get red hot. This in turn heats the metal sleeve surrounding the filament. Special chemicals called barium and strontium oxide cover the sleeve, and upon being heated these chemicals give off quantities of free electrons. 3 X *Any* surface which *emits* electrons is called a *cathode.* So this sleeve is called the *cathode* of the radio tube.

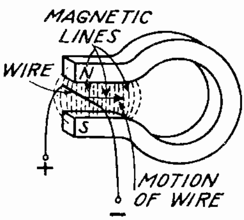


Fig. 3

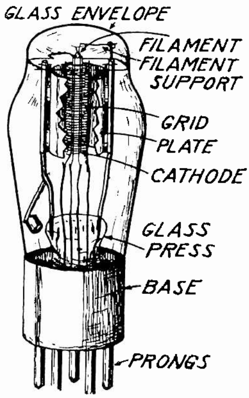
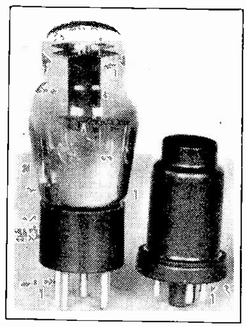


Fig. 4A


B C

Figs. 4B and 4C

Surrounding the cathode are two more elements or *electrodes;* the 4X internal parts of a tube are called the electrodes. Farthest away from the cathode is a large cylindrical or pipe shaped element, used to attract the electrons. It is called the *anode. Any* element that *attracts* electrons is called an *anode.* It is also called the *plate,* because in the vacuum tubes first made for radio purposes the anode was shaped like a little plate.

If a positive charge is placed on the anode or plate, for example by connecting it to the positive terminal of an electron generator, it will attract or draw over the free electrons emitted from the cathode. In fact, if the negative terminal of the generator is electrically connected to the cathode, the electrons will flow (or move) from the cathode to the plate, through the electron generator, back to the cathode, over and over again.

Naturally the easiest way to show this on paper is to draw a tube in a simplified or symbolic form, as shown in Fig. *5*. The latter is easier to draw than Fig. *4A*, and with a little practice in reading drawings like this, it will mean just as much. Observe in this *circuit diagram* (as this sketch is called) that the electrons take the path described in the above paragraph.

How does this device act as an amplifier? It will only act as an amplifier if the other element between the plate and the cathode is used. This element is a coil or helix of very fine wire, and the electrons flowing from the cathode to the plate have no real trouble in going straight through the coil, as if it were not there. This element is called a *grid,* simply because in the very first tubes made this element was really a small rectangular screen or grid. Although this element is rarely made this way, it is still called a *grid.* Now if a negative charge * is placed on the grid, that is, electrons are placed on the grid by an electron generator, these electrons will repel the free electrons coming from the cathode, preventing some of the electrons from reaching the plate. Because the grid is so close to the cathode, it has considerable influence on the electrons streaming through the tube. As you will later learn, the charge on an electrode with respect to another may be measured in terms of voltage (electromotive force). Thus we say a plus voltage (with respect to the cathode) is placed on the plate; a negative voltage (with respect to the cathode) is placed on the grid. Since the grid is nearer to the cathode than the plate is, a small change in negative voltage at the grid-cathode will influence (alter) the flow of electrons as much as a large positive plate voltage change. If a 1 volt change at the grid influences the electron flow as much as a 10 volt change at the plate, the tube is able to amplify 10 times. Although the electrons flow from the cathode to the plate (inside the tube), and from the plate to the cathode (outside the tube) through a connecting wire, the electron flow in which we are interested is that part from the plate to the cathode connection, or the plate circuit as it is called.

If we connect the varying voltage † produced by the microphone, to the grid and cathode of the amplifying tube, the electron flow from the plate to the cathode (outside flow) will vary, and with proper adjustments the electron flow will vary exactly like the original

* A positive charge on the grid will help the plate draw electrons out of the cathode. However, a positive charge is rarely used, as it is the variation in electron flow rather than the amount that is wanted. The negative charge will do just as well. In fact, by using a negative charge there is less chance for the radio tube to alter the characteristic of the sound signal. This will be studied in a later lesson.

† Which happens to be a varying negative charge.

sound. But if we can apply a larger voltage variation (applied to the grid and cathode terminals of the radio tube) the electron flow in the plate part of the circuit will vary to a greater extent.

Connecting a transformer (see Fig. *6A*) between the microphone and the grid and cathode terminals of the tube will increase the grid voltage variation, if that is what is desired. What is a transformer, and how does it increase a voltage? A transformer is nothing more than stacks of thin rectangular iron sheets arranged in the form of a frame, as shown in Fig. *6B*. Around one of the sides (or legs as it is often called) are many turns of wire; over this coil, or on another leg is another coil of many more turns of wire. If an electric current flows through one of the coils, the iron will be magnetized. If the current varies the number of magnetic lines of force will vary. What happens in the other coil? Again, you memorize another electrical principle.

If the number of magnetic lines of force through the core of a coil of wire varies, more electrons will tend to pile up at one terminal

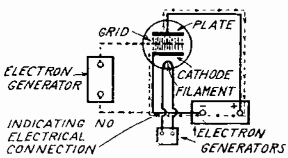


FIG. 5

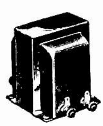


FIG. 6A

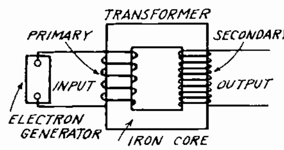


FIG. 6B

of the coil winding and the number of electrons will reduce at the other terminal—in other words a voltage is being created. If the magnetic lines of force increase in number, one of the terminals will be negative (accumulating electrons); if the lines of force decrease in number, that same terminal will be positive (losing electrons). This is a fundamental electric phenomenon which you must memorize.

Going back to our transformer, we see that a varying current in one coil will produce a varying magnetic field in the iron core, which in turn will produce, or as we say *induce,* a varying voltage in the second coil. The original coil in which the current is varying is called the *primary,* the coil in which a voltage is being induced is called the *secondary.* And, this is important: If the secondary coil has more turns of wire than the primary coil, the secondary voltage will be greater than the voltage that produced the current change in the primary. We say that the voltage has been stepped up.

Before I leave this first contact with a transformer I want to repeat; that a varying current in the primary (no matter how produced or regardless of the original character of the current flowing in the primary) will produce a varying voltage in the secondary.

CONVEYING AND AMPLIFYING THE MICROPHONE SIGNAL

Let us now return to our microphone, which I said was being influenced by sound in the studio, and which because of this action converts sound energy into electrical energy in the form of a variable voltage. You know that if the terminals of the microphone, which we recognize as an electron generator, are connected with a conductor, electrons or an electric current will flow. But instead of a short length of wire let us take a very long length, enough to run from the microphone to the control room of the studio and back to the microphone—a double wire cable, each lead (or wire) insulated from the other. At the control room the cable is cut and the two resulting terminals connected to the primary of the transformer; at the microphone the terminals are connected to the microphone as shown in the schematic or line sketch of Fig. 7. Again the line in front of a curl represents a microphone, the two wires indicating a cable, and the double curl separated by straight lines symbolizing a transformer. When you see these *symbols* as they are called, picture in your own mind a real microphone, a real cable, and a real transformer. That is what a *schematic* or *circuit diagram* is supposed to do.

Obviously, the cable and the primary of the transformer connected to it act as a completing circuit for the electrons generated by the microphone. As you would expect, electrons flow from the negative terminal of the microphone down the lead connected to this terminal, through the primary of the transformer back up the other lead, to the positive terminal of the microphone. Now, if the voltage at the microphone varies, the number of electrons flowing will vary; if the voltage produced by the microphone changes its direction, so will the electrons. Actually the electrons in the wire do not move very far, but their action is relayed at the speed of light throughout the entire microphone-cable-primary circuit. If it were possible to see what happens to the electrons at point *e*, we would see, as shown, a varying number of electrons flowing first in one direction, only to reverse their direction and flow the other way. A picture of this variation looks just like the sound variation at the microphone, or will if the circuit is properly designed.

Now we may continue. The varying current in the primary of the transformer, or the signal current as we may call it, causes a signal voltage to appear at the terminals of the secondary. This signal voltage acting on the grid and cathode of the vacuum tube, causes the electron current in the plate to cathode path (circuit outside the tube) to vary; and this *variation* is, with proper circuit adjustments, identical to the current in the microphone cable. Again the varying plate current (that is, the plate signal current) is sent through the primary of another transformer, which in turn produces a signal voltage at its secondary terminals. If the transformers used are made so the secondaries have many more turns than the primaries, and the tube has amplifying ability, the signal voltage at the output of the second transformer will be much larger than the signal voltage at the terminals of the microphone. In other words, the signal has been amplified, perhaps one hundred times.

But the signal may have to be amplified more than a million times before it has any value for purposes of broadcasting. How can this be done? Of course, we could use transformers with more turns on their secondaries, or we may use a tube with more amplifying ability. Theoretically this can be done until we get the desired amplification. Practically there is a limit to this procedure, because we would have to use transformers and a radio tube which would change the characteristic of the signal, and that is one thing that must not be done.

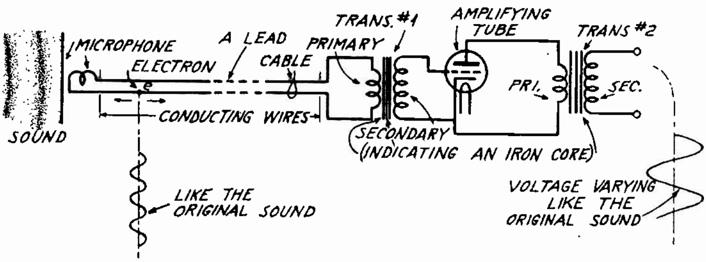


FIG. 7

So the logical procedure is to make transformer #2, see Fig. 7, feed its voltage into another tube, which in turn has a transformer connected to its plate and cathode. If more amplification is desired another tube and transformer is used, each group referred to as a *stage of amplification.* In this way the desired step-up in signal voltage is possible without altering (we technicians say distorting) the signal *characteristic* (the drawing or curve which portrayed the sound wave's special features).

In drawing Fig. 7 I omitted the generator or voltage supply which makes the plate positive with respect to the cathode—the voltage supply to heat the filament—and many other radio parts. Only a more detailed study will make their purpose mean anything. At this time I only want you to learn "how a radio program is sent from the studio to your home."

Before I continue, I want to present a few new special technical words, so you can use them like other Radio-Tricians. An electron generator is referred to as a *generator* or *voltage source,* or *voltage supply.* If the terminals always have the same polarity, that is if one is always charged positively with respect to the other, which is negative, the generator is called a *direct current* (D.C.* for short) generator; and of course the current that will be produced is a *D.C. current,* one which always flows in the same direction. If the polarity of the generator changes from instant to instant, the current will vary and alternately move in opposite directions, and we call it an *alternating current* or an *A.C. current;* the generator of such a voltage is called an *A.C. generator.* From the last definition it is easy to realize that a signal voltage is therefore an A.C. voltage; a signal current an A.C. current. I will occasionally use these words, to get you familiar with them.

SOUND SIGNAL CURRENTS WILL NOT PRODUCE RADIO WAVES; IMPORTANCE OF FREQUENCY

Supposing the sound signal current were fed to a wire in space, would this current create radio waves? After all, the electrons will be vibrating, that is moving "to and fro" in jerks. Theoretically, they should produce radio waves, but they would be radiated only a few hundred feet, and at that the current would have to be very strong. Practically, the vibration is not fast enough to throw off enough magnetic and electric lines of force (radio waves) to serve the needs of broadcasting.

Apparently the degree or speed of vibration has a lot to do with sending or *radiating* radio waves. Hence, it is worth our while to study vibration a little more in detail. If you will refer to Fig. *1B*, studying the simple mechanism to record the characteristics of sound waves, you will see that points *1* and *2* represent a condition when the diaphragm was not pushed or pulled. Point x represents the condition when the sound wave was pulling the diaphragm towards the performer in the studio, while point y represents a condition where the sound is pushing the diaphragm. Observe that this *in and out* motion of the diaphragm, and of course, the corresponding variation of the sound wave, the signal current and the signal voltage have gone through one complete vibration. Technicians call it a *cycle,* and furthermore this cycle repeats itself over and over again. The wave represented by Fig. *1C* is very complex, but as you will learn in other lessons, is nothing more than many simple wave vibrations, like the one shown in Fig. *1B,* all acting at the same time. That is what gives the difference between a man, a woman, or a child saying

* When written this way, D.C. is read just as it is printed.

"ah" as "a" in "father," or any other expression, word or musical note.

6 X What I am getting to is this. The highest sound vibration that we can hear is about 16,000 cycles per second, the lowest about 32 cycles per second—16,000 and 32 complete vibrations existing in each second of time. We also say the *frequency* of vibration is between 32 and 16,000 cycles per second. It takes a high frequency electron current vibration to create a radio wave, at least 100,000 cycles per second to send radio waves any reasonable distance. In fact, you know that the frequencies of the current producing radio waves for reception with broadcast receivers are between 550,000 cycles per second and 1,500,000 cycles per second.

When people, even radio technicians, talk about frequency, they very often do not say what they mean. Let me clear up a few of these misunderstandings. Perhaps the radio program column to which you refer in the daily newspaper indicates that the desired broadcasts are to be received at 620 k.c., or 700 k.c., or 1,410 k.c. The letters *k.c.* are an abbreviation for the word *kilocycles,* just as the letters *c.p.s.* are an abbreviation for the words *cycles per second,* and *m.c.* an abbreviation for the word *megacycles.* People get into the habit of saying *cycles* instead of *cycles per second, kilocycles* instead of *kilocycles per second.* You should realize this. However, kilocycles per second means 1,000 cycles per second, kilo meaning 1,000 (one thousand); megacycles means 1,000,000 (one million) cycles. These words are used because: it is easier and quicker to say and write 530 k.c. instead of 530,000 cycles per second; or it is more convenient to write 12.6 m.c. instead of 12,600,000 cycles, or even 12,600 k.c.

If it takes high frequency currents to produce radio waves, how are we to radiate the sound currents which have comparatively very low frequency vibrations? The solution to this problem is quite simple, of course, after you know it. Produce a high frequency current or radio frequency current as it is called, and make it carry the sound frequency currents. You will shortly understand how this is done.

GENERATING AND AMPLIFYING RADIO FREQUENCY CURRENTS

There are two practical ways a radio frequency current may be produced; one method employs a radio tube, the other method makes use of a crystal vibrator. As the latter is always used in a modern broadcasting station, that will be the one I will now describe. Quartz crystals are generally employed and when they are ground to shape for use as vibrators they either look like round discs about the size of a U. S. fifty-cent piece, or like little thin squares. Both resemble frosted glass in appearance. The crystal as shown in Fig. *8A* is placed between two metal discs, each disc connected to a terminal or prong. The crystal is placed in a box to protect it from dust and dirt, and the general appearance is like that shown in Fig. *8B*.

A crystal is useful for radio work only when it has been cut in a special way. When a quartz crystal vibrates, the free electrons in the crystal will tend to pile up on one of the flat faces, while the other flat face loses free electrons. This action is roughly indicated by

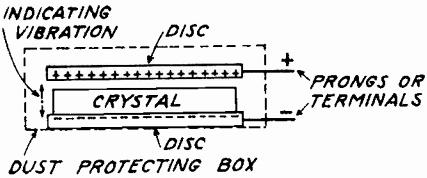


FIG. 8A

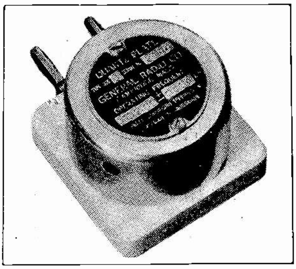


FIG. 8B

Fig. *8A*. The crystal vibrates very much like a strip of spring steel, but moves so rapidly and such a short distance that your eye can see no movement. The vibrations push electrons from one face to the other continually, so that a face is positively charged one instant and negatively charged the next.

The number of vibrations of the crystal per second will depend on its size, and particularly on the thickness of the crystal; it is not at all difficult to make a crystal vibrate millions of times per second.

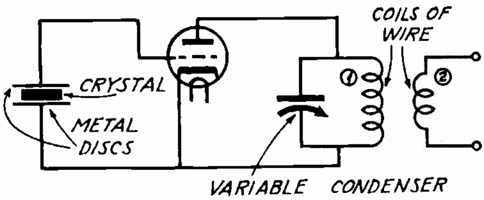


FIG. 9

The metal discs placed against the faces of the crystal collect the positive and negative charges formed by the vibrations; these charges make up an A.C. voltage having the same frequency as that at which the crystal is vibrating. The frequency of the A.C. voltage produced by a crystal thus depends upon the dimensions of the crystal.

As you would naturally expect, the voltage which can be produced by the crystal is very, very small. Vacuum tubes connected as shown in Fig. *9* are used to build up this voltage sufficiently to feed a transmitting antenna with radio power.

You already know that when an A.C. voltage is applied to the grid and cathode of a radio tube, a strong varying current of the same frequency flows from the plate to the cathode. Observe, however, that the varying plate current in the circuit shown in Fig. *9* is compelled to flow through a coil (the curly line symbol) and a condenser (the line-arrow symbol). (If you are not familiar with these radio parts: a condenser, in this case one in which the electrical value can be changed, is shown in Fig. *10A;* a coil is shown in Fig. *10B.*)

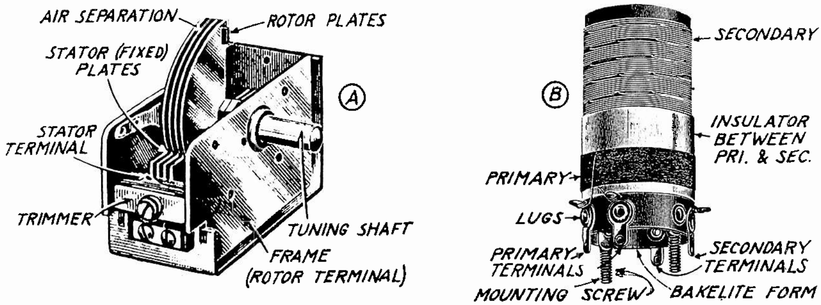


Fig. 10

A shows a variable condenser, that is, a condenser in which the electrical capacity can be varied. You can quickly locate the variable condensers in your own receiver. Be sure to inspect them. You will see a set of rectangular aluminum plates, each plate separated from the next; a set of half-round (or nearly half-round) plates, separated and clamped on a shaft Turning the shaft causes the rotor plates to mesh with the stator plates, but without touching them. The stator plates are insulated from the frame that supports both stator and rotor plates. As you rotate the plates so they mesh more with each other, the capacity of the condenser is increased. Several variable condensers are built into a single unit, called a gang of variable condensers. Although the rotors are electrically connected, each stator is electrically separated. With expert manufacture, each variable section has the same capacity, regardless of its position. For a final adjustment, a trimmer (a miniature book type) condenser is connected to each section; and quite often the outside rotor plates are split (or serrated). Split rotors and trimmers are important to radio service men, as they are used in adjusting the receiver for best performance.

B shows a common type of radio frequency transformer, which is really two coils closely associated. The secondary is generally tuned with a variable condenser, and because of the special circuit requirements has more turns of wire than the primary. Furthermore, the winding that is tuned should have low electrical resistance. However, it is not unusual for the coil that is being tuned to be a primary, an example is shown in Fig. *9*. The usual procedure is shown in Fig. *15*.

Why are these parts used? First, what is the function (or purpose) of each part? A coil, as you will later learn, will oppose any variation in current; that is, will oppose the flow of an A.C. current, and the higher the frequency of variation the more opposition the coil shows. On the other hand, a condenser is an electrical device that will allow A.C. current to pass through the circuit in which it is located, in fact the higher the frequency the more readily does the current flow in the circuit. When both a coil and a condenser are connected, as shown in Fig. *9*, so the varying plate current may flow through either one, a balancing action takes place, the current opposition of the coil balanced by the current acceptance of the condenser. And, for a definite frequency of current variation there is a definite amount of condenser, of course meaning its electrical value, when the action of the condenser removes very nearly all the opposition that the coil may have—and a very large A.C. current flows through the coil. A.C. current flowing through coil *1* produces, as you would expect, varying number of magnetic lines of force through the coil. Because coil *2* is in this varying magnetic field * an A.C. voltage having the same frequency as the vibration of the crystal is induced into this second coil.

To get this coil-condenser balance at the frequency of the vibrating crystal the number of turns on the coil, or the electrical size or capacity of the condenser is varied. The latter method is best accomplished by making half round plates of some conductive material rotate in or out of stationary plates. The variable condenser method is the more convenient procedure and is the method generally used. Varying the position of the rotor plates, or as we say, varying the capacity of the condenser, so as to get this coil and condenser balance is called "tuning"; and in this case we tune the coil and condenser circuit to the frequency of the crystal.

Why is tuning so important? Although I said that the crystal vibrated at a definite frequency, let us say at 1,000 k.c., it will at the very same time vibrate at 2,000, 3,000, 4,000, 5,000, etc., kilocycles per second. That is, the characteristic vibration of a crystal vibrator is quite complex. But we need only one radio frequency current to carry the sound signal current. So, we must select only one. Tuning the coil and condenser unit to the frequency we need allows only that frequency to pass while the others are suppressed. At the same time, the tuning circuit (as you will learn to call this coil and condenser combination) has the additional desirable effect of making the crystal work better by helping it vibrate and making this vacuum tube system give a large amount of amplification.

The radio frequency current delivered by a single stage amplifier is hardly sufficient to produce a strong radio wave. Hence, several vacuum tube stages are required, one stage following another and each one considered a stage of radio frequency amplification. As many as five and six stages are required in a moderate sized broadcasting station. Each succeeding tube is more powerful † for it takes more powerful tubes to handle large radio frequency currents.

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* For high frequency currents it is not practical to use a steel core, so it is omitted.

† Usually larger in dimensions, as this permits the tube to handle more current without getting too hot.

CHANGING RADIO FREQUENCY CURRENT TO RADIO WAVES

Having produced a strong radio frequency current, the latter must be converted to radio waves. The steel tower at the radio transmitter, or the wires suspended from two or more towers—the antenna—are responsible for radiating radio waves. A closer examination of the tower type antenna will reveal a tall steel mast supported by insulators at the base. The radio operator at the station will tell you that under the mast and in the ground are thousands of feet of heavy copper wire. A wire conductor from the ground wires and another conductor from the steel mast connect to the coil, which is associated with the tuning circuit of the last radio frequency stage of the transmitter. An R.F. (abbreviation for radio frequency, read *R.F.*) voltage

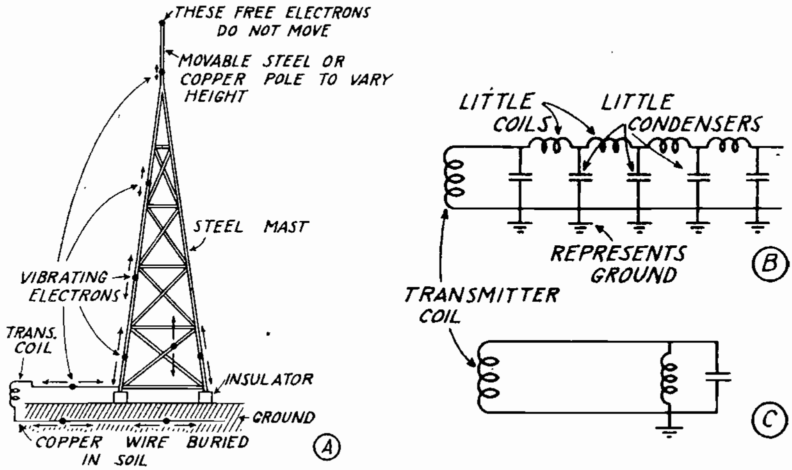


Fig. 11

is induced in this coil, and this causes a current to flow up the mast and in the ground wire network, as shown in Fig. *11A*. The electrons vibrating in the mast * "shake off" electric and magnetic lines of force which travel through space as a radio wave.

The beginner wonders how the mast can have a current, since the mast is insulated from the ground, preventing a return path for the electrons. But there is a path for an A.C. current, as you will shortly see. The steel tower with the ground forms a huge condenser (not necessarily its electrical size), allowing an A.C. current to flow through

* The mast is made of steel, each part riveted or welded together. This steel mast acts like a large vertical electron conductor. If a wooden mast is used, a large wire running parallel with and held by the mast acts as the antenna.

the condenser circuit. I mentioned this fact before. To be sure, the electrons do not jump from the mast to the ground, but electrons in the mast produce electric lines of force between the mast and the ground, influencing the free electrons in the ground, and they move.

Actually when you look at an antenna through the eyes of a radio expert you imagine the antenna system as little coils and condensers arranged as shown in Fig. *11B*, or roughly like the circuit suggested by Fig. *11C*. You will recognize at once that the antenna is a tuning

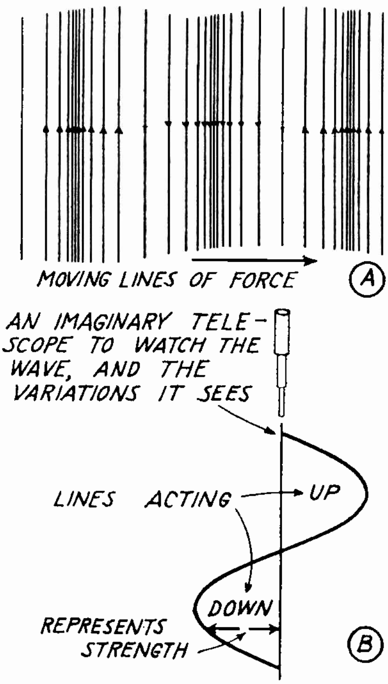
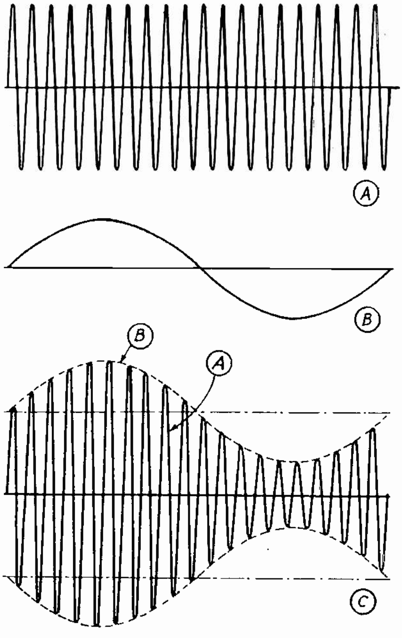


FIG. 12

circuit, the electrical size of the condenser and coil depending on the length of the mast. As a large radio current will produce a strong radio wave, the antenna when installed is tuned by varying its height.

Although the electrons are vibrating all along the mast, except at the top, the vibrations at the base are usually the strongest. The distribution of the current in the antenna determines whether the radio wave will be shot up to the sky or along the ground. The fact that it is shot up in the sky does not mean the radio waves so directed are of no use. The space above the earth (about thirty to eighty miles) has electrons and ionized air atoms which bend the radio waves back to earth. In fact, most of the long distance radio reception we get on our receiver is produced by this so-called sky wave. Radio engineers design the antenna to radiate either ground or sky radio waves, or both, in definite amounts, so either local or distant receivers may get the correct amount of broadcast signals.

If you were able to place yourself in space some distance away from the transmitting antenna, and were able to watch the radio waves go by, you would observe something like that portrayed in Fig. *12*. You would see electric and magnetic lines of force at right angles to each other, streaming by, acting first in one and then in the other direction, getting weak and strong alternately. A picture of this characteristic would look like Fig *12B*, a regular variation of magnetic or electric lines of force.



FIGS. 13A, 13B, and 13C

HOW THE RADIO WAVES CARRY SOUND SIGNALS

I already said that the radio currents are made to carry the sound signals, but how this is done is important. In fact, the method used determines how the sound signal is removed from the radio signal by the radio receiver.

So far, you have learned that a radio frequency current or voltage, and a sound signal current or voltage have definite characteristics. For example, in Fig. *13A* I show the characteristic of a radio frequency voltage, while Fig. *13B* shows the characteristic of a simple sound signal voltage. *A* is, *B* is not able to produce radio waves, primarily because of their frequency of vibrations. Suppose we were to make the radio frequency swell and contract, so the swelling duplicates the characteristic of the sound signal, and this modified (we technicians say *modulated*) radio frequency current, see Fig. *13C*, was fed to the antenna, then the antenna would send out waves that are varying in strength as well as vibrating at a definite frequency. If you were able to place yourself in space and view the magnetic or electric field, it would appear as shown in Fig. *13C*. And this is exactly what is done in a radio broadcasting transmitter, except more complex sound signals, like that shown in Fig. *1C*, are modulating the radio frequency current.

Figure *13D* shows one method of producing modulation. One of the radio frequency amplifiers is simultaneously (at the same time) fed with the sound signal voltage, and the radio frequency voltage (originally produced by the crystal vibrator). The tube is operated in a

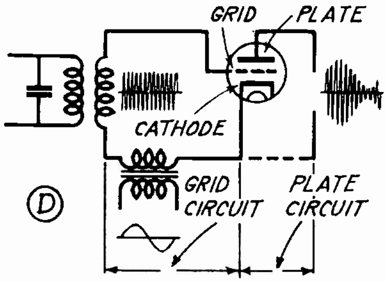


Fig. 13D

special way to permit modulation. These two voltages, *A* and *B*, are sent into the grid circuit resulting in modulated radio frequency plate current, *C*. The latter may be amplified several times before being fed to the antenna which, you know, throws off radio waves—and in this case carries the sound signal. Incidentally, this radio frequency current which carries the sound signal is called the "carrier current." X7

HOW THE RECEIVER ANTENNA PICKS UP THE RADIO TRANSMITTED PROGRAM

A few miles away from the broadcasting station, the *ground radio wave* passes the antenna of a broadcast receiver. Hundreds of miles away from the transmitter, the *sky wave* crosses a receiving antenna. The electric and magnetic fields of the radio waves force the free electrons in the antenna system to vibrate. Let me tell you how this is done.

Let us focus our attention on a single electron in the exposed portion of the antenna, as shown in Fig. *14*. At first it is moving around in a haphazard manner. When an electron moves it has associated with it an electric and magnetic field. As it takes many electrons moving in a definite direction to produce a current, this electron, as far as the antenna is concerned, is not producing a current; nor is any other electron. Going back to electrons in the presence of a radio wave, it is not difficult to see that the electric field of some electron may react with the electric field of the radio wave; and its magnetic field react with the magnetic field of the radio waves. The electron is moved back and forth by the electric and magnetic lines of force of the radio wave, in fact is made to vibrate about its location in the same manner in which the radio wave is varying. This vibrating electron and others affected in the same way relay their action to other electrons in the antenna and a radio frequency current is transmitted down the antenna, through a coil of wire, and as you know, to the ground, usually by the water pipe path.

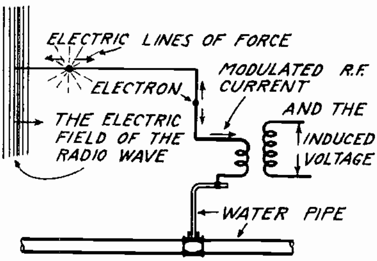


FIG. 14

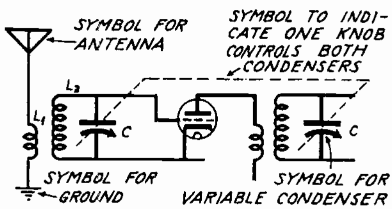


FIG. 15

Of course, the receiving antenna is, from an electrical viewpoint, a condenser and a coil. If it happens to be of the correct length, the radio current is "tuned in," becoming very strong. For broadcast reception tuning the antenna is not so important, because the receiver will amplify any signal which is reasonably large. But in many special antennas erected for all-wave reception, the exposed part is often of a definite length. In commercial stations which receive the radio waves from a definite transmitter, it is highly important that the antenna be tuned. If the antenna is not of the correct length, a variable condenser or a coil in which the number of turns may be changed can be used for tuning.

THE R.F. AMPLIFIER

Of course, the radio frequency current in the antenna circuit is modulated with sound current, but this circuit is apparently only able to act on the R.F. characteristic. The coil in the antenna circuit, L_1 in Fig. *15* induces a voltage in coil L_2 and immediately an R.F. current circulates in the circuit comprising coil L_2 and C, the condenser. C in this case is a variable condenser; that is, by rotating its movable plates, its electrical value or capacity changes. For the frequency of the radio wave "picked up" there is an electrical value that will make the circulating current very large. That is what the broadcast listener does when he tunes in a radio broadcast.

The tuning circuit composed of L_2 and C causes a large radio frequency voltage to appear across the terminals of the coil or the condenser. Technicians refer to this phenomenon as *resonance* or *tuning voltage step-up*. As this feature is quite important in radio we will study it, as well as many other factors presented here, in greater detail in a future lesson. Now the resonance, stepped-up, sound modulated, radio frequency voltage is fed to the grid and cathode of an amplifying tube, which produces a modulated R.F. current in its plate circuit—much stronger than the current in the antenna. As this amplification is insufficient, several more stages of R.F. amplification * are used before any attempt is made to separate the sound signal from the radio frequency carrier current.

Each successive R.F. amplifier has a duty to perform equally as important as amplifying the radio frequency current. Each tuning unit, a coil and a condenser, accepts the radio signal to which it is tuned and rejects to a certain extent all others. If enough tuned stages are used, the rejection of all but the desired one will be complete. In this way the tuned R.F. amplifier is provided with the additional ability to accept desired and reject undesired broadcasts. To make this action simple all the variable condensers are tuned at one time by a mechanical arrangement.

X3

WHAT THE DETECTOR DOES

Just as it is possible to make a radio tube amplify radio or sound frequency voltages, or modulate a radio signal with a sound signal, so is it possible to make a tube separate the sound signal from its carrier. Although the tube must be operated in a special way, which you will eventually master, the general procedure is shown in Fig. *16*.

* In modern receivers it is customary to introduce a system which reduces the frequency of the radio current, as better amplifiers are possible at lower frequencies. The system which does this is called a frequency converter, and the entire R.F. system is referred to as a superheterodyne. As in this lesson I only want to give you a general idea of how programs are sent and received, I am leaving this method of reception for a later lesson. The only fundamental difference is the frequency of the radio current which carries the sound signal through the R.F. amplifier of the receiver.

X 9 The tube that performs the function of separating the sound and radio signals is called a detector, or more technically, a demodulator.

The modulated radio frequency signal which has not changed its characteristic from the point it was created in the transmitter is fed to the grid and cathode of the so-called detector tube. This is signal *1* in Fig. *16*. The detector tube cuts off one-half of the signal, giving a characteristic similar to curve *2*. Observe that one-half of the swelling has been removed. Now the plate current portrayed by curve *2* is not as simple a characteristic as the original modulated R.F. current (curve *1*) for by this simple process of cutting off one-half the characteristic, considerable change has been made, in fact many different kinds of currents have been produced. To be sure, the sound characteristic still exists, and by expert design of the detector section of a radio receiver, the all important sound characteristic signal predominates, as well as the radio frequency carrier current. The important currents are shown as curves *3* and *4*.

But as we only want the sound signal we insert a coil *L*, and a condenser *C*. The coil opposes the high frequency current more than

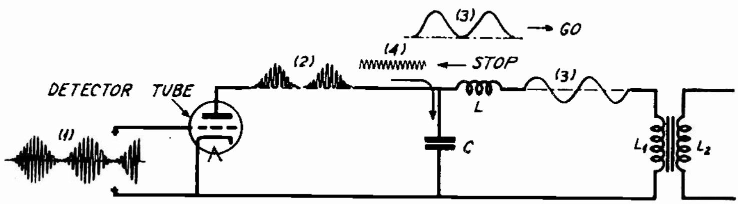


FIG. 16

the sound signal, in fact bars the way. The condenser *C*, accepts the radio frequency current and passes the high frequency electron vibration back to the cathode. If coil *L* is made electrically too large, it too will stop the sound signal; if the condenser *C* is made too large it will pass the sound signal. Therefore it is important that the electrical values of *C* and *L* be just right.

It is a fact that much of the unwanted change in the sound signal characteristic takes place in the detector, and it will be your duty as a Radio-Trician to see that the detector in the receiver brought to you for poor quality of reception is operated just as the maker prescribed.

THE AUDIO AMPLIFIER

The sound signal current or the audio signal, as it is often called, flowing through coil L_1 of Fig. *16* produces an audio voltage in the secondary, L_2. Together L_1 and L_2 constitute an audio transformer. Even this audio signal is too weak to do much good, just about strong enough to operate headphones, such as used by telephone operators. In a modern receiver we want sound created that can be heard in the room where the receiver is located. To do this one or more stages of audio amplification are employed, just like the amplifier in the transmitter following the microphone. When the audio voltage is strong enough, and in a modern radio receiver usually only one amplifier is necessary, the audio voltage controls a powerful tube, called a power tube. A strong audio current is produced in its plate circuit.

THE LOUDSPEAKER

The power tube is connected to another transformer, and the audio current flowing through its primary, L_1 in Fig. *17A*, produces an audio voltage in the secondary, L_2. A loudspeaker is connected in this final circuit, a device which is much like the microphone shown in Fig. *2A*. In this case the diaphragm is about eight inches in diameter and shaped into a funnel or cone. The cone is cemented to the moving coil. If the wire on the coil is pushed, the cone moves, pumping the surrounding air.

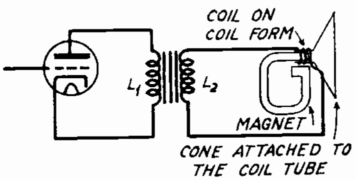


FIG. 17A

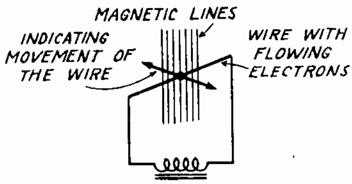


FIG. 17B

To learn how a loudspeaker operates, we turn to another fundamental principle of electricity. We know that a wire carrying current will produce a magnetic field. We also know that magnetic fields react on each other. Therefore, by placing (as shown in Fig. *17B*) the wire carrying current in a magnetic field produced either by an electromagnet or a permanent magnet, the wire will be pushed to one side.

Returning to Fig. *17A*, the voltage induced in coil L_2 causes an audio current to flow through the coil of the loudspeaker, the magnetic field produced reacts with the magnetic field of the magnet, moving the coil form and cone. Now, when the signal current vibrates, the cone vibrates, producing sound waves. And in this manner a strong electrical current with a sound characteristic is changed into sound.

If the entire broadcasting and receiving system does not change the *characteristic* of the sound signal, the sound emitted by the loudspeaker is identical to the original. Thanks to the ability of the engineers who designed and supervised the construction of radio transmitters and receivers, thanks to the technicians who operate the transmitter, and the service man who keeps the receiver in the proper condition, this intricate system works to perfection. Listen to a modern transmitting station, on a modern high fidelity receiver, and judge for yourself. One mistake, one wrong adjustment, one improper receiver repair, and faithful reproduction is gone. As a Radio-Trician it will be your duty to maintain this chain in perfect condition.

A REVIEW

I appreciate that I have covered a "lot of territory," telling you facts that were presented to you for the first time. I presented them now rather than later in the course so you will have a general idea of radio transmission and reception. As you proceed with your other lessons, the subjects given here will be studied again, and many difficulties and questions will be cleared away. Now let us review the

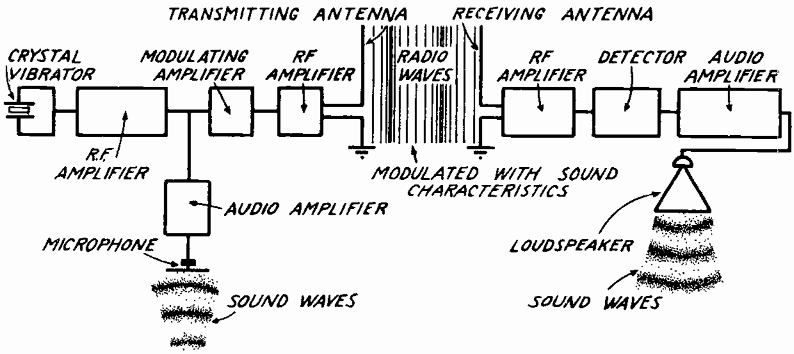


Fig. 18

process of sending and receiving a radio broadcast. If you understand this review this lesson has served its purpose. I shall use Fig. *18* as a guide.

The performers in the studio produce *sound waves,* which are picked up by the *microphone* and converted at once to a *varying electric current,* which corresponds in its *characteristic* to the sound waves. The *audio signal* produced by the microphone is repeatedly *amplified* by stages of vacuum tube amplifiers.

The amplified audio signal is fed to a vacuum tube, which is at the same time fed with a *radio frequency signal* produced by a *crystal vibrator* amplified by several R.F. (radio frequency) stages. If the *signal* delivered by the *modulated amplifier* is not strong enough it is further amplified before being sent into the *transmitting antenna.* The antenna is the outlet for the electric and magnetic fields—which are the *radio waves*—produced by the vibrating electrons.

Over the ground, or up to the sky ceiling and back to the ground, speed the radio waves, at 186,000 miles per second, to be intercepted by the *receiving antenna.* The radio waves set the electrons in the antenna into vibration, producing a *radio current.* After sufficient *amplification,* the *detector* separates the *sound signal* from its *carrier* and feeds the signal into an *audio amplifier.* A strong audio signal feeds into a *loudspeaker,* causing its cone to pump the surrounding air, giving the listener a true reproduction of the sound which was created in the studio of the broadcasting station.

HOW A TELEVISION SYSTEM WORKS

Strange as it at first may seem, a television system differs very little from a sound broadcasting system. Of course, the purpose of a television system is to convey a scene viewed in the studio, or at some important event, to your eyes in your home. Here we deal with visible objects, things that we see; whereas in sound broadcasting it is the sounds we want to hear that are being transmitted. I need not stress the fact that what we see is *light,* of various colors, including black and white, in a variety of shades or intensity. Technically, when you look at an object or a scene, your eyes see *reflected light,* and from years of experience you recognize this or that thing.

Perhaps you have already guessed how a television system differs from a sound system. A device changes the *reflected light* to an *electric current,* which in turn is conveyed and worked on by the transmitter—radiated in the form of a signal on a *carrier wave*—intercepted by a receiver—amplified, and the signal demodulated from the carrier. The signal is then amplified, and instead of feeding it to a loudspeaker, it is fed to a device which changes a varying electric current into varying light. Although the main differences are in the devices which change *light to electricity* and *electricity to light,* it must not be assumed that all a technician has to do is connect these devices to a regular transmitter and receiver. The peculiar nature of the television signal (we technicians call it a *picture signal* to distinguish it from a sound signal), makes extra demands on the transmitter and receiver, problems which are pretty well solved. However, a good idea of how a television system works is obtained by briefly learning how the pick-up device or television camera, and the picture reconstructor or radiovisor operates.

THE TELEVISION PICK-UP

The human eye is often compared to a camera, the exposed portion acting as a lens. In back of the human lens is a light sensitive membrane or surface (called the retina), which converts light to impulses which are conveyed to our brain for interpretation. But the photographic plate in the camera, the retina in our eye, sees a whole surface, each little portion of these light sensitive surfaces acting at one time. Unfortunately we have no simple scheme to send thousands of impressions over a wire or on a single radio frequency carrier. So, in television transmission the view is taken apart before it is converted into a picture signal, and at the receiver, the picture signal is changed to light and put together.

Supposing you were given the problem of sending a picture from one room to another, and the only path was a small metal tube, so small that it would be impossible to roll up the picture and blow it through. One way would be to cut the picture into narrow strips, blow each strip through in order, reassembling them in the other room,

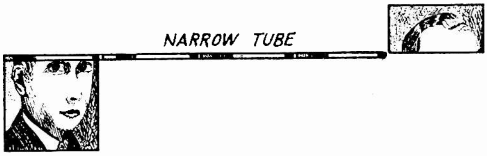


Fig. 19

as crudely shown in Fig. *19*. If you were to inspect each strip you would not be able to recognize the picture, but would see a strip of various shades of grey, or green, or blue, depending on the color of the picture. But put them together, and you see the original picture.

Now if we can find an electric device which will see these variations in shades, converting what it sees into a current corresponding to the light characteristic, we could use an electric cable to send the electrical equivalent of the varying shades on the strip. Fortunately we have an electric eye, or photoelectric cell as it is called, which will do this. It is nothing more than a plate covered with a special chemical (a commonly used substance being the chemical caesium oxide), and a metal ring placed in front of this special plate. These

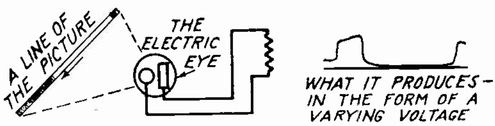


Fig. 20

two elements are placed in a glass tube, the air drawn out and the leads connected to them through the glass. The caesium oxide will give off electrons when hit by light waves, which happen to be electromagnetic waves of about a million million cycles per second. This light sensitive surface is therefore the cathode. The ring or anode is charged positively with respect to the cathode and attracts the electrons emitted by the action of the light. Electrons will flow through the outside circuit, if an outside connection is made. Moving a strip of the view we wish to transmit in front of the electric eye allows the latter to view the varying shades of light; and a varying electric current flows, an electric equivalent of the light shades. Figure *20* will help you understand the above electronic process.

With this information I can turn to a practical television camera, the important parts of one type being shown in Fig. *21A*. You will get a better idea of how it works from Fig. *21B*. To begin with, K is the light sensitive surface and as it emits electrons when covered with light, it is the cathode. By means of a camera type lens the object or scene is focused on the cathode, which immediately emits electrons, the amount in each little area differing, depending on how much light reaches that little area. With a little imagination you

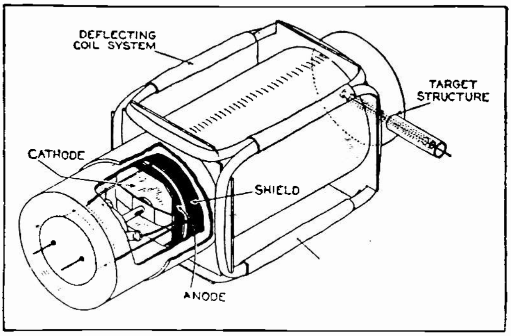


FIG. 21A

will realize that the electrons coming off the cathode produce an image of the scene, in fact it is called the electron image. Close to the cathode is an anode, fine wires constructed in a zigzag manner. So fine are these wires and so much space exists between adjacent wires that electrons have no difficulty in going straight through. This anode is positively charged with respect to the cathode, pulling the electrons off the cathode. In fact, they gain so much speed that they go

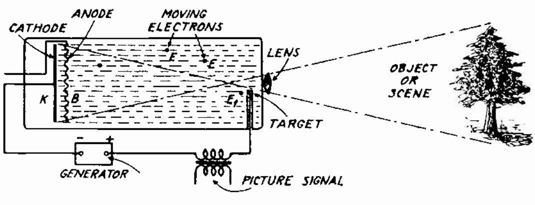


FIG. 21B

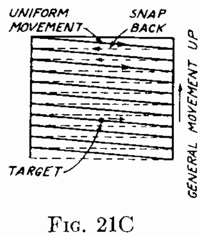


FIG. 21C

straight through to the end of the glass cylinder, which encloses the entire system in a vacuum.

At the end of the glass tube a small metal pin point (or target) faces the cathode, and all but its end is protected from electrons by a glass insulator. Electrons E_1 strike it (E_1 may be one or a thousand electrons, depending on the electron image), are drawn to the target by the positive charge that it is given with respect to the cathode, causing a current to flow through the primary of a transformer, the generator and back to the cathode. All other electrons are gathered by a metal surface inside of the tube which is charged positive with respect to the cathode, returning the remaining electrons to the cathode.

Now we return to Fig. *21A* and turn our attention to the rectangular coils of wire referred to as the "deflecting coil system." These are really electromagnets with the inside of the tube as a core. Recall that I said earlier in this lesson: "A magnetic field will repel or attract a wire carrying an electric current." If the current exists without the aid of a conductor (wire) then the current is attracted or repelled; and as the current is a flow of electrons the electrons are moved or *deflected,* as it is usually said.

Two opposite coils in Fig. *21A* are really two parts of the same electromagnet. Note that there are two deflecting systems at right angles to each other. One is fed by a special characteristic current which moves the electrons uniformly from one side to the other, only to be snapped back to the starting side. While this is going on, the other electromagnet is slowly moving the entire electron image from the bottom up. After the electron image of the whole scene has been moved

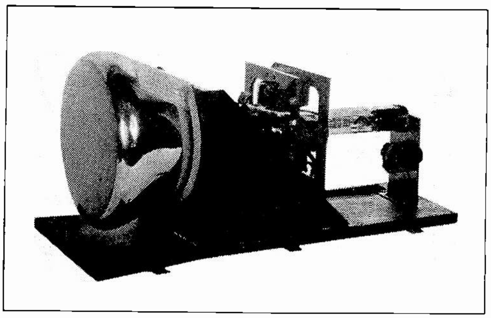


FIG. 22A

up, the second coil system snaps the whole scene back to the level of the target and the process begins all over again. What the target sees is line after line, or strip after strip, one after the other, passing at the same time the varying amounts of electrons into the generator-transformer circuit; and the over-all effect is a varying current. This varying current is the picture signal, which is to the television system what the audio signal produced by the microphone is to the sound system of radio transmission.

THE RADIOVISOR

At the output of the radio receiver (the plate circuit of the last tube) the picture signal is delivered to an image reconstructor, which changes electricity to light. A typical modern device is shown in Fig. *22A*. Again Fig. *22B*, the schematic diagram, will tell us more concerning how the radiovisor operates. To begin with we find a small pin point cathode *k* heated by a hot filament wire, emitting millions of electrons. They are drawn through a tubular shaped anode and into a fine stream of electrons. These electrons flying at an enormous speed strike the end of the funnel shaped glass tube. Here is where electronic impact is converted into light. The end of the tube, the inside of course, is covered with another special substance called willemite, which glows when hit with electrons. The energy of impact sets the electrons in the willemite into vibration, giving off a greenish light. The faster the electrons or the more electrons in the stream, the brighter the spot.

While the electrons are streaming from the cathode-anode system, commonly called an electron gun, the two sets of deflecting coils are, by means of special characteristic currents, moving (or sweeping) the beam, hence the spot sidewise and from the top to bottom. At the same time the picture signal is being fed to the grid and cathode of the device, causing the electrons in the electron stream to vary in number and in accordance with the picture signal. In this way, the spot reconstructs the original scene, in what is called the cathode ray tube method.

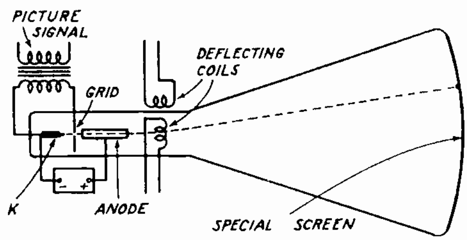


FIG. 22B

How is it possible that a picture or view that has been taken apart, only to be reassembled again, can appear to our eyes as a complete scene? Simply that the human eye can be "tricked" into seeing the whole instead of the part, for the eye cannot follow changes of more than about ten a second. In fact, when changes occur at twenty-four times each second, and it is the practice of motion pictures to show twenty-four pictures per second one after the other, and each slightly different, the eye is never aware that anything but an active scene is presented. This virtue of the eye as far as "movies" and television are involved, is called *persistence of vision.*

LESSONS TO FOLLOW

In this presentation of how sound or television broadcasts are made possible, naturally I could only briefly touch each phase of the subject. To be able to understand the subject thoroughly, each phase must be studied in greater detail. Then too, in this discussion I could show only one method of doing each job; yet there are, as a rule, many ways of amplifying a signal; there are many more types of tubes than the three-element tubes used in this lesson. I showed you how a signal was transferred from one tube to another by means of a transformer. Yet the same thing can be done with a combination of resistors and condensers; or resistors, coils and condensers in combination, and often these are better suited for the purpose in mind.

You must learn all important methods. But first you must learn more about electric currents and how they are generated; then more about resistors, coils, transformers and condensers; more about tuning circuits; more about the other vacuum tubes in use—before you can really understand, as an expert should, how amplifiers and detectors work and eventually how a complete radio system operates.

In the very next lesson, you will study the important practical electron generators or voltage supplies, which you as a Radio-Trician should understand. Your first two lessons clearly show the importance of generators in radio. You will also master the basic difference between the various forms of electrical and radio currents.

TEST QUESTIONS

Be sure to number your Answer Sheet 2FR-3.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and the best possible lesson service.

1. What is sound?
2. What is the purpose of the microphone?
3. What is the name given to any surface which emits electrons?
4. What is the name given to any element which attracts electrons?
5. What will a transformer do to the grid voltage variation when connected between a microphone and the grid and cathode terminals of a tube?
6. What is the highest and what is the lowest frequency of sound vibration that we can hear?
7. What is the radio frequency *current* which carries the sound signal called?
8. In addition to amplifying the radio frequency current, what ability is provided by a tuned R.F. amplifier in a radio receiver?
9. What is the function of the detector?
10. What will happen to a wire carrying current placed in a magnetic field?

INSTRUCTIONS FOR PERFORMING EXPERIMENTS 11-20

2BA-1

PRACTICAL LABORATORY
TRAINING COURSE

PIONEER HOME STUDY RADIO SCHOOL
NRI

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

HELPFUL INFORMATION FOR WIRING RADIO CIRCUITS

Wiring diagrams are intended only to show which terminals are connected into groups. There may be two terminals in a group or there may be more. The wires connecting the groups may be, and generally are placed different than shown in the diagrams. Comparison of Fig. *19* (on page *14*) with *19A, B, C* and *D* (given below) will show how changes can be made to suit the person who does the wiring.

First note that the socket has four terminals which you will mark if needed as shown in Fig. *16*. The milliammeter has two terminals. These two terminals are marked plus (+) and minus (—). (Many manufacturers mark only one of the terminals, in which case the unmarked terminal is of opposite polarity.) The voltmeter also has two terminals which are marked plus and minus. The potentiometer terminals are not marked, but if you will refer to Fig. *15* you will see that the numbers *1, 2* and *3* are shown which have the same meaning as the numbers in Fig. *19*.

The dry cell which is used for heating the filament is known as the "A battery." The "A battery" has two terminals. The positive terminal is known as "A+." The negative terminal is known as "A—."

The battery which you use for supplying the plate current of a vacuum tube is known as the "B battery." The "B battery" also has two terminals. The positive terminal is known as "B+." The negative terminal is called "B—."

Notice that Fig. *19A* shows all of the above mentioned terminals on the symbols and that no connecting wires are shown. Now we are ready to connect the wires for Fig. *19*. We will select a group of three terminals.

Cut a length of wire and attach one end of it to the plus terminal of the milliammeter. Attach the other end of this wire to terminal *2* on the potentiometer. Scrape the insulation from the wire at a place where the wire also will connect to the plus terminal of the voltmeter.

When you have finished, draw a line in Fig. *19A* between the three terminals you just connected together. You will have a drawing which is the same as shown in Fig. *19B*. Here I would like to give you the important explanation that three or more terminals joined like this may be connected in any manner which will join them together. Therefore, you could make the connection like that shown in Fig. *19C* or Fig. *19D* and still have the circuit wired correctly for these particular three connections.

Next, see to it that the group of five terminals, in which B— is included, is connected in any manner which will join them together.

If you will keep in mind that three or more terminals may be joined in any manner which will connect them together, then you will make wiring connections without difficulty. A wiring diagram is intended to show you which terminals are located in any one group.

IMPORTANT SUGGESTIONS AND HINTS

Under any circumstances do not allow the ends of wires, which connect to terminals *1, 2* and *3* on the potentiometer to touch each other or the metal cover of the potentiometer. Also do not allow the ends of the wires which connect to the meter terminals to touch the metal cases of the meters. These faulty "shorted" connections may cause the potentiometer to burn out when the dial is rotated in Fig. *15* or *19*, or burn out the tube in Fig. *17* or *18*. Follow these suggestions and you will not experience trouble.

Should an accident occur, a burned out potentiometer in Fig. *19* will be indicated by the voltmeter failing to show a gradual change in reading from zero to maximum while the dial on the potentiometer is rotated.

A burned out tube will be indicated when tested as in Fig. *18* and gradual changes in filament voltage do not take place while regulating the movable contact on the 30 ohm resistor. Low or no plate current readings are generally due to the filament voltage being less than 1.4 volts while a good tube is in the socket. Use two dry cells if necessary to maintain the filament voltage between 1.4 and 2 volts.

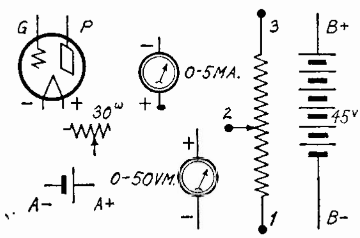


FIG. 19A.

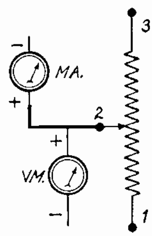


FIG. 19B.

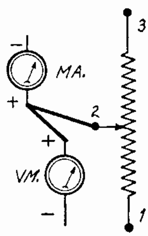


FIG. 19C.

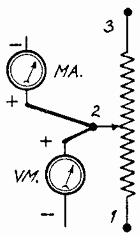


FIG. 19D.

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Instructions for Performing Experiments 11-20

INTRODUCTION

In this set of experiments you are going to study vacuum tubes. You will observe their behavior as amplifiers and learn how to test them.

You will learn that a filament emits electrons, that a positively charged plate will attract electrons, and that a negatively charged plate will repel electrons. You also learn that increased filament emission will increase current flow through the tube and that the use of an electrically charged third electrode will increase or decrease the amount of current flow.

You will find that the wiring of apparatus for the first experiments is explained in detail. These instructions are accompanied with symbol diagrams as well as picture diagrams.

The wiring for later experiments is carried out from symbol diagrams entirely. In practical work, all wiring is done from symbol diagrams and these first experiments give you an opportunity to see how symbol diagrams are used to represent the connections which are made.

SIGNIFICANT FIGURES: In radio work of all kinds it is frequently necessary to use formulas. Of course, in using a formula we take an equation that has been developed for us and substitute numbers for the symbols, then solve for the answer. Taking the formula of Ohm's law for example, we know that $I = \frac{E}{R}$. Suppose we know that E is 10 volts and R is 5 ohms. Our problem then becomes $I = \frac{10}{5} = 2$ and we find the value of the current by very simple arithmetic.

In the majority of cases we get the values that we substitute in formulas from meter readings. Most meter readings are approximations beyond two *significant* figures. Realizing this, we can simplify the working out of formulas a great deal—by considering only significant figures. Suppose we wanted to find the value of E across a 26 ohm resistor and we measured the current as being 12 amperes. Substituting in the formula $E = IR$, we would get $E = 12 \times 26$ or 312 volts. But a meter can only read two figures with any meaning attached, therefore for all practical purposes, if we said E was 310 volts we would be just as correct as if we said E was 312 volts. In other words, only the first two numbers in our answer are significant. The whole idea of significant numbers is based on the accuracy of the instruments used and the closeness with which readings can be made. The average 0–50 voltmeter permits readings within 1 volt. Thus a reading of 39 volts might indicate 39.4, 39.8 or 39.5 volts. As the voltmeter readings show only 2 significant figures, and with manufacturing tolerances plus or minus 10 per cent, it is useless to have more than two significant figures in the answer.

In some cases the use of three and four significant figures is possible, when exceptionally accurate meters with finely divided scales are used and when all the factors to be used can be obtained with the same precision. However, throughout your experimental and practical work, remember that two significant figures will be sufficient in most cases.

OUTFIT NO. 2 CONSISTS OF:

(See Fig. 14)

Item No.	*Quantity*	*Description*
(10)	1	Type '30 vacuum tube
(11)	1	4-prong socket
(12)	1	0–50 D.C. voltmeter
(13)	1	10,000$^{\omega}$ potentiometer
(14)	1	30$^{\omega}$ resistor
(15)	1	Meter stand
(16)	1	Baseboard
(17)	1	Potentiometer bracket
(18)	1	Dial for potentiometer
(19)	4	Fahnestock clips
(20)	7	No. 4 screws, ¼ in. long
(21)	2	No. 4 screws, ⅝ in. long
You Supply:		
	1	45^{v} battery with 22½^{v} terminal
	1	4½^{v} C battery with 1½^{v} and 3^{v} terminals

EXPERIMENT NO. 11

Object: To show how a visual continuity tester can be made to measure resistance in ohms (made into an ohmmeter).

Apparatus Required: Voltmeter (item No. 12); meter stand (15); 45^{v} battery; test prods; potentiometer (13); dial (18); baseboard (16); ¼ in. screw (20).

Apparatus Assembly:

1. Assemble potentiometer on baseboard as in Fig. 15.
   (a) Screw down the potentiometer bracket on the baseboard, placing the screw about 1 in. from the front edge and about 2 in. from the right edge. Be sure that the reference mark on the top of the bracket faces the front.
   (b) Remove the large nut from the potentiometer shaft, slip the potentiometer shaft through the hole in the bracket from the back with the terminal lugs extending upwards.

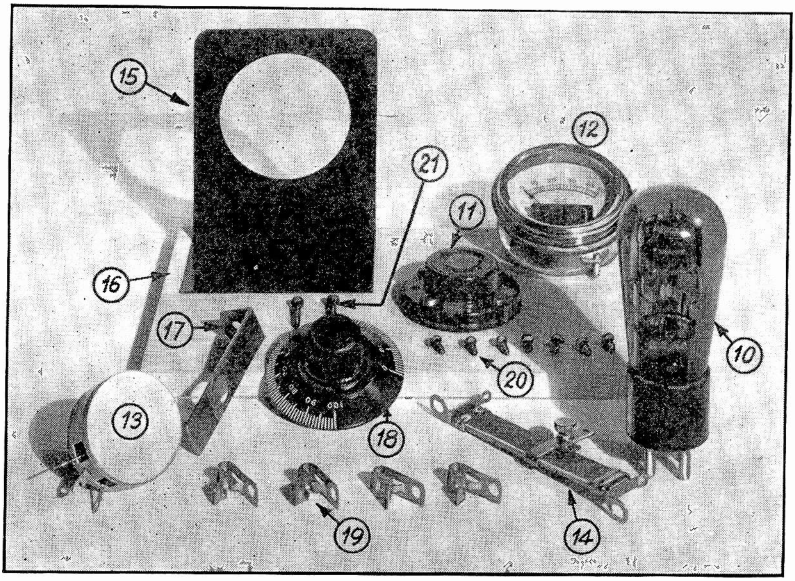

Fig. 14

   (c) Replace nut on potentiometer shaft and draw up tightly.
2. Place dial on potentiometer shaft.
   (a) Turn shaft all the way to the left (in a counterclockwise direction).
   (b) Loosen the set screw in the dial and slide the dial onto the potentiometer shaft.
   (c) Set the dial so that the reference mark on the bracket points to zero on the dial and tighten the set screw.

direct comparison makes it unnecessary to calibrate an ohmmeter by calculation, using Ohm's law, in which case we would calculate the amounts of resistance required to give various current meter readings using the formula $R = E/I$. However, R would then include the meter resistance which would have to be subtracted, so that the procedure would become rather complicated.*

Supplementary Experiments:

1. Calibrate the ohmmeter with 22½ volts instead of 45 volts.

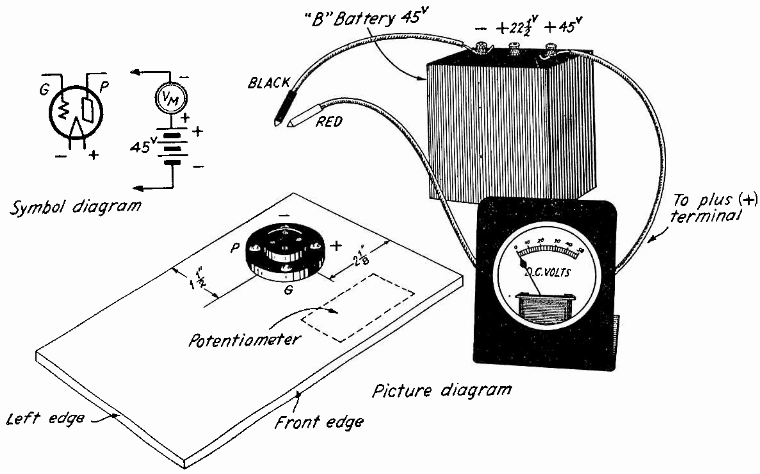

Fig. 16

2. Use the 0–5 milliammeter and a 4½ volt battery as an ohmmeter and calibrate it. Your milliammeter may be used as a voltmeter because of its relatively high resistance and for this reason can be used in an ohmmeter arrangement.
   Note: A low resistance milliammeter can be used as a voltmeter only if used in conjunction with a series resistor to limit the current and prevent burning out the meter.

Practical Applications: An ohmmeter is one of the Radio-

* The formula is $R = E/I - r_m$, where r_m is the meter resistance. This can be simplified to $R = (D/d - 1)r_m$, where D and d are deflections before and after testing the resistor.

Trician's most used pieces of equipment. With it he tests the continuity of circuits and determines the amount of resistance in the circuits. He also tests radio devices such as coils and resistors in this way. If the resistance of a device is not within about 10 per cent of its rated resistance it can be considered that the device is unsuitable for use.

Report Statement: At this point refer to Statement No. 11 on the separate "Report on Experiments" sheet and circle the proper word or words.

EXPERIMENT NO. 12

Object: To show how vacuum tubes and tube sockets are tested for short circuits.

Apparatus Required: Tube socket (item No. 11) ; '30 type tube (10) ; two ½ in. wood screws (21) ; ohmmeter from Experiment No. 11.

Apparatus Assembly: Screw the socket to baseboard behind the potentiometer as shown in Fig. 16 with the *G* and *P* terminals to the left.

Experimental Procedure:

1. Test the ohmmeter itself by touching the test prods together. If no meter reading is obtained, check the battery and meter connections.
2. Test the socket for short circuits—without the tube inserted.
   - (a) With one test prod on any socket terminal, touch the other test prods to the other socket terminals.
   - (b) Move the first test prod to the next terminal and repeat.
   - (c) Test across the two terminals across which no tests have been made. No meter readings should be obtained on any of these tests.
3. Test the tube for continuity and short circuits.
   - (a) Insert the tube in the socket and test across various pairs of socket terminals as before, noting the meter reading for each test. Be sure that the meter is not short circuited. Should the resistance of the meter not be in the circuit when testing the filament, the full 45 volts of the battery would be applied directly to the filament which would cause it to burn out.

Observations:

1. If any of the tests on the socket with the tube out of the socket show that there is continuity between the terminals, the socket is short circuited. Should your socket be shorted, remove it from the baseboard, turn it upside down and check the position of the metal blades into which the tube prongs fit. If any two are touching, separate them with a screwdriver.
2. When the tube is tested for continuity, in the socket, there should be continuity only between the two filament terminals (marked $F+$ and $F-$ or $+$ and $-$ or simply F and F). Should this connection not show continuity, the tube prongs are not making contact in the socket or the filament is burned out and the tube should be returned for replacement. If there is continuity between any two terminals other than between $F+$ and $F-$, the tube elements are short circuited and again the tube should be returned for replacement.

Practical Application:

1. It frequently happens that the cause of a defect in a receiver is traced to a shorted socket or tube. Service men make a practice of testing sockets in the manner described in this experiment—new ones as well as old ones.
2. In some cases it is a simple matter to tell whether the filament is burned out when the tube is in its receiver and the set is turned on—the filament will light up visibly if the filament is not burned out. In most cases, however, the filament is designed to emit electrons without lighting; therefore it is advisable to test the filament for continuity.
3. The test for shorted elements is an important one for in many receivers a short in one tube may result in damage to the other tubes or the associated apparatus.
4. It sometimes happens that tube prongs and socket terminals are unmarked. In this case a continuity test would make possible the identification of the filament terminals from which the position of the other terminals could be found.

Report Statement: At this point refer to Statement No. 12 on the separate "Report on Experiments" sheet and circle the proper word or words.

EXPERIMENT NO. 13

Object: To show continuity conditions in a vacuum tube when voltages are applied to the elements.

Apparatus Required: Same as in Experiment No. 12; 1½ volt dry cell.

Apparatus Assembly: Connect dry cell to filament terminals of socket as in Fig. 17, positive of dry cell to $F+$ on socket.*
Insert the tube in socket.

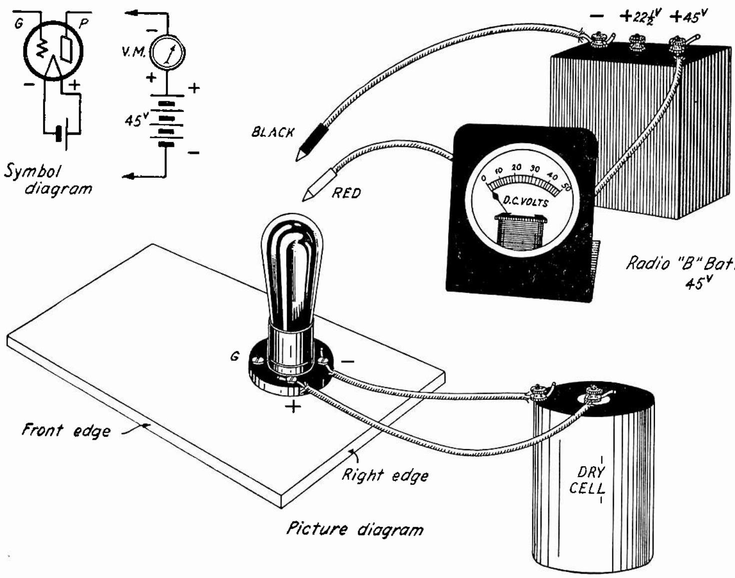

Fig. 17

Experimental Procedure:

1. Test the ohmmeter by touching the test prods together.
2. Test across all the socket terminals in succession following the plan given in Table No. 2. Note the meter readings and record them in the spaces provided in the table.

---

* Whenever changes are made in the wiring the tube should be out of the socket.

Observations:

1. Of the twelve tests made, only six should cause the meter to deflect.
2. In Test No. 1, the voltage of the $1\frac{1}{2}$ volt dry cell "bucks" and subtracts from the 45 volt B battery.*
3. In Test No. 6, the $1\frac{1}{2}$ volts add to the 45 volts.
4. In Test No. 8, the positive potential of the 45 volt battery connects to the plate and attracts electrons emitted from the cathode (filament). This flow of electrons constitutes a flow of current through the tube but notice that the reading is reduced to about 3 because of the high cathode-to-plate resistance of the tube.

TABLE No. 2

Test No.	*Red Test Prod on*	*Black Test Prod on*	*Approximate Meter Reading*	*Your Reading Shows*
(1)	$F+$	$F-$	43	______
(2)	$F+$	P	0	______
(3)	$F+$	G	0	______
(4)	$F-$	P	0	______
(5)	$F-$	G	0	______
(6)	$F-$	$F+$	46	______
(7)	P	G	0	______
(8)	P	$F+$	3	______
(9)	P	$F-$	2	______
(10)	G	$F+$	7 to 24†	______
(11)	G	$F-$	6 to 23†	______
(12)	G	P	0	______

† Depending on circuit conditions and tube elements construction.

5. In Test No. 2, no reading is obtained because the negative potential of the 45 volt battery is applied to the plate and, as you know, electrons cannot pass from the plate to the cathode.
6. In Test No. 9, a lower reading is obtained than in No. 8, because the plate voltage is 45 volts, while in Test No. 8 the effective plate voltage is $46\frac{1}{2}$ volts caused by the $1\frac{1}{2}$ volts of the dry cell adding to the 45 volts of the B battery.

* Notice that the table gives 43 volts instead of the calculated 43.5^{v}. This, of course, is because we are considering only two significant figures again. The same is true in Observation No. 3.

7. For the same reason, Test No. 10 gives a higher reading than Test No. 11.
8. Test No. 10 gives a higher reading than Test No. 8 because the grid is closer than the plate to the cathode. This also shows that the grid-to-cathode resistance is less than the plate to cathode resistance. If a tube socket is not marked you can readily distinguish the plate terminal from the grid terminal by applying this test.
9. Tests 2, 3, 4, 5, 7 and 12 will result in no meter reading unless the tube elements are shorted.

Theory of Operation: When the filament of a vacuum is heated it emits electrons. These electrons will be attracted to anything in the tube that may be positive. The plate and the grid of the tube even without any voltages applied to them are positive with respect to the electrons—actually they are at zero potential, but the filament being negative because of electron emission, an element at zero potential will be positive with respect to it.

If you tap the phone tips across the *G* and *F* terminals with the filament heated, you will hear slight clicks in the phones, indicating that there is a difference of potential across the grid and the filament. Looking at it in another way, the electrons emitted from the filament flow to the grid and through the phone circuit.

You will not hear any clicks if you touch the *P* and *F* terminals because only a few emitted electrons reach the plate, due both to the distance of the plate from the filament and the repelling effect of those electrons that have collected on the grid on the electrons emitted from the filament.

When you connect the ohmmeter to the tube with the positive to the plate or grid and the negative to the filament, you are really applying a positive potential to the plate or grid. This high positive potential attracts emitted electrons so that there is a flow of current through the tube.

Practical Application: In any vacuum tube circuit, a positive potential is applied to the plate for it is necessary to obtain a plate current through the tube before amplification or detection can be obtained. The amount of potential varies with the type of tube and the function of the tube in the circuit. In a later experiment we shall see the effect of applying a voltage to the grid.

Report Statement: At this point refer to Statement No. 13 on the separate "Report on Experiments" sheet and circle the proper word or words.

EXPERIMENT NO. 14

Object: To show that with a given plate voltage the amount of plate current is dependent on the amount of current flowing through the filament.

Apparatus Required: Same set-up used in Experiment No.

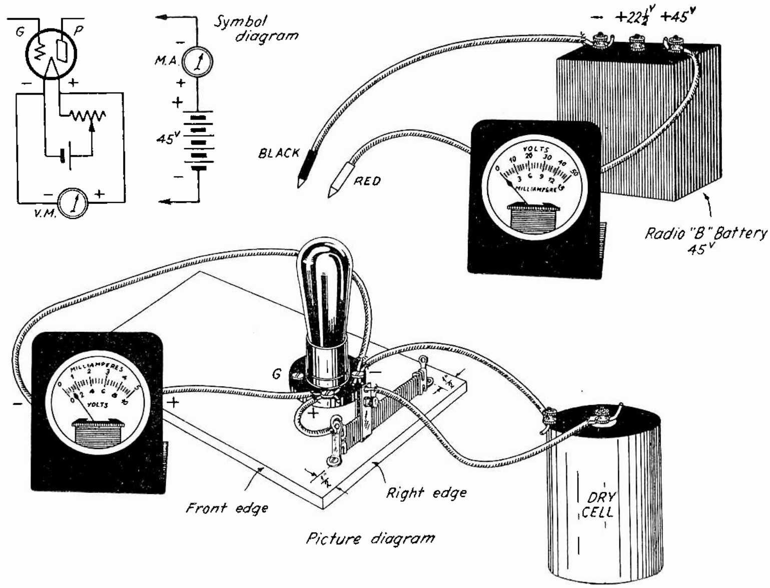

FIG. 18

13; 30 ohm resistor (item No. 14), two ¼-in. screws (20); 0–5 milliammeter.

Apparatus Assembly:

1. Fasten the 30 ohm resistor on the baseboard, to the right of the tube socket, near the right edge of the baseboard. Be sure that the thumb nut is on the side away from the tube socket. See Fig. 18.
2. Connect the 30 ohm resistor in the filament circuit.
   (a) Remove the positive battery connection at $F+$ and connect it to the sliding contact of the resistance unit.

(b) Connect $F+$ to the nearest end of the 30 ohm resistor with about a 3 in. lead. In making connections of this kind, run the wire through the eyelet and wrap several turns around the terminal strip.

3. Join the $F+$ terminal of the socket to the + terminal of the milliammeter and $F-$ to the negative terminal of the meter. As the milliammeter is connected *across* the filament terminals, we are using it as a voltmeter.

Experimental Procedure:

1. With the filament resistor arm set so that the 0–5 milliammeter reads ¾ ma. which is equivalent to 1½ volts as shown on the extra scale in Fig. 18, apply 45 volts positive to the plate by placing the red test prod on P and the black one on $F+$ or $F-$. Read the plate current on the 0–50 voltmeter using the extra scale shown in the figure to obtain the value of the current in milliamperes.
2. Set the filament resistor arm until the 0–10 voltmeter reads 1 volt (½ ma.). Note reading on 0–15 plate milliammeter with red prod on P and black prod on $F+$ or $F-$.

Observations: In procedures 1 and 2 above the same plate voltage is applied in both instances but a difference in plate current is noted when the filament voltage is changed from 1½ to 1 volt, or, what is the same thing, when the current through the filament circuit is decreased. Thus it is obvious that the amount of plate current is dependent on the current through the filament for a given plate voltage.

Theory of Operation: Of course, the more current that flows through the filament, the greater is the amount of power dissipated as heat. Thus the filament temperature rises with increased current—electron emission from the filament goes up, and the plate current increases.

The use of the 0–50 voltmeter as a 0–15 milliammeter and the 0–5 milliammeter as a 0–10 voltmeter deserves a brief explanation. It has already been mentioned that a voltmeter is nothing more than a milliammeter used in series with a resistance, and connected across any two points in a circuit instead of in series with the devices in the circuit. The amount of voltage that can be measured by a milliammeter and the amount of current that can be measured by a voltmeter are determined by the internal resistance of the meter.

Your 0–50 voltmeter has a resistance of about 3300 ohms. Using Ohm's law, $I = \frac{E}{R}$, we can see that a current of .015 amp. or 15 ma. will cause a full scale deflection so that, when connected in series in a circuit, the current scale will be from 0-15 ma. as shown on the meter scale in Fig. 18 ($I = \frac{50}{3300} = .015$ amp.).

The 0-5 milliammeter has a resistance of about 2000 ohms. From Ohm's law, $E = IR$ we can see that a voltage of 10 connected across the meter will cause full scale deflection

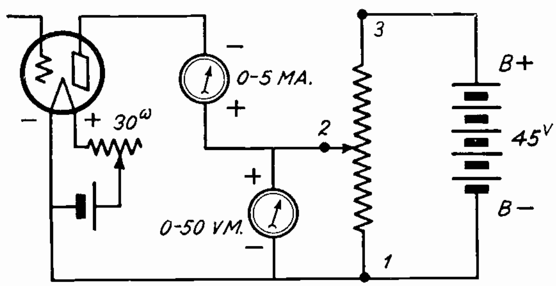

FIG. 19 (See footnote, page 15)

($E = .005 \times 2000 = 10$), so that the voltage scale will be from 0–10 volts as indicated in Fig. 18.

Practical Application: In old type battery sets volume was controlled by means of a variable resistance in the filament circuit by which the temperature of the filaments could be controlled. This experiment shows you how this would serve to control volume.

In modern receivers this type of volume control is never used but from this experiment we can see that the proper voltages must be applied to the tube filaments for efficient operation. Should the filament voltage drop off for one reason or another, the plate current would be decreased and the signal output of the receiver would be decreased.

Report Statement: At this point refer to Statement No. 14 on the separate "Report on Experiments" sheet and circle the proper word or words.

EXPERIMENT NO. 15

Object: To study the effect of changes in plate voltage on plate current.

Apparatus Required: Same as in Experiment No. 14.

Apparatus Assembly: Connect up the apparatus as shown by the symbol diagram in Fig. 19.

1. Remove the 0–5 milliammeter leads from the filament terminals but leave the 1½ volt supply connections as before.
2. Connect terminal *2* of the potentiometer to the + terminal of the 0–50 voltmeter and to the + terminal of the milliammeter.
3. Connect the − terminal of the 0–50 voltmeter to *B*−, *A*− or terminal *1* of the potentiometer.
4. Connect the − terminal of the 0–5 milliammeter to the *P* terminal of the tube socket.
5. Connect *B*− to the minus terminal of the 1½ volt filament supply.
6. Connect terminal *1* of the 10,000 ohm potentiometer to *B*− and terminal *3* to the +45 battery terminal.*

Experimental Procedure:

1. Set the potentiometer so that the voltmeter reads 45 volts, then note the milliammeter reading. Record this value in the last column of Table No. 3.
2. Read the voltage drop across the milliammeter by using the 0–10 voltmeter scale in Fig. 18 (the voltage reading is double the milliampere reading). Record this value in the third column in Table No. 3.
3. Subtract the voltage drop across the milliammeter from the 0–50 voltmeter reading (in this case 45) to obtain the true voltage applied to the plate. Record this value in the "Actual Plate Voltage" column of Table No. 3.
4. Repeat procedures 1, 2 and 3 with the potentiometer set so that the plate voltmeter reads 40^v, 35^v, 30^v, etc., as indicated in the second column of Table No. 3, and record all readings carefully.

---

*Note: To prevent *burning out* the potentiometer, extreme care should be taken to insure that the minus terminal and the plus 45 volt terminal of the B battery are connected to the *outside* terminals (1 and 3) of the potentiometer. The plus 45 volt connection is made last to save the B battery's life and when the potentiometer is connected across this, current is drawn from it. Open the plus 45 volt B battery connection when not making observations. See Fig. 15 or Fig. 25 for location of terminals 1, 2 and 3.

5. Plot a graph showing the relation between plate current and plate voltage for your tube, using the readings you obtained. Use the blank graph provided for this purpose in Fig. 20b.
   (a) Locate the position of point No. 1 by drawing a light vertical line upward from the bottom scale, starting at the point representing your "actual plate voltage" value.
   (b) Draw a light horizontal line starting from the left scale at the point representing your plate current reading (as recorded in the last column of Table No. 3).

TABLE No. 3*

Readings For Points on Graph	*Voltmeter Reading (Volts)*	*Milliammeter Voltage Drop (Volts)*	*Actual Plate Voltage (Volts)*	*Milliammeter Current (M.A.)*
No. 1	45	3.2	42	1.6
No. 2	40	2.6	37	1.3
No. 3	35	2.2	33	1.1
No. 4	30	1.6	28	0.8
No. 5	25	1.0	24	0.5
No. 6	20	.4	20	0.2
No. 7	15	.2	15	0.1
No. 8	10	0.0	10	0.0
No. 9	5	0.0	5	0.0

   (c) The point where these two lines intersect (meet) is point No. 1.
   (d) Locate points for all other values of "actual plate voltage" as recorded in the table.
   (e) Join the points with a smooth curve as in the graph worked out for you in Fig. 20a for which laboratory values were used and you will have the plate voltage-plate current (E_p—I_p) curve of your tube for plate voltages from 5 to 45 volts.

Observations: From the results of this experiment it can be seen that increases in plate voltage above 25 volts result in corresponding increases in plate current. Below 25 volts, the

* Notice the use of only two significant figures.

plate current increases slowly as the relatively low voltage has difficulty in driving current through the high tube resistance. With only 5 or 10 volts on the plate, no milliammeter reading is obtained.

The procedure outlined for obtaining the E_p—I_p characteristic of a tube can be followed with higher plate voltages. The curve obtained with voltages from about 20 to 200 would be the

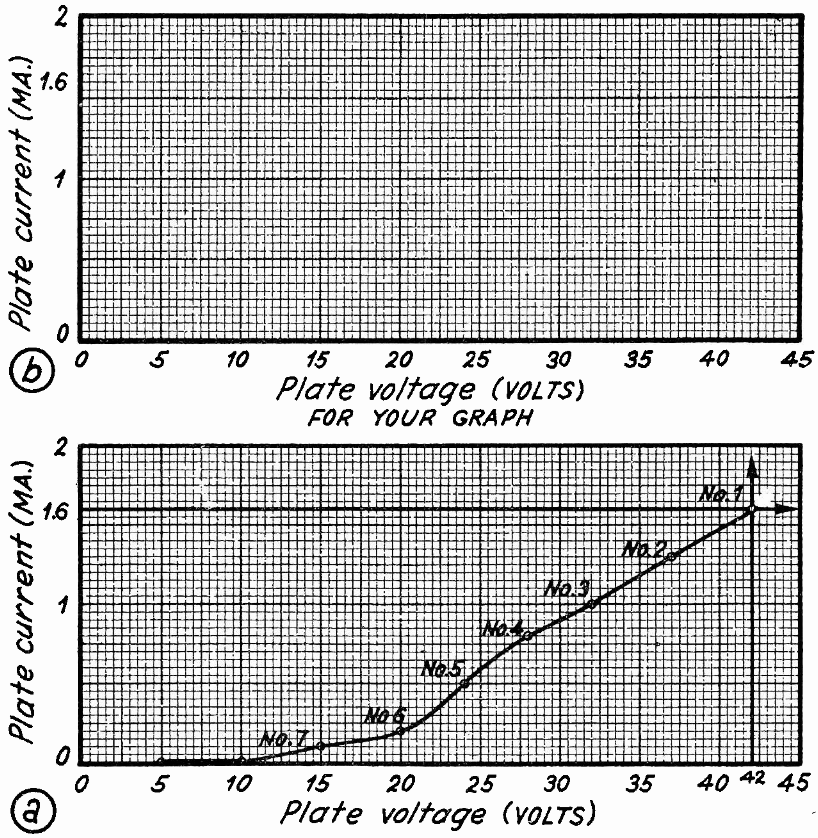

FIG. 20

sort of E_p—I_p curve that manufacturers get up for the benefit of receiver designers.

Notice that a voltage will be read on the plate voltmeter even without the tube in the socket. This is because there is a closed circuit through the potentiometer and it is for this reason that it is always best to disconnect $B+$ or $B-$ when not making measurements.

Theory of Operation:

1. Increasing the plate voltage places a greater positive potential on the plate so that more of the emitted electrons are attracted to it, which is another way of saying that the current through the tube is larger, as our observations indicated.
2. The actual plate voltage—the voltage across P and F—is the difference between the voltage read on the 0–50 voltmeter and the voltage registered on the 0–5 milliammeter. In other words, the milliammeter requires a certain number of volts to swing the needle. This voltage doesn't get to the plate but subtracts from the battery voltage.

Practical Application: Radio engineers and service men often refer to graphs of the sort we made in this experiment.

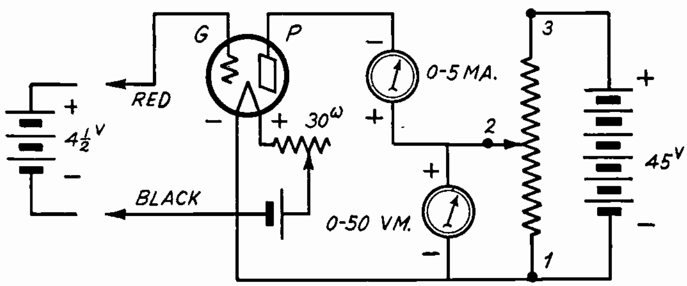

FIG. 21 (See footnote, page 15)

Whenever it must be known what plate current to expect for a certain plate voltage, manufacturers' E_p—I_p curves are used. From them the relation of I_p to E_p can be seen at a glance.

Using our graphs for purposes of illustration, suppose you wanted to know what plate current to expect with 30 volts applied to the plate. You would read up from 30 on the bottom scale and find that the curve intersected the .9 line on the vertical scale and you would expect a plate current of .9 ma.

Report Statement: At this point refer to Statement No. 15 on the separate "Report on Experiments" sheet and circle the proper word or words.

EXPERIMENT NO. 16

Object: To study the controlling effect of the grid and the amplifying action of the tube.

Apparatus Required: Same as in Experiment No. 15; 4½ volt C battery; test prods.

Apparatus Assembly:

1. Connect the red and black test prods as shown in Fig. 21—the red prod to *G* and the black to *A*—.

Experimental Procedure:

1. Adjust the potentiometer so that the plate voltmeter reads 45^{v}.
2. Adjust the slider on the 30 ohm filament resistor for minimum resistance (highest plate current reading).
3. Place 4½ volts positive on the grid by touching red test prod to the + terminal of the C battery and the black test prod to the terminal marked −4½. Record the milliammeter reading in Table No. 4.

TABLE No. 4

Readings for Points on Graph	*Grid Bias (Volts)*	*Plate Current (MA.)*	*Your Reading of Plate Current (MA.)*
No. 1	+4.5	4.4	______
No. 2	+3.	3.7	______
No. 3	+1.5	2.7	______
No. 4	0	1.8	______
No. 5	−1.5	.9	______
No. 6	−3.	.3	______
No. 7	−4.5	.0	______

4. In the same way apply various voltages to the grid; 3 volts positive, 1½ volts positive, then 1½, 3, and 4½ volts negative (negative values are obtained by placing red test prod on 1½, 3, and 4½ volt terminals, with the back test prod on the + terminal of the C battery). Zero bias is obtained by touching the test prods together. Record all readings in Table No. 4.

Observation:

1. Notice that a positive bias on the grid will increase the plate current while a negative bias will decrease the plate current.
2. With a negative bias of 4½ volts, the plate current meter shows no reading.

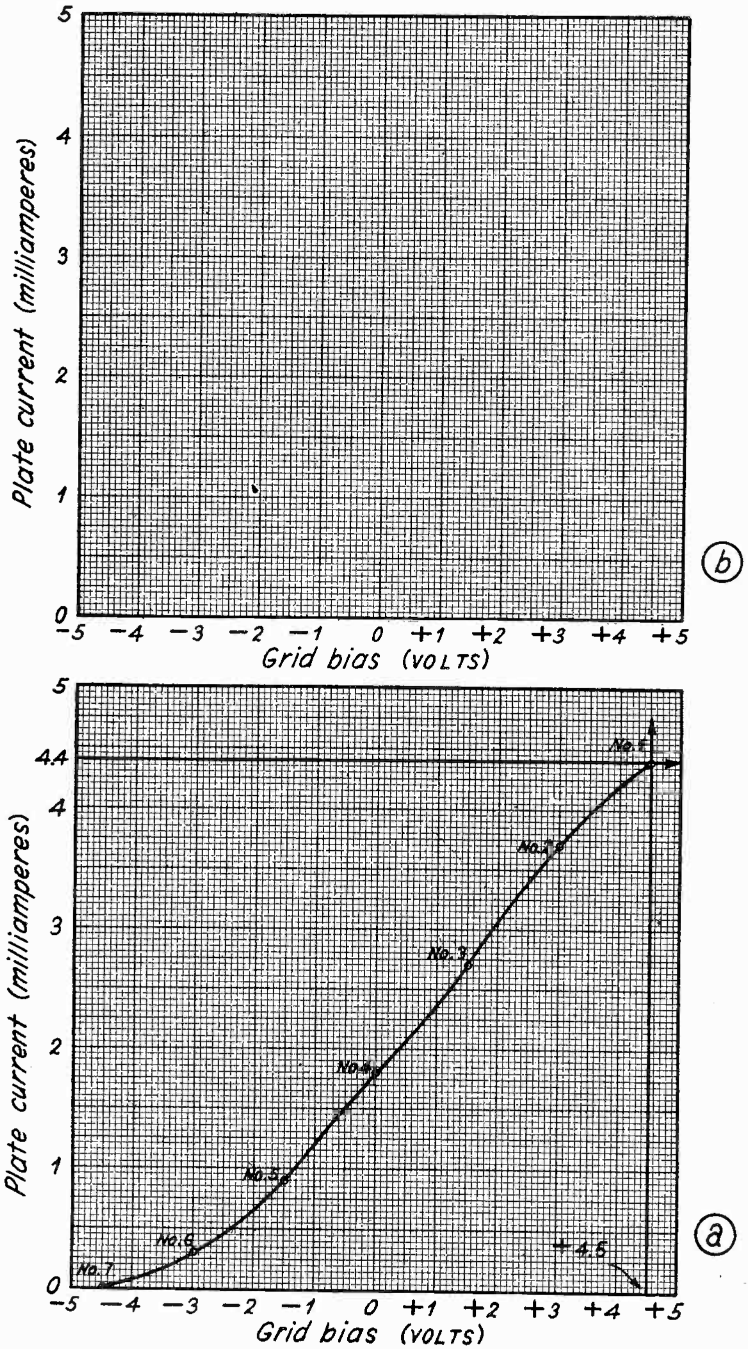
Plate current (milliamperes)
Grid bias (VOLTS)
b
No. 1
No. 2
No. 3
No. 4
No. 5
No. 6
No. 7
4.4
+4.5
a

Fig. 22

3. Plot your plate current readings on the blank graph in Fig. 22b and see how nearly your curve corresponds with the curve in Fig. 22a.
4. The curves in Fig. 22 are now E_g—I_p curves, that is grid voltage—plate current curves, which are even more useful to service men than E_p—I_p curves.
5. The fact that a 4½ volt negative bias will reduce the plate current to zero shows that E_g has a much greater effect on the plate current than E_p has. Thus if 4½ volts in the grid will serve to overcome the effect of 45 volts on the plate, it is clear that the controlling effect of grid voltage is about 10 times that of a similar plate voltage. Because of this the tube will amplify.

Theory of Operation: A positive potential on the grid serves to increase the number of electrons that get to the plate and its effect is that of a greatly increased positive potential on the plate.

A negative grid bias reduces the number of electrons that reach the plate from the filament for the emitted electrons are repelled by the negative grid which is in their direct path. Thus plate current is reduced by a negative grid.

Practical Application: In practice, the biasing voltage on the grid of a tube is determined by the function of the tube and by its design. If we consider the voltages we applied to the grid as signal voltages, we can get a clear picture of how a tube amplifies. The signal being A. C. causes the grid to swing from a high potential to a low potential, or from a positive potential to a negative potential. These swings cause variations in plate current which are passed on to the next stage or to a loudspeaker as much larger voltage swings than the original grid swing.

Report Statement: At this point refer to Statement No. 16 on the separate "Report on Experiments" sheet and circle the proper word or words.

EXPERIMENT NO. 17

Object: To show how the mutual conductance test, which indicates the condition of a tube, is made.

Apparatus Required: Same as in Experiment No. 16—no change in wiring.

Experimental Procedure:

1. With a filament voltage (E_f) of 1½' and a plate

voltage (E_p) of 45^v, place zero bias on the grid by touching the test prods together. Record the plate current reading.

2. Place a negative $1\frac{1}{2}^v$ bias on the grid by touching the red test prod to the $-1\frac{1}{2}$ terminal of the C battery and the black test prod to the + terminal of the C battery. Record the plate current (I_p) reading.
3. Calculate the mutual conductance of your tube by substituting in the formula:

   g_m (mutual conductance in micromhos) =

   $$\frac{\text{change in plate current in ma.}}{\text{change in grid voltage in volts}} \times 1000$$

   The change in plate current is the value obtained in procedure 2 subtracted from the value obtained in procedure 1. Using the N. R. I. laboratory figures, this would be $1.8 - .9 = .9$ ma. Of course the change in grid voltage is $1\frac{1}{2}$ or 1.5^v. Then $g_m = \frac{.9}{1.5} \times 1000$ $= 600$ micromhos.

Observations:

1. Your I_p values may differ from these obtained in the N. R. I. laboratory due to differences in battery voltages and tubes. Follow the procedure above in calculating the g_m of your tube.
2. If you refer to a tube chart you will note that the g_m of the '30 type tube is given as 700 micromhos. This value of g_m is for rated plate and filament voltages: $E_f = 2.0^v$ and $E_p = 90^v$. 600 micromhos is the g_m when $E_f = 1\frac{1}{2}^v$ and $E_p = 45^v$.
3. Having once obtained the g_m of a tube known to be in good condition, with any set of voltages, the I_p change for other tubes can be measured and the g_m calculated. Then by comparing this value with the g_m of a good tube, the condition of the tubes can be determined.

Practical Application: The mutual conductance test is fundamental in all tube testing. Commercial tube testers measure the mutual conductance of tubes. Provisions are made for changing the grid voltage a certain amount automatically—there is a push-button which when depressed will change the

E_g. A meter indicates the change in plate current for the given change in E_g, and the amount of change that should be expected is indicated on the tester. Thus a minimum change in I_p is used for reference, and if the change observed falls below this value the tube should be discarded.

While commercial tube testers do not usually give readings of g_m in micromhos, the underlying principle is that of the g_m test, without the final calculation.

Report Statement: At this point refer to Statement No. 17 on the separate "Report on Experiments" sheet and circle the proper word or words.

EXPERIMENT NO. 18

Object: To show that current flows in the grid circuit only when a positive bias is placed on the grid.

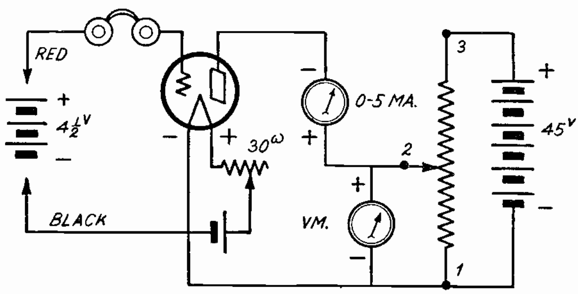

FIG. 23 (See footnote, page 15)

Apparatus Required: Same as in Experiment No. 17; phone.

Apparatus Assembly: Connect the phone in series with the red test prod and the grid as in Fig. 23.

Experimental Procedure: Place various values of positive and negative bias on the grid as in Experiment No. 16, and listen for clicks in the phone when the various C battery terminals are touched with the test prods.

Observations:

1. Clicks will be heard in the phone when the red test prod is on the + terminal of the C battery and the black test prod is on —1½, —3 or —4½, that is, when there is a positive bias on the grid.
2. If you compare the plate milliammeter readings when the grid is positive with the corresponding

readings in Table No. 4 you may note that they are slightly lower. This is due to the voltage drop across the phones which serves to decrease the positive grid bias.

3. When the grid is biased negatively, the plate milliammeter readings will be the same as the corresponding readings in Table No. 4 for there is no current through the phone, consequently no voltage drop across it.

Theory of Operation: The fact that current in the grid circuit causes clicks in the phones does not require explanation here. However the effect of a resistance in the grid circuit should be thoroughly understood. Unless there is current flowing through a resistor there is no voltage drop across it. In receivers we often see very high resistances in the grid circuit.

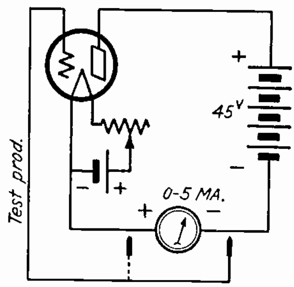

FIG. 24

These, however, do not affect the bias on the tube provided no current flows in the grid circuit.

Practical Application: When a tube is used as an amplifier the grids are always biased negatively to prevent distortion. Should current ever flow in the grid circuit the signal would be distorted.

With a zero bias or no bias on the tube it can readily be seen that there would be distortion. The signal is, of course, A.C.; that is, it swings from a positive value to a negative value. On the negative alternations there would be no grid current but on the positive alternations some of the electrons emitted from the filament would be attracted to the grid and flow through the grid circuit. This flow of current would decrease the plate current on the positive alternations of the signal and the result would be distorted sound from the loudspeaker.

In practice the grid is biased negatively to prevent the grid from swinging positive and to prevent the grid from drawing current. With a 3 volt negative bias, the A.C. signal could swing from 3 volts negative to 3 volts positive without causing the grid to become positive and draw current.

Report Statement: At this point refer to Statement No. 18 on the separate "Report on Experiments" sheet and circle the proper word or words.

EXPERIMENT NO. 19

Object: To show how a negative bias is obtained without using a C battery.

Apparatus Required: Baseboard, socket, 30 ohm resistor, test prod, milliammeter, dry cell, B battery, tube.

Apparatus Assembly: Rewire the apparatus as shown in Fig. 24.

Experimental Procedure:

1. Touch the test prod to the + terminal on the milliammeter or *A*—. Record the meter reading.
2. Touch the test prod to the — terminal on the 0–5 meter or *B*—. Record the milliammeter reading.

Observation:

1. The 0–5 meter indicates the plate current flowing with zero bias. The voltage drop across its 2000 ohm resistance can be determined by referring to the voltage scale for this meter shown in Fig. 18 or by noting that the voltage will be twice the scale reading.
2. Touching the test prod to the — terminal of the meter or *B*— places a negative bias on the grid which reduces the plate current. The value of negative bias is the voltage which is obtained across the 2000 ohm meter resistance, that is, it is the voltage drop recorded by the meter itself.

   The fact that it is a negative bias can be checked by noting that the plate current decreases.

Theory of Operation: A voltage drop exists in any resistance through which a current flows. In this experiment the resistance of the meter was used as an ordinary fixed resistance and the voltage drop across the resistance was used to bias the tube. Using the meter as a 2000 ohm resistance has the advantage of indicating the voltage which exists across its terminals.

Report Statement: At this point refer to Statement No. 19 on the separate "Report on Experiments" sheet and circle the proper word or words.

EXPERIMENT NO. 20

Object: To show how the amplification factor (μ) of a tube is measured.

Apparatus Required: Same as in Experiment No. 16.

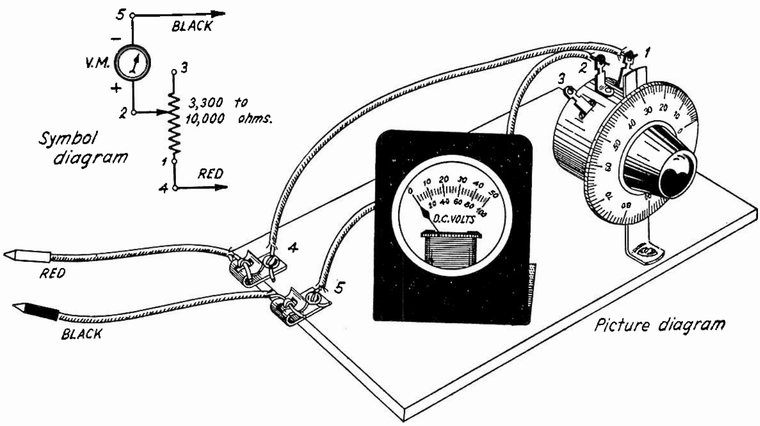

FIG. 25

Apparatus Assembly: Rewire as in Fig. 21.

Experimental Procedure:

1. With 45 volts on the plate and the test prods touched together read and record the plate current value.
2. With the same plate voltage place a negative 1½^v bias on the grid. Read and record the new value of I_p.
3. With zero bias on the grid (test prods touched together) adjust the plate potentiometer to a point where the plate current is the same value as in Procedure 2. Read and record the new plate voltage reading on the 0–50 voltmeter.
4. Calculate the amplification factor from the formula:

$$\mu = \frac{\text{change of plate voltage}}{\text{change of grid voltage}}$$

Observations:

1. With zero bias you will get a value of I_p of about 1.8 ma.
2. With a $1\frac{1}{2}^v$ negative grid bias the I_p value will be about .9.
3. To reduce the plate current from 1.8 to .9 ma. by changing E_p (with zero bias) requires a change of about 15 volts (from 45 to 30^v).
4. Using these approximate values in the formula we find that $\mu = \frac{15}{1.5} = 10$, the approximate amplification factor of the tube.

Theory of Operation: All we did when we calculated the value of μ for the tube was to compare the amount the plate voltage would have to be changed in order to reduce the plate current as much as it is reduced by a certain grid voltage change. Here we see very clearly the controlling effect of the grid.

Practical Application: So far we have only controlled plate current and it is the output voltage of the tube we are interested in. When the grid of an amplifier is properly biased and an A.C. signal voltage is fed to the grid, the plate current will vary according to the signal variations. But these variations will be the same as those which would be caused if a signal voltage 10 times as large as our grid voltage, were applied to the plate.

From this it can be seen that when the signal-carrying plate current is made to flow through a load which may be the primary of a transformer or a resistance, a voltage drop will appear across the load which is almost 10 times as large as the voltage fed to the grids. Actually the full amplification of a tube is never obtained in practice because of the internal resistance of the tube. Maximum output voltage is obtained by making the load resistance extremely high as compared with the tube's resistance. This amplified voltage then feeds the grid of another tube or is made to operate a phone or a loudspeaker.

The principles illustrated in this experiment are fundamental principles of vacuum tube operation, and working them out in this way in connection with your lesson work, you will get a very thorough insight into the use of vacuum tubes as amplifiers.

Report Statement: At this point refer to Statement No. 20 on the separate "Report on Experiments" sheet and circle the proper word or words.

Practical Testing Epuipment Made From Outfit No. 2BA-1

Multi-range, D.C. Voltmeter: The 0–50^v meter can be used to measure any higher value of voltage by connecting additional resistance in series with it.

The meter has a resistance of 3300 ohms. An additional 3300 ohms in series with it will allow the meter to measure voltages from 0 to 100^v. All scale readings will be multiplied by 2. Connect the meter and the potentiometer as shown in Fig. 25 and use 3300 ohms between terminals *1* and *2* on the potentiometer by turning the dial to 33.

With the circuit arranged as in Fig. 25, use 6600 ohms between terminals *1* and *2*. All scale readings on the voltmeter will be multiplied by 3. This will allow the meter to measure voltages from 0 to 150^v.

With the circuit arranged as in Fig. 25, use 10,000 ohms between terminals *1* and *2*. All scale readings will be multiplied by 4. This will allow the meter to measure voltages from 0 to 200^v.

The 0–5 milliammeter can be used as an 0–25^v voltmeter by using 3000 ohms in series with it. Use the circuit shown in Fig. 25, with dial turned to 30.

Tube Tester: The circuit shown in Fig. 21 makes it possible to test quickly individual tubes to determine their mutual conductance, the best index of their worth.

The procedure for making the test is given in the Practical Application for Experiment No. 17.

By using rated filament, grid bias and plate voltage, the mutual conductance under operating conditions may be measured, and then compared with values given by tube manufacturers.

REPORT STATEMENTS—OUTFIT 2BA-1

DIRECTIONS FOR MAKING OUT REPORT: As you complete each Experiment, study the Report Statement on it and give what you consider to be the correct answer.

Give your answer to each Statement by *circling* with a pencil the word or words *in italics* that correctly describe the result you get when you perform the Experiment.

PRACTICAL RADIO CIRCUITS

4 FR

PIONEER HOME STUDY RADIO SCHOOL

NRI

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

ONE THING AT A TIME

I want to tell you about Student .... He wrote me sometime ago saying that he had completed something like fifteen lessons in the course and was still unable to repair receivers satisfactorily. He asked me to advise him where his trouble lay.

I devoted practically one whole morning to his problem, for if a student comes to me for advice as to his progress, I certainly want to give him all the help I can.

To make a long story short, I looked up his record and went over all his correspondence with the Institute and here is what I found—when this student was studying simple receiving circuits, he sent in one letter after another to the Institute, requesting information on transmitting apparatus, television apparatus, everything in fact except simple receiving circuits. And that's the way it was all through his course—his mind was way ahead of his work—his head was in the clouds most of the time.

Now you know as well as I do what his trouble was—he wasn't digging into his lessons in the proper spirit. To get the benefit of each lesson, the student must exhaust the possibilities in that lesson and he must devote all his energies to that one lesson. Of course questions arise in your mind, many of which anticipate subjects which will be taken up in later lessons and it is a great temptation to write to me for answers to these questions. Personally, I like to answer questions of any sort and I used to feel that if a student asked rather advanced questions that it showed real interest in Radio. But I have been convinced that a man learning Radio in his spare time must put everything out of his mind, as far as Radio is concerned, but the lesson he is working on at the time.

Keep your feet on the ground. Study each lesson thoroughly, understand it thoroughly. If there are any questions on the lesson that you can't answer for yourself no matter how hard you try, then write to me and I'll be glad to help you. As for related questions or advanced questions, save them. They will be answered in later texts just when that particular information will be of most value to you.

Do each day's work thoroughly—leave tomorrow's work for tomorrow.

J. E. SMITH.

WASHINGTON, D.C.

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Practical Radio Circuits

SIMPLE CIRCUITS

In previous lessons, when we studied the production and some of the actions of electricity, we met the word "circuit" several times. Whenever we speak about electricity in action, that is current, we must speak about circuits—for current will act only when in a circuit.

Radio-Tricians speak in terms of circuits—you might hear one mention a tuned radio frequency circuit, or a superheterodyne circuit, or the circuit diagram of some particular receiver. Very obviously, it is important that we get a clear idea of what we mean by a Radio circuit.

The word itself is very clearly connected with the word "circle." In fact, both of them are taken from the same Latin word, which peculiarly enough is the same as our English word "circus." The Roman "circus" was the track on which chariot races were held. Our modern circus takes its name from the fact that in the main tent there is always a track on which some of the performance is held, usually races of some sort or other.

A circle is an unbroken ring—and a circuit is an unbroken path over which electrons can flow. The main point of comparison between a circuit and a circle is that both must be unbroken, that is, complete, before they are rightly called a circuit or a circle. However, an electrical or Radio circuit need not be circular in form, the chief essential being that a circuit provides a complete conducting path for moving electrons, that is, current flow.

Having spoken about current flowing in a circuit, we can see that another essential part of any circuit is a source of e.m.f. But the whole purpose of a circuit is to get the e.m.f. supplied by the source to do some useful work—therefore another essential part of a circuit is the "load," the device in which electrical energy is converted into some other kind of energy, and made use of. To connect the load and source of e.m.f., there is another essential part, that is, the conducting wires which complete the circuit.

Thus in the circuit shown in Fig. 1, the dry cell is the source of e.m.f., and the light bulb is the load. An l this is a good example of a fundamental electrical circuit. It is shown schematically in Fig. 2.

The switch shown in Figs. 1 and 2 is provided so that there will be a means of opening and closing the circuit without the necessity of disconnecting either the dry cell or the lamp. You remember that a single break in a circuit will prevent current from flowing in it—a switch as shown, placed anywhere in the circuit provides an effective control—when opened, the current will not flow and the lamp will not light—when closed, the circuit is complete, current will flow and the lamp will light.

It is important to remember that the switch can be in any part of the circuit—it could be anywhere in the left conducting wire, as well as any place in the right conducting wire.

The source of supply may be one or more dry cells, a storage battery, a generator, in fact, any kind of generating device, or the source of supply may be a wall or panel socket, as in the case of a house lighting system where the immediate source of supply for an individual light, for example, is the house line, which connects ultimately to the generators in the power house.

The load in the circuit may be an electric bell, a light bulb, an electric motor, a coffee percolator, a vacuum tube or a complete Radio set. In the simple circuit shown in Fig. 1, the load is, of course, the lamp which is a means of converting electrical energy supplied by the dry cell into light energy. The light is incidental to the conversion into heat energy as you possibly know, but it is the light we are interested in because that is what we make use of. This simple circuit is interesting to us as Radio-Tricians because it is very similar to the filament circuit in a Radio receiver, but in this case we are interested in heat, rather than light, for filament heat is necessary for the operation of vacuum tubes.

You will want to know now, how electrical energy is converted into heat energy in an electric light bulb or in a vacuum tube. Referring again to Fig. 1, "R," in the center of the lamp, is a very fine carbon or Tungsten wire, having high resistance. In a previous lesson it was mentioned that the effect of resistance in an electrical circuit was to slow down current flow, because electrons can't pass through a resistance readily, and the electrons becoming violently agitated, bump against each other with terrific speed, causing the resistance to become hot. When metal is white hot it glows brightly. Put this hot metal into a vacuum, as it is in a light bulb, and the result is an intense bright light.

If an electric motor is the load in our circuit, it is the means of converting electrical energy into mechanical energy which is motion. If a toaster is the load, electrical energy is converted into heat. And the same is true if the load is an electric stove.

From this simple, fundamental circuit all sorts of complicated circuits arise. Look at a diagram of a Radio circuit, it may seem extremely complicated. But there is this cheering thought, that no matter how complex a circuit may be, it can always be divided up into fundamental circuits—and there will always be a source of e.m.f., conducting wires, and one or more loads in each.

We shall go on to consider slightly more complex circuits, building up our knowledge gradually, so that by the time you finish this lesson, even the diagram of a complex modern Radio

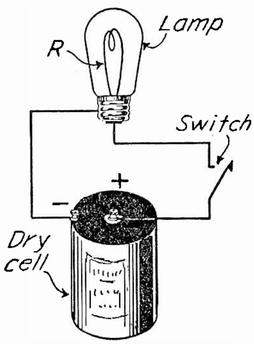

Fig. 1

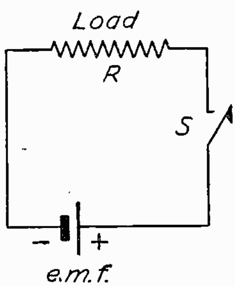

Fig. 2

receiving "circuit" will mean much more to you than a maze of lines and symbols.

As you learned in the last lesson, several dry cells may be connected either in series or in parallel to form the source of e.m.f. In the same way, the load in the circuit may consist of several parts, or as we more commonly say, there may be several loads in the circuit. These loads may be connected either in series or in parallel in the same manner as several dry cells would be connected together. But no matter how many parts there are to the source, or how many parts the load has, the thing to remember is that they must all be connected together so that there can be a continuous path for the current through each dry cell and through each load.

Very naturally, when we add a second load to a circuit, the electrical energy in that circuit is going to be divided between the two loads. If we were to put another light in series with the light in Fig. 1, both lights would glow with less brilliancy than one light alone in the circuit. Now if it were desired to reduce the brilliancy of one light in a circuit without putting another light in the circuit, how could it be done? Very clearly, it could be done by putting some other load in the circuit, one which would not produce light. Of course you know what we would use for this second load—some form of resistance. And if we want to have a control over the brilliance of the lamp, so that we can make it glow dimly or brightly at will, we place in the circuit, in series with the lamp, a variable resistance.

Now refer to Fig. 3 where we have a vacuum tube filament circuit. This is very much like our first circuit—it has a source of e.m.f., conducting wires, a load (the filament of the vacuum tube), and in addition to these three essentials we have a switch

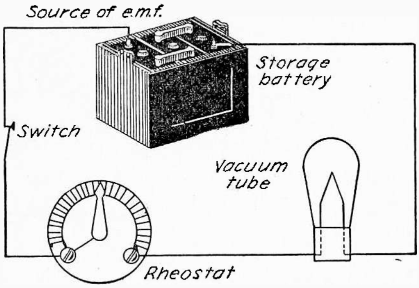

Fig. 3

which is an on-off control, and a variable resistance, which we call a rheostat.

This resistance is a second load in the circuit, and as it is variable we can adjust the amount of energy it will take away from the filament. The arm of the rheostat can be rotated over the high resistance winding so as to include more or less of it in the circuit. When the arm points to the right, very little of the resistance is included in the circuit and most of the current will flow through the filament. But as the arm is moved to the left, more resistance is included in the circuit and more of the electrical energy in the circuit is used up in the resistance, taking energy away from the filament.

Our rheostat may well be compared to a faucet in a plumbing system—opening the faucet wide allows a great deal of water to flow from it, but as the faucet is closed, less and less water will flow.

So far we have not changed our fundamental circuit very much—we have merely added a control. Now look at Fig. 4. A bit more complex, it is true, but you have no difficulty in analyzing it. What do we have? We have two circuits, each of which has its source of e.m.f., its load, and its controlling device P and S. But they are not two distinct circuits because both make use of

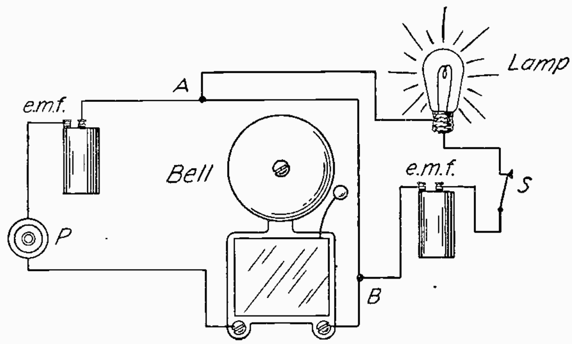

Fig. 4

that portion of the conducting wire between A and B. We see that conductor AB is common to both circuits. But even though this is the case here, each circuit will function independently, the one will have no effect at all on the other. The fact that two circuits can have one conducting wire in common, is made use of in power

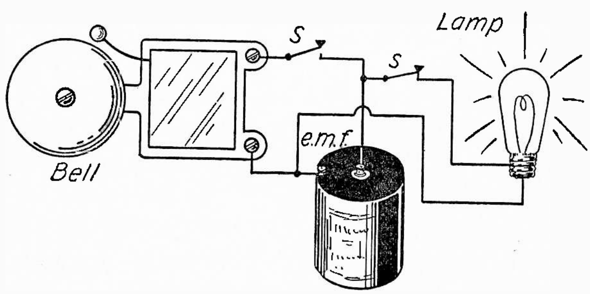

Fig. 5

transmission where the output of two generators is transmitted by what is known as the three wire system, one of them being common to both circuits.

And here in Fig. 4 we have our first introduction to an electrical network. In Radio we hear much about networks of one kind or another as for example, broadcasting networks—and our receiver circuit should properly be called a network for it is made up of many circuits which have much in common as we shall see.

In Fig. 5 we have another type of network. In this case the source of e.m.f. is common to both circuits. As there is a separate switch for each circuit, each load is independent of the other and both circuits can be made to operate simultaneously or

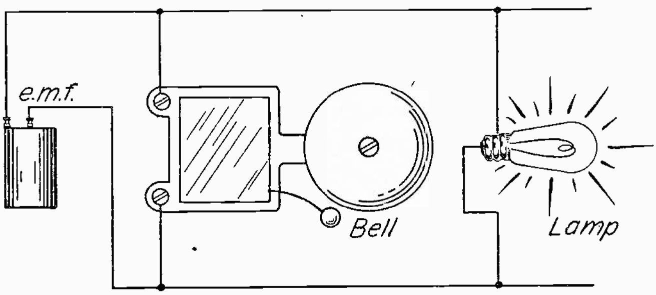

Fig. 6

individually at will. Examine this circuit carefully. Are the loads connected in series or in parallel? The electrical equivalent of this circuit is shown in Fig. 6. Now we can see that the loads are in parallel. Notice, however, that in this equivalent circuit, the transmission lines are shown as common to both loads. In this respect it differs from the circuit in Fig. 5, where each cir-

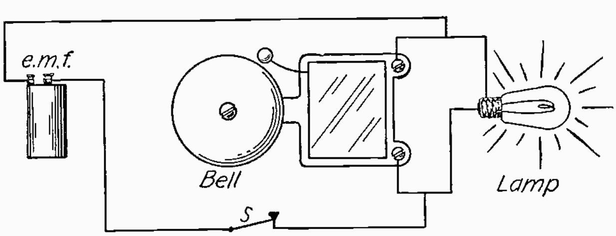

Fig. 7

cuit has its own conducting wire and only the source of e.m.f. is common to both circuits.

Figure 7 shows a parallel arrangement of loads connected to a common source through common transmission lines. We can look at the circuit in Fig. 7 in two ways—the first as a double circuit having a common source of e.m.f. and common transmission lines; second, we could consider it as a network of three circuits, one being the source of e.m.f., the transmission lines and the double load, and the other two being the individual loads and their circuits including the conducting wires up to the point where they meet the common transmission lines. In this case, we must consider the source of e.m.f. for each load as the ends of the wire to which connection with the load is made.

This is practically what we do when we consider a wall socket as a source of e.m.f. Of course, the ultimate source is the generator in the power house, but the immediate source is the transmission lines in the house which are brought out at the wall socket.

Now we come to a simple network which is part of the complete network of a Radio receiver. In Fig. 8 is shown how vacuum tube filaments are connected in parallel, that is, as parallel loads, to a battery source of supply. Figure 9 shows the same parallel connection of the filaments in an A.C. set in which

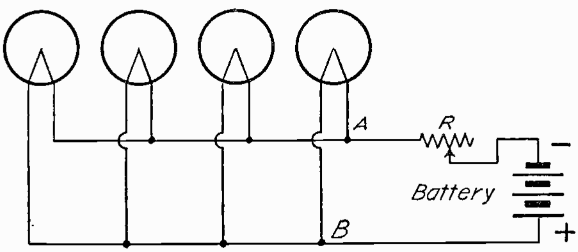

Fig. 8—Four Vacuum Tube Filament Circuits Connected In Parallel.

the source of supply is another circuit, through the transformer. Notice that in Fig. 8 there is a rheostat connected *in series* with the source of supply. In this sort of circuit the rheostat will control the current flowing through all the tubes and varying the adjustment of the rheostat will cause all the tubes to burn more brightly or more dimly simultaneously.

This is really a parallel-series circuit. The rheostat must be considered a load and this part is in series. The rest of the load, the filaments, is in parallel. In a series circuit the electrical energy is divided between the loads. Thus increasing the resistance of the rheostat, will take away energy from the filaments.

We can trace through this circuit and see why this should be. In tracing through circuits we can start at either side of the source of e.m.f. and the result will always be the same. It is, however, customary to trace from the positive to negative because until very recently it was thought that electricity flowed from positive to negative. Even today there are some scientists who insist that current flows from positive to negative, even though they admit that electron flow is from negative to positive. This confusion won't disturb us at all if we realize that circuits can be traced either way. Starting at the positive pole of the battery in Fig. 8 and tracing through the circuit we can see that all the current from the source will have to pass through and divide between filaments before it reaches the rheostat. Tracing through from the negative to positive we observe that all the current must pass through the resistance before passing through the filaments. It doesn't make any difference which we consider the correct procedure—the effect is always the same, that is, the rheostat provides a control over all the current flowing in the filaments.

Now let us suppose that the rheostat is set to a mid-position, meaning that just half its resistance is included in the circuit, and that the filaments are glowing normally. What will happen if we place another tube in the circuit in parallel? All the tubes will become dim—we have increased the load. But if we adjust the rheostat so that it offers less resistance to current flow we can bring all the filaments up to normal brilliancy. What we are really doing is re-distributing the energy in the circuit, decreasing part of the load (the rheostat load) to compensate for the added load of another filament.

In a Radio receiver anywhere from three to five circuits meet at the vacuum tube. In later lessons we shall study each of these circuits by itself, the plate circuit, the grid circuit, the screen grid circuit in the case of screen grid tubes, and two screen grid circuits in the Pentode. This may seem difficult at first sight—and it is true that a complete Radio circuit is by no means a simple matter—but if you bear in mind that no matter how complicated any network is, it can be resolved into simple circuits, each of which has its load, its source of e.m.f. and its connecting wires, we shall never have any trouble getting the full significance of a Radio "circuit" diagram.

There is just one more thing we must consider before we leave these very simple circuits. Look at Fig. 8 again. Suppose a metal bar or a piece of bare wire fell across the connecting point A and B. What would happen? Naturally a low resistance path would be provided for current flow through the resistance and through A and B back to the source of e.m.f. And current would flow along this path because current always takes the path of least resistance. What would happen to the filaments? They wouldn't light at all. The current would be side-tracked and kept away from the filaments, and the circuit would be "shorted." This then, would be a short circuit,* about which you have probably heard many times. And short circuits are a frequent cause of trouble in Radio circuits—many times in your work as a Radio-Trician it will be necessary for you to track down short circuits and remove their cause so that current can flow over the proper path.

In any kind of electrical or Radio circuit, great care must be exercised to prevent the possibility of shorting. Conducting wires are insulated, oftentimes electrical and Radio apparatus must be mounted on non-conducting material, many types of insulators are in use to keep the current in the proper path so there will be no "short" either within the circuit or between one circuit and an adjacent circuit.

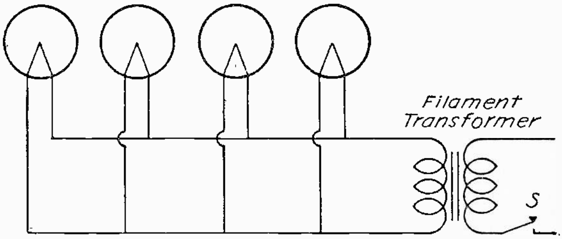

Fig. 9

The word insulate also is taken from the language of the old Romans. Their word "insula" meant island, a body of land sursounded entirely by water. A wire is insulated when it is surrounded entirely by non-conducting material. A piece of Radio apparatus is insulated when it is entirely surrounded by non-conducting material.

CONDUCTORS AND INSULATORS

All substances, natural or manufactured, can be divided for electrical purposes into three classes—conductors, resistors and insulators. Conductors are so-called because current can flow in them easily. Current will flow in resistors but not quite so easily, it will be held back. For practical purposes we say that current cannot flow at all through insulating material although this is true only up to a certain point, for a too high voltage will cause an insulator to break down and become a conductor.

*A short-circuit occurs when two wires of opposite polarity come in contact with one another without any controlling device.

Between these three groups there are no hard and fast dividing lines. However, engineers arbitrarily list various substances in the various groups, depending on the ease with which they conduct electricity.

Under the first group the following substances are considered to fall: Silver, copper, aluminum, zinc, brass, platinum, iron, nickel, tin, lead, in fact nearly all metals.

The substances classed as resistors are: German silver, carbon, graphite, nichrome, and various metallic alloys.

The insulators are: Slate, porcelain, bakelite, dry wood, glass, silk, cotton, rubber, mica, dry air, in fact, most non-metallic materials.

But don't forget, however, that no material is a perfect conductor and no material is a perfect insulator. Even the best conductors known offer some resistance to current flow. On the other hand, even such good insulators as glass, mica, and porcelain break down, if called upon to handle too high an e.m.f. However, below this point, which is known as the break-down point, insulators are for all practical purposes, non-conductors.

RESISTANCE IN CONDUCTORS

An electrical conductor may well be compared to a water pipe. When water is flowing through the pipe, its flow will be hindered to some extent by friction, that is, the inner walls of the pipe offer some frictional resistance to the flow of water through it. If these walls are rough, the friction will be considerable and the resistance to water flow will be high. If these walls are smooth, the resistance will be less, but some will be there all the same and we can't eliminate it.

A large pipe will offer less resistance to water flow than a small pipe—and if too high a pressure is exerted on a small pipe, it will burst. The longer the pipe, the greater will be the loss in pressure through the pipe.

So too, an electrical conductor offers some resistance to current flow and this resistance is greater in a small wire, less in a larger wire, and varies with the length of the wire.

What happens to the energy that is lost because of resistance in a water pipe? It may seem peculiar, but the energy that is lost is converted into heat energy and dissipated. The amount of heat generated in a water system is so small that it is inappreciable, but in an electrical circuit, energy passing through conductors which possess resistance is converted into heat. In fact, if this heat is considerable it can be made use of in electrical cooking devices. But in an ordinary conductor where it is desired to keep resistance to a minimum, there is only a small part of the total energy lost in heat although you may notice that some conductors which are designed to carry very heavy current have asbestos insulation so that the heat generated cannot do any harm.

A large wire can carry heavier current than a small wire. If too heavy a current is passed through a small wire, it will become excessively hot even to the point of melting.

A simple example will bring home to us very forcibly the effect of length of conductors on power loss. A man in New York speaking to a friend in San Francisco might think he is on a single circuit, the conductors of which connect him and the Pacific Coast. If this were the case, it would mean that there would be six thousand miles of wire, and all the resistance in six thousand miles of wire would have to be overcome by the current carrying his voice. But this resistance is so high that if there were only one circuit, the amount of power required to transmit a voice across the country would be so great as to be commercially impossible. How is it done then? Every fifty miles or so there is a sub-station where the voice is amplified several hundred times, in the same manner as sound signals are amplified in our Radio receiver. Were it not for these amplifying stations and the fact that the voice is amplified hundreds of times on its way across the country, trans-continental telephone service would be an impossibility. At the bottom of all this, is the fact that although copper wire is used for transmission lines and has the least resistance of any of the commercially used wire, it has considerable resistance when miles of it are used.

Silver offers slightly less resistance to current flow than copper, but of course it would be impractical to use silver wires in general electrical and Radio work, due to its cost.

From what has been said about copper wire as a conductor of electricity, it is clear that the size of the wire to be used for any particular purpose is important. If made too small, energy will be lost in heat—and if there is too much heat generated to be dissipated rapidly enough, the wire will melt and the circuit will be opened. On the other hand, if we make the wire too large, that is larger than necessary, we are wasting copper. Therefore, the size of wire depends largely on the amount of current it will be called on to carry.

Wire sizes are designated by numbers which correspond to numbers on a standard gauge. Of course, wire sizes could be given in thousandths of an inch but it has been found that the use of a certain number to designate a certain size wire simplifies matters a great deal. A standard wire gauge is the B & S Gauge, named after the Brown and Sharp Tool Manufacturing Company. This is sometimes called the "American Wire Gauge." Details of wire gauges and wire tables will be given in a later lesson text.

When considering various materials of which conductors and resistors are made, it is customary to talk about their resistance as compared to the resistance of copper. In other words, copper is used as a standard and the resistance of any

TABLE NO. 1

Conductor	Relative Resistance (as compared with copper)
Silver	0.95
Copper	1.00
Aluminum	1.64
Zinc	3.50
Nickel	4.53
Iron	6.50
Steel	8.00
German Silver	19.10

other metal is given as being so many times that of copper. Of course in doing this we must assume that the metals we are considering are of the same shape, form and size. The wire used for the filament rheostat in Fig. 8 to regulate the amount of current flow in the circuit has many times the resistance of a copper wire, the same size and same length. Considering copper as the starting point, that is, 1, iron wire will have a certain number of times more resistance than copper, as will steel, German silver, and wires of other metals. For example, German silver has 19.10 times as much resistance as copper; an aluminum wire will have 1.64 times as much resistance as copper. A table is given above in which the approximate relative resistances of various metals are given, using copper as the standard.

CHARACTERISTICS OF SERIES CIRCUITS

We are well acquainted with the word series as it is used in general life. The World Series is a *succession* of baseball games to decide the championship. A series of numbers is a succession of numbers. In Radio when we speak of series circuits, we mean the arrangement of apparatus in succession, one after the other, in such a way that the current must flow through one before it flows through the others. In series circuits, if one part is defective and current can't pass through it, the entire circuit is opened. And this is the chief characteristic of series circuits—every part in that circuit is dependent on the other parts and every part must be intact, current must go through it, otherwise current cannot flow in the circuit.

Figure 10 shows a closed series circuit consisting of three cells connected in series with three resistances, R_1, R_2 and R_3 and a switch (S). The cells are connected in series—the positive

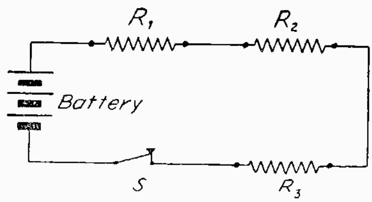

Fig. 10—Series Circuit

terminal of each cell is joined with the negative terminal of the next cell in the series. As you learned in a previous lesson, the total e.m.f. acting in this circuit with the switch closed will be the sum of the e.m.f.'s of the individual cells.

The total resistance of the three resistance loads in series is the sum of the individual resistances, that is $R_1 + R_2 + R_3$.

CHARACTERISTICS OF PARALLEL CIRCUITS

Sources of e.m.f. are said to be connected in parallel when their positive terminals are joined to one conductor and their negative terminals to the other. Parallel connections of dry cells were shown in the previous lesson text. Another way of describing a parallel connection of dry cells is to say that all their positive poles are connected together and all their negative poles are connected together.

When loads are connected in parallel, each carries only part of the total current. Instead of having one main circuit as in a series circuit, in parallel circuits we have one main circuit and various branches, each branch having a current of its own taken from the main circuit. In parallel circuits it is not necessary that current flow in each branch to have current flowing in the main circuit. In a parallel connection of lights, one light may be burnt out but still the other lights would light. In a series connection of lights, if one is burnt out, the whole circuit is dead.

Now let us take the parts used in Fig. 10 and connect them in parallel. See Fig. 11 which shows how this parallel circuit would look. You can trace through this circuit and follow the current as it flows from the battery, starting either at the negative pole or the positive pole, it doesn't make any difference. Some of the current will flow through R_1, some through R_2 and some through R_3. If R_1 were broken, current would still flow through R_2 and R_3 as can easily be seen. But with R_1, R_2 and R_3 in the circuit, will the total resistance be $R_1 + R_2 + R_3$? Not at all. In fact, the more resistances we have in parallel, the more current will flow through the main circuit A and B.

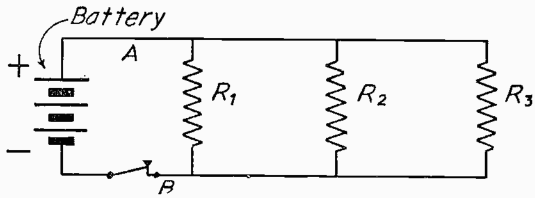

Fig. 11—Parallel Circuit

The total resistance in the circuit will be less than the sum of the three resistances because the current has three paths to travel over, making it easier for the current to flow, than if the resistances were connected in series.

The water system shown in Fig. 12 will help to make clear the action of loads in parallel. The branches marked T correspond with the resistances in our former example. Notice that the branches are pipes of smaller diameter than the main pipe and so can really be called water resistances. But as these are connected in parallel as shown, altogether they will not offer much resistance to water flow. If there were only one it might hold back the water considerably. But as there are four in parallel, there are four paths for the water to flow through which it manages to do very easily.

Now returning to Fig. 11, trace through it again. It is apparent that the same amount of current won't flow through every point in that circuit. It divides between the branches and the amount that flows in each branch depends on the amount of resistance in it.

We can carry our discussion of this circuit one step farther, and anticipate what we are going to learn in the next lesson. The total resistance in the circuit is less than the value of the smallest resistance in parallel. Furthermore, the current in each branch is less than the total current since the sum of the currents in all the branches is equal to the total current. See if you can't figure this out from the water analysis shown in Fig. 12.

Most practical electrical circuits are combinations of series and parallel, known as the series-parallel, or parallel-series circuits. In fact, the circuit shown in Fig. 8 is really a series-parallel circuit—the source of e.m.f. and rheostat are connected in series and the loads in parallel.

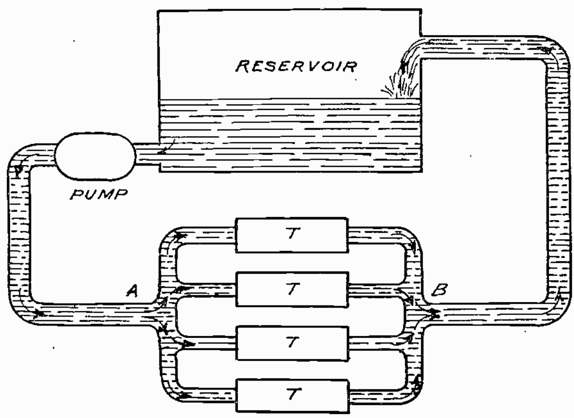

Fig. 12

A series-parallel arrangement is usually used where it is desired to operate a number of similar electrical devices, such as lamps or motors, from a line, the voltage of which is several times that required to operate a single lamp or motor. For example, a series-parallel circuit is used in the light wiring of street cars. Here the source of supply is generally 550 volts, therefore five 110-volt lamps of similar current carrying capacity are connected in series across the circuit and groups of five connected in parallel as shown in Fig. 13 (a). From what you have learned about series circuits you know the great disadvantage of this arrangement—if any lamp in a series group burns out, the remaining lamps in that series group will not light. You will see later that this is exactly the same procedure employed in D.C. socket powered receivers, where the filaments of the vacuum tubes are connected in series.

Some of this may seem rather far from Radio, but the Radio-Trician should know considerable about the simple problems of general electricity. A large portion of Radio receivers receive their operating current from city lines and the Radio-Trician must make sure, not only that the receiver is connected properly to the source of supply but that the proper voltage is being obtained for best operation. A fundamental knowledge of electrical wiring often enables Radio-Tricians to prevent serious damage to Radio receivers or other electrical apparatus.

It is never wise to connect any piece of apparatus to a source of supply until you know that the voltage and current requirements are met. For example, electricity for lighting purposes in some places may be direct current and in other places alternating current.

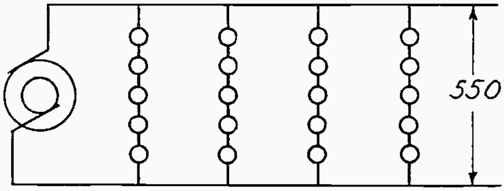

Fig. 13 (a)—Series-Parallel Circuit

Current supplied by a generating station to most electric light circuits is ordinarily alternating current and of course, the Radio-Trician who knows his electricity would not try to operate a D.C. receiver from an A.C. line or an A.C. receiver from a D.C. line. A universal receiver can be operated from an A.C. or D.C. line.

In most cases where A.C. is supplied, this information is given on the name plate of the watt meter installed in the building, where no reference is made to frequency in cycles you can be sure that D.C. is supplied.*

Before leaving the subject of electrical power systems, it will be well to consider briefly an ordinary three-wire transmission system. You may have noticed three wires entering a house and you may have wondered why there were three wires instead of two. As previously mentioned, one wire is common so that in a three-wire system we really have two circuits each of which

* If in doubt phone the office of the power supply company for this information.

uses a common return wire. This common wire is often called the neutral wire.

In a system of this sort the output supply of two 110-volt generators connected in series is carried. Thus we can get 110 volts across either of the outer wires and the neutral (center) wire. Across both outside wires we would get the output of both generators which would be (110 x 2) or 220 volts. See Fig. 13 (b).

This is of importance to Radio-Tricians—they must understand this fact about three-wire systems so that they will never connect a 110-volt receiver across the outer lines, as 220 volts applied to a 110-volt receiver would burn it out completely.

It is clear from what was said about the resistance of conductors why three-wire systems are used. Aside from the fact that 220 volts may be required for some types of apparatus, the three-wire system allows double the amount of current to be carried in the most economical manner. For large homes, where a great deal of current is drawn from the lines, if only a two-

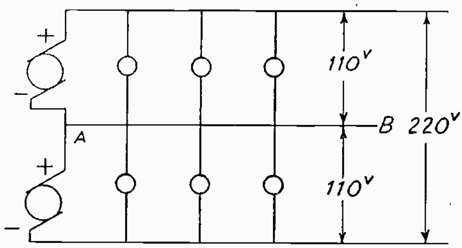

Fig. 13 (b)—Three-wire Transmission System

wire system were used the wires would have to be extremely large to handle the heavy current drain. But by the use of three wires the same amount of current can be carried using only one extra wire of ordinary size. The use of the neutral wire which is common to tube circuits results in a great saving of copper.

RADIO CIRCUITS

Now that we have laid the groundwork, having gotten a good knowledge of fundamental electrical circuits, we can go on to consider simple Radio circuits. Look at Fig. 14 which shows the complete transmitting and receiving network in outline form. The illustration is largely self-explanatory. Radio energy is sent out from the transmitting aerial and is picked up by the receiving aerial. Do we have one complete circuit? No, for the transmitter is not directly connected to the receiver. What we have is a *chain* of circuits one feeding into the other in order. Just as in our telephone line we have a boosting action as we proceed from coast to coast. The transmitter connects with the receiver by sending out Radio waves which the latter intercepts and passes through its various circuits. This then is strictly a case of networks, and clearly a *chain* network.

Now let us forget for the moment, the transmitter and consider the receiver network itself—for in Radio we have networks within networks and circuits within circuits. And at the present time we are interested chiefly in receivers. Figure 15 shows a simple, fundamental Radio circuit, of the most elementary type. Here we have nothing but an aerial, a crystal detector, a pair of headphones and a ground connection. It doesn't look much like a closed circuit and yet it really is one as shown by the dotted

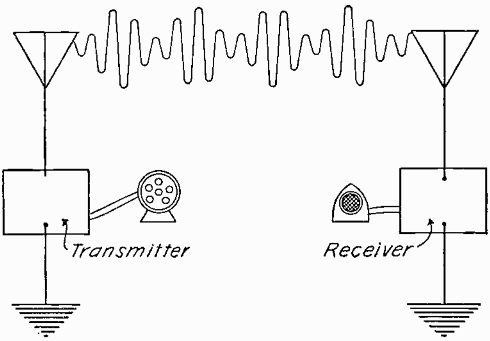

Fig. 14

line. There is no visible connection between the aerial and ground other than through the receiving apparatus, but it is there just the same or current could not flow in it. Just what this unseen connection is we shall have to leave until later.

Tracing through this circuit is a very simple matter—and for practical purposes it doesn't matter whether we start at the ground or at the aerial. Let us, however, start with the aerial and trace the incoming signal through the circuit. The Radio wave striking the aerial becomes a very small electrical current which flows through the detector "D" where it is changed to audio frequency current, then it flows through the earphones "P" causing the diaphragm of them to vibrate and produce sounds, the same sounds that were impressed on the microphone in the transmitting station. The current flows through the phones into the ground.

Notice that current must flow through each part of the circuit—if there were a break in any point in this circuit the current could not flow. Therefore it is a series circuit—the detector and earphones are in series with the antenna and ground.

Figure 16 shows the same circuit but has included in it a tuning coil, marked "L" which acts as a station selector. Of course these very simple circuits are not efficient—they won't pick up signals from stations more than a few miles away. The untuned circuit shown in Fig. 15 will respond to signals of several stations if equally powerful and at an equal distance from the receiver. The circuit in Fig. 16 can be tuned, but only to nearby powerful stations.

When we come to Fig. 17 we have what should properly be

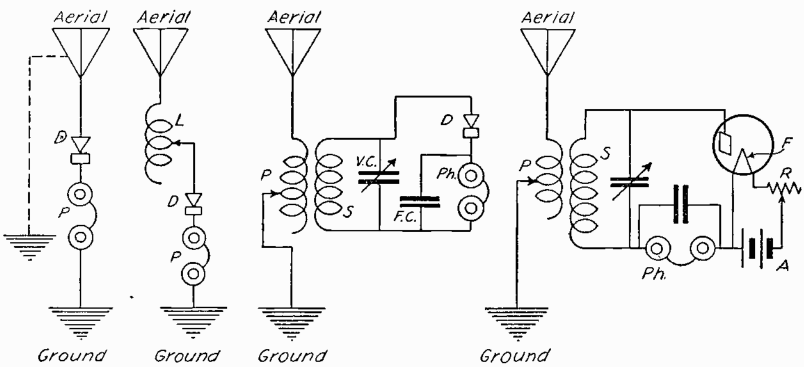

Fig. 15 Fig. 16 Fig. 17 Fig. 18

called a receiving network, for here we have two circuits. In the antenna circuit there is a coil in series with the aerial and ground. The other circuit is a series-parallel circuit—notice the crystal detector "D" and the earphones "Ph" in series. In this circuit the source of supply is "S," a coil. The two coils marked "P" and "S" are the primary and secondary or a transformer by means of which energy is passed on from the aerial circuit to the second circuit. Just how energy can be passed from one coil to another is another matter which we must leave until later. For the present, however, we must consider "S" as the source of supply in the second circuit. The load in the circuit consists of the detector and the phones. The variable condenser, in parallel with "S" is a tuning device. It regulates current flow as would a resistance, in that it adjusts its resistance so that the circuit responds to only one of the various broadcasting stations. To the other stations it acts like a very high resistance circuit.

Figure 18 shows practically the same circuit except that in place of the crystal detector we have a simple two-element vacuum tube. You will notice that in the preceding circuits, the source of supply was primarily the antenna—no batteries were needed. But just as soon as we put a vacuum tube in a circuit, we must use a local source of supply to operate the vacuum tube. We have spoken about the necessity of heating the filament of a vacuum tube—we have studied a filament circuit in detail. Here you can see it in a practical application. Trace through the filament circuit—F-R-A. Then notice that the filament is common to two circuits—it is in the RA circuit and also in series with the phones.

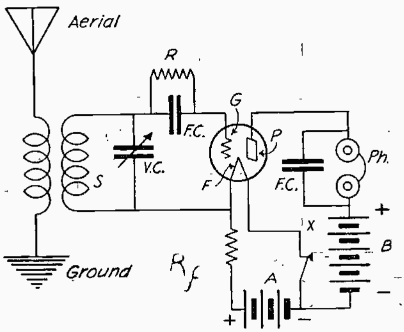

Fig. 19

Fig. 19—Simple Receiving circuit using a three element vacuum tube.

Now we're beginning to get to the point we started out for. Look at Fig. 19. Look at the vacuum tube—a regular 3-element vacuum tube—the grid "G" at the left, the filament "F" in the center and the plate "P" shown at the right. Our circuit is beginning to look like something. In this tube we have three circuits meeting, the filament circuit, the grid circuit and the plate circuit. We can easily trace each of these circuits by this time. Let us start with the filament circuit because we are already so familiar with filament circuits. Starting at A+, or A—, it really doesn't make a bit of difference, we trace through R*f*., F, X and A. The A battery heats the filament and that's all it does. The filament is common to both filament circuit and plate circuit as it was in the previous circuit and we can trace the plate circuit through the phones, "Ph," through the "B" bat-

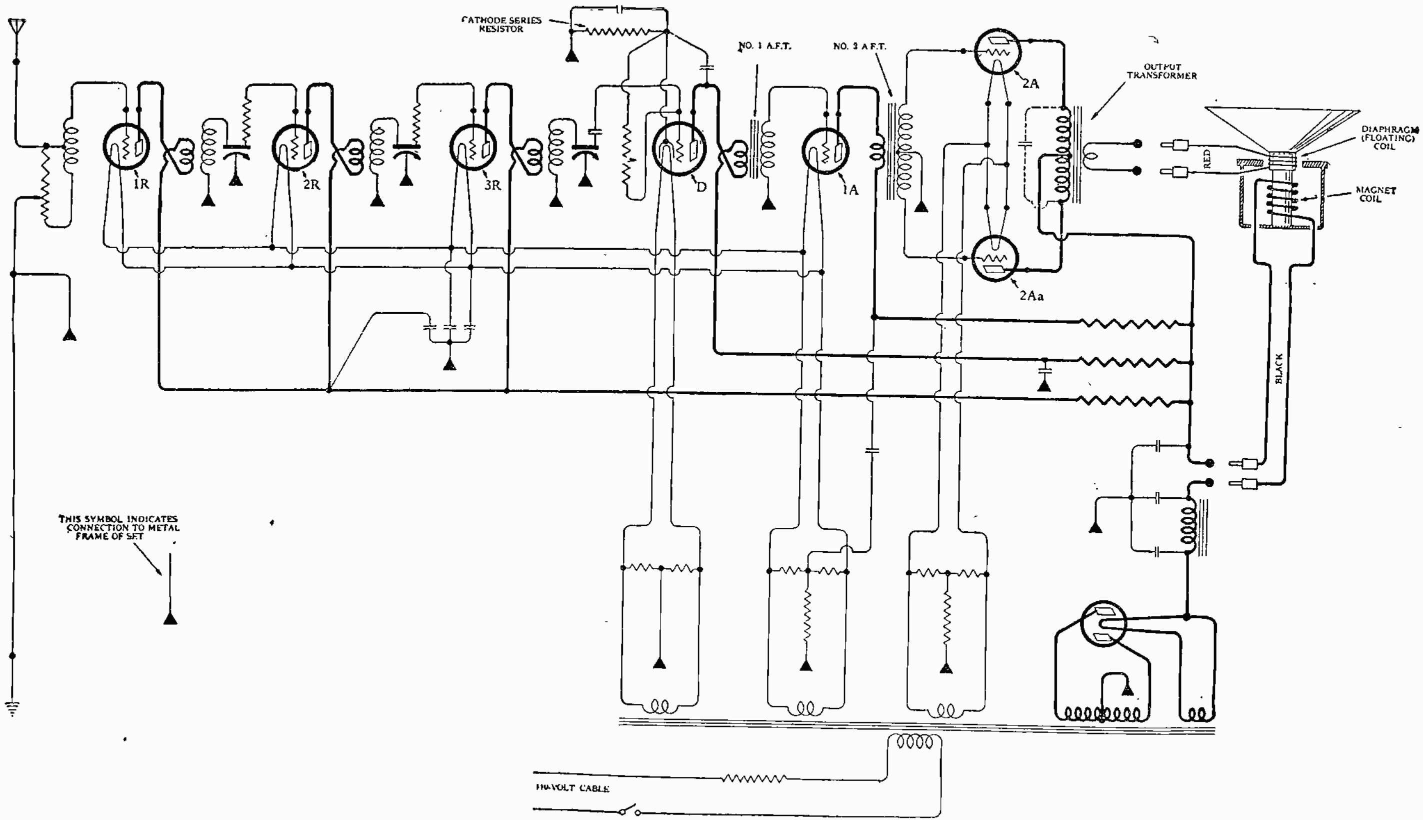

Fig. 20—Diagram of a Typical Radio Receiving Set and Power Unit.

NOTE.—This diagram is shown in this elementary text book simply to introduce you to a practical circuit of a typical Radio Receiver. You are not expected to spend too much time tracing these individual circuits.

tery, through point "X," through "F" and back to "P."* In the plate circuit we have the phones in series with the plate and B battery. Notice the fixed condenser connected across the phones—really a parallel connection, or as we sometimes say the condenser is "in shunt" with the phones.

Now for the grid circuit—starting at "S," through "R" and a fixed condenser, through "G," through F and back to S. And the variable condenser "VC" in parallel with "S," the secondary of the transformer.

Tracing through circuits isn't a bit difficult, is it, provided you remember that in every simple circuit there is a source of e.m.f., a load and connecting wires. Of course there are many questions which come into your mind at this point as to the use of various parts in these circuits, but don't allow them to distract your mind from your present work. All your questions will be answered in time. Right now you are preparing yourself to understand the answers to all these questions, so devote all your energies to getting a clear mental picture of the things brought up in this lesson—everything that isn't clear at the present time about the function of the grid, for example, in this circuit will be made clear to you very shortly.

We are ready now to look at a diagram of a typical receiver. Refer to Fig. 20. Of course, it looks complicated, but if you isolate each individual circuit and trace it through, you will be surprised to learn how easily it can be resolved into various sections, each of which has its source of e.m.f., its load and its connecting wires.

Figure 21 shows substantially the same circuit stripped of some of its parts so that we can follow the signal through the circuit with greater ease. The source of signal current for the receiver is the antenna, and this current flows in the antenna circuit as was brought out previously. Energy is transferred from the aerial circuit to the first vacuum tube circuit and here it is boosted, stepped up, by the first radio frequency amplifier.

The source of supply for the first R.F. stage is the secondary of the transformer marked S, the variable condenser in parallel with the secondary is a control used to adjust the circuit for signals from a particular station, and the load of the circuit consists of the vacuum tube and the primary of the second R.F. transformer.

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*Later we will learn that there are circuits through the vacuum tube even if there are no conducting wires.

In the second R.F. stage, the source of e.m.f. is the secondary of the second transformer and the load consists of the second tube and the primary of the third transformer. The same is true for each succeeding circuit. In the third stage, the presence of the grid leak, GL, causes the tube to act as a detector which serves to convert the radio frequency current into current of audio frequency and at the same time give it a slight boost. The last stage, the output stage, is shown as a single tube stage but in the complete diagram this is shown as a 2-tube stage, the two tubes being arranged in a special double tube circuit.

Try to trace each circuit of Fig. 20 to the best of your ability. Don't bother about the cathode series resistor in the detector stage or the push-pull arrangement as these will be

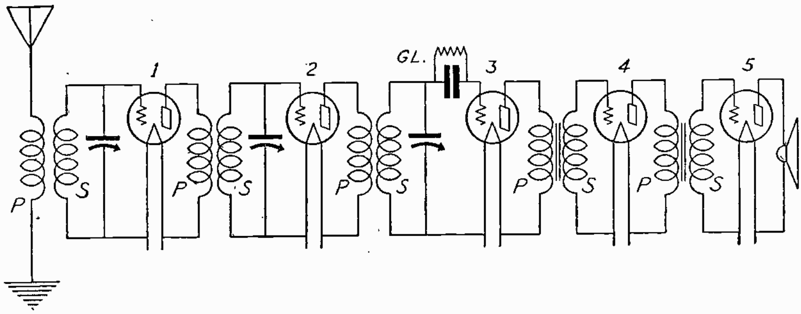


Fig. 21—The circuit of a five tube receiver employing two stages of tuned radio frequency amplification (1 and 2), a detector (3) and two stages of Audio frequency Amplification (4 and 5)

explained in detail later on in the course. Notice that the plate circuit is shown with darker lines than the other circuits which will make it easy for you to trace them through. Just one hint —the question will probably arise in your mind regarding the return conductor of the plate circuit. As it is shown, there is only one conductor, the plate supply—how then can the plate circuit be complete? You remember that when we were considering Fig 18 it was mentioned that the filament is common to both filament circuit and the plate circuit. Therefore, it should be apparent that there must be some direct connection between the plate circuit and the filament circuit. If you study the supply system shown at the lower right-hand portion of the diagram, you will see that the plate supply is grounded and that the filament supply is also grounded. It is this ground that provides the connection between the plate and filament circuits and so the plate circuit is completed through the ground connection.

There is one more thing that might cause you a little trouble —the output of the rectifier tube, the tube having two plates shown in the lower right-hand corner, goes through a choke coil, then it goes through the magnet coil of the speaker before going through the plates of the other tubes. If the speaker is disconnected as shown, there can be no plate current in the receiver.

Circuits like Fig. 20 will become easy to understand as you proceed with your course. The ability to trace circuits from diagrams or in a receiver is an important part of the Radio-Trician's equipment. Become accustomed to doing it now and it will make your study of Radio a good deal easier and enable you to start servicing receivers soon.

ELECTRICAL MEASUREMENTS

In practical electricity and in Radio we have units of measurement just as in every day life we have the units, foot, yard, mile, quart and ounce. Some of these have already been mentioned, such as the "volt"—the unit of electrical force—the "ampere," the unit of current flow; and the coulomb, the quantity of electricity; the "ohm," the unit of electrical resistance.

The pressure (voltage) and the "quantity per second" (in amperes) in a circuit can easily be determined by the use of meters (measuring devices). The "voltmeter" measures the voltages, the "ammeter" (ampere-meter) measures the current flowing. Knowing the value of the e.m.f. and the current, a Radio-Trician can make many of the calculations needed in his work—he can determine the resistance in the circuit, he can determine with the use of a voltmeter and an ammeter just where the trouble is in defective sets or what steps he must take to repair or improve a radio receiver or transmitter.

THE D. C. AMMETER

The voltmeter and the ammeter both employ principles with which you already are familiar, namely, those of magnetic attraction. Figure 22 shows the internal construction of an ammeter in sketch form. The particular meter shown is a milliammeter. The rectangular coil of wire is mounted over a stationary iron core, on a shaft fitted in bearings at each end so that it is free to rotate in a magnetic field produced by a permanent magnet. The armature assembly (coil on shaft) is held in position by pivots at the top and bottom of the shaft. To the shaft is connected a pointer which moves over a graduated scale.

Springs are so arranged that they hold the pointer to a zero position on the scale.

The armature of an ammeter is a small load, which is placed in series with the main load in a circuit. A very small part of the energy passing through the circuit is converted into magnetic energy in the coil. The armature coil of an ammeter or milliammeter has very little resistance so it should not be connected across a source of e.m.f. without an extra load to limit the current to the safe carrying capacity of the size of wire used in the coil.

The small current flows through the springs and through the coil. You know what happens then—a magnetic field is set up about the armature coil. This field joins forces with the field

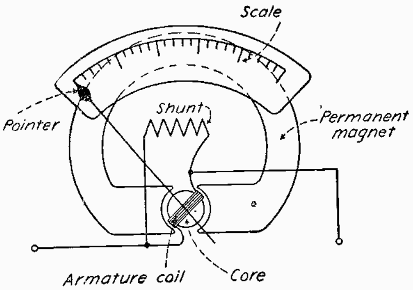


Fig. 22

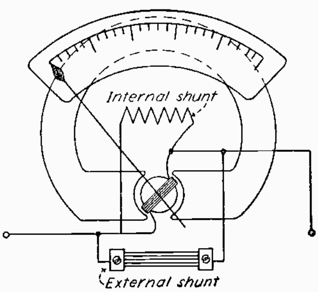


Fig. 23

of the permanent magnet—the tendency being for the lines of force of each field to get into a straight line with each other. A force is exerted, which either pushes or pulls the armature, depending upon the direction of current flow, overcoming the pressure exerted in the opposite direction by the spiral springs to a degree depending on the current in the coil. The greater the current, the more lines of force about the armature and the nearer these lines of force will approach a parallel position in respect to the field of the permanent magnet. Of course, as the lines of force move, the armature moves along with them, causing the pointer attached to it, to move over the dial.

If larger currents are to be measured with a small current-carrying ammeter, several alloy strips of comparatively low resistance, placed between two copper lugs (the assembly is called a "shunt") are connected across the terminals of the ammeter as shown in Fig. 23. The shunt divides the current so that only a small part of the total current flows through the meter. The dial is then marked to read large values of current, although here again, only a small current is actually passing through the armature coil. Thus it is possible to measure amperes while using a milliammeter with a shunt. External shunts as in Fig. 23, can also be used.

An ammeter must be connected in series with the load. The same readings will result whether the ammeter is placed in the negative connecting wire or in the positive wire—it is a very interesting principle of electricity that the same amount of current flows through any point in a series circuit. The energy used to produce the movement of the needle, and consequently the deflection of the needle, is in proportion to the amount of current

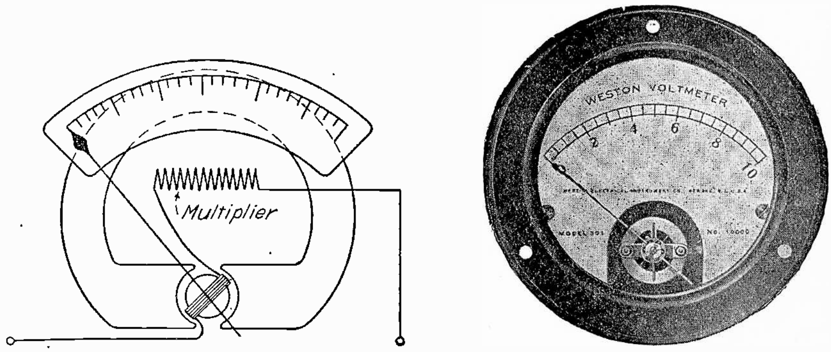


Fig. 24

flowing through the circuit. Therefore, by first knowing how much current flows, the scale of Fig. 22 can be marked in amperes, or milliamperes, then when the same amount flows at some other time, the meter will tell us so by deflecting the needle to the same position.

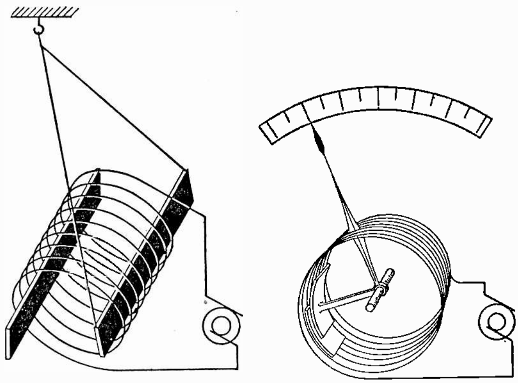
THE D. C. VOLTMETER

If we take any ammeter with a series resistance load and change the amount of *voltage* across the circuit, then the needle will deflect in proportion to the change in voltage. Reduce the voltage one-half, then the current through the meter will be one-half. Reduce the voltage still more and the meter needle will deflect less. The amount of voltage used each time can be marked on the scale and it is evident that such an arrangement will show when similar voltages are used again. The combined instrument of an ammeter and a comparatively large load in series, as shown in Fig. 24, is known as a voltmeter.

Therefore a voltmeter consists of an ammeter (always a milliammeter) in series with a resistance. The resistance is used as a fixed load to send known currents through the armature as different voltages are applied. The fixed load is known as a multiplier and it is a permanent part of a voltmeter.

A voltmeter is connected across a source of e.m.f. (in parallel) to measure its voltage. Likewise when measuring any voltage, the voltmeter is connected in parallel to the points where the difference in potential is measured.

In measuring voltage it is desirable to use a current meter which will draw very little current. Consequently, the multiplier must be of high resistance.



(a) Fig. 25 (b)

A *galvanometer* which is used in experimental and laboratory work is nothing more than a very sensitive ammeter, designed to read in milliamperes or microamperes. The principles involved in its construction are the same as those of the voltmeter and ammeter.

By using resistances or shunts of known values, a galvanometer can be used as a very accurate voltmeter or ammeter.

A. C. METERS

Up to this point we have been speaking of meters used in measuring D.C. currents. Different types of meters must be used with A.C. current—if an ordinary galvanometer were put in an A.C. circuit, the needle would tend to swing back and forth with each reversal of current flow—and if the frequency of the current was anything but very low, the reversals would be too rapid for the needle to follow and it would stand perfectly still at the zero line.

But alternating currents must be measured, and Weston adapted the D'Arsonval principle to A.C. use in a very simple and ingenious way. He made use of the principle that "like poles repel." See Fig. 25a.

The working elements of the A.C. meter are a coil and two iron plates inside the coil, one fastened to the coil, the other free to move. The pointer is attached to the free plate and when the pointer is at zero, the plates are together and in line—the free plate held in place by a fine spring, as in Fig. 25b.

When an A.C. current is passed through the coil, the iron plates are magnetized by the magnetic field about the coil. Both plates are magnetized alike. Because the north poles and south poles of these two plates, which are now magnets, are near each other, the free plate tends to move away from the fixed plate. When the current reverses, the ends of the plates which had been the north poles become the south poles and vice versa. But the repelling force is still there—the free plate will still be repelled by the fixed plate, and the greater the current, the greater will be the magnetism set up in the plates and the farther away the free plate will move, causing the needle to show a correspondingly larger reading.

A.C. meters read only about 70% of the maximum voltages —this being known as the "*effective*" voltage. Now you will ask, "How about the time when no current is flowing, twice during each cycle?" You will say that there is bound to be some change or flicker in the reading as the current rises and drops to zero. This is taken care of by a damping vane on the needle. It is a thin plate attached to the pointer needle, and moves in a closed air compartment. Thus, when the maximum repelling effect has taken place, the damping vane will tend to hold the pointer in position momentarily, just long enough so that the next half of the cycle will catch it before it has a chance to drop back toward zero.

Meters working on this principle are "repulsion" type meters. They can, by special construction, also be used to measure direct currents in which case the polarity of the plates does not change but the repelling effect is still present.

And now we come to the end of our fourth lesson. In this lesson, we have learned quite a great deal of the way an electric current acts in series and in parallel circuits and how the voltage and current are measured. In this lesson we have considered only the elementary circuits and measuring devices used in electrical work and Radio; more complete circuits, and various types of measuring devices will be studied in future lessons. Your knowledge of Radio is increasing quite rapidly, and with each lesson we dig deeper into the great storehouse of interesting information and knowledge the study of Radio opens up for us.

TEST QUESTIONS

Be sure to number your Answer Sheet 4 FR.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and the best possible lesson service.

1. What is an electrical circuit?

2. Name the three essential parts of every electrical circuit.

3. What is meant by the load in a circuit?

4. Explain briefly the difference between conductors, resistors and insulators.

5. What is the purpose of using insulating material on conducting wires?

6. Name the different ways in which sources of e.m.f. (voltage), conductors or loads can be connected together.

7. What happens to electrical energy passing through conductors having resistance?

8. Why is copper wire usually used for the transmission wires in an electrical or Radio circuit?

9. How would you connect an ammeter in a circuit?

10. How is a voltmeter connected in a circuit?

HOW RESISTORS ARE USED IN RADIO TO CONTROL CURRENT FLOW

5 FR-1

PIONEER HOME STUDY RADIO SCHOOL

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

HEAD-WORK IN RADIO

With this lesson we start what might well be called the "head-work" of Radio. We have already gotten a very clear idea of the Radio process, we know the principles of electricity and its use in circuits on which Radio is based. Now we are going to learn how to work out problems of Radio with pencil and paper—and it is this knowledge that marks the real Radio Expert.

Leave guess work for the Radio "fixer" who trusts to luck and hopes that he'll be able to stumble onto the solution of a Radio problem. You don't want to have to tear down a whole set looking for the trouble—you want to go right to it without wasting any time. You want to be the kind of Radio Expert that can figure out on paper where the trouble must be, so you won't have to take each piece of apparatus out and try to discover whether it is okay just by looking at it.

Many of the facts and methods you will learn in this lesson are expressed in the form of equations and formulas which have already been worked out to prove certain statements made in the text. It is not necessary for you to memorize them—just become familiar with them, learn how to use them, and learn what they are used for. Then should you need to use any of them anytime you will know where to refer to them.

J. E. SMITH.

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How Resistors Are Used In Radio To Control Current Flow

RESISTANCES IN SIMPLE CIRCUITS

Now that we have learned how to divide electrical and Radio circuits into groups of single circuits which can be traced (followed) through, we must learn how to calculate the values of the currents flowing in these circuits; knowing the *voltages* and the various electrical factors that oppose the flow of current, namely, *resistance*, *inductance* and *capacity* opposition. This text-book, however, will be devoted to the first of these—*resistance.*

Fig. 1 (*a*) shows the simplest of all circuits, a source of e.m.f. and a load which consists of a resistance. The e.m.f. in

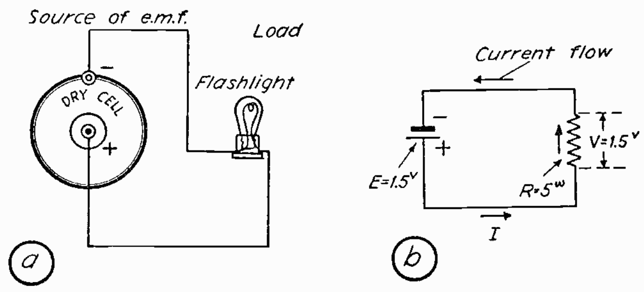


Fig. 1—A simple electric circuit.

this circuit is produced by a dry cell and the load is a flash light bulb, such as used in electric Radio receivers to light up the tuning dial. An electric light bulb is nothing more than a resistance wire in a glass bulb out of which the air has been withdrawn—that is, a resistance wire in a vacuum.

Fig. 1 (*b*) shows this simple circuit in diagram form, using the symbols for the apparatus.

When a source of e.m.f. is connected to a resistance forming a complete circuit as shown in Figs. 1 (*a*) and (*b*), a current will flow, its value being determined by the resistance of the circuit.

Ohm's Law, as you know, states that the current (*I*) is always equal to the e.m.f. (*E*) divided by the resistance (*R*). The e.m.f. is measured in volts and the resistance in ohms, the current will be in amperes. This can be stated more simply in equation form—

(1) $$I = \frac{E}{R}$$ where I is the current in amperes
E is the e.m.f. in volts
R is the resistance in ohms

The symbol "=" always means "equals."

The symbol — between E and R means that E is divided by R.

There is, therefore, something in addition to the e.m.f. (pressure) that determines the amount of the current that will flow. This something is the resistance of the wires making up the circuit and other devices used in the electric circuit. The greater the resistance, the less the current or the less the resistance the greater the current (keeping the voltage unchanged). When a resistance device of any kind is placed in a series circuit, the current is forced through it, and heat is produced by the friction between the moving electrons and the obstructing material of the

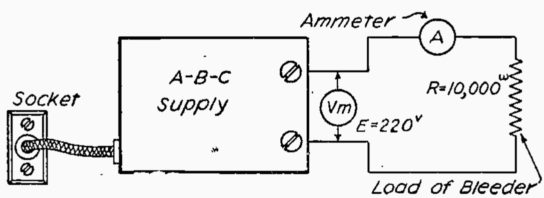


Fig. 2

NOTE.—A represents a milliammeter in this circuit.

conductor. That is exactly what happens in the case of the flash light bulb, and enough heat is produced to make the resistance wire "white hot." And because this white hot wire is in a vacuum, it glows brightly without burning up, and we have a light. Accordingly, we can make the general statement that *a flow of current in a resistance always results in heat.*

Returning to Fig. 1(*b*), let us assume that the resistance is 5^{ω} (*the Greek letter ω "omega" is universally used by Radio men to represent "ohms" and is placed to the right, above the number;* 5^{ω} *would be read 5 ohms*). The e.m.f. produced by a dry cell is known to be 1.5^{V} or one and a half volts ("V", symbol for volts). What current will flow?

From equation (1): I equals E divided by R. Substituti the known values for E and R, we find that I equals 1.5 v divided by 5 ohms which gives us .3 or $\frac{3}{10}$ of an ampere.

Let us work another problem:—The "B" side of an A-B-C power supply such as used for radio receiving sets and amplifiers (which we shall learn all about soon) delivers an e.m.f. of 220 volts. A 10,000 ohm resistance is placed across this 220 volts as in Fig. 2. What current will flow? Again substituting known values for *E* and *R*, we get *I* which is equal to

$$\frac{220^{V}}{10{,}000^{\omega}} = .022 \textit{ of an ampere.}$$

To prove this answer is correct you can multiply 10,000 by .022 which gives us 220 volts. When dealing with radio apparatus we do not talk about thousandths of amperes—instead we change these small values of currents to milliamperes. A milliampere as you know is one-thousandth of an ampere. Then

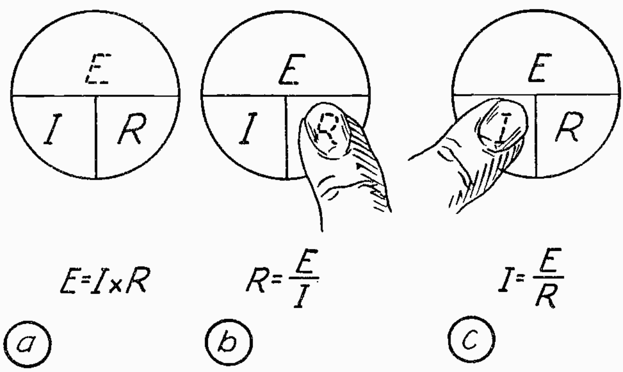


Fig. 3—A simple method for using Ohm's Law in three forms.

to convert our answer ".022 of an ampere" to milliamperes, all we have to do is to multiply .022 by 1,000 and we get 22 milliamperes.

Incidentally, this 10,000 ohm resistance is referred to as the "*bleeder*" resistance (a resistance placed across the B supply to prevent the internal voltage of the supply from getting great enough to damage itself). Now suppose a 5,000 ohm bleeder resistance was used and a milliammeter placed in the circuit showed that 38 milliamperes of current* were flowing. Can we calculate the supply voltage?

Easily—because you know if the values of any two (voltage, resistance or current) are known, the third can be found. Equation (1) may be expressed in the three ways shown in Fig. 3. This is a very easy way to remember Ohm's Law. By covering the unknown value with the forefinger, the procedure to be fol-

*This is due to the drop in the supply voltage when more current is drawn.

lowed in finding the unknown will be made clear. In this case, we want to find E. So we cover E and find that we will have to multiply I by R or, the current by the resistance. Now, to find the value of E (voltage) we can substitute our known values. But in this case I is expressed in milliamperes—therefore it must be converted to amperes. To do this we must divide 38 by 1,000, which gives us .038 of an ampere. Then by multiplying this by 5000 we obtain 190 volts. Therefore our equation will read

$$E = \frac{38}{1{,}000} \times 5{,}000 = 190^{V}.$$

Note that the voltage is not 220^{V} in spite of the fact that we used the same supply system. Something happened in the A-B-C supply when we put a greater load *on it. Just what happened we shall have to leave until later, but this decrease in e.m.f. is to be expected in Radio.

Often we do not know the resistance of the load; in such a case we use Ohm's Law most frequently to determine the value of R. We can always find the value of E and I by the use of a voltmeter and an ammeter. Let us suppose that we take meter readings of our power supply circuit and find that the e.m.f. is 230 volts, and the current is 8 milliamperes. What is the resistance of the load?

From Fig. 3 (*b*), $R = \frac{E}{I}$ We know that E is 230^{V} and that I is 8 milliamperes or $\frac{8}{1{,}000}$ (.008 ampere). Then substituting we get $R = \frac{230}{.008} = 28{,}750^{\omega}$.

Students who are not familiar with working out problems using decimals are advised to take these figures for granted, until they find an opportunity to brush up on this work.

Now we have seen how the value of E, I or R can be found when any two values are known, and you can see the importance of understanding the use of Ohm's Law. Other equations like these you will find are just as valuable as this one and will seem just as simple to you when you get to know them as well as you know Ohm's equation.

Not all circuits are as simple as the one we have been speaking about, but with the understanding we have of this circuit we can go on and solve other circuits.

* By a greater load we mean drawing more power (See formula (9).) With the 10,000 ohm load the power loss is 220 × .022 = 4.84 watts; with the 5,000 ohm load the power loss is 190 × .038 = 7.22 watts.

Fig. 4 shows a slightly different circuit. Three dry cells are connected in series, supplying an e.m.f. of 4.5 volts or 4½ volts. Instead of a fixed resistance, there is in the circuit what is known as a *potentiometer*. This consists of one continuous winding of resistance wire, the ends of which are connected to the terminals 1 and 2 in Fig. 4, and there is also a sliding contact "*S*." A potentiometer always has 3 terminals. The dry cells are now connected to terminals 1 and 2 and the current will flow in the resistance between 1 and 2 as determined by Ohm's Law—that is,

$$I = \frac{E}{R} = \frac{4.5^{V}}{45^{\omega}} = .1 \text{ of an ampere.}$$

A voltmeter (V_m) is now connected between the slider "*S*" and terminal 1. When *S* is at one end of the resistance, at point

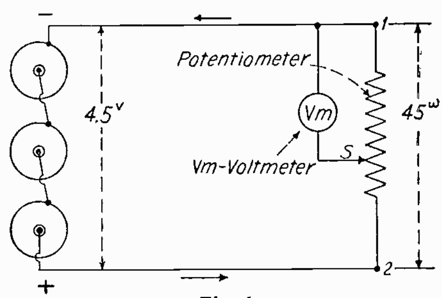


Fig. 4

1, the voltmeter reads zero. As it is moved from point 1 to point 2, the voltmeter reading increases gradually until it reads 4.5V at point 2.

In fact, when slider *S* is one-third across, the voltmeter will read 1.5 volts; two-thirds of the way from 1, the voltmeter will read 3.0 volts and when totally across (from 1 to 2), it will read 4.5 volts. We must also realize that when the slider is one-third across, the resistance (between 1 and *S*) is 15 ohms; when two-thirds of the way across, the resistance (between 1 and *S*) is 30 ohms and when totally across from 1 to 2, the resistance is 45 ohms.

What does this all mean? The generated 4.5V of the battery has been applied to the resistance and has caused a current of .1 of an ampere or one-tenth of an ampere to flow. In doing so, it has lost its entire voltage in forcing the current through the resistance. It lost 1/3 of its voltage one-third of the way (1.5V); 3.0V two-thirds of the way and all its voltage in the entire resistance.

The battery voltage is called a *generated voltage, a voltage rise* or a *plus voltage.* The voltage lost in a resistance is called a *voltage loss* or a *voltage drop.* A voltage must be measured between two terminals and is therefore called a potential difference. The voltage drop (potential difference *PD*) measured across 1 and S as the slider is varied may be expressed in the following equation—

$PD = R \times I$ where R is the resistance across which the PD exists.
I is the current through the resistance.

The method shown in Fig. 4 is used practically in every radio receiver to supply various voltages to one or more circuits that may be suitably connected to the various terminals.

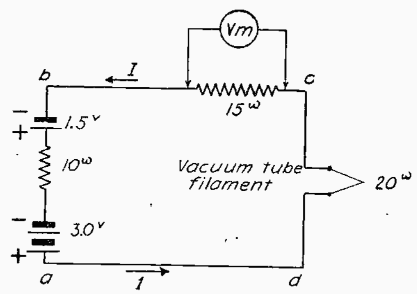


Fig. 5

The "B" supply of an electric radio receiver uses a device something like this known as a "voltage divider." By connecting the two outside terminals of a high resistance across the voltage supply system and making suitable taps at points along the resistance we may obtain from a 250 volt supply, 45, 90, 180 and 250 volts—the entire range required for the plates of the vacuum tubes.

Voltage dividers will be taken up in detail when we study A-B-C power supplies.

In Fig. 5 we have the same total resistance—45 ohms (20 + 15 + 10) as in Fig. 4 and the same total e.m.f. 4.5 volts ($3.0^V + 1.5^V$) all in a series circuit. What is the value of the current in this circuit? Obviously, since each part is in series with the other parts of the circuit, all the current will flow through each. Thus, the current must be the same in each, for none can "spill out." The current will be equal to all the generated voltages divided by all the resistances in series and expressed in equation form will appear thus:

$$(2)\quad I = \frac{All\ E\ added}{All\ R\ added} = \frac{3 + 1.5}{20 + 15 + 10} = \frac{4.5}{45} = .1 \text{ of an ampere.}$$

A voltmeter placed across any resistance will measure the potential difference (*PD*). Let us call it *voltage drop* as is the custom. There are three voltage drops; across the 20 ohm. 15 ohm and the 10 ohm resistances. There are two generated voltages; 1.5^V and 3^V which we shall call *voltage rises.*

In the early part of the 19th Century there lived an eminent scientist, Gustav Kirchhoff, who was a contemporary of Dr. G. S. Ohm, who gave us "Ohm's Law." Kirchhoff expanded on Ohm's Law and gave us what we know as Kirchhoff's Law No. 1; *"In a complete electrical circuit, the voltage rises always equal the voltage drops."* Referring back to Fig. 5, we must realize that the 3 volts and 1.5 volts are generated voltages and are voltage rises. Voltages are lost or dropped across the vacuum tube resistance, which is 20 ohms and across the 15 ohm and the 10 ohm resistors. The voltages that exist across these resistances are voltage drops. Let us check Kirchhoff's Law from our previous study of potential differences.

$$Voltage\ Rises = Voltage\ Drops.$$

Step (a) $1.5^V + 3^V = (.1 \times 20^\omega) + (.1 \times 15^\omega) + (.1 \times 10^\omega)$

Step (b) $4.5^V = 2.0^V + 1.5^V + 1^V$

Step (c) 4.5 volts rise = 4.5 volts drop

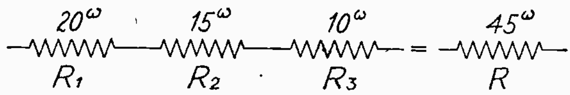
which proves Kirchhoff's Law.

Kirchhoff's Law No. 1 is quite often expressed in circuits containing only resistances and electromotive forces as follows:

> "When there are several electromotive forces acting at different points of a circuit, the total of the e.m.f.'s around the circuit is equal to the sum of the resistances each multiplied by the strength of the current that flows through them. If one electromotive force should be reversed, that electromotive force is to be subtracted."

This Law of Kirchhoff's, leads us to this statement that resistances in series are added together in order to find the total resistance in a circuit. Thus— $20 + 15 + 10 = 45$ *Ohms.*

(3)

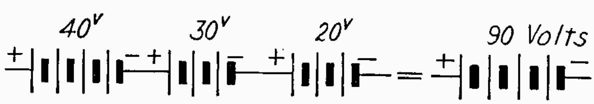


$$R = R_1 + R_2 + R_3 \text{ etc.}$$

It is very simple to compute resistances in series when we have two or more resistances of the same value connected one after the other in the circuit. Let us say we have, as in direct current socket-power receivers, 5 filaments of 20 ohms each connected in series. The total resistance will be equal to the number of resistances, multiplied by the resistance of a single one and in this case, $5 \times 20 = 100$ *ohms.*

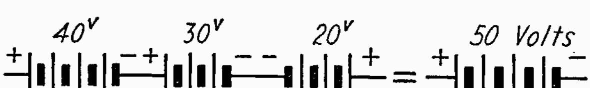
This particular Law of Kirchhoff's also teaches us that *voltages* in series are added in order to determine the total. Thus, $40 + 30 + 20 = 90$ *volts.*

(4)



$$E_1 + E_2 + E_3 = E$$

We must be very careful. Should one of the voltages be reversed—as shown below then the total voltage would be $40 + 30 - 20 = 50$ *volts.*



$$E_1 + E_2 - E_3 = E$$

This is by no means impossible, in fact, this is exactly what we do in some battery circuits.

Now suppose the voltages and resistances were connected together in series to form a single circuit, as shown in Fig. 6, what would be the current?

From equation (2)

$$I = \frac{All\ E\ added}{All\ R\ added} = \frac{40 + 30 + 20}{20 + 15 + 10} = \frac{90\ Volts}{45\ Ohms} = 2\ amperes.$$

Fig. 7 shows the *equivalent* circuit. It is not the same circuit by any means but it is called an equivalent circuit because all the e.m.f.'s can be considered as one and all the resistances

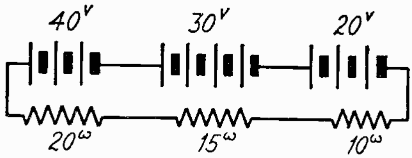


Fig. 6

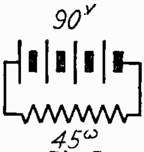


Fig. 7

can be considered as one resistance, the values of which are the totals of the individual e.m.f.'s and resistances.

Now we have a rather complete knowledge of *series* circuits. But in Radio we often have batteries, generators or transformers supplying power to vacuum tubes connected in *parallel* as in Fig. 8. We know that (c,b,a,d,c) is a complete circuit and that (c,b,g,f,a,d,c) is another complete circuit. Kirchhoff's

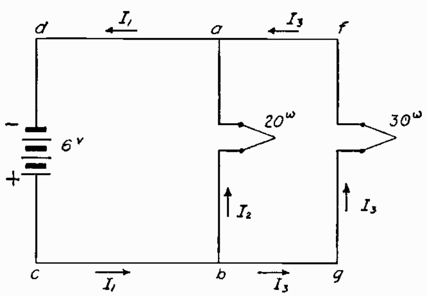


Fig. 8—Two resistances in parallel.

Law No. 1 still holds true but now the problem that confronts us is whether the current from b to a is the same as from g to f also what is the current from c to b. Kirchhoff Law No. 2 takes care of this, which states: *the current flowing to a point* (such as b) *equals the sum of the currents flowing away from that point.* Thus the current flowing from c to b equals the sum of the currents flowing from b to a and b to g or:

(5) $$I_1 = I_2 + I_3$$

From Ohm's Law, we can calculate current I_2 and current I_3.

I_2 is equal to the voltage a-b (6 volts) divided by the resistance (20 ohms)—that is

$$I_2 = \frac{6}{20} = .3 \text{ of an ampere.}$$

Similarly, from Ohm's Law, I_3 is equal to 6 volts divided by 30 ohms—that is

$$I_3 = \frac{6}{30} = .2 \text{ of an ampere.}$$

From Kirchhoff's Law No. 2, I_1 is equal to the sum of these two currents, or—

$$I_1 = .3 + .2 = .5 \text{ of an ampere.}$$

Resistances, therefore, are not always connected in series—sometimes they are connected in parallel as we have just shown. For example, in Fig. 8, the 20 ohm and the 30 ohm resistances

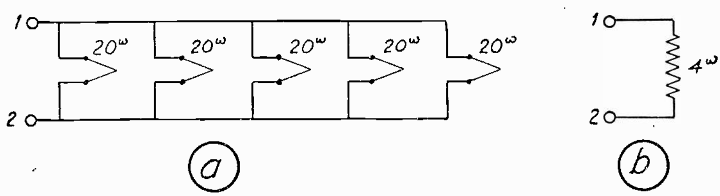


Fig. 9

are in parallel. We may have in some cases 3, 4, 5 or more resistances in parallel and when we do, we must know how to determine the equivalent resistance.

The simplest case is the condition when all the resistances are alike. For example, five '01A type tube filaments, each having a resistance of 20 ohms, are all connected in parallel as shown in Fig. 9(a). What is the total resistance?

When all the resistances are alike and in parallel, the total resistance is equal to the resistance of one *divided* by the number of resistances and in this case, it will be 20 divided by 5, which gives us a total resistance of 4 ohms.

The calculation of unequal resistances in parallel circuits differs from the calculation for equal resistances.

When there are only two unequal resistances such as 20 ohms and 30 ohms in parallel, their total resistance can be found by using the following simple equation.

$$(6) \qquad R = \frac{R_1 \times R_2}{R_1 + R_2} = \frac{20 \times 30}{20 + 30} = \frac{600}{50} = 12 \text{ ohms.}$$

When there are more than two unequal resistances in parallel the combined resistances can be determined in two ways; first the currents through the individual resistance branches may be found, their sum obtained and this total current divided into the applied voltage. This will give the total resistance of the parallel combination of the unequal resistances.

The total resistance of unequal parallel resistances can also be determined by the conductance or reciprocal method which is explained in the following paragraphs.

When a definite resistor opposes the flow of current, we say that it has resistance. The same resistor may be considered to have the ability to carry or conduct a certain amount of current, or as it is usually expressed: it has conductance. By definition: The conductance of a circuit is the reciprocal of its resistance, that is, the reciprocal of a number is the quotient obtained

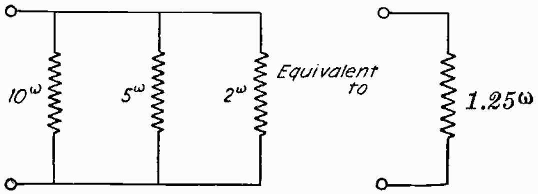


Fig. 10

by dividing one by that number, as the reciprocal of 4 is ¼. The conductance of a circuit is expressed in units called *mhos*, which is derived from the word *ohm* written backwards. The symbol for conductance is "*G*," therefore "*G*" $= \frac{1}{R}$.

Now we are ready to fully understand the second method for determining the total resistance of several resistances in parallel.

Suppose we have three resistances in parallel as shown in Fig. 10, having resistances of 2, 5, and 10 ohms respectively. From what we have already said, their respective conductance will be $\frac{1}{2}$, $\frac{1}{5}$ and $\frac{1}{10}$ mho—that is, the total conductance would be equal to $G_1 + G_2 + G_3$. Since $G = \frac{1}{R}$, the total conductance would be

(7) $$\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Then the total resistance must be equal to the reciprocal of the total conductance, $R = \frac{1}{G}$.

Now what is the total resistance of Fig. 10? There is no difficulty in solving this particular problem using equation (7).

$$G = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{2} + \frac{1}{5} + \frac{1}{10}$$

By simple arithmetic—

$$\begin{aligned} &\text{1 divided by 2} = .5 \\ &\text{1 divided by 5} = .2 \\ &\text{1 divided by 10} = .1 \end{aligned}$$

$$G = .5 + .2 + .1 = .8 \text{ of a mho—Total Conductance.}$$

$$\text{Therefore } R = \frac{1}{G} = \frac{1}{.8} = 1.25 \text{ Ohms—Total Resistance.}$$

Some radio circuits are combinations of series and parallel resistors like that shown in Fig. 11. Ohm's Law applies to every

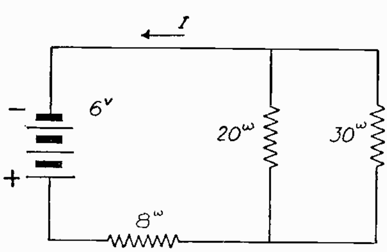


Fig. 11—A combination series-parallel arrangement of resistances.

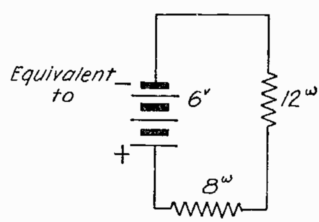


Fig. 12

part of this circuit. To find the total resistance, it is necessary first to reduce each parallel combination to its equivalent series resistance before combining it with the series resistance. For example, 20 ohms and 30 ohms in parallel are equal to 12 ohms. (See formula (6) page 10.) Now we may replace Fig. 11 by the equivalent circuit in Fig. 12. Therefore, $12 + 8 = 20$, the total resistance of this series-parallel circuit. Series and parallel resistances will always be simple to understand especially if you are able to handle fractions and decimals, and have a clear understanding of the meaning of what reciprocal means. If you should find some of the methods used to obtain the total resistance of series and parallel resistors are not clear to you at first reading, a study of elementary arithmetic will clear matters up for you.

MEASURING RESISTANCES

A working knowledge of these simple formulas you will find very helpful when servicing Radio receivers. In most cases when a resistance in a receiver or power supply device burns out it is as a rule a simple matter to find out the value of the resistance as very often the value of the resistance is marked on it, but in other cases it will be necessary to use your knowledge of Ohm's and Kirchhoff's Laws.

For example, in Fig. 13 we have a Radio arrangement of resistances as used in power supply devices. The resistance R between the 180^V and 90^V terminals is the one that usually burns out. If we had to replace this resistance and we did not know its resistance value, how could we calculate it?

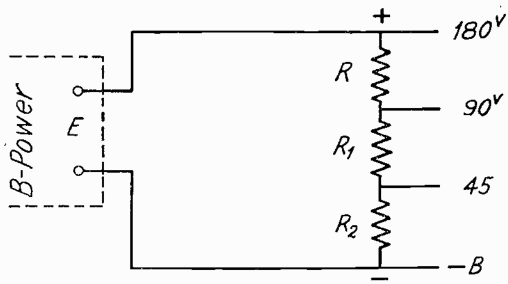


Fig. 13—A voltage divider.

The easiest way, if a duplicate power supply device was available, would be to measure the value of the good resistance with an Ohmmeter, or we might remove the good resistance R temporarily and measure its resistance by applying a certain voltage to it and measuring its current and then using Ohm's Law—Resistance equals the voltage divided by the current.

In case that a good resistance is not available, then procure a variable wire-wound resistance and use it in place of R. Connect a voltmeter between the 90^V tap and the B minus terminal then vary the resistance until the correct voltage is shown by the voltmeter. After this has been done, the variable resistance will have the correct value of the resistor R which was burned out, it can be removed and measured as explained above for measuring a good resistance and the proper substitution made.

CALCULATING RESISTANCES

When servicing a Radio receiver sometimes it is necessary to wind a resistance (resistor) when replacement parts are not available. A well equipped service shop always carries in stock resistance wires. In making resistors the value wanted must be known in ohms, and then this value can be built into a resistor by carefully calculating the length of the wire, taking into consideration the size of wire used and the kind of material of which the wire is composed.

While copper is regularly considered a good conductor, it must not be forgotten that even the best conductors offer some resistance to current flow, and that the smaller the conductor, the greater the resistance.

In comparing different materials, some standard of unit dimensions must be adopted. The commercial copper wire standard generally used is the Annealed Copper Standard (See

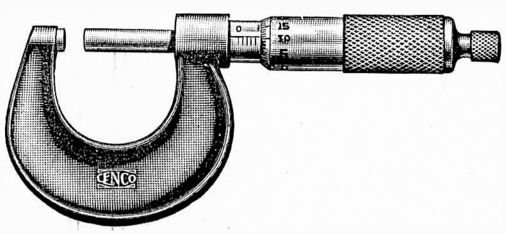


Fig. 14—A micrometer.

Table No. 1) recommended by the United States Bureau of Standards of Washington, D. C. When a wire is referred to by a certain number, as for example, No. 16 or No. 32, this number means the gauge of the wire. It is a way of specifying the diameter.

A number of wire gauges differing slightly from each other, have been originated by different manufacturers of wire, but the one generally used in this country is the B & S Gauge (Brown & Sharpe Manufacturing Co.) commonly called the American Wire Gauge.

You will notice in Table No. 1 that the gauge (size) of copper wire ranges from No. 0000, which is one-half of an inch in diameter, to No. 40, which is as thin as a hair. In other words, the size decreases as the gauge numbers increase.

As most wires used are perfectly round, a circular measure is used to express the area—the circular mil. *One circular mil is the area of a circle whose diameter is 1 mil.* The term mil means one-thousandth of an inch ($\frac{1}{1,000}$ *or 0.001 inch = 1 mil*).

If the diameter of a wire measures 20.10 mils then it has a cross-sectional area of 404.0 circular mils, the area being obtained by squaring the diameter of the wire in mils (multiplying it by itself).

When purchasing spools of copper wire you will find the number of the wire marked on the spool in most cases, but occasionally you may find it necessary to measure the size of the wire yourself. In that case you can use a micrometer such as every tool maker has, one of which is shown in Fig. 14, or better still

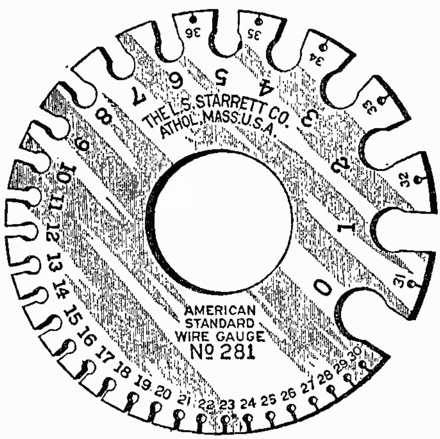


Fig. 15—A pocket wire gauge which can be purchased from any hardware store handling copper wire.

you can use a regular American Standard Wire Gauge as shown in Fig. 15. The slots or holes in which the wire is placed you will notice are numbered to designate the sizes of the wire.

Copper wire sizes number 16 to number 36, 50.82 mils to 5 mils in diameter are generally used in power transformers, chokes, audio transformers, radio frequency coils, radio frequency chokes, speakers—in practically every part of a radio receiver or transmitter. The wire is usually round—although sometimes it may be square or rectangular; it may be soft or hard; bare or covered with cotton or silk to insulate it and allow the wires to be placed close together without the current or voltage jumping across; it may be coated with an insulating material or it may be enamelled and then covered with silk or cotton insulation.

TABLE NO. 1

Table of Wire Constants for Standard Annealed Copper Wire.

Gauge No.	Diameter in mils.	Cross-section		Resistance at 20°C. or 68°F.	Turns per Linear Inch			
		Circular mils.	Square inches	Ohms per 1000 feet	S.C.C.	D.C.C.	S.S.C.	D.S.C.
0000	460.0	211,600	0.1662	0.04901	2.14	2.10		
000	409.6	167,800	0.1318	0.06180	2.39			
00	364.8	133,100	0.1045	0.07793	2.68	2.62		
0	324.9	105,500	0.08289	0.09827	3.00			
1	289.3	83,690	0.06573	0.1239	3.33	3.25		
2	257.6	66,370	0.05213	0.1563	3.75			
3	229.4	52,640	0.04134	0.1970	4.18	4.03		
4	204.3	41,740	0.03278	0.2485	4.67			
5	181.9	33,100	0.02600	0.3133	5.21	5.00		
6	162.0	26,250	0.02062	0.3951	5.88			
7	144.3	20,820	0.01635	0.4982	6.54	6.25		
8	128.5	16,510	0.01297	0.6282	7.35			
10	101.9	10,380	0.008155	0.9989	9.25			
12	80.81	6,530	0.005129	1.588	11.5			
14	64.08	4,107	0.003225	2.525	14.3			
15	57.07	3,257	0.002558	3.184	15.9	14.9		
16	50.82	2,583	0.002028	4.016	17.9	16.7	18.9	18.3
17	45.26	2,048	0.001609	5.064	20.0			
18	40.30	1,624	0.001276	6.385	22.2	20.4	23.4	22.7
19	35.89	1,288	0.001012	8.051	24.4			
20	31.96	1,022	0.0008023	10.15	27.0	24.4	29.4	28.0
21	28.46	810.1	0.0006363	12.80	29.9			
22	25.35	642.4	0.0005046	16.14	33.9	30.0	36.6	34.4
23	22.57	509.5	0.0004002	20.36	37.6			
24	20.10	404.0	0.0003173	25.67	41.5	35.6	45.3	41.8
25	17.90	320.4	0.0002517	32.37	45.7			
26	15.94	254.1	0.0001996	40.81	50.2	41.8	55.9	50.8
27	14.20	201.5	0.0001583	51.47	55.0			
28	12.64	159.8	0.0001255	64.90	60.2	48.6	68.5	61.0
29	11.26	126.7	0.00009953	81.83	65.4			
30	10.03	100.6	0.00007894	103.2	71.4	55.6	83.3	72.5
31	8.928	79.70	0.00006260	130.1	77.5			
32	7.950	63.20	0.00004964	164.0	83.4	62.9	101	84.8
33	7.080	50.13	0.00003937	206.9	90.0			
34	6.305	39.75	0.00003122	260.9	97.1	70.0	121	99.0
35	5.615	31.52	0.00002476	329.0	104			
36	5.000	25.00	0.00001964	414.8	111	77.0	143	114
38	3.965	15.72	0.00001235	659.6	125	83.3	167	128
40	3.145	9.888	0.000007766	1049	141	90.9	196	145

S.C.C.—Single Cotton Covered. D.C.C.—Double Cotton Covered.
S.S.C.—Single Silk Covered. D.S.C.—Double Silk Covered.

To change ohms per thousand feet to ohms per foot, divide by one thousand.

No. 32 wire has a diameter of 7.950 mils; 1000 ft. of this wire will have a resistance of 164 ohms, according to Table No. 1. Therefore a foot of this wire would have .164 of an ohm resistance. How many ohms are there in the primary of an audio transformer, the winding of which consists of 745 ft. of No. 32 wire? This is a very simple problem, because we have studied resistance in series and 745 ft. of No. 32 wire is the same as 745 resistances of .164 of an ohm connected in series. By multiply-

TABLE NO. 2

	*Relative Resistance	†Resistance in ohms per circular mil.-foot
Aluminum	1.64	17.1
Antomony	2.42	25.2
Bismuth	69.0	717.
Brass	4.07	42.4
Constantan	28.5	296.
Copper		
Annealed Intnl. Standard	1.00*	10.4
Hard drawn	1.03	10.7
Pure, annealed	.98	10.2
German Silver	19.1	199.
Gold	1.42	14.8
Iron, Commercial	6.5 to 8.0	67.5 to 83.0
Hard cast	56.8	590.
Lead	12.8	133.
Manganin	24. to 43	253. to 447.
Monel Metal	24.3	253.
Mercury	56.	583.
Nickel	4.53	47.3
Platinum	5.8	60.4
Platinum-iridium	14.3	148.5
Silver	.95 to 1.07	9.85 to 11.14
Steel, Hard	27.3	284.
Soft	10.1	105.
Rail	8.0 to 12.5	83. to 130.
Tantalum	9.	93.6
Tin	6.0 to 7.3	62.5 to 76.
Tungsten	3.2	33.3
Zinc	3.5 to 3.8	36.4 to 39.5
Advance Metal	28.3	294.
Iala	28.4	295.
Superior	50.0	520.
Nichrome	57.8	600.
Nichrome II	63.5	660.
Calorite	69.5	722.

*International Standard Annealed Copper is taken as the standard of reference.

†These values were computed from the first column using 10.4 per C.M.F. as the resistance for Standard Annealed Copper. K in formula (8).

ing 745 by .164 you will find that the total resistance will be 122.18 ohms. Whether the wire is number 11, 22, or 40, etc., if the resistance per foot is known the resistance of any length in feet may be obtained by multiplication as explained.

Table No. 1 is for soft standard annealed copper wire. In

Table No. 2 the relative resistivities of various wires are given using copper as a standard. If hard drawn copper wire is used, the answer contained in the previous paragraph must be multiplied by 1.03 for correction. If the wire is aluminum, the answer is multiplied by 1.64. In other words, 1000 ft. of No. 36 wire of copper would have a resistance of 414.8 ohms and 1 ft. would have a resistance of .4148 of an ohm. A foot of No. 36 iron wire would have a resistance of approximately 2.9036 ohms, because iron wire has a relative resistivity approximately seven times as great as that of copper.

For commercial purposes where the least resistance is desired, copper is always used. Aluminum may be used where lightness is important, however, in Radio it is fairly safe to assume that copper is universally used.

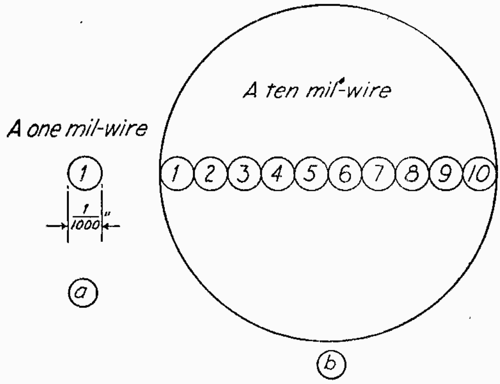


Fig. 16

For resistors, German silver, manganin, constantan and nichrome are most commonly used. These are trade names for alloys (mixtures of various metals such as nickel, iron, copper, etc., in varying proportions). Usually the resistance per foot of an alloy wire is marked on the spool on which the wire is wound, and we are saved these computations.

Note from Table No. 1 that No. 22 copper wire has twice the resistance of No. 19 copper wire and that the cross-sectional area of No. 22 is one-half that of No. 19. Thus, No. 19 wire is equivalent to two No. 22 wires in parallel.

If the area of the wire is doubled, the resistance is halved; if increased three times, the resistance will be one-third, etc.

Any resistance can be calculated if we know its area and the resistance of a circular mil of such a wire one foot long. Fig. 16(a) is a circular wire. Let it represent a magnified circular mil area with the wire having a diameter of one mil (.001 inch). Fig. 16(*b*) represents a magnified No. 30 wire. Note that ten one-mil diameter wires span across it. Clearly many one circular mil wires can be threaded into the space occupied by this ten-mil diameter wire. In fact, it will take very close to 100 wires such as "*a*" to make a wire such as "*b*." For simplicity, remember that if the diameter of a wire is 32 mils, its circular area will be its diameter in mils multiplied by itself—

$$32 \times 32 = 1024 \text{ circular mils.}$$

With this knowledge, the resistance of any particular wire can be found from the formula

$$(8) \qquad R = K \times \frac{L}{a}$$

Where R is the resistance to be computed
K is the resistance for a wire one circular mil in area and one foot long
a is the area in circular mils
L is the length in feet

For copper, K is 10.4 ohms per foot. See Table No. 2. For aluminum, 17.1 ohms; for nichrome 600 ohms, etc.

Formula (8)—for nichrome which is the most common Radio resistance wire—

$$R = 600 \times \frac{L}{a}$$

Example:—What resistance would 503 feet No. 30 nichrome wire have?

Solution:—A number 30 wire would have an area of 10.03 × 10.03 or 100.6 circular mils. Substituting in formula (8)

$$R = 600 \times \frac{503}{100.6} = 600 \times 5 = 3000 \text{ ohms.}$$

Many resistances composed of wires like nichrome are used in Radio work. The above is the exact method used in designing Radio resistances.

EFFECT OF TEMPERATURE ON RESISTANCES

The electrical resistance of all substances is found to change more or less with any change in temperature. All pure metals, such as nickel, copper, aluminum and iron show an increased resistance with rise in temperature. Thin wires heat much more rapidly than thick ones of a like resistance when carrying the same amount of current.

In most metallic alloys, such as nichrome, constantan, etc., the mixture is so compounded that the percentage of increased resistance with temperature is very small and we usually assume that the heat does not change the value of the resistance. For this reason, such wires are exclusively used in Radio apparatus for resistors.

In power transformers, in power chokes and in resistors excessive heat is not desirable, therefore, manufacturers of these devices take precautions to prevent them from getting too hot. This is accomplished by means of proper ventilation and by using the proper sized wire that will safely carry the current without overheating the wire and damaging the insulation.

In a vacuum tube filament and in a line ballast, the temperature increase is important for satisfactory operation of these devices.

POWER

Electricity is valuable to man because of the work it can be made to do for him. The amount of work electricity can do in a second of time is its *power*. A generator, a battery, or an A-B-C supply for a receiver or amplifier will deliver power. Power is measured in *watts*. The power delivered by any *direct current supply* is: the *e.m.f.* in *volts multiplied* by the *current* in *amperes*.

Power (watts) = e.m.f. (volts) × current (amperes).

(9) $$P = E \times I$$

In any direct current circuit, regardless of whether the power is being dissipated in heat or being converted into some form of energy, such as motion, the amount of power used or delivered can be determined by connecting a voltmeter and an ammeter in the circuit. For example: the generator in Fig. 17 delivers 110 volts, 60 volts of which are supplied to the motor and 50 volts are supplied to a resistance.* A current of two amperes is flowing in this simple series circuit and because it is a series circuit this amount of current is flowing through the generator, the motor and the resistance.

*The 110 volts of the generator is now the voltage rise, the 60 and 50 volts are voltage drops.

According to equation (9), the power delivered by the generator is *110 volts* $\times$ *2 amperes* = *220 watts.* The power used by the motor is *60* $\times$ *2* = *120 watts,* and thus except for some loss, 120 watts of electrical power are converted into mechanical power. The resistance is using up *50* $\times$ *2* = *100 watts* in heat. Power represents energy. Thus, the 220 watts generated are accounted for (*120* + *100* = *220*).

We know that in a motor electrical energy is converted into mechanical energy—but what about the power used up in the resistance? *Power delivered to a resistance is converted into heat.* In a vacuum tube filament, we make use of the heat generated by the electrical resistance of the filament, but in most cases it is necessary to avoid heat losses as far as possible.

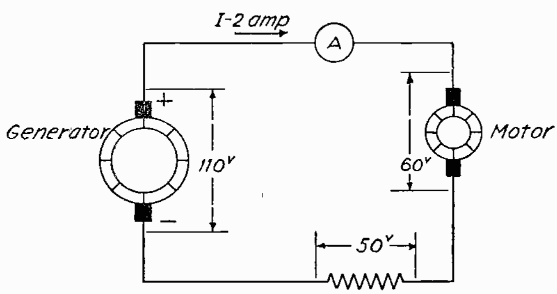


Fig. 17

In a Radio receiver, the more resistance we use, the more heat is generated. Therefore, a receiver must have proper ventilation, as resistances are used in abundance. The back of the cabinet is open or is covered by only a wire screen. Holes in the bottom of the console (the Radio cabinet) may even be necessary to assist ventilation. Table model receivers must have perfect air circulation.

The power lost as heat in any resistance may be computed by another formula:

Power = *Current* $\times$ *Current* $\times$ *Resistance.*

Instead of saying I$\times$I, the expression I^2 is used (I squared). Therefore, our formula in its common form is

(10) $$P = I^2R$$

WHAT HAPPENS WHEN A RESISTOR IS CONNECTED TO AN A.C. VOLTAGE

What we have been discussing up to the present time applies only to resistances in simple circuits in which a D.C. electromotive force acts.

Let us imagine a D.C. generator connected in a circuit with an ordinary resistance. We know from Ohm's Law that the current will have a definite value, determined by the value of the resistor and the voltage applied. We also know that if we were to increase the voltage, the current through this simple circuit would increase; and if the voltage were decreased, the current would decrease. This particular action takes place instantaneously.

What would take place if the voltage should gradually drop, remain steady for a time, gradually rise, then become steady, and

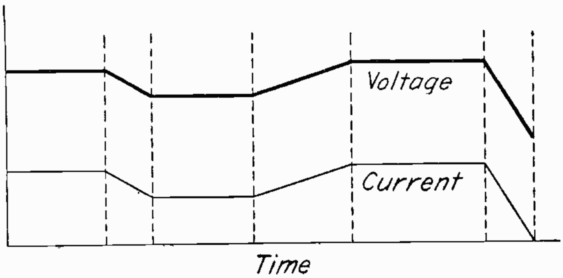


Fig. 18

sharply drop off, as shown in Fig. 18. Notice that whenever the voltage is constant, the current remains constant. When the voltage drops, the current drops and if you will notice the connecting dotted line you will see that these actions take place "in step," that is, the current values are in step with the voltage values. When one goes up, the other goes up too.

If this is clear in your mind, we are ready to see what would happen if an A.C. generator were connected to a resistance. We know from our study so far that the voltage generated by an A.C. generator starts from zero, gradually increases to maximum, then drops off again, becoming zero. This is represented in Fig. 19 by the portion above the zero line. Then the voltage reverses its direction. In other words, the generator terminal which was originally plus becomes minus, the minus terminal becomes plus, and the voltage acts on the resistance in the opposite direction. We can plot this a as in Fig. 19—the portion of the curve below the zero li That is, the voltage starts from zero, increases to a maxim negative direction, and then returns to zero.

From what we learned in connection with Fig. 18, we know that when the voltage increases, the current increases. At any particular instant of time, the current could be determined by Ohm's Law, that is, the voltage at that particular instant divided by the value of the resistance, which never changes, is equal to the current at that instant. We can therefore see that the current is maximum when the voltage is maximum, the current is zero when the voltage is zero, and when the voltage reverses its direction the current reverses its direction—that is, current follows voltage *exactly in step.*

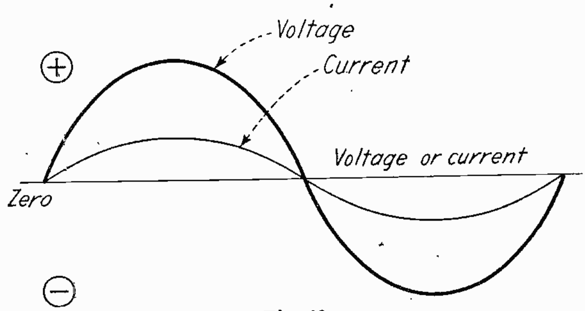


Fig. 19

Radio and electrical men, however, prefer to use the word phase instead of "in step." They say then that, "The voltage and current are *in phase.*" In later lessons we shall study circuits in which the voltage and current are not in phase, due to the presence of electrical properties other than resistance. The important thing to remember now is merely that with only resistance in an A.C. circuit, current and voltage are in phase.

POWER LOST IN A RESISTOR WHEN SUPPLIED WITH A.C.

Formulas (9) and (10) apply to circuits containing a source of D.C. electromotive force and resistance. In order to get the information to be used in these formulas for D.C. circuits, direct current ammeters and voltmeters would be required.

Now if an A.C. voltage was fed to a resistor, you know that an alternating current will flow through the resistor. Therefore if you used A.C. ammeters and voltmeters to find the A.C. voltage drop across a resist the alternating current flowing through it, formulas (9) and) would still hold true.

You might ask what value of current or voltage is indicated by A.C. meters as you know that the current voltage is increasing and decreasing, even changing in direction so that the average value is zero. A.C. meters measure the *effective* voltage and current. However, even though the voltage continually changes in value, the current through a resistor is producing heat. An A.C. generator which will produce as much heat through a resistor as a D.C. generator, would have the same effective A.C. voltage as the D.C. voltage of the latter. Of course the current would have the same *effective** value, too. This effective voltage or current is called the "root mean square" value, by radio men abbreviated r.m.s.

For example, you might see (*a*) 10^V D.C. and (*b*) 10^V (r.m.s.). The first you would recognize as a direct current, the second as an alternating current value. You would know that a D.C. meter measuring (*a*) would read 10 volts, and an A.C. voltmeter measuring (*b*) would read 10 volts. You would also know with absolute assurance that if connected to the same value of resistance, both will produce the same heat, and both will force the same amount of current through the resistor, of course, one a D.C. current, the other an A.C. current.

The important thing to remember, then, is that an r.m.s. value of alternating current is an indication of the amount of A.C. that will produce as much heat or do as much work as a direct current of the same value.

RADIO RESISTANCES IN EVERY DAY USE

A Radio receiver may be divided into four sections; the radio frequency amplifier, the detector, the audio frequency amplifier and the power supply. In all of these sections, fixed or variable resistors are used, each resistor varying in type or construction depending upon the power in watts to be dissipated and the value of resistance.

The number of commercial resistances used in Radio is indeed quite vast. We could not possibly describe in detail in this text-book all the resistances used and their exact construction and design, but a study of the following figures and a little

* The effective value is .707 times the maximum value. Conversely the maximum value is equal to 1.41 multiplied by the effective value.

explanation on each will give you a clear idea of how some of the most important ones look and how they are built so that when you come across any of these when servicing a receiving set you will know something about them and why they are used.

Roughly, Radio resistances may be divided into several classes—*fixed resistances, variable resistances, tapped fixed resistances* and automatic resistance controls.

Fig. 20 shows three typical low power wire wound fixed resistances usually used for biasing the grid of vacuum tubes or as suppressors of radio frequency oscillations.

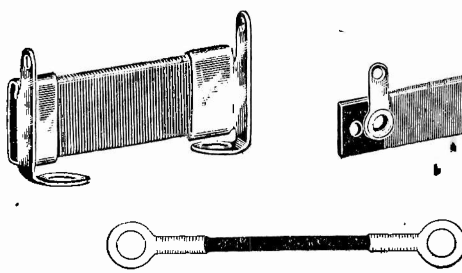
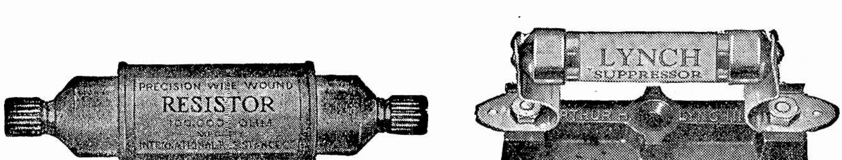


Fig. 20—Low power wire-wound fixed resistors.

The wire is wound on a bakelite or fibre strip attached to lugs at each end for connections in the circuit in which it is placed. The one shown at the bottom of Fig. 20 is a flexible resistor made of fine nichrome wire wound on a specially treated silk cord and then completely covered by impregnated fibre. These are especially adapted for use in small sets as they can be bent into any desired shape.

A standard precision fixed wire resistor is shown in Fig. 21 (*a*). Resistors of this type are used very often as multipliers



(a)—Precision laboratory wire wound fixed resistor.

(b)—Interchangeable grid resistor. Non-inductive.

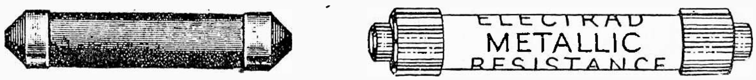
Fig. 21

and shunts for converting voltmeters and milliammeters into high reading voltmeters and ammeters. They are also suitable to conduct special experiments when precise resistances are of importance. Fig. 21 (*b*) shows such a resistor used as a grid suppressor installed in a clip mounting.

Resistors used as grid leaks in some detector circuits may be either of the carbon or metallic film resistance type.

A typicaal carbon and a metallic grid leak resistance for use in clip mountings are shown in Fig. 22. These may have any value from one-half to 10 megohms, depending upon the type of tube used as a detector.

The carbon resistance is made of a thin glass rod, which is coated with a solution of carbon. The metallic resistance consists of a special metallic deposit on a glass rod, permanently sealed in a glass tube. The ends are copper plated and soldered

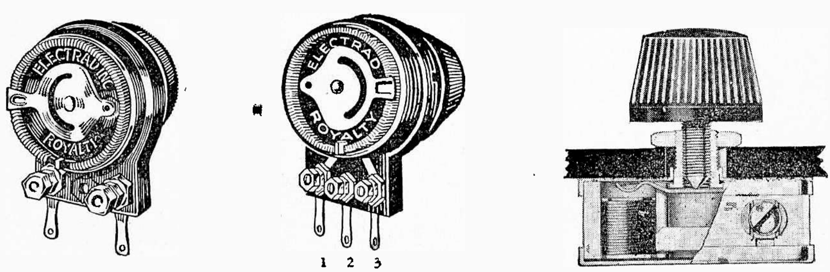


(a) (b)
Fig. 22

to caps by means of which the resistor is supported between clips of a standard grid leak mounting.

Variable resistors are made in two general types; the wire wound and the carbon or graphite. Wire wound variable resistors usually consist of resistance wire wound on a fibre or bakelite strip and a contact arm sliding over the turns of wire is used for changing the resistance value. See Fig. 23 (*a*).

Potentiometers are built similar to this variable wire wound resistor with the exception that the beginning and the end of the wire wound on the fibre or bakelite strip, are brought to termi-



(a) (b) (c)
Fig. 23

nals as well as the moving arm. In other words, the variable resistor shown in Fig. 23 (*a*) has two terminals where the potentiometer shown in Fig. 23 (*b*) has three terminals.

Where extremely high resistance values are needed or where fine adjustments are desired the carbon type of resistor is generally used. See Fig. 23 (*c*).

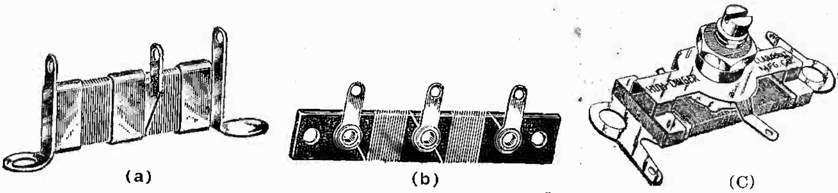
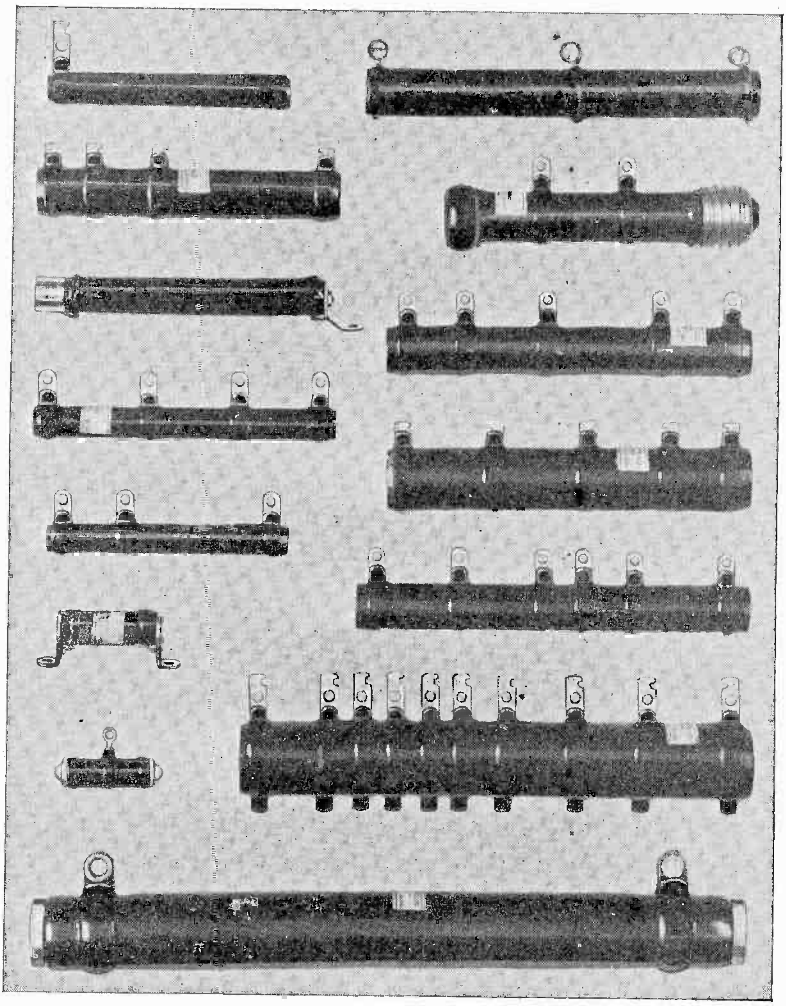


Fig. 24—(a) and (b) Typical mid-tap resistors used to eliminate tube hum. (c) Variable mid-tap resistor for hum control.



(Courtesy Ohmite Co.)

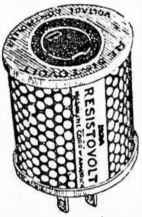
Fig. 25—Group of resistors, wire wound on grooved porcelain tubing, covered with insulating enamel and baked.

These make use of carbon or graphite discs or powder which when pressed together tightly by a screw control knob or handle, decrease in resistance, or if allowed to separate increase in resistance.

In Fig. 24 there are shown several types of mid-tap low power fixed resistances which are especially designed for use in A.C. filament circuits to obtain an electrical center of the filament by means of the mid-tap on the resistor. This eliminates hum from the raw alternating current supplied from the transformer.

The one shown on the right has an adjustable center contact which is regulated by a set screw.

Tapped resistors or voltage dividers, as they are usually called, have their resistance wire wound on large threaded porcelain tubes. Copper clamps are fastened at various positions on



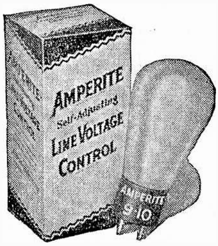


Fig. 26—Typical line ballast resistor which works on the principle that "increased current causes more heat in the resistance element thereby increasing the ballast resistance, resulting in a decrease of line current."

the wound tubing, determined, of course, by what resistances are desired between adjacent taps. The whole assembly is then dipped in enamel or a porcelain solution and baked. A group of excellently designed porcelain tapped power resistances or voltage dividers is shown in Fig. 25. These are mostly used in power packs. Their resistances is rated in ohms and power dissipation in watts. They are mounted by means of end brackets or by means of a lamp-socket plug end or are supplied with pig tails or solder lugs. When having more than two terminals, they are used as voltage dividers, primarily required for power pack use.

In our study of effects of temperature on certain resistance wires, we found that as the temperature of nickel and iron wire increased the resistance went up. This particular phenomenon is used quite extensively in automatic line controls or ballasts as they are called. Fig. 26 shows two such devices.

RADIO COILS---WHY AND HOW THEY WORK

6 FR-1

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

DETERMINATION

The man who has made up his mind to be successful, is already well on the way to success. Determination is the soul of achievement. There are other factors that help to determine a man's future, it is true, but if he has determination to succeed, a real determination, he is like a steam-roller under full steam, nothing can stop him.

Look ahead to the success and happiness that will come to you if you throw yourself, body and soul, behind your determination to succeed. Each lesson well completed is one step taken toward your goal. Give your best to each lesson—make the knowledge contained therein part of you. Learning parrot fashion won't do much good; satisfy yourself that you *understand* everything—then your lesson grades will take care of themselves and you'll have the sort of knowledge you can use.

Of course it isn't going to be easy. It's hard for most people to lay out a plan and stick to it absolutely. But on the other hand, nothing that is easy is worthwhile. You can succeed just as others have—so keep your determination alive. I'm with you.

J. E. SMITH.

NATIONAL RADIO INSTITUTE

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Radio Coils—Why and How They Work

MAGNETIC EFFECT OF CURRENT FLOW

From what you have learned in the previous lessons of the course, you know that coils are essential for Radio reception—a receiver built without including coils in its construction would be useless. The same thing can be said for resistors and condensers. In fact, these three are largely responsible for Radio reception—and not only reception, but transmission as well. Every transmitter and every receiver has resistors of definite values, coils built according to very close specifications, and condensers that are carefully designed and accurately built.

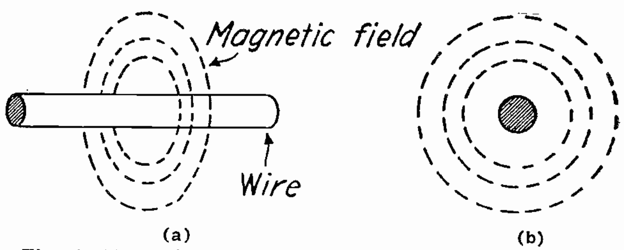


Fig. 1—Magnetic Effect Around a Wire When Current Is Flowing.

We have already studied resistors and the effect of resistance in electrical circuits with particular reference to Radio circuits. We learned that resistance is the *property* of resistors, that some electrical energy is converted into heat energy in a resistor, and that resistance can be used to control current flow—in fact, we now have a very clear idea of resistance, we know how to measure it, and how to connect various resistors together in order to get desired values of resistance.

In this text book we are going to learn about coils in the same practical manner—why coils are used, what property they have that is made use of in Radio, how this property (inductance) affects electric currents, in what units it is measured, and all about it.

But as is so often the case in the study of Radio, we can't start out immediately by studying inductance itself. We must first study the simple electrical effects which are at the bottom of what we know as inductance.

Some of these effects have already been studied, such as the movement of the lines of magnetic force about a conductor carrying current. You will remember that the needle of a small compass held near a "live" wire will deflect, proving the existence of a magnetic field, consisting of lines of force, about the wire. It is so essential that we understand thoroughly the relation of this field to the current in the conductor, and the effect of one field on another, that a careful review of the subject will be extremely valuable.

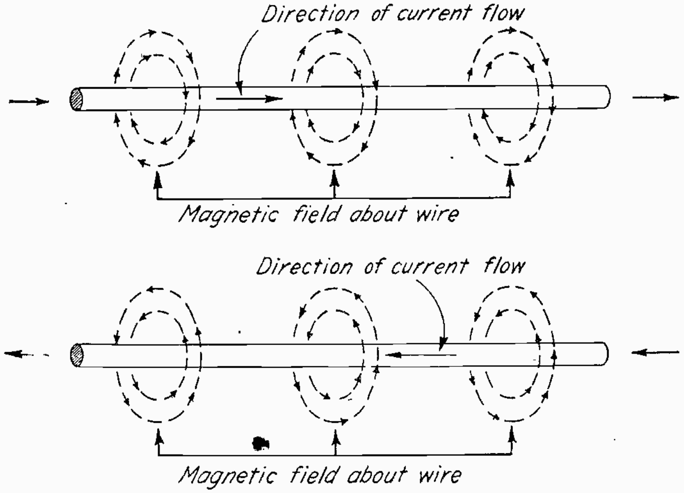


Fig. 2

The lines of force surround a wire carrying current in the form of concentric circles, that is, circles at right angles to the wire, all having the wire as a common center. If the lines of force were visible, a side view of the conductor would appear as shown in Fig. 1 (a) and an end view as shown in Fig. 1 (b).

The number of lines of force around a conductor depends upon the strength of current (number of amperes) flowing through the conductor. If the current is increased, the lines of force expand and spread outward at right angles away from the wire and new lines are formed, while if the current is decreased the lines of force collapse back upon the wire and their number is reduced. If the current stops flowing altogether, the lines of force collapse completely. Thus as the current within the conductor varies, the lines of force around the conductor also change, that is, they expand and collapse as the current increases and decreases.

The direction of the magnetic lines of force around the conductor depends upon the direction of the flow of current. If the current reverses in direction the magnetic lines of force around the conductor will reverse as shown in Fig. 2.

When the direction of the current in a straight wire is known, the direction of the circular magnetic field around it can be determined by the "right-hand" rule. Grasp the wire with the fingers of the right-hand, with the thumb extended in the direction of current flow. The direction in which the fingers are pointed will indicate the direction of the magnetic lines of force.

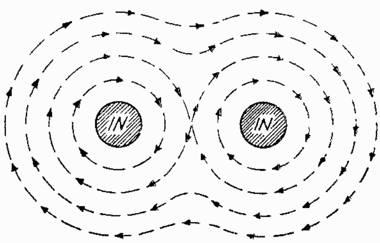


Fig. 3

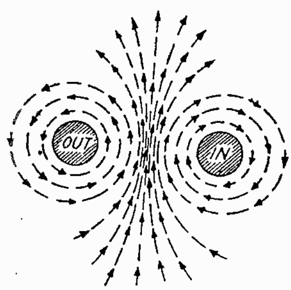


Fig. 4

Now, if two wires, each carrying current, are placed parallel and close together, the resultant magnetic field is a combination of the two fields.

Fig. 3 shows two wires close together, each carrying current in the same direction. The lines of force about each wire have the same direction and tend to combine as shown, making one large magnetic field.

If the current is flowing in opposite directions in the same two wires, the magnetic field will be as shown in Fig. 4.

If the wire carrying current is wound in a loop as shown in Fig. 5, all of the magnetic lines of force about the wire combine and pass through the loop in the same direction as shown, that is, as the current is passed through the loop in the direction shown in Fig. 5, the magnetic lines are all upward on the inside of the loop of wire and in a downward direction on the outside of the loop.

If, instead of making only one turn of wire, we make a coil of wire consisting of several turns, the lines of force produced by each turn of wire, instead of acting right around the conductor will combine with those produced by the next turn of wire thus giving the effect shown in Fig. 6.

The end of the coil from which the lines of force leave is said to be the north pole and the end into which the lines of force enter is called the south pole of the coil.

MUTUAL INDUCTION

When two electric circuits are close to one another a current flowing in one will induce a voltage into the other, whenever the current in the first circuit increases or decreases, or

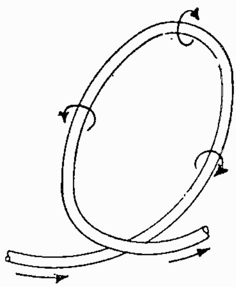


Fig. 5

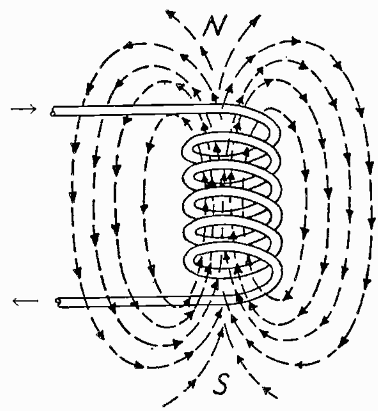


Fig. 6

changes its direction of flow. We say that this induced voltage in the second circuit is accomplished by means of "mutual induction."

Consider the simple experiment set up in Fig. 7. Here we have two wires, that is, two electrical conductors laid side by side, but not touching each other. To wire *AB*, in circuit *No. 1*, a source of direct current is connected which is in this case a battery. In the same circuit is a key, *K*, connected in series to act as an off-on switch so that we can open or close the circuit at will. We also place in this circuit an ammeter so that we can keep a check on the current flow.

The second wire *CD* in circuit *No. 2* is connected to a sensitive voltmeter (a galvanometer) to form a second circuit. As you see, this voltmeter is of the type which has its zero position in the center of the scale so that it will indicate in which direction voltage is acting. Very obviously, there is no direct electrical or mechanical connection between circuits *No. 1* and *No. 2.*

Now let us depress the key, allowing current to flow in circuit *No. 1.* Watch the voltmeter in circuit *No. 2* carefully. At the instant the key is depressed, it will be noted that the voltmeter needle in circuit *No. 2* deflects, showing of course that there is a voltage in the circuit. In all cases, the voltage thus induced is relatively small.

If we keep circuit *No. 1* closed, that is, if we don't release the key, we notice that the voltmeter in circuit *No. 2* now shows a zero reading—after its first deflection the needle returns to zero. How can we explain this? If there is a voltage in circuit *No. 2* when current begins to flow in circuit *No. 1,* why shouldn't there be a voltage present as long as there is current flowing in circuit *No. 1?*

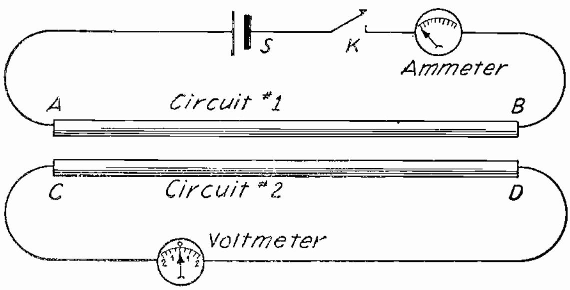


Fig. 7

But let us continue our experiments before we stop to explain this. We release the key, opening circuit *No. 1.* Current stops flowing, very naturally. We are watching the voltmeter in circuit *No. 2* carefully. And here we notice something else peculiar—at the instant circuit *No. 1* is opened, the voltmeter needle deflects, but this time in a direction *opposite* to the direction of the first deflection. This can mean only one thing—that somehow or other, when we released the key, a voltage was again induced in circuit *No. 2,* but this time the voltage was in a direction *opposite* to the direction of the first induced voltage.

Our first conclusion after observing this experiment is that there are evidences of voltage in circuit *No. 2* only when current flow in circuit *No. 1* is starting or stopping. Can this be explained?

You remember that about a wire carrying current there are always magnetic lines of force, usually referred to as "flux." And it is because of this flux about the wire in circuit *No. 1* that a voltage was induced in circuit *No. 2.* This leads us to the statement of another fundamental principal of electricity and Radio—that when moving flux *cuts* across a wire, an electrical conductor, or when a moving conductor cuts through flux, a voltage will be induced in that conductor. Notice, however, that there must be *motion,* either the conductor must be moving and cutting through the flux, or the flux must be in motion, before a voltage can be induced.

This explains why there was no meter reading possible in circuit *No. 2,* when the current in circuit *No. 1* was flowing steadily—the flux was stationary. But when current started to flow in circuit *No. 1,* the flux about the conductor had to be built up—and as it built up from nothing to maximum it cut across circuit *No. 2,* inducing in it a voltage. But just as soon as the flux reached maximum and the continuous current flowing in circuit *No. 1* maintained it at maximum, it became stationary, there was no cutting and consequently no voltage induced.

Then when the current in circuit *No. 1* was suddenly cut off, its magnetic field collapsed. The collapse of course constitutes a motion, a movement of flux *inward,* instead of *outward.* This movement induces another voltage into circuit *No. 2* but in the opposite direction, because the flux is now moving toward wire *AB* instead of away from wire *AB.* The deflection of the voltmeter needle will show this change.

There are several things of interest in connection with this experiment which must be cleared up before we thoroughly understand everything that happens when a voltage is induced in circuit *No. 2.* We know that if a voltage exists in circuit *No. 2,* a current must flow as the circuit is closed. Does the current in the wire *CD* in Fig. 7 flow in the same direction as that in *AB?*

To make this clear, study carefully Fig. 8 in which the conductors in Fig. 7 are shown in perspective. A current is flowing from *A* to *B* as shown by the large arrow, and from our right-hand rule for the direction of magnetic field resulting from current flow, we find that the magnetic field around the wire *AB* is in a clockwise direction as shown by the circular lines.

As the current starts to flow in *AB,* these magnetic lines of force spread out around the wire *AB,* moving towards the parallel wire *CD,* and pass through it.

At the instant of passing through the wire *CD,* these magnetic lines of force induce a voltage into it, and if this wire *CD* is part of a complete circuit, as it is in Fig. 7, a current will flow in it.

Before we can determine in what direction the current will flow in *CD*, we must thoroughly understand the law of magnetic flux action discovered by Lenz, a German scientist, from whom it derives the name "Lenz's law."

Lenz's law states, "The direction of the induced voltage is such that it sets up a current in a closed circuit, the magnetic field of which always opposes any change in the field that produced it."

In accordance with Lenz's law the direction of voltage in wire *CD* in Fig. 8 must be such that the field produced by a current flowing opposes any change in the magnetic field of wire *AB*. The magnetic field around the wire *AB* is expanding, therefore, to oppose this change, the field around the wire *CD* must be in opposition to that in the wire *AB*. To be in opposition to the field of *AB*, the field of *CD* must be caused by a current of opposite direction to the current in *AB*. And the voltage induced in *CD* will be opposite in direction to the voltage acting in *AB*.

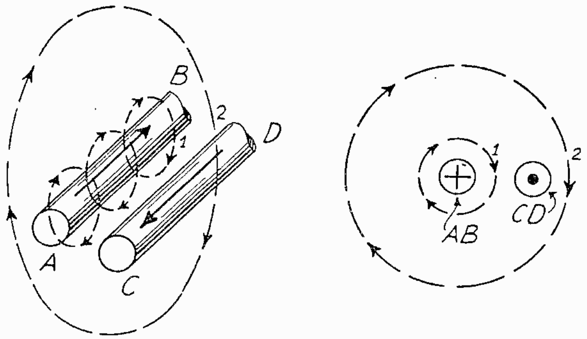


Fig. 8

When the current stops flowing in *AB*, the magnetic field about *AB* collapses. This collapse also induces a voltage in *CD*, and, according to Lenz's law the current through *CD* must be in such a direction as to produce a magnetic field that opposes the decrease in this magnetic field of *AB*, and therefore the current during this collapse must be opposite to the direction of current flow in wire *CD* when the field of *AB* was expanding. We now have the current *CD* flowing in the original direction of *AB*. From this, if the current in wire *AB* was decreasing, the current in *AB* and *CD* would be in the same direction, and if the current in *AB* was increasing the current in *CD* would be in a direction opposite to that in *AB*.

SELF-INDUCTION

When the magnetic field about *AB* collapses due to a decrease in the current in *AB* the collapsing field induces a voltage in its own conductor and the resultant voltage thus induced will act in the same direction as the original voltage, tending to prolong current flow in *AB*.

When a voltage is induced in a conductor by its own collapsing field, it is, we say, *self-induced* and the action is called *self-induction* to distinguish it from *mutual induction,* the creation of a voltage by magnetic interaction (flux linkage) between two separate conductors.

If a collapsing magnetic field creates an e.m.f. in the conductor about which the field was created, will an e.m.f. be induced in that conductor while the field is being built up? Of course, and this is the result of self-induction just as an e.m.f.

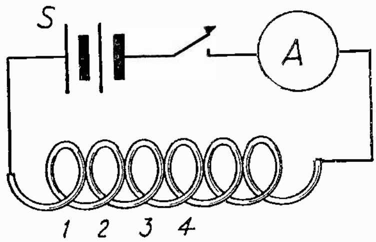


Fig. 9

was created by self-induction when the field collapsed on itself.

According to Lenz's law, when a current is increasing in a circuit, the e.m.f. of self-induction opposes the increase; when a current in a circuit decreases, the e.m.f. of self-induction tends to prevent the decrease. From this it is clear that a collapsing magnetic field will induce a voltage in its conductor, in the same direction as the original voltage.

Now we are ready to go a step further. Let us take the conductor *AB*, in Fig. 7, and wind it on some tubular form, making a small coil as shown in Fig. 9. We have the same amount of wire, but it is arranged differently. Will this new arrangement have any effect on a current flowing through the circuit? You can answer that question from what you have already learned about self-induction and mutual induction in this lesson, can't you? We know that there is a magnetic field built up about each turn of wire when current begins to flow through the coil. We know that as long as this field keeps moving, in this case, increasing, a counter-e.m.f. due to self-induction will be induced in each turn. But each turn of wire has its own magnetic field which at the instant we are considering it, is *moving* outward from the portion of the conductor about which it is created. Will the flux about turn *1* have any effect on turn *2?* Certainly. Between adjacent turns, there is a *mutual induction* just as though the two turns were in separate circuits. The increasing flux about *1* will induce a voltage in turn *2*. The increasing flux about turn *2* will induce a voltage in *1*. There will be the same interlinkage of flux between *2* and *3*, and between *3* and *4*. Since turns *1*, *2*, *3*, etc., are in series the induced voltage due to mutual induction will oppose the original current flow.

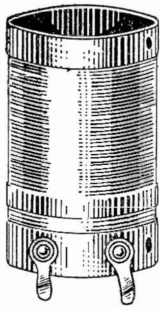


Fig. 10 (a)

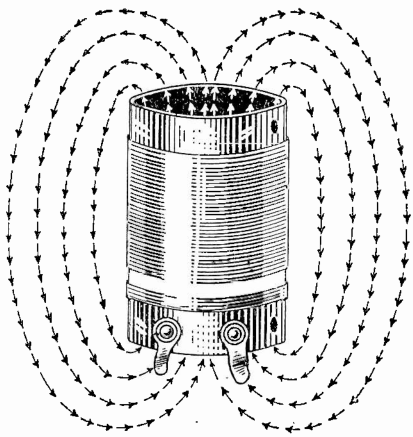


Fig. 10 (b)

You can see what we are getting at. The total counter-e.m.f. (back e.m.f.) induced in the coil until the flux reaches maximum will be much greater than the back e.m.f. induced in a straight conductor. Of course when the flux is stationary, that is, when it has reached maximum and the current flowing through the coil keeps it at maximum, there is no magnetic interaction between turns and there is nothing to prevent the free passage of current through the coil except the resistance of the wire. But suppose we suddenly remove the original voltage *S* in Fig. 9, the magnetic fields collapse, inducting an e.m.f. in their own turns and adjacent turns in the same direction as the original current that created the fields, according to Lenz's law—and the current tries to keep on flowing for a short time in the circuit.

Now in place of this improvised coil we can place in the circuit the sort of coil we are familiar with in Radio work. Let it be a coil such as shown in Fig. 10(*a*). The windings are close together, almost touching, so that very little flux can flow between the windings. The result is that all the fields of the individual wires combine to form a complete, single field for the entire coil as shown in Fig. 10(*b*). We know what effect the coil will have on the current flow—that it will be impeded to some extent, it will be opposed by the counter-e.m.f. induced in its turns by the expanding magnetic field. We know that when the field becomes stationary, the current will flow practically unimpeded. We know that when the key is opened the current will "want" to keep flowing due to the collapse of the coil's magnetic field. If our coil were large enough, at the

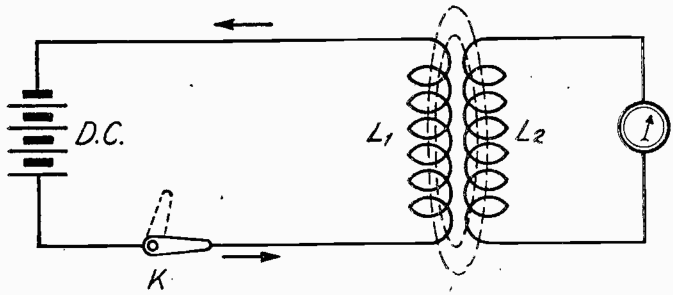


Fig. 11

instant we opened the circuit, a spark would jump across the key contacts proving that the energy stored in the magnetic field has been reconverted into electrical energy.

In the earlier pages of this text-book, it was stated that if a wire was cut by a varying magnetic field, a voltage would be induced into it, and that if we wound a wire into a coil in which there was a varying current, the fields about the individual wires would combine to form a complete, single varying field for the entire coil. Now, if we place this coil which we will call L_1 close to another coil which we will call L_2 as shown in Fig. 11, and then close and open this D.C. circuit so many times per second by the key (K), the varying lines of force set up by the interrupted direct current passing through coil L_1 will cut the second coil L_2 and the current in L_2 will be an alternating current.

Now suppose we connect a source of alternating current to coil L_1 as shown in Fig. 12. What would happen? We know that an alternating current rises and falls to zero a number of times per second, and if the current falls to zero, then the magnetic field must collapse with it and rise with it when the current builds up again.

We can picture an alternating magnetic field as having a sort of a breathing effect. It rises and falls like your chest when you breathe. In other words, it is constantly in motion. If there is an alternating magnetic field about the primary coil L_1, the secondary coil L_2 will constantly be cut by these varying magnetic lines of force, and alternating current of the same frequency will be generated in L_2. This is the principle upon which all electrical transformers operate.

INDUCTANCE

The combined effects of the mutual induction between the turns of a coil and self-induction in the individual turns, give the coil the property of *inductance*, which is always represented

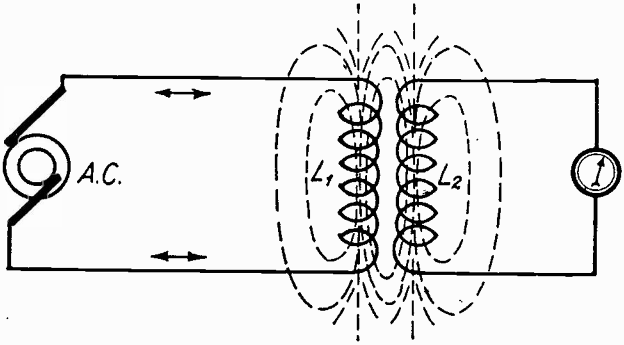


Fig. 12

by the letter "L." It is *inductance* that tends to hold back current flow when a voltage is applied to a circuit with a coil in it. And it is inductance that tends to prolong current flow when the applied voltage is removed.

In the same way, if the applied voltage is increased or decreased in the circuit containing the source of e.m.f. and the coil, inductance tends to keep current flowing at the original rate. All this can be stated very briefly—inductance tends to prevent any *change* in current flow. This of course doesn't mean that the current will remain constant no matter what changes are made in voltage—it means only that if there is inductance in the circuit, the current change will not follow a voltage change instantaneously, but there will be a certain length of *time* between an increase or decrease in voltage and the resulting increase or decrease in current.

Inductance in an electrical circuit is often compared to mechanical inertia.* Every fly wheel provides an example of mechanical inertia. Suppose at normal running speed a heavy fly wheel revolves at 100 revolutions per minute. Is it possible to get it moving at 100 r.p.m. from a dead stop instantly? Of course not—and considerable energy or power is required to get it moving at that speed. After it is moving at this speed, however, less power is required to keep it up to speed. Now, if the driving force is removed, the fly wheel does not come to a stop instantly—in fact, if it is desired to bring it to an instant stop considerable energy must be applied in the opposite direction,

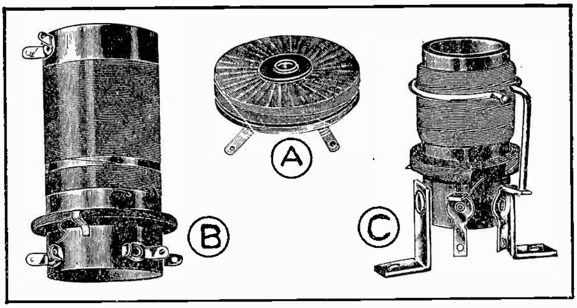


Fig. 13—Typical radio frequency coils used in modern radio receivers of all types, without shielding. A is a radio frequency choke coil of the criss-cross wire wound type, used extensively for preventing the flow of R.F. current in the circuit in which the coil is placed. B is a typical radio transformer (coil system); the criss-cross winding is the primary, the single layer winding the low R.F. resistance secondary. The gap in the secondary is to reduce the coil's distributed capacity (existing between turns of winding). Short-wave (high frequency) coils are made in this manner except less turns are used on the primary and secondary; the latter is very often wound with a very few turns, which are spaced over the form. C is another R.F. transformer, the secondary bank wound; that is, the coil turns are overlapped in two or more layers. The heavy wire single loop is used to capacity-couple the primary and secondary, giving better (more uniform) reception over the tuning range.

in the form of a braking force. We say that the fly wheel in motion has momentum and this momentum must be overcome by some form of resistance before the wheel will stop revolving.

A simple explanation of this is that when we are overcoming the inertia of the fly wheel, which requires more energy than to keep it moving, we are storing energy in the wheel in the form of momentum. When the driving force is removed from the wheel, the energy stored in it is converted into motion. And as soon as all the stored energy is used up, the wheel comes to a stop.

* Because it tends to oppose any change of current flow, it tends to keep it from starting and when started, tends to keep it going at the same rate, opposing any increase or decrease, acting just like a fly wheel in a mechanical circuit.

The same thing is true if we want to increase speed. To build up the speed we must overcome some more inertia, storing more energy in the form of momentum. When decreasing the speed, the energy stored will tend to keep the wheel moving at the faster speed—until the energy stored has been entirely dissipated by resistance, the resistance at the center bearing and the air resistance.

You can see how close this analogy is. Inductance in a cir-
5 cuit is comparable to both inertia and momentum, it tends to prevent current from flowing, and once the current is flowing "at full speed," it tends to keep it flowing even though the driving force (the source of e.m.f.) is removed. Energy is stored in the magnetic field about the coil—when the driving force is removed, the magnetic energy is converted into electrical energy and delivered to the circuit again. Moreover, inductance tends

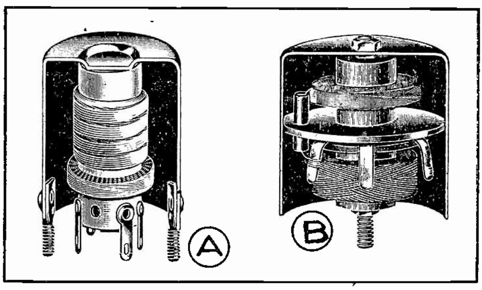


Fig. 14—Radio frequency coils in a metal shield to prevent other coils in the receiver from affecting their operation. A is a tuned secondary transformer; B is a self-tuned secondary, depending on its own capacity for tuning.

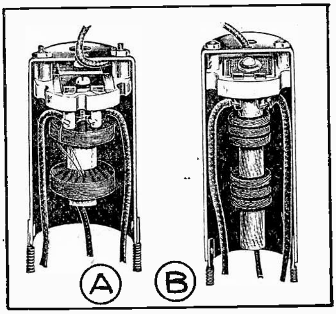
to prevent any change in current flow, whether from a lower to to a higher value, or from a higher to a lower value.

There has always been a great deal of confusion in the terminology of this subject. Mutual induction is often called mutual inductance; self-induction, self-inductance. We have been very consistent in this lesson and it should be perfectly clear to you that *inductance is the result of self-induction in the turns of a coil and mutual induction between adjacent turns.* Then, too, inductance is, strictly speaking, the property of coils, not the coil itself, although Radio engineers and Radio-Tricians often speak of a coil as an "inductance." While this is not really correct, it is convenient and is often heard, and seen for that matter, even in text-books.

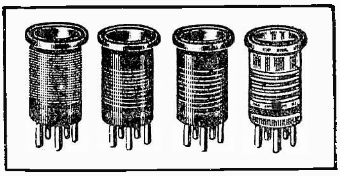
In Figs. 13 to 16 are pictured various types of coils used in Radio. The captions explain their construction and use.

Enough pictures of coils have been shown to give you an idea of the many different forms they may take. The design of a coil depends primarily on how much inductance it is to

Fig. 15—Two typical transformers used in the intermediate frequency amplifier section of modern all-wave superheterodyne receivers. The tuning condensers are directly above the two criss-cross primary and secondary coils. A shows a single coil primary and secondary; B shows triple coil primary and secondary. All three coils in each coil section are in series. The spaced coil method reduces coil capacity and results in a more efficient transformer.



have and how much current its windings are to carry. There are other secondary factors that enter into coil design, but consideration of them must be kept for later.



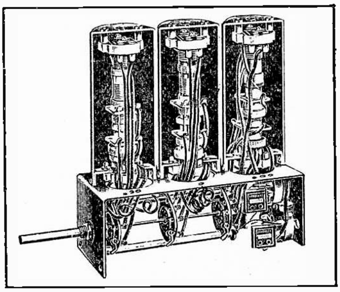


Fig. 16—Above are shown modern plug-in coils used in all-wave receivers, when the receiver is to be used on different radio bands. Each section requires a plug-in coil for each band of frequencies. If two tuning circuits are involved, and tuning in four frequency bands is wanted, eight plug-in coils are required. To the right is a modern all-wave coil switching system used in modern all-wave superheterodyne receivers. All the coils in a definite section are enclosed in a metal shield (three sections are shown) and the coils for each band of frequencies are switched in the circuit by the multiple point switch shown under the coils, controlled by the so-called "band selector knob." Special adjusting (or trimmer) condensers are included in this coil unit.

Figures 13 to 16 Courtesy of General Mfg. Co., Chicago, Ill.

Coils may be used together, either connected in series or in parallel. If connected in series, their inductances *add* just as the resistances of two resistors in series add. Suppose we have three coils in series—the total inductance will be $L_1 + L_2 + L_3$, provided that there is no magnetic interaction (mutual induction) between coils. If there is mutual induction between coils, the total inductance will be greater or smaller. The total inductance of coils in parallel must be calculated in the same manner as resistance for resistors in parallel. The total inductance L, if L_1, L_2, and L_3 are in parallel, will be found from the formula:

$$\frac{1}{L} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3}$$

At this point it is necessary to digress for a moment from the subject of inductance. You may have realized before this that a coil cannot be built to have only inductance. No matter what we do, every coil we build will have a certain amount of

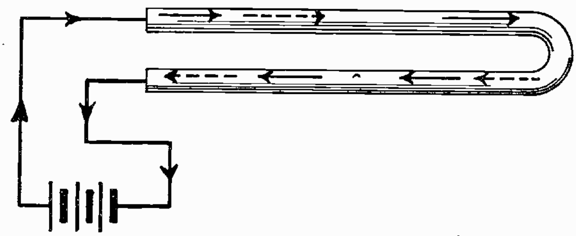


Fig. 17

resistance. We can't get away from the fact that wire has resistance, whether it is straight or coiled. Conversely, every winding has inductance, even though it is intended as a resistance. In wire-wound resistors this inductance must be kept as low as possible, otherwise it will add to the inductance in its circuit and upset the balance of the circuit. For this reason some form of non-inductive winding is often used.

Figure 17 will help to make clear the principle underlying non-inductive winding. If a wire is turned back on itself as shown, the magnetic fields of individual turns will be in opposite directions to each other. Consequently, the magnetic effect of the current flowing in one direction neutralizes that of the same current flowing in the opposite direction, and the coil is said to be non-inductive while an ordinary-wound coil is almost entirely inductive.

See Fig. 18 for a practical application of a non-inductive arrangement of wires—filament feed wires in A.C. receivers are arranged in this manner so there won't be any inductive effects between them and other circuits. The chief purpose is to keep A.C. hum signal from getting into the signal carrying circuits of the receiver.

Referring to Fig. 18, if conductor *AB* were by itself, its field would induce a voltage in conductor *EF*. Likewise if conductor *CD* were by itself, its field would induce a voltage in conductor *EF*. But with *AB* and *CD* twisted as shown, their fields are equal and opposite. Thus the fields cancel and no voltage is induced in *EF* by them.

Of course, there is still the very small e.m.f. of self-induction in each conductor opposing the starting and stopping of current, but this can't be helped, any more than we can make wire without resistance.

THE UNITS OF INDUCTANCE

Whenever a coil is made, a certain *amount* of inductance is built into it. The fact that we talk about the amount of inductance, shows that it is quantitative, that is, it can be measured, and the amount of inductance expressed numerically. You remember that resistance is measured in ohms—and the ohm is the unit of resistance. Inductance is measured in henries—the unit of inductance is the *henry*, so called after Joseph Henry, an American scientist.

Now you want to know just how much inductance one henry is. When a voltage is applied to a coil, the inductance of the coil attempts to keep the current from flowing, that is, there is a self-induced e.m.f. which opposes the applied e.m.f. (for this reason it is often called a back e.m.f. or counter-e.m.f.). The greater the back e.m.f. the more difficult will it be for the current to change as the applied voltage changes. If the current increases or decreases at the rate of one ampere per second and the back e.m.f. is one volt, the coil has an inductance of one henry.

Notice that the current must be changing, otherwise the flux would be stationary and there could be no induced voltage. This change of current could be from 5 amperes to 4 amperes, from 22 to 21 amperes—anything, just so the change would be at the rate of 1 ampere per second of time. It could even be a very small change in current, as for example, a change from 9 to 10 milliamperes. If the inductance is 1 henry and the back e.m.f. is one volt, it will take one-thousandth ($\frac{1}{1000}$) of a second for the current to change 1 milliampere.

The henry is quite a large unit, much too large for convenience when considering coils in radio frequency circuits, where we deal with very small voltages, currents and periods of time. Suppose the coil shown in Fig. 10, which is a typical R.F. coil, is built to have an inductance of .00025 henry—25 hundred-thousandths of a henry. It would be much more convenient to have a smaller unit for use with coils like this so that very

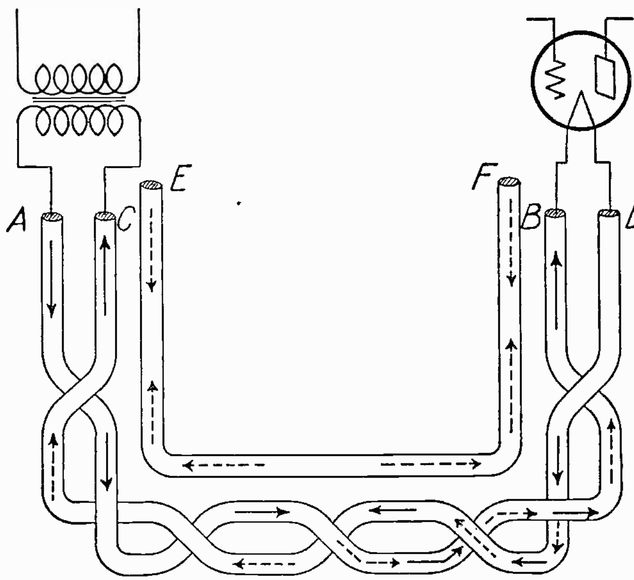


Fig. 18

small fractions would be unnecessary. So we divide a henry into a million parts, each of which is called a *microhenry*. Now what would the inductance of this coil be in microhenries? 250 microhenries, of course. And here we have a whole number which is much easier to work with than decimals of five and six places. Sometimes a henry is divided into a thousand parts each of which is a *millihenry*.

Inductances used in audio systems and in power supply systems which are of course parts of the Radio receiver, are considerably larger—some power pack inductances are as large as 50 henries. These coils are wound on iron cores to increase the inductance.

Coils are designed to have a certain amount of inductance, depending on the particular circuit in which they are to be used. We shall now go on and see what factors determine a coil's inductance.

INDUCTANCE OF R.F. COILS

In this lesson we are going to confine ourselves to a brief study of the factors which determine the amount of inductance a certain coil will have. We are not going to attempt to learn how the inductance of a coil is measured nor how a coil is designed to have a certain amount of inductance. Both of these procedures are rather complicated, requiring the use of mathematical formulas. Later on in the course you will be given the formulas for inductance that are in most common use and also coil design data. But before we can make use of information of this nature, we shall have to understand the factors which determine the amount of inductance of a coil, such as the *number*
4 *of turns*, the *diameter*, the *length*, and the *spacing* of the turns.

From what we have already learned about self-induction and mutual induction between turns of a coil, we realize that the number of turns must have considerable to do with the inductance of a coil. We can easily see that if we have two similar coils, but the second one has twice the number of turns as the first, the inductance of the second coil with the greater number of turns will be higher than the inductance of the first. But will the inductance of the second coil be twice that of the first? We must not forget that there are two effects which result in inductance—self-induction and mutual induction between turns. It is for this reason that the inductance of our second coil is going to be more than twice the inductance of the first coil. In fact, the inductance of our second coil will be approximately four times the inductance of the first coil.

In the same way, if the second coil has three times the number of turns of the first coil, the inductance of the second coil will be nine times that of the first coil. Thus, the inductance of a coil is proportional to its number of turns. However, it is not a direct proportion—the inductance is proportional to the *square* of the number of turns.

As you know, when you square a number, you multiply it by itself. Thus, 4^2 is equal to 16 and if we have two similar coils, one having four times as many turns as the other, the one with the greater number of turns would have 16 times the inductance of the other, not 4 times as would be the case if the inductance were directly proportional to the *number* of turns.

We can fix this in our minds by a simple practical example. Suppose we have a coil of ten turns, which, let us say, has an inductance of 1 microhenry. A 20-turn coil of similar shape and size would have an inductance of 4 microhenries. The second coil has twice the number of turns as the first and to determine how much greater its inductance is, we must square 2, that is multiply 2 by 2 which gives us 4.

At this point you might ask how we can double the number of turns without changing the length of the coil. This is done by using a smaller sized wire. If we use a still smaller sized wire and make a coil having 30 turns, the inductance of the coil would be 9 microhenries, because we have increased the number of turns three times and when we square 3 we get 9. In the same way a 40-turn coil would have an inductance of 16 microhenries. That is 4^2 or 4×4 times as much inductance as the 10-turn coil.

But suppose our original coil, instead of having an inductance of one microhenry, had an inductance of 6 microhenries. The 20-turn coil in this case would have an inductance of 24 microhenries (4×6), which is four times as great as that of the 10-turn coil. The inductance of a 30-turn coil would be 54 microhenries (9×6); of a 60-turn coil, 216 microhenries (36×6).

Now let us consider the diameter of the coil. We would naturally expect a coil having a larger diameter than another similar coil to have more inductance than the coil with a smaller diameter, because in a coil of larger diameter, each turn is longer and there is more self-induction and more mutual induction between turns. Then we can easily see that as the diameter is increased, the inductance will increase and here again this increase is not directly proportional because we have to consider the two effects, but varies as the square of the diameter. Thus, a coil having a diameter of 2 inches, will have 4 times the inductance of a similar coil having a diameter of only 1 inch.

We still have one more dimension to consider—the length of the coil. Now, if the statement were made that inductance varied directly with the length of the coil, would you accept it as correct? A little thought on your part would soon show that this statement cannot be true. For a given coil, having a certain number of turns and having a certain diameter, any increase in the length of the coil would necessitate greater spacing between turns. Greater spacing would mean less mutual induction between adjacent turns and would mean a reduction in the inductance of the coil. Now, we can make the general statement that as the spacing between turns of a coil is increased, the inductance of that coil decreases. This leads to the statement that as the length of the coil is increased, its inductance is decreased. But, as only mutual induction is involved and not self-induction, this decrease in inductance is directly proportional to the increase in length. The customary way of saying this is that induction is inversely proportional to the length of the coil. Then, a coil two inches long will have only half the inductance of a similar coil, one inch long. Let us say that a 300 microhenry coil is two inches long. A similar coil one inch long would have an inductance of 600 microhenries, and a similar coil four inches long would have an inductance of only 150 microhenries.

And now we have considered all the factors that affect the inductance of a coil—length, diameter and number of turns. In each case practical examples have been given so that now you should have a very clear idea of not only the meaning of inductance but also of the factors that must be considered when calculating the inductance of a coil.

Summing up all that has been said in this chapter—inductance is directly proportional to the square of the number of turns, to the square of the diameter and inversely proportional to the length of the coil.

For the sake of completeness it must be mentioned here that what has been said about the inductance of R.F. coils in this chapter applies strictly only to R.F. coils whose length is considerably greater than their diameter. For example, if we had a coil one inch long and two inches in diameter, and another coil two inches long, with the same diameter and the same number of turns, the inductance of the first may not be exactly two times that of the second. Thus, the proportionalities given are for approximation only, but they serve very well to illustrate the effects of self-induction and mutual induction between individual turns on inductance.

The rules given in the previous paragraphs are of practical value in altering coils of known inductance. For example, if you had a 100 turn coil having an inductance of 240 microhenries: you can reduce the inductance to one quarter, that is, to 60 microhenries, by reducing the turns to 50, and spreading out the 50 turns so that they would be the same length as the 100 turn coil.

INDUCTIVE REACTANCE

In most of the experiments we have shown so far with coils, we used a source of D.C. voltage. We could see the effect of inductance in a circuit very clearly if we were to place a coil having a large amount of inductance, in series with an electric light bulb, in a 110-volt D.C. circuit, as in Fig. 19. Turning the current on we notice that the light does not glow with full brilliance instantly—the inductance of the coil momentarily hinders the flow of current. But after this momentary sluggishness, the lamp will glow with its usual brilliancy, just as though the

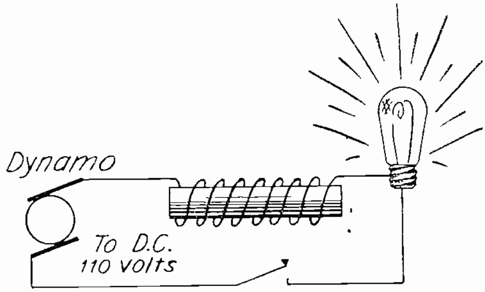


Fig. 19

inductance were not in the circuit. Upon breaking the circuit, we should notice a large spark at the switch contact, the result of the magnetic field about the coil returning its energy to the circuit in the form of a back e.m.f.

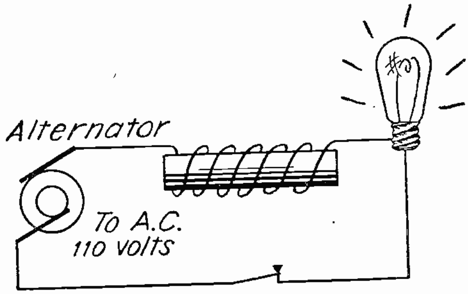


Fig. 20

Now we want to see what will happen if we place our coil in an A.C. circuit. And we are chiefly interested in this because, in Radio, the R.F. coils are used in Radio frequency circuits, which are of course A.C. circuits. We change the circuit shown in Fig. 19 merely by changing the source of e.m.f.—we connect our coil and lamp to an A.C. source. See Fig. 20. Turning on the current, we find that the light is very dim, much dimmer than it would be without the inductance in the circuit. From this we can gather that the current is not flowing through the coil readily and that the inductance is affecting the current flow.

During the first period, the first half cycle, of the alternating current flow, the action of the inductance is exactly the same as when direct current is made to start and stop in an inductive circuit. Even after the applied voltage has swung to zero, current continues to flow in the same direction as the original current, according to Lenz's law. This current is the result of the voltage induced by the collapsing magnetic field about the coil. Now we are interested in knowing what happens during the second period, the second half cycle, when the alternating current flow reverses its direction.

It isn't at all difficult to realize that the e.m.f. of the second period will be opposed by the induced e.m.f. of the previous period. And so with every following period—each will be opposed by the induced e.m.f. of the previous period. Therefore we say that the induced e.m.f. reacts (acts back) on the original e.m.f. This reaction hinders the flow of current. And the greater the inductance, the greater will be the reaction.

Inductance therefore reacts on the A.C. current flowing through a coil in such a way that the current is decreased. And this property of inductance is called *inductive reactance.** 9

Now the question uppermost in your mind is: "What is the difference between reactance and resistance, as both limit current flow?" There is one important difference that we can mention here—others we must keep until later. You remember that when a resistance is used to cut down current flow, a certain amount of energy is lost in heat. But no energy is lost in the magnetic field of a coil—energy is merely stored in the coil's magnetic field and when the field is caused to become smaller or collapse, this energy is returned to the circuit. Of course it must be remembered that this applies only to A.C. circuits—for limiting direct current flow, resistance is the only means at our disposal.

Coming back to inductive reactance, it is obvious that the greater the inductance, the greater will be the inductive react-

*An important fact to remember for future studies in radio is the effect that a coil has on a pulsating current. The inductance will only effect the A.C. portion of the pulsating current, that is, reduce its value. Only the D.C. resistance of the coil will reduce the D.C. component of the pulsating current.

ance. But A.C. current has frequency, as you well know. If the frequency is low, say 60 cycles per second, the inductive reactance will be small, because the flux will expand and collapse slowly thus inducing only a small back e.m.f. in the coil turns. If, however, the frequency is increased, the flux will have to move faster, and cutting the turns in the coil faster, will induce in them a correspondingly larger e.m.f. Thus inductive reactance is proportional to the frequency. In other words if the frequency is increased the reactance increases.

THE EFFECT OF INDUCTANCE ON PHASE

In the previous lesson you were introduced to the subject of "phase." It was brought out then that the voltage and current in a circuit could be "in phase" in which case current reaches maximum at the same time voltage reaches maximum. In some circuits, current will lead voltage, in others, current will lag behind voltage. From what you know about the effects of inductance in a circuit it won't be difficult to figure out the

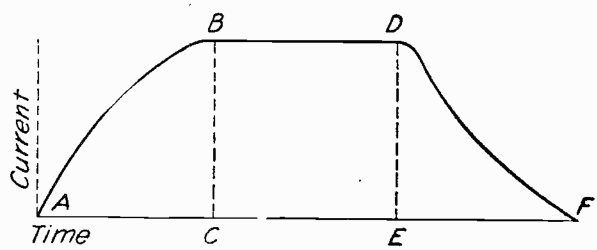


Fig. 21

phase relations between voltage and current in an inductive circuit. We can go back to our D.C. experiment, the one shown in Fig. 19. You'll remember that when we turned on the current, the lamp did not glow normally immediately—there was a period of time during which the current was building up to maximum. But the instant we closed the circuit, the voltage was maximum. Therefore it is obvious that current lags behind voltage in inductive circuits.

Figure 21 illustrates this effect very nicely. The rise in current (*AB*) requires a definite period (*AC*). If it were not for the opposing voltage, the induced back e.m.f., the current would rise immediately to its maximum value and line *AB* would be a straight vertical line rather than a sloping curve.

The curve to the right of Fig. 21 (*DF*) shows how the inductance affects current when the source of e.m.f. is removed. Notice that it is just the reverse of the starting current curve, showing that when the source of e.m.f. is shorted out of the circuit, the current tends to keep on flowing for the same length of time it took the current to build up to maximum at the start.

Another way of describing this effect of inductance on phase, is to say that voltage is made to lead current. We can follow through several cycles of alternating current in an inductive circuit, and then we can see the two effects that an induc-

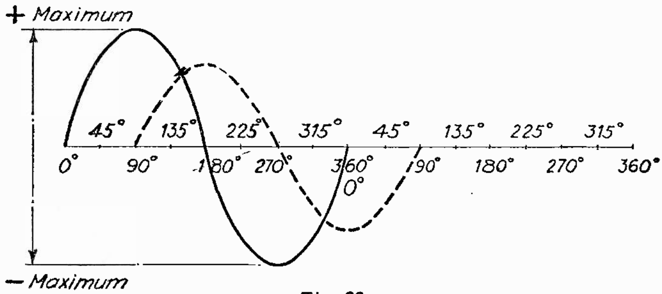


Fig. 22

tance will have in an A.C. circuit. First it reduces the value of the current due to the inductance and resistance of the coil and secondly it will cause the current to lag behind the voltage, or what is the same thing, it makes the voltage lead the current.

The instant current starts flowing through the coil, a voltage is induced in the coil opposing the flow of current, tending

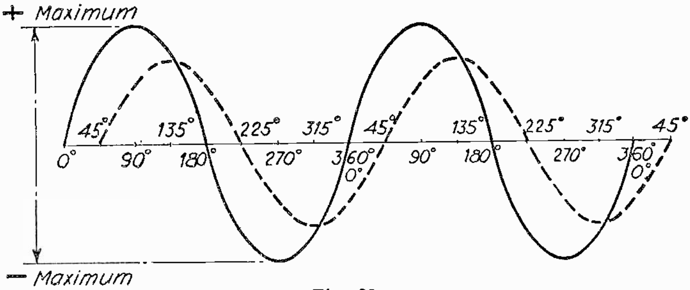


Fig. 23

to hold it back. Because of this induced voltage, the current reaches maximum after the applied voltage reaches maximum. And the applied voltage is zero before the current reaches zero. The same is true for each succeeding cycle.

In an inductive circuit, the current lags behind the voltage by almost a quarter of a cycle. For convenience, a cycle is divided into 360 equal periods, each of which is called a degree. In other words, we consider a cycle as a circle. A quarter of a cycle will be 90° (ninety degrees). Therefore in a purely inductive circuit (no resistance), the voltage and current are 90° out of phase—current is 90° behind the voltage. This is brought out clearly by the dotted current curve in Fig. 22.

The effect of resistance in an inductive circuit is to decrease the angle of lag. The curve shown in Fig. 22 is really an ideal curve, impossible in practice because we cannot have a circuit or a coil without resistance.

Figure 23 shows current lagging behind voltage by 45°, due to the resistance in the circuit. Bear in mind that the lag may be any angle between 0 and 90 degrees depending on the resistance in the circuit, that is, the resistance value of the coil and any other resistance in series with the coil.

In a circuit containing only resistance there would be no phase difference and the curve would appear as in Fig. 24.

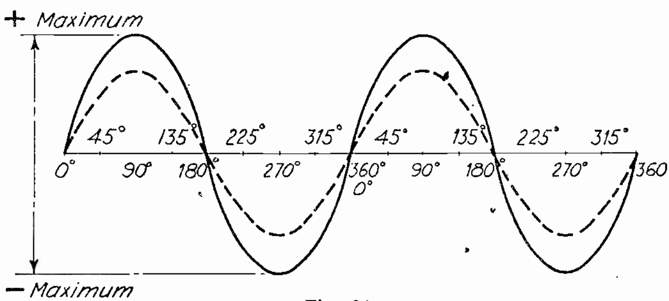


Fig. 24

INDUCTANCE IN THE RADIO RECEIVER

The uses of inductance in a Radio Receiver are many as a glance at the complete circuit diagram of a modern set in Fig. 25 will convince you. This diagram is used here only to make you realize the importance of a thorough knowledge of the subjects taken up in this lesson.

The complete circuit diagram may seem at this time a little complicated to you, but don't let this worry you, as you will find, just as other students do, that you will gradually get to understand schematic diagrams much better as you progress with your lessons. Before we close this lesson let us start right at the antenna and go through the circuit, examining each inductance so we can become acquainted with the various uses of inductance coils in Radio Receivers.

The first inductance we see is marked by the Fig. (2) in a circle. Notice that there are two coils. They make up what is known as an R.F. transformer which is nothing more than a means of getting energy to pass from one circuit to another by mutual induction, the phenomenon you have gotten to know so well in this lesson. But in this case we have mutual induction between coils instead of between conductors. And about mutual induction between coils you will learn much more in a later lesson.

Although R.F. transformers are shown in the diagram separated into two parts, both windings of most R.F. transformers are placed on the same form which is cardboard or bakelite tubing.

The coil or winding shown to the right has a second function—it supplies inductance for the first tuning circuit. Tuning circuits will also be taken up in detail in later lessons.

The inductance marked (5) is the second R.F. coil. In this case the two windings are connected in series. The lower half of the winding is connected directly to the first tuned circuit so that it also provides part of the total inductance of the circuit. The upper half of (5) supplies the inductance for the second tuned circuit which is made up of this inductance and the variable condenser (3) to the right of it.

You will recognize (8) as another R.F. transformer, the third, which is very much like the first R.F. transformer. The winding on the left is the "primary" winding and the winding to the right is the "secondary" winding. The secondary winding in this case provides the inductance for the third tuned circuit.

At (12) we have still another R.F. transformer. However, in this case neither of the windings is in a tuned circuit.

After leaving (12) we do not see our symbol for inductance, which by this time we are very familiar with, until we reach No. (22). And here we have something new—notice the three lines drawn between the symbols for the windings. These lines mean that the windings are placed on an iron core. Why should an iron core be used here and not at (2) or in any of the radio frequency transformers? Notice that the preceding tube is a '27 tube which in this case is used as the first audio frequency tube. Very early in the course we learned that the stages preceding the detector tube handled high radio frequency currents and that stages past the detector tube stage handled audio frequency currents. In A.F. circuits where lower frequencies are dealt with, larger values of inductance must be used and as winding a coil on an iron core increases the inductance considerably, iron core coils are always used in A.F. circuits. The effect of

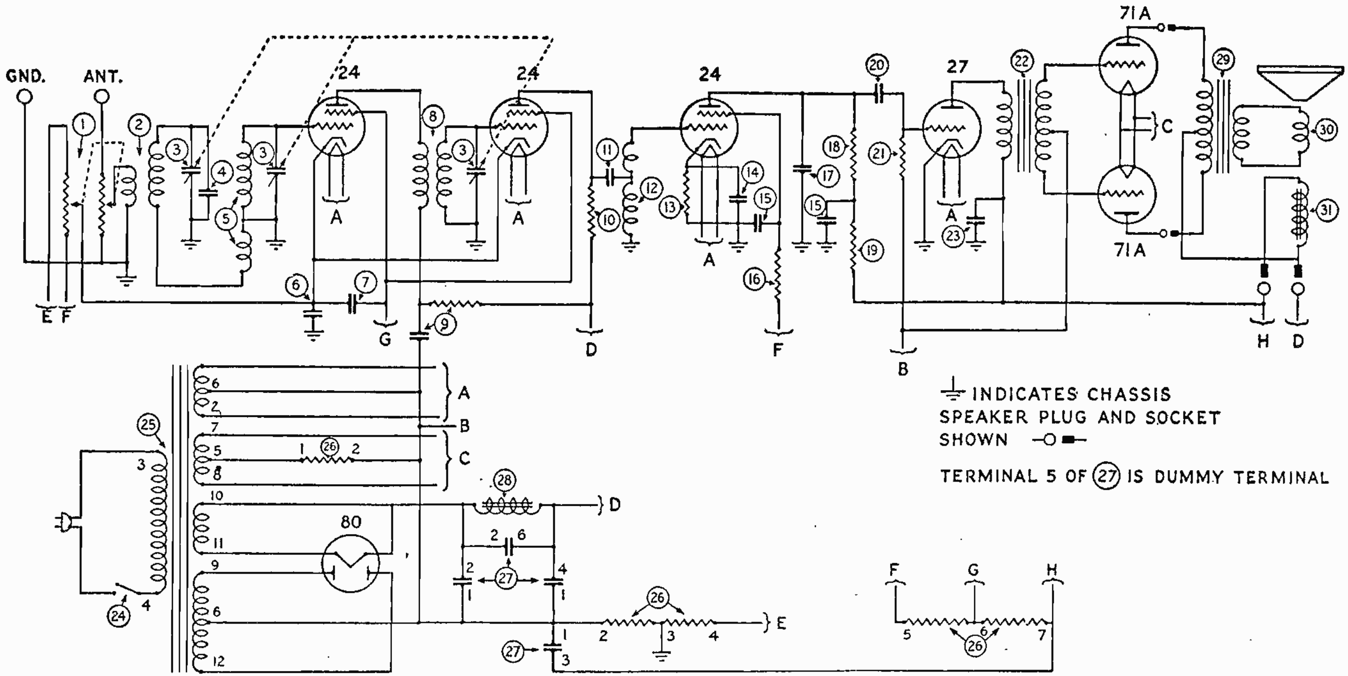


Fig. 25—Circuit Diagram of a Typical Broadcast Receiver with Its Power Supply Circuits.

an iron core is to provide a better path for the flux—for magnetic lines of force travel through iron with much greater ease than through air.

This brief description of an audio frequency transformer is merely to act as an introduction to the subject. We shall study these, too, in great detail later in the course.

The transformer at (29) is another A.F. transformer. The small inductance shown at (30) is the voice coil of the loud-speaker. The coil at (31), shown as a single winding over an iron core, is a filter coil. The purpose of filter coils is to smooth out pulsating current into almost perfect direct current. Pulsating current is direct current which varies periodically in strength and thus is equivalent to a pure direct current with an alternating current mixed with it. Our inductance will have very little effect on the direct current part of this pulsating current, but the A.C. variations will cause flux to build up and collapse about the windings of the coil periodically.

Let us consider the rising cycle of pulsating current—that is, consider the current at the time when the A.C. component is building up to maximum in one direction. The increase in current causes a field to be built up about the windings but as the flux builds up it induces a back e.m.f. in the windings, reacting on the original current in such a way as to hold it back slightly, just about to the extent of the surge. Then the A.C. component (part) returns to zero and begins to reverse in direction. What happens to the field? It collapses, inducing in the winding a voltage in the original direction, then the flux builds up in the opposite direction continuing current flow in the same direction. Thus in this coil, the rises above the level of the direct current are cut off, and the depressions, that is, the decreases in current flow, are filled in. We can say that this is taking out the A.C. component which if allowed to go through the speaker windings would result in a loud 60-cycle hum.

The inductance at (28) is another filter coil, used to filter out 60-cycle hum.

The large transformer at (25) with the multiple winding, is the power supply transformer. The various secondary windings are for various voltages.

This is about as far as we can go in this brief description of inductances used in a modern Radio Receiver. You will find that we go fully into detail on receiving sets and power packs in advanced text-books.

TEST QUESTIONS

Be sure to number your Answer Sheet 6 FR-1.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and the best possible lesson service.

1. What happens to the lines of force around a conductor when the current in the circuit varies?

2. Do the lines of force around a conductor reverse when the current reverses its direction?

3. What does Lenz's law state?

4. How can a voltage be induced into a circuit from another in which there is a varying current flowing, even though there is no direct connection between them?

5. Why is inductance in an electrical circuit comparable to mechanical inertia?

6. What is the unit of measurement of inductance?

7. Suppose you had a coil of wire and you spaced its turns farther apart. What effect would you expect this to have on the inductance of the coil?

8. What factors determine the amount of inductance a coil will have?

9. What *two* effects does an inductance have upon an alternating current?

10. Name several uses to which inductance coils are put in a radio receiver.

10 CIRCUIT DIAGRAMS EACH WITH TESTING INFORMATION

19 SS

SERVICE MANUAL

PIONEER HOME STUDY RADIO SCHOOL

NRI

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

FOREWORD

This booklet is one of a series of service manuals which contain service sheets giving typical information on radio receivers. Each service sheet shows the circuit diagram in the usual symbolic form for that radio receiver. Many of the service sheets will contain such special service information as space will permit.

By studying each service sheet, you will gradually develop the ability to read any diagram or manufacturer's service manual and learn the usual methods of set adjustment. Enough typical receivers have been selected to give you quickly a good insight to the entire radio problem.

In reading a circuit diagram, learn to trace independently the power supply and the signal circuits. Then locate the special control circuits, such as the automatic volume controls, tuning indicators, manual volume controls, etc. Detailed information on power, supply, signal and control circuits, as well as set servicing, is given in the course, to which reference should be made.

J. E. SMITH.

WPC4M5536

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RADIO-TRICIAN

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Service Sheet

Compiled Solely for Students and Graduates

NATIONAL RADIO INSTITUTE, WASHINGTON, D. C.

MAJESTIC MODEL 15 AND 15B CHASSIS ELLSWOOD, SHERWOOD AND FYFEWOOD MODELS

Alignment

In checking the alignment of Model 15 (and also the 25) chassis the intermediate frequency transformers should not be aligned unless there is a definite reason to believe that they are out of alignment. The alignment of these transformers at the factory is more or less permanent and should not need further adjustment except in rare cases. In all alignment procedure an output meter must be used.

R. F. and Oscillator Alignment

Tune in station in the vicinity of 1500 kilocycles, or put output of local oscillator (if available) into receiver. Align R. F. stage, and oscillator tuning condenser. The R. F. stage and oscillator aligning condensers are on the gang condenser.

Oscillator Tracking Condenser Alignment

Tune in local oscillator to 600 kilocycles.

Adjust both tuning control and tracking condenser simultaneously to give maximum signal as noted on output meter. This will be obtained by rocking tuning control across resonance point while adjusting tracking condenser to give maximum output at the point of resonance. This operation cannot be performed without local oscillator and output meter.

Method of Biasing

The necessary bias is obtained on the first detector and oscillator stage through a 10,000 ohm resistor between cathode and ground. The intermediate frequency amplifier is biased through the volume control and a balance resistor of 264 ohms which is contained in the volume control. The second detector is biased through a 40,000 ohm resistor to ground in the cathode circuit.

Volume Control System

Control of volume is obtained in the Model 15 chassis by a 11,500 ohm control which controls the bias of the oscillator, first detector and I. F. amplifier stages. This control is so arranged in the circuit that in addition to controlling the bias of these two tubes, it also controls the input voltage to the pre-selector stage.

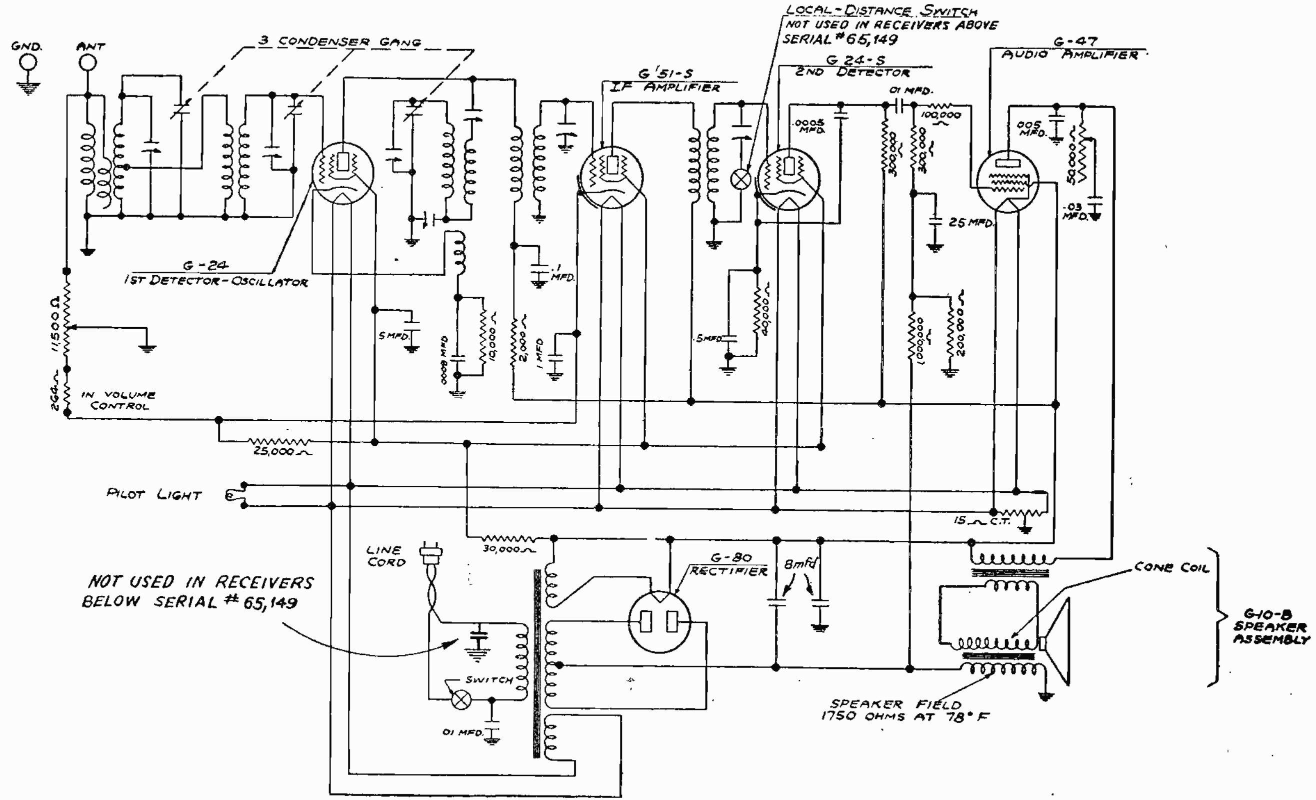
MODEL 15 CHASSIS
Table of Voltages to Ground

Tube		Fil. Volts A. C.	Plate Volts D. C.	Grid Volts D. C.	Cathode Volts D. C.	Plate Current M A.— D. C.	Screen Volts D. C.
Purpose	Type						
1st Det.—Osc.	G-24	2.5	250	——	9	0.9	90
I. F. Amplifier	G-51-S	2.5	250	——	30**	7.0	90
2nd Detector	G-24-S	2.5	250	——	9	0.17	90
Power and Amplifier	G-47	2.5	250	—16.5*	—	32	250
Rectifier	G-80	5.0	—	——	—	54	—

*This cannot be measured with the customary 1000 ohm per volt meter because of the high resistance between the grid and ground. If there is any doubt about the pentode bias, check the 100,000 ohm, 1 megohm, 200,000 and 300,000 ohm resistors and .25 M F.D. Condenser in this circuit and be sure the speaker field voltage is correct, 112 volts. Also measure the pentode plate and screen voltages and if they are 250 volts, the plate current should be 32 M.A.

**This should rise to 42 when the volume control is turned to minimum.

SCHEMATIC DIAGRAM OF MAJESTIC SCREEN GRID SUPERHETERODYNE RECEIVER
MODEL 15 CHASSIS 115 AND 230 VOLTS, 25-50 AND 50-60 CYCLES.
POWER REQD.—60 WATTS



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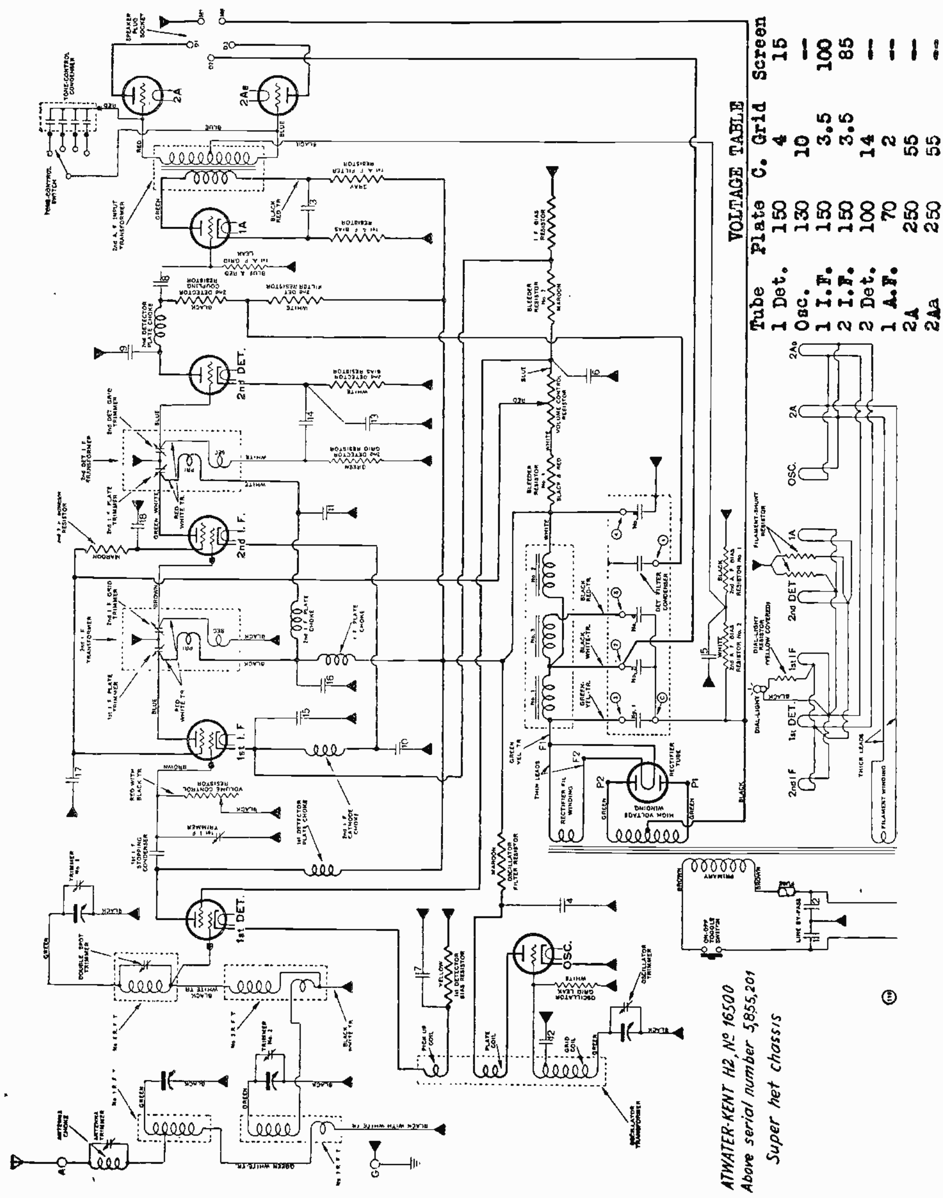
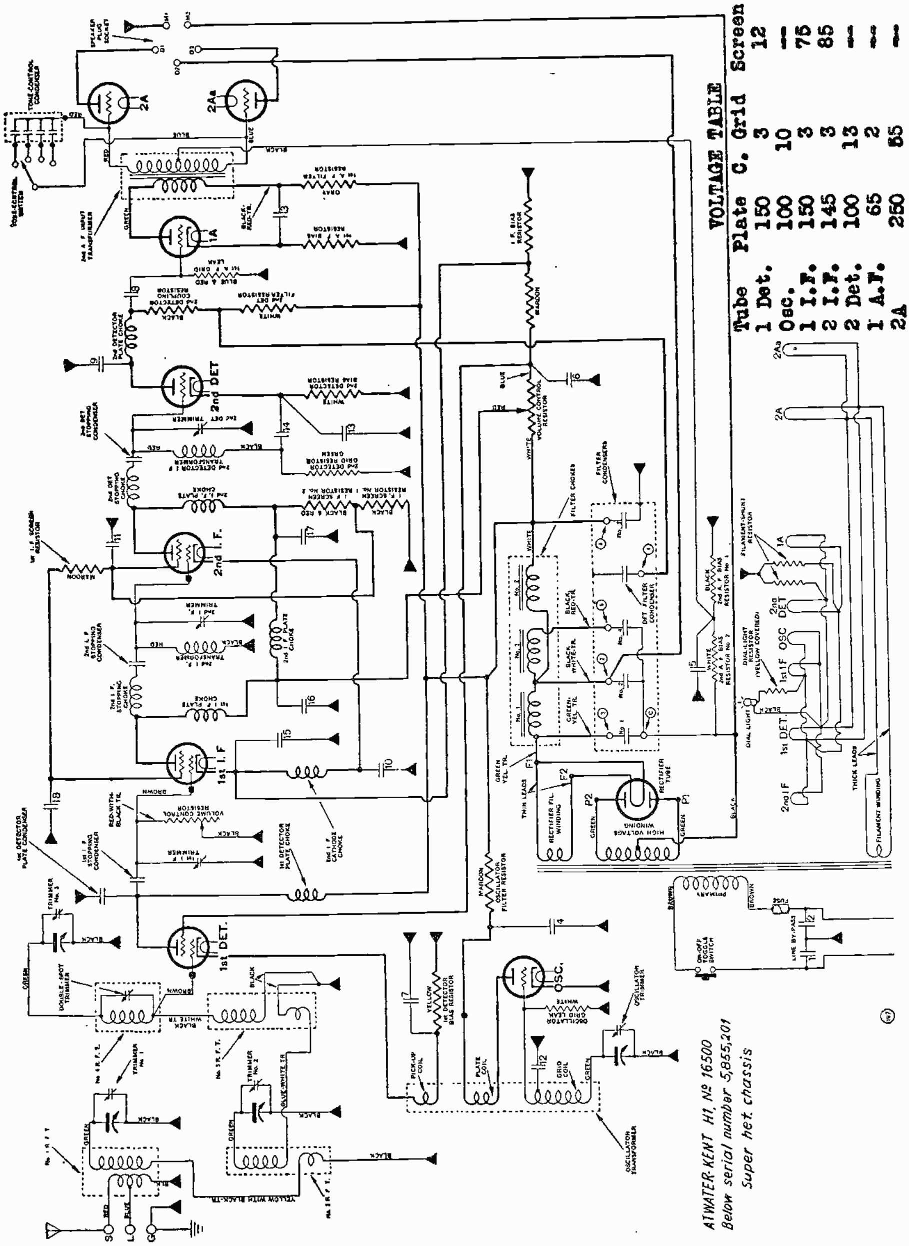
Atwater-Kent Superheterodyne Receivers, Type H Chassis



VOLTAGE TABLE

Tube	Plate	C. Grid	Screen
1 Det.	150	4	15
Osc.	130	10	—
1 I.F.	150	3.5	100
2 I.F.	150	3.5	85
2 Det.	100	14	—
1 A.F.	70	2	—
2A	250	55	—
2Aa	250	55	—

Atwater-Kent Superheterodyne Receivers, Type H Chassis



VOLTAGE TABLE

Tube	Plate	C. Grid	Screen
1 Det.	150	3	12
Osc.	100	10	—
1 I.F.	150	3	75
2 I.F.	145	3	85
2 Det.	100	13	—
1 A.F.	65	2	—
2A	250	55	—
2Aa	250	55	—

ATWATER-KENT H1, № 16500
Below serial number 5,855,201
Super het. chassis

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GRAYBAR 700, GENERAL ELECTRIC 31, RADIOLA 80 AND WESTINGHOUSE WR5 SUPERHETERODYNE RECEIVERS

The circuit used in these receivers is the screen grid superheterodyne type employing four —24, two —27 and two —45 type tubes. The antenna is coupled to a tuned link circuit by means of a high inductance concentrated coil connected from antenna to ground. The tuned circuit consists of a coil and condenser which tunes exactly with the tuned R.F. and first detector. The purpose of this circuit is to eliminate any cross-modulation from stations to which the set is not tuned, or heterodyne whistles as far as possible, and to improve the selectivity of the receiver. There is no amplification gained in this circuit, it being merely a selection circuit.

The schematic diagram shown on the next page illustrates the various circuits and will be valuable in repairing these sets. Special attention is called to the fact that the exact resistance and capacity of the different parts is given on the diagram which will enable the Radio-Trician to successfully test each individual circuit and determine whether or not the circuit is in good condition. The voltage table on this page gives the approximate voltages that should be obtained when testing the receiver with a set analyzer.

Noisy Volume Control

Noisy operation of the volume control is usually caused by dirt between the resistance element and the contact arm. Turning the volume control back and forth several times will usually clear the trouble. If it does not, however, the use of a pipe cleaner and one of the various cigarette lighter fluids, using the pipe cleaner to apply the fluid to the resistance element will usually clear up the trouble. If neither of these remedies clears the trouble, the volume control must be replaced.

Oscillation

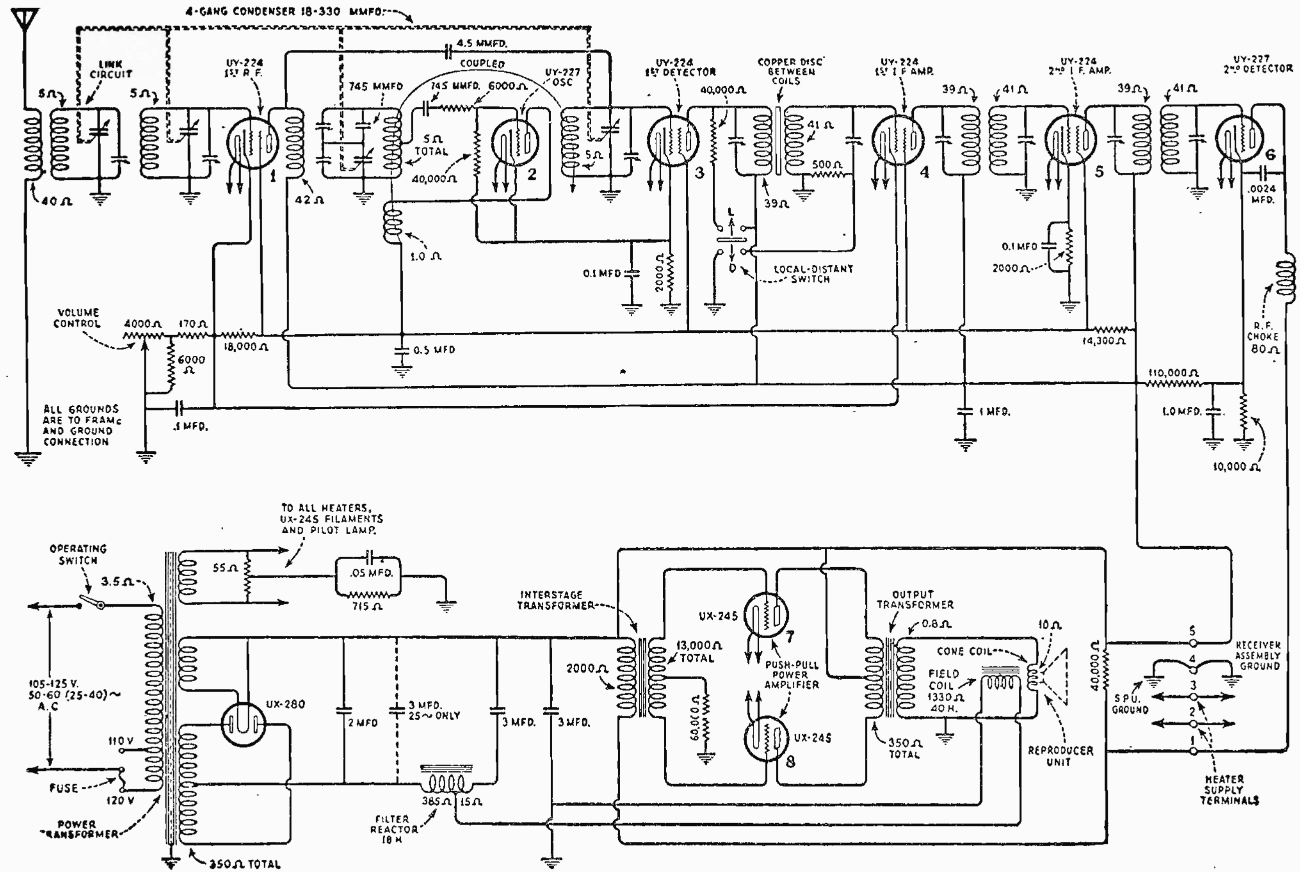
Oscillation in the R. F. or I. F. stages may be due to:

(a) Failure of shielding of —24 tubes or their control grid leads not in place. Make sure all shielding and leads are as originally intended.
(b) Open by-pass condensers in receiver assembly.
(c) Lead from by-pass condenser not properly connected. A separate lead is brought out of the by-pass condenser case for the ground connection to the condenser that is connected to R. F. and I. F. plate voltage supply leads. While the condenser is still electrically in the circuit, if this lead is not connected, oscillation in the intermediate stages will result.
(d) Defective —24 tube. A defective —24 tube may cause oscillation and should be replaced by a tube known to be in good operating condition.

If unusual trouble is encountered the Radio-Trician should obtain a complete Service Manual from his nearest distributor.

APPROXIMATE VOLTAGE READINGS AT SOCKETS

Tube	Cathode to Heater Volts D. C.	Cathode or Filament to Control Grid Volts, D.C.	Cathode to Screen Grid Volts, D.C.	Cathode or Filament to plate Volts, D.C.	Plate Current M. A.	Heater or Filament Volts	Screen Grid Current M. A.
		Volume Control at Maximum					
UY-224 1st R.F.	—34	—2.2	80	240	3.2	2.2	.5
UY-227 Oscillator	—22	—	—	60	6.5	2.2	—
UY-224 1st Det.	—25	—9.5	72	230	0.25	2.2	.1
UY-224 1st I. F. Amp.	—34	—2.2	78	240	4.0	2.2	.5
UY-224 2nd I. F. Amp.	—31.5	—4.2	78	240	1.6	2.2	.5
UY-227 2nd Det.	—12	—22	—	212	0.25	2.2	—
UX-245 A. F. Amp.	—	—19	—	200	25.0	2.2	—
UX-245 A. F. Amp.	—	—19	—	200	25.0	2.2	—



Graybar 700; General Electric 31; Radiola 80; Westinghouse WR5

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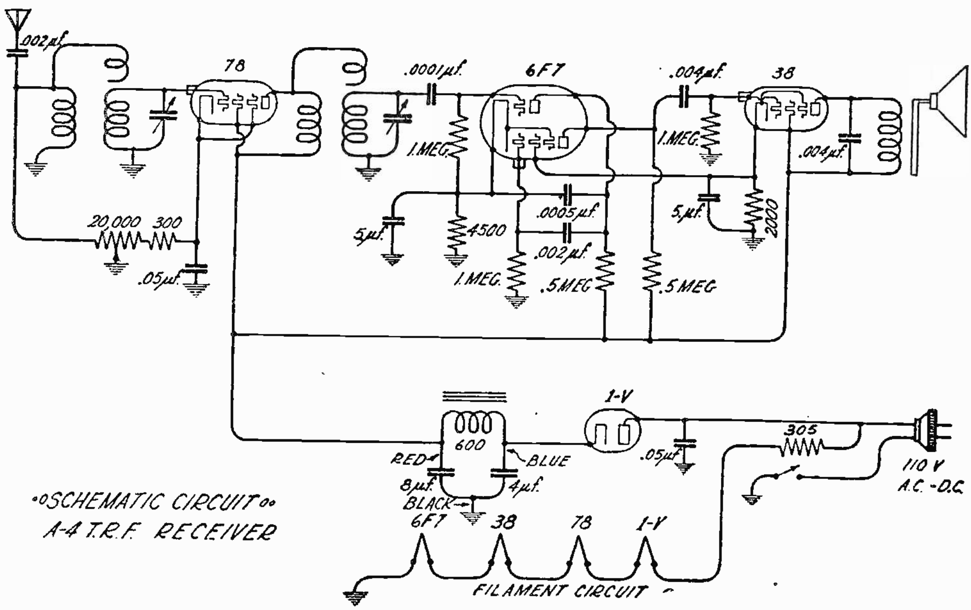
EMERSON "MICKEY MOUSE" UNIVERSAL FOUR-TUBE RADIO RECEIVER MODELS 409-410-411-414

The Emerson "Mickey Mouse" Radio is a Universal Compact All-Electric Receiver specially designed to operate on direct current or alternating current, 105-130 volts. It may also be used on 200 volts by attaching the extra ballast resistor.



SCHEMATIC CIRCUIT
A-4 T.R.F. RECEIVER

TUBES

The tubes employed are as follows: 1—78 R. F. Pentode as first Radio frequency amplifier; 1—6F7 Triode-Pentode as detector and first audio amplifier; 1—38 Power Pentode as output-power tube; 1—1V Rectifier as rectifier.

VOLTAGE READING

All readings were made with a voltmeter having a resistance of 1,000 ohms per volt, and are subject to slight variations. Line voltage, 115 A. C.

	300 Volts Plate	300 Volts Screen	30 Volts Cathode	30 Volts Suppressor
78	105	105	2.5	2.5
6F7 Triode	15	...	1.5	..
6F7 Pentode	35	11	1.5	..
38	103	105	11.	..

All above voltages measured to chassis.

EMERSON MODEL L-AC-4 AND SL

The L-AC-4 is a four-tube receiver, employing the following tubes:

1 type 58 Pentode R. F. Amplifier Tube
1 type 57 Pentode Detector Tube
1 type 47 Pentode Power Tube
1 type Rectifier Tube

The set is designed to operate on from 110 to 120 volt, 60 cycle A. C., and to cover the regular broadcast band of 200 to 500 meters.

DO NOT CONNECT TO DIRECT CURRENT (D. C.).

VOLTAGE READINGS

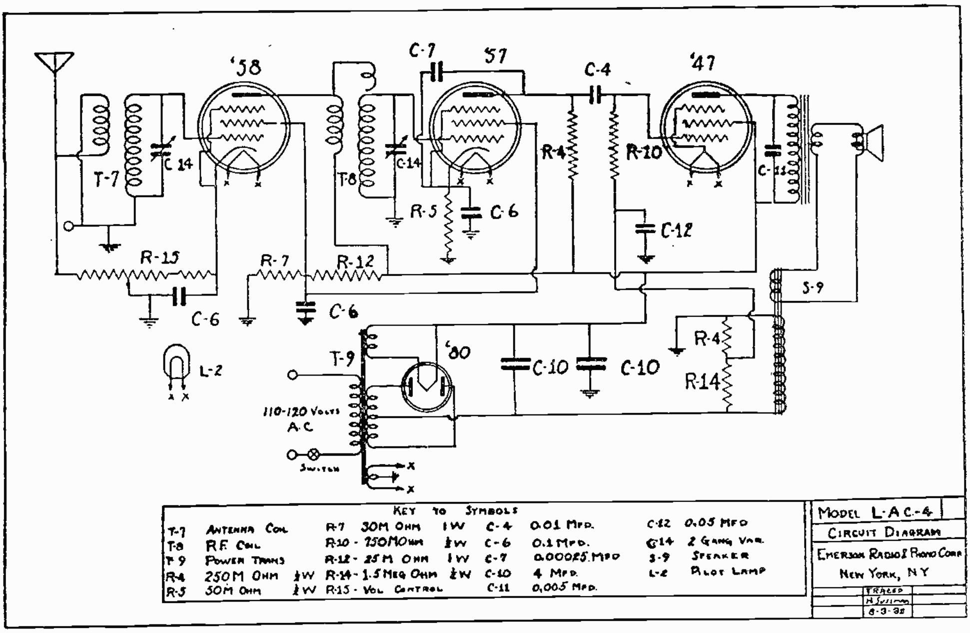
Readings should be taken with volume control all the way on and tuning control set for high wave length stations. Use a 250-volt D. C. meter having a resistance of 1,000 ohms per volt.

	Plate	Screen	Cathode
47 Tube—ground to	215	237	none
57 Tube—ground to	115	92	4.5
58 Tube—ground to	237	92	2

Line voltage, 119

The bias on the pentode cannot be read on the voltmeter.

These readings are approximate and will vary slightly with sets, tubes, etc.



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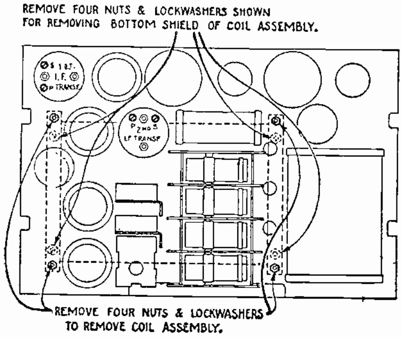
RCA-VICTOR MODELS 140, 141, 141-E AND 240; GENERAL ELECTRIC K-80, K-80X, K-85; WESTINGHOUSE WR-30, WR-31; CANADIAN RCA-VICTOR 140; CANADIAN G. E. K-80, K-85; CANADIAN WESTINGHOUSE W83AW.

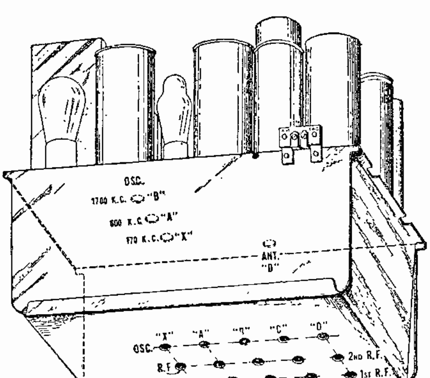
LINE-UP CAPACITOR ADJUSTMENTS

This receiver is aligned in a similar manner to that of a standard broadcast band receiver. That is, the three main tuning capacitors are aligned by means of three trimmers in each band and, on the three lowest frequency bands, a series trimmer is adjusted for aligning the oscillator circuit. The other two bands do not require this low-frequency trimmer, it being fixed in value. In the case of band D, it is necessary to adjust four trimmers, due to the additional R. F. stage used.

The chart on the right gives the details of all line-up adjustments. The receiver should be lined up in the order of the adjustments given on the chart. Refer to the diagrams below for the location of the line-up capacitors.



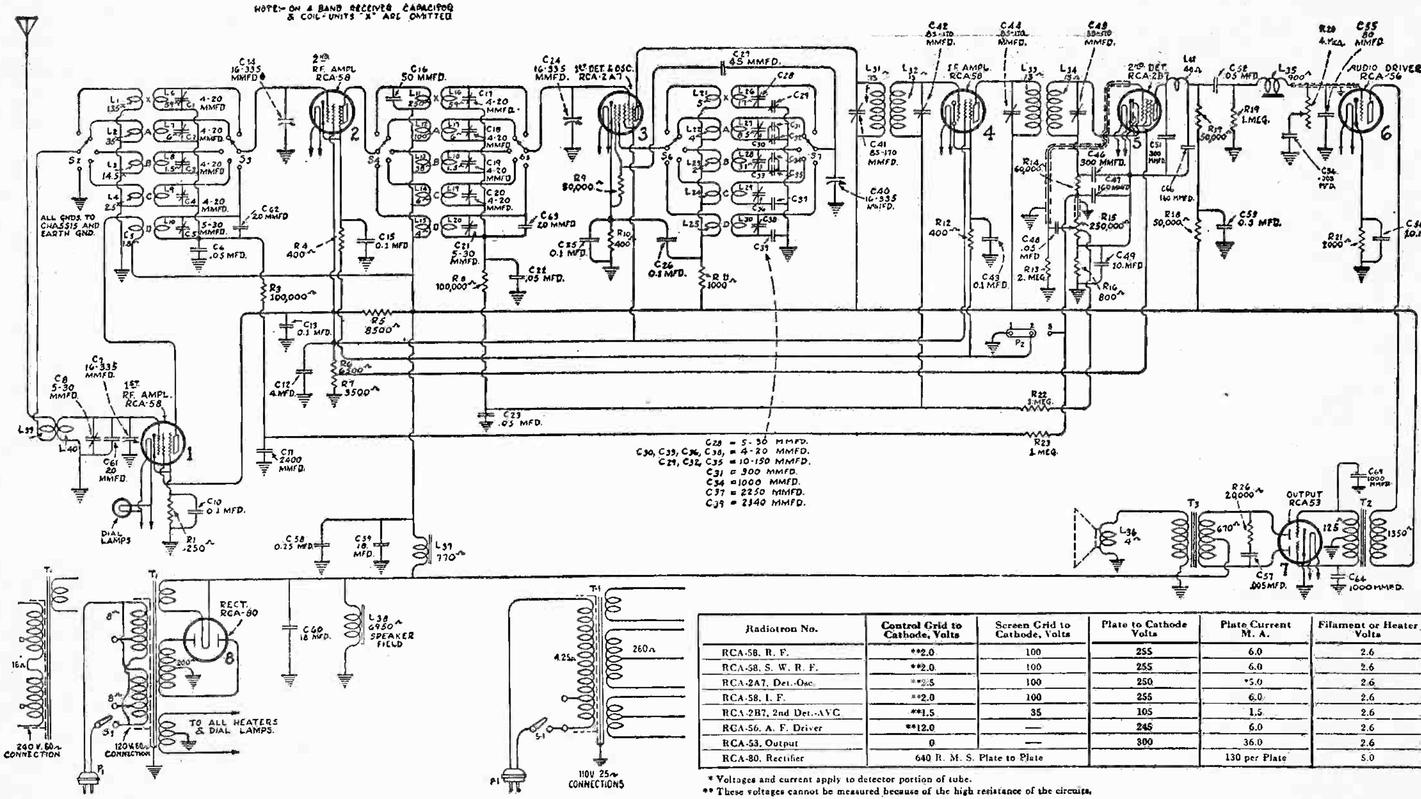
Location of nuts and lockwashers holding



Location of line-up capacities

External Oscillator Frequency	Dial Setting	Location of Line-Up Capacitors	Position of Selector Switch	Adjust for	Number of Adjustments To be Made
445 K. C.	Any setting that does not bring in station.	At rear of chassis.	Any position that does not bring in station.	Maximum output.	4
370 K. C.	370 K. C.	Bottom of chassis.	X	Maximum output.	3
175 K. C.	Set for signal.	Top of chassis.	X	Maximum output while rocking dial back and forth.	1
1400 K. C.	1400 K. C.	Bottom of chassis.	A	Maximum output.	3
600 K. C.	Set for signal.	Top of chassis.	A	Maximum output while rocking dial back and forth.	1
3900 K. C.	3900 K. C.	Bottom of chassis.	B	Maximum output.	3
1710 K. C.	Set for signal.	Top of chassis.	B	Maximum output while rocking dial back and forth.	1
10 M. C.	10 M. C.	Bottom of chassis.	C	Maximum output. (See Note.)	3
15 or 18 M. C.	15 or 18 M. C.	Bottom and top.	D	Maximum output. (See Note.)	4

NOTE—It is important to note, when aligning bands C and D, that two peaks will be observed on the trimmers for the oscillator and for the first detector. The correct oscillator peak is the one obtained using the lower trimmer capacitance, whereas the correct detector peak is the one obtained with the greater capacitance. It is essential that the proper peak be chosen, as otherwise tracking and sensitivity will be very poor at other frequencies. When adjusting the detector trimmer, the tuning capacitor should be rocked, since there is a reaction on the oscillator tuning.



Radiotron No.	Control Grid to Cathode, Volts	Screen Grid to Cathode, Volts	Plate to Cathode Volts	Plate Current M. A.	Filament or Heater Volts
RCA-58, R. F.	**2.0	100	255	6.0	2.6
RCA-58, S. W. R. F.	**2.0	100	255	6.0	2.6
RCA-2A7, Det.-Osc.	**2.5	100	250	*5.0	2.6
RCA-58, I. F.	**2.0	100	255	6.0	2.6
RCA-2B7, 2nd Det.-AVC	**1.5	35	105	1.5	2.6
RCA-56, A. F. Driver	**12.0	—	245	6.0	2.6
RCA-53, Output	0	—	300	36.0	2.6
RCA-80, Rectifier	640 R. M. S. Plate to Plate			130 per Plate	5.0

* Voltages and current apply to detector portion of tube.
** These voltages cannot be measured because of the high resistance of the circuits.

BROAD TUNING on broadcast band is a normal condition. The same tuning condenser gang is used on short wave bands and because of wide band of frequencies covered is so designed that tuning of high frequencies will not be too critical.

LOW HUM increasing as set is tuned to resonance is sometimes caused by the 2B7 second detector. Try another one as trouble will not show up on tube checker.

CODE INTERFERENCE can often be eliminated by connecting the secondary of a 456 k.c. I.F. transformer in series with the antenna as close as possible to the receiver. Tune the secondary to the frequency of the interfering signal.

NOISY AND INTERMITTENT RECEPTION is sometimes caused by the 2A7 tube. Try a new tube as this trouble may not show up on tube checker.

A CARRIER HUM can often be eliminated by inter-changing the position of all the 58 tubes, or substituting one or more new ones.

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NATIONAL RADIO INSTITUTE, WASHINGTON, D.C.

VICTOR RADIO R-32, RE-45, RE-52, R-75

This instrument comprises three standard units as follows:

(1) Radio, in which are contained the R. F. stages and the detector; (2) Power amplifier, containing the first audio, the power stage of push-pull amplification, and the rectifier; (3) Electrodynamic Reproducer. The units are so designed that all parts are readily accessible for servicing.

ANTENNA.—For best average sensitivity and selectivity the antenna should be from 50 to 75 feet long including the lead-in and ground wires, and should be as high above ground as possible. A short antenna tends to decrease the sensitivity and increase the selectivity; a long antenna tends to increase the sensitivity and decrease the selectivity. For local reception sufficient sensitivity can usually be obtained without the use of an antenna by connecting the ground wire to the antenna binding post instead of the ground binding post.

GROUND.—A good ground connection is highly important for the proper operation of the instrument and must be used at all times. The connection should be made to a well scraped and cleaned portion of a water pipe by clamping with a ground clamp. If such a connection is not available, a pipe or metal rod may be driven three or four feet into the ground, preferably where the soil is moist. Attention is called to the fact that a spark may be produced if the ground is connected to the instrument while the power plug is attached. This condition, which is caused by the condenser discharge from the power line, is quite normal and will cause no harm to the instrument.

ADJUSTING HUM CONTROLS.—The two hum control potentiometers should be adjusted at the time of installation in the following manner:

a. Place the transfer switch in the "record" position to the right.

b. With a small screw-driver turn the UX-226 hum control in the base of the power amplifier unit slightly in either direction as required until the hum is a minimum.

c. Turn the transfer switch tc the left to the "radio" position, turn the radio volume control to minimum, and adjust the UY-227 hum control near the UY-227 in the radio set until the hum is a minimum.

ADJUSTING HARMONIC MODULATOR.—The harmonic modulator or tone control in the bottom of the power amplifier controls emphasis on the bass section of the scale, increasing the bass and decreasing the high notes as the adjusting screw is turned to the right. Ordinarily, the control will not require any change in setting from that made in the factory. It may be desirable in some cases, however, to change the adjustment because of unusual room characteristics, a customer's preference for stronger bass, or to reduce record scratch and static. The control arm can be turned with a small screw-driver as desired.

General Tests

EXCESSIVE HUM.—This condition can be caused by:

a. Improperly adjusted or faulty hum controls.

b. Defective UX-280 or UY-227.

c. Shorted condenser across UX-226 filament supply.

d. Open connections to one of the various grounds.

e. Open or shorted center tap resistor across UX-226 filament supply.

f. Shorted condenser across power line in power amplifier unit.

g. Shorted condenser in condenser bank of power amplifier unit.

HOWL.—Microphonic howl can be traced to:

a. Defective Radiotron, particularly in the detector or audio stages.

b. Improper neutralization.

c. Speaker not felt insulated from baffle. Remove speaker and arrange felt properly.

d. Open condenser.

e. Loose metal parts such as shielding, screws, etc., or improperly centered cone may set up a howl or mechanical rattle.

RADIO RECEIVER VOLTAGE TESTS

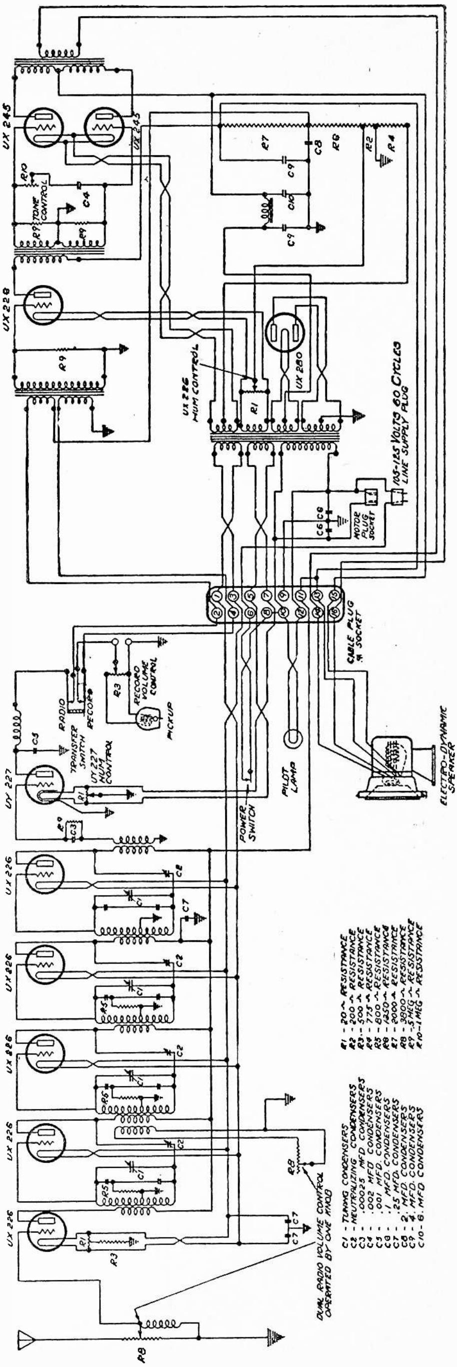
TESTS	SOCKET NO.	NORMAL VOLTAGE
Filament	1	1.40 Volts A.C.
	2	1.40 Volts A.C.
	3	1.40 Volts A.C.
	4	1.45 Volts A.C.
	5	1.50 Volts A.C.
	6	2.1 Volts A.C.
Plate	1	105 Volts D.C.
	2	105 Volts D.C.
	3	105 Volts D.C.
	4	105 Volts D.C.
	5	105 Volts D.C.
	6	40 Volts D.C.
Grid	1	9 Volts D.C.
	2	9 Volts D.C.
	3	9 Volts D.C.
	4	9 Volts D.C.
	5	9 Volts D.C.
	6	0 Volts D.C.

POWER AMPLIFIER VOLTAGE TESTS

TEST	SOCKET	NORMAL VOLTAGE
Filament	UX-226	1.40 Volts A.C.
	UX-245	2.2 Volts A.C.
	UX-280	4.6 Volts A.C.
Plate	UX-226	100 Volts D.C.
	UX-245	230 Volts D.C.
Grid	UX-226	6 Volts D.C.
	UX-245	40 Volts D.C.

CABLE TERMINAL VOLTAGE TESTS

TEST BETWEEN TERMINALS	NORMAL VOLTAGE
1 and 3	1.70 Volts A.C.
5 and 7	2.35 Volts A.C.
2 and 9	39 Volts D.C.
9 and 11	105 Volts D.C.
13 and 15	185 Volts D.C.



Circuit of Victor Micro-Synchronous Radio R-32 and RE-45.

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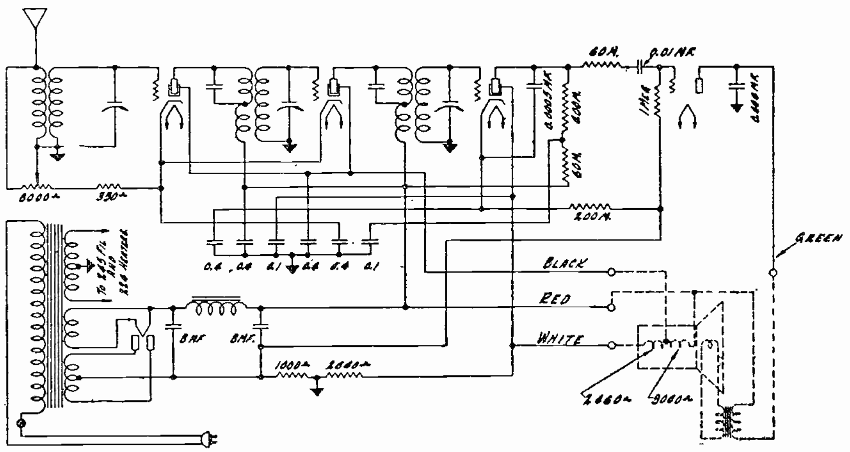
NATIONAL RADIO INSTITUTE, WASHINGTON, D.C.

GLORITONE "MANTEL" TYPE RECEIVERS MODELS 26 AND 27

TABLE OF VOLTAGES FOR NO. 26 CHASSIS—VOLUME CONTROL AT MAXIMUM LINE VOLTAGE, 115—PLUG IN SOCKET OF RECEIVER—TUBE IN TEST SET.

Type of Tube	Position of Tube	Function	"A" Volts	"B" Volts	Control Grid "C" Volts	Screen Volts	Screen Current MA	Cathode Volts	Plate MA
224	1	1st Radio	2.2	245	2.5	80		2.5	2.9
224	2	2nd Radio	2.2	245	2.5	80	.6	2.5	2.9
224	3	Detector	2.2	130	3.	40	.6	3.	.25
245	4	Audio	2.35	245	50.		.1		28.
280	5	Rectifier	4.6						25. per plate



GLORITONE mantel type
Model 26

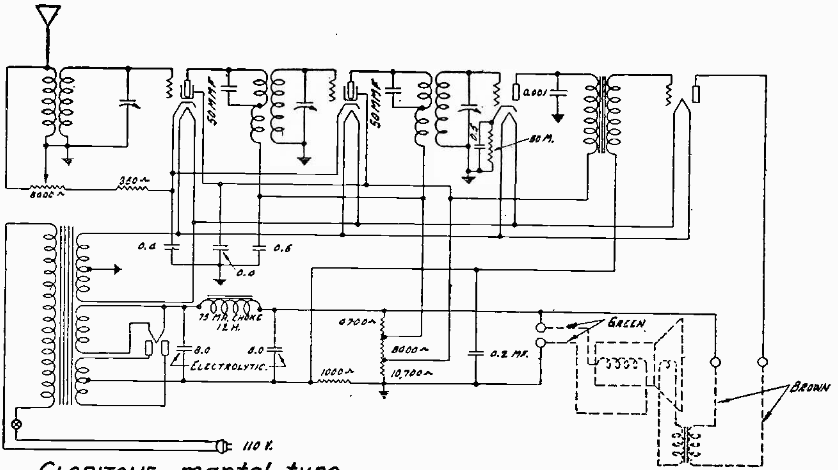
DOTTED LINES SHOWN ARE IN SPEAKER.

THE CAUSE AND REMEDY OF OSCILLATION IN THE GLORITONE "MANTEL" TYPE RECEIVERS

The most common causes of oscillation in this type receiver is in the majority of cases due to an open section of the Multiple section by-pass condenser. The reason that a good many service men have difficulty in locating this cause is because they do not seem to thoroughly understand the testing of a fixed condenser other than for a short circuit. We recommend that when a service man is testing one of these sets for oscillation and a suitable continuity tester is not available for determining whether or not a section of the by-pass condenser is open that a test condenser can be used. This test condenser may have a capacity of .5 Mfd. and to its terminals are connected test leads.

With the oscillating chassis in operation, one of the test leads should be grounded to the frame and the other test lead touched to the various contacts of the multiple section by-pass condenser. It is of course obvious that when the defective section of the by-pass condenser is located the receiver will cease to oscillate, that is, providing a defective section of the condenser is causing the excessive oscillation. It is, of course, also very important that a by-pass condenser be properly grounded and the various sections of this condenser have a common ground which is made within the container of the condenser.

Tuning condensers are used in the design of the receivers which have the rotor sections grounded with a tension spring. It sometimes happens in rare instances that dirt or dust will accumulate at the point of contact thus causing a high resistance ground at this point and a subsequent oscillating condition in the receiver. The remedy in this case is of course obvious, that is, the springs should be removed (easily removed) and thoroughly cleaned and in addition to this the point of contact on the rotor section of the tuning condenser should also be cleaned of all foreign material.



GLORITONE mantel type
Model 27

DOTTED LINES SHOWN ARE IN SPEAKER.

TABLE OF VOLTAGES FOR NO. 27 CHASSIS—VOLUME CONTROL AT MAXIMUM LINE VOLTAGE, 115—PLUG IN SOCKET OF RECEIVER—TUBE IN TEST SET

Type of Tube	Position of Tube	Function	"A" Volts	"B" Volts	Control Grid "C" Volts	Screen Volts	Screen Current MA	Cathode Volts	Plate MA
224	1	1st Radio	2.25	160	2.5	80	.6	2.5	3.
224	2	2nd Radio	2.25	160	2.5	80	.6	2.5	3.
227	3	Detector	2.25	70	8.5			8.5	.1
245	4	Audio	2.35	238	44.				19.
280	5	Rectifier	4.8						26.5 per plate

EXCESSIVE HUM

The design of the power unit and arrangement of the filter condensers is such that the hum output voltage is very low. With no signal it is scarcely audible. If there is an excessive A.C. hum this may be due to a number of causes.

Among the most prominent causes for excessive A.C. hum are defective tubes, of which the 280 and 227 are generally responsible. In every case, therefore, of excessive hum try out a new set of tubes and note any difference in performance. The hum may be due to external pick-up. Disconnect antenna and ground from set and see if hum disappears.

Other causes of hum are shorted filter choke and open filter condenser or filter condenser with considerable electrolyte leakage. If the shield plate in the power transformer between the primary and secondary is not properly grounded, excessive hum will result.

A heater to cathode short in one of the 224 tubes will cause an excessive hum due to the introduction of the A.C. component of the heater voltage into the grid circuit. An open cathode connection in this type of tube also causes hum.

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PHILCO MODEL 16

THE PHILCO RADIO MODEL 16 is an eleven-tube superheterodyne broadcast and short-wave receiver, operating upon alternating current and employing the high-efficiency 6.3 volt tubes, automatic interstation noise suppression, and a frequency (wave-band) coverage that permits reception of the short-wave (high-frequency) broadcast programs. The same superheterodyne circuit is used for all reception. The Receiver is equipped with a five-point wave-band switch. The ranges are—

(1) 520 K.C. to 1500 K.C. (3) 3.2 M.C. to 6.0 M.C.
(2) 1.5 M.C. to 4.0 M.C. (4) 5.8 M.C. to 12.0 M.C.
(5) 11.0 M.C. to 23.0 M.C.

The Receiver employs a Philco Type 77 tube for first detector, a Type 76 for oscillator, a Type 78 for first I. F., a Type 78 for second I. F., and a Type 37 for second detector. The automatic interstation noise suppression circuit uses a Type 78, the first A. F., a Type 77. The driver (second A. F.) is a Type 42; the class "A" amplification is accomplished with two Type 42 tubes as triodes; the rectifier is a Type 5-Z-3. The intermediate frequency is 460 kilocycles. The power consumption of Model 16-122 is 130 watts; of Model 16-121, 120 watts.

Table 1—Tube Socket Data*—A. C. Line Voltage 115 Volts

Circuit	1st Det.	Osc.	1st. I. F.	2nd I. F.	2nd Det.	Inter-Station Noise Supr. Circuit	1st A. F.	2nd A. F. (Driver)	Output		Rectifier
Type Tube	77	76	78	78	37	78	77	42	42	42	5-Z-3
Filament Volts—F to F........	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	4.7
Plate Volts—P to K...........	220	53	225	230	0	1.8	130	220	340	340	400
Screen Grid Volts—SG to K....	80	—	80	80	—	1.8	1.8	220	340	340	—
Control Grid Volts—CG to K...	1.6	6.4	0	0	.2	1.6	.4	.6	34	34	—
Cathode Volts—K to F........	4.2	1.9	2.2	2.5	0	0	0	0	0	0	—

* All of the above readings were taken from the underside of the chassis, using test prods and leads, with a suitable A. C. voltmeter for filament voltages, and a high-resistance multi-range D. C. voltmeter for other readings. The *Philco Model 048 All-Purpose Set Tester* is highly recommended for this use. Volume control set at maximum and station selector turned to low frequency end; interstation noise suppression circuit potentiometer turned all the way to the right; and toggle switch (interstation noise suppression circuit) in "ON" ("S") position. Readings taken with a plug-in adapter will NOT be satisfactory.

NOTE—These values are for Model 16-122. Model 16-121 uses a Type 80 Rectifier Tube.

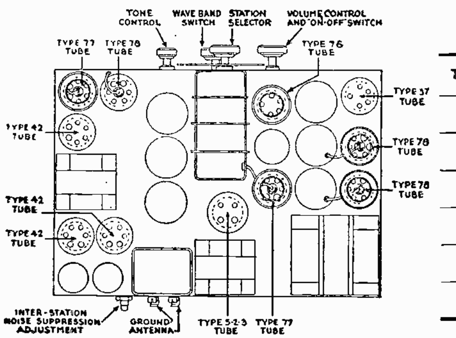
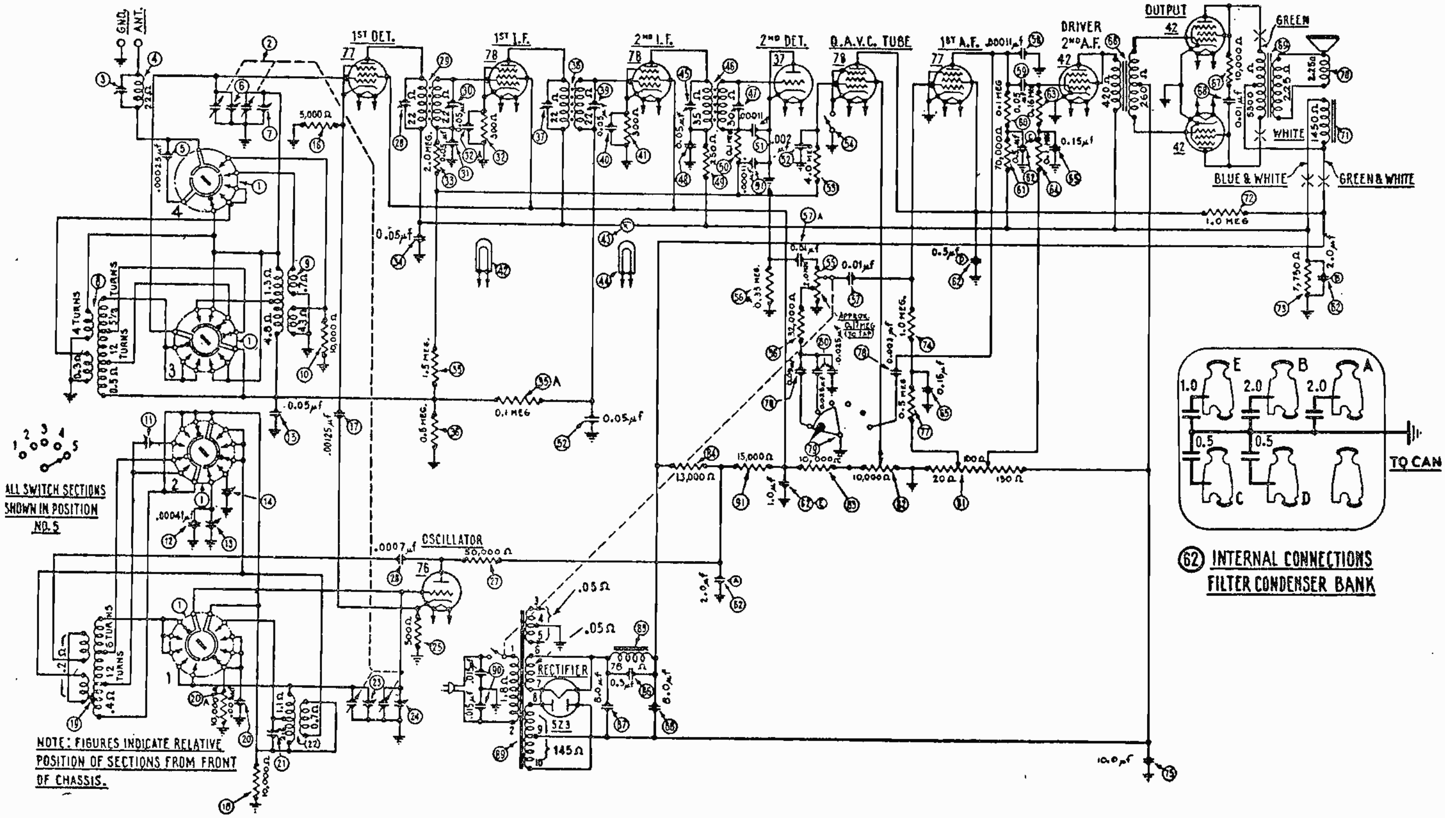


Fig. 1—Top View of Chassis, Showing Tube Locations and Major Parts

Table 2—Power Transformer Data

Terminal	A. C. Volts	Circuit	Color
1—2	105—125	Primary	White
3—5	6.3	Filament	Black
6—7	5.0	Filament of 5-Z-3	Blue
8—10	800	Plates of 5-Z-3	Yellow
4	—	Center Tap of 3—5	Black—Yellow Tracer
9	—	Center Tap of 8—10	Yellow—Green Tracer

Terminal Arrangement of Tube Sockets Viewed from Underside of Chassis


GND.
ANT.
1ST DET.
77
1ST I.F.
78
2ND I.F.
78
2ND DET.
37
Q.A.V.C. TUBE
78
1ST A.F.
77
DRIVER
2ND A.F.
42
OUTPUT
42
42
GREEN
WHITE
BLUE & WHITE
GREEN & WHITE
OSCILLATOR
76
RECTIFIER
5Z3
145Ω
TO CAN
62 INTERNAL CONNECTIONS
FILTER CONDENSER BANK
ALL SWITCH SECTIONS
SHOWN IN POSITION
NO. 5
NOTE: FIGURES INDICATE RELATIVE
POSITION OF SECTIONS FROM FRONT
OF CHASSIS.

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SILVERTONE MODELS 1700—7062

GENERAL NOTES: The A.V.C. action can be rendered inoperative, when peaking the I.F. transformers, by shortening Resistors R3 and R4. A preferable method is to use an oscillator with variable output power. The output should be made no greater than is necessary to obtain a satisfactory signal or output meter reading.

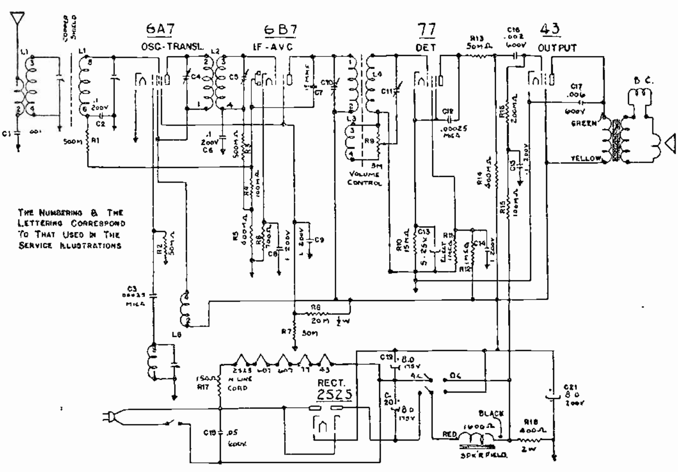
The four tuning condenser adjustments for the I.F. transformers are accessible from the front of the chassis as illustrated. The I.F. frequency is 175 Kc.

The loudspeaker can be removed for replacement by taking off the 6B7 tube shield and removing the three speaker mounting screws. Be certain that the speaker leads color code, indicated in the schematic, is followed. Improper connection will cause excessive hum due to the hum bucking coil's increasing hum instead of cancelling it out.

Speaker rattle may be due to the cone's being off center. Loosen the center adjusting screw, insert four ⅛ inch wide strips of heavy writing paper between the pole piece and the inside of the voice coil, retighten the adjusting screw, and remove the paper spacing strips.

Increased pickup can be had by splicing the antenna lead to an additional length of wire or to a regular antenna if available.

All metal parts of the chassis (including the AC-DC Switch) are at high potential to ground. DO NOT touch chassis while the line cord is plugged into an outlet.



ALL RESISTORS ARE 1/3 WATT UNLESS OTHERWISE MARKED

TUBE VOLTAGE AND CURRENT CHART

MODELS 1700 - 7062

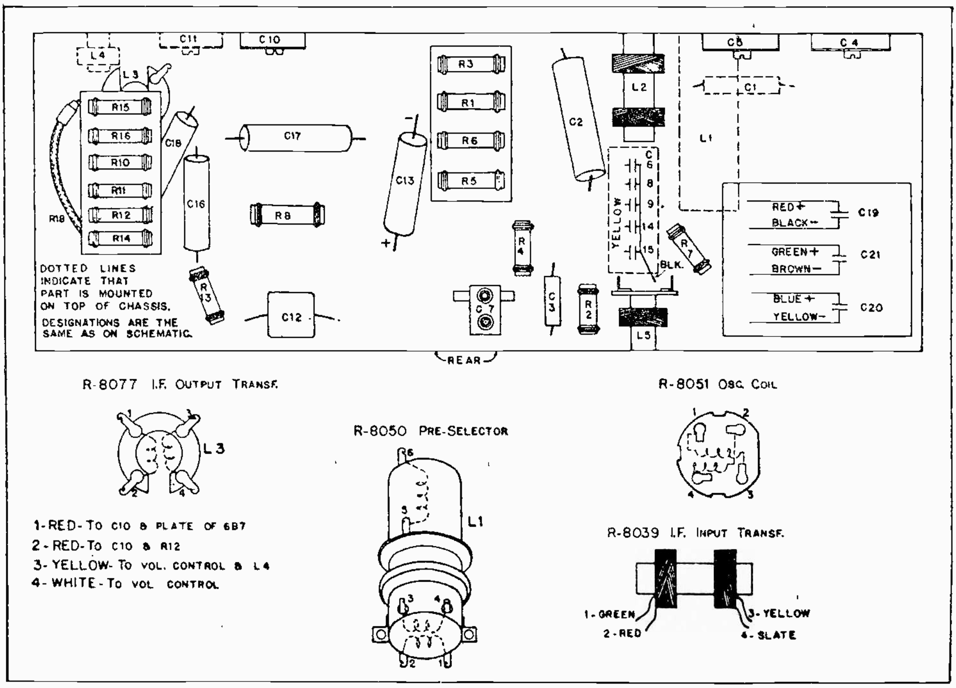
TUBE	PLATE VOLTS	SCREEN VOLTS	GRID VOLTS	PLATE MA	SCREEN MA
6B7 IF-AVC	110	55	-7*	.4	.2
77 Detector	50	22	-1.5	.1	.04
43 Output	100	120	-10*	26	5
6A7 Osc-Transl	Ep=105v EG#4=*	EG#1=-5v Ip=2ma	EG#2=105v Ig#2=1.3ma	EG#3 and 5=55v Ig-#3&5=1.2ma	
25Z5 Rectifier	Plate Current	- 40 M.A.per plate			

Speaker Field Voltage = 70 v

Eg=Grid Voltage Ip=Plate Current
Ep=Plate Voltage Ig=Grid Current

* Indicates high series resistor

Tube heaters are in series so that if one burns out, none will light. These measurements were made with a 500 volt, 1000 ohms per volt meter. Power supply 118 volts A.C. Measurements made with set detuned, and speaker field hot. Care should be used when taking readings with a set analyzer as the capacity of the cables may cause circuits to oscillate, giving rise to erratic readings. Usually, touching the finger to grid or plate is sufficient to stop oscillation.



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FADA MODEL 1462 SERIES

VOLTAGE READINGS.

No Signal Input — Wave Band Switch — Right

Type of Tube	*Position*	*Plate Volts*	*Plate MA Current*	*Cathode Volts*	*Screen Grid Volts*
6A7	1st Det.-Osc.	121	2.4	3	70
6D6	Int. Freq.	117	5.3	7	117
75	1st Aud.	58*	.1	1	...
	2nd Det.	...	..	..	...
43	2nd Aud.	99	22.0	17	107
37	Spk. Rectifier	...	26.0	..	...
25Z5	"B" Rectifier	...	42.0 TOTAL	..	...

6A7 Osc. Anode Voltage—100 and Current—3.3 ma.

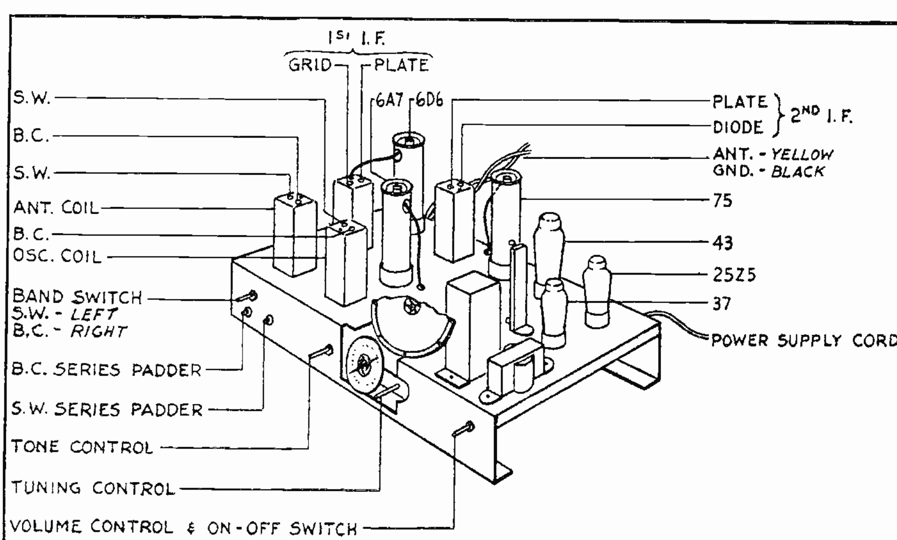
*Readings taken with 1,000 ohm per volt meter; not indicative of effective voltages.

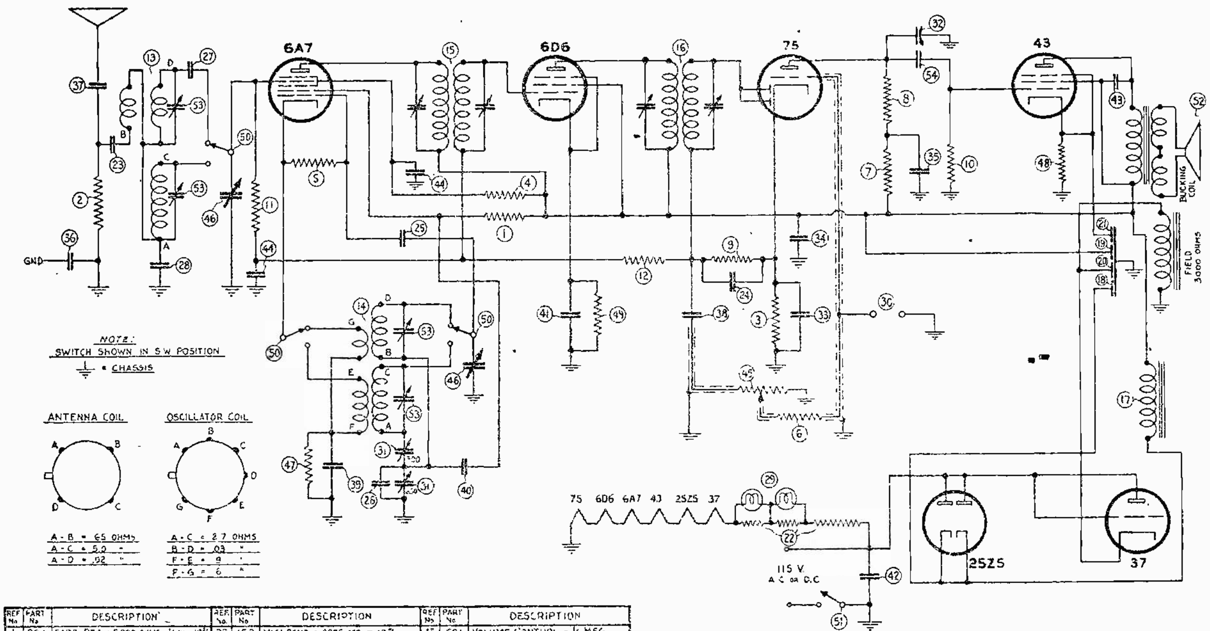
* * * * *

Voltage Across Electrolytic Condenser: 1st Section 139; 2nd Section 124.
Voltage across speaker field 80 volts; voltage across filter choke 15 volts.

D. C. Resistance Values

Speaker input transformer; Primary 330. ohms; Secondary .42 ohms.
Speaker field coil; Primary 3,000. ohms.
Speaker voice coil; Primary 3. ohms.
Speaker bucking coil; Primary .38 ohms.





REF No	PART No	DESCRIPTION	REF No	PART No	DESCRIPTION	REF No	PART No	DESCRIPTION
1	30.1	CARB. RES. - 5,000 OHMS - ½ W ± 10%	23	15.2	MICA COND. - .0005 MF ± 10%	45	50.1	VOLUME CONTROL - ½ MEG.
2	30.31	" " 10,000 " " " 20%	24	15.2	" " .0005 " "	46	25.2	VARIABLE COND.
3	30.31	" " 10,000 " " " "	25	15.3	" " .0001 " "	47	130.2	WIRE RES. - 350 OHMS ½ W. FX
4	30.7	" " 15,000 " " " 10%	26	15.19	" " .0015 " "	48	130.1	" " 625 " " " "
5	30.3	" " 50,000 " " " "	27	15.5	" " .002 " 3%	49	130.3	" " 1000 " " " "
6	30.26	" " 50,000 " " " 20%	28	15.6	" " .0025 " "	50	45.1	BAND SWITCH
7	30.26	" " 50,000 " "	29	120.1	PILOT LIGHTS 6-8 V. .25 A.	51		ON-OFF SW. ON VOL. CONT. (45)
8	30.20	" " 250,000 " " " "	30	125.1	PHONO JACK	52	105.1	SPEAKER - 3,000 OHMS
9	30.23	" " 500,000 " " " "	31	25.1	PADDING COND. - 650 - 500 MMF	53		MIN. ADJ. ON COILS
10	30.23	" " 500,000 " " " "	32	55.1	TONE CONTROL	54	10.4	TUBULAR COND. - .01 MF. - 200 V
11	30.22	" " 1 MEG " " "	33	10.12	TUBULAR COND. - 1.0 MF. - 200 V			
12	30.22	" " 1 " " " "	34	10.2	" " 1 " " "			
13	202.6	ANTENNA COIL	35	10.2	" " 1 " " "			
14	31.6	OSCILLATOR	36	10.3	" " .006 " 400 "			
15	38.79	1ST I.F. "	37	10.4	" " .01 " 200 "			
16	38.80	2ND I.F. "	38	10.4	" " .01 " " "			
17	40.1	CHOKE " " 300 OHMS	39	10.5	" " .05 " " "			
18	20.1	ELECTRO COND. BLOCK - 16 MF - 400 V	40	10.5	" " .05 " " "			
19	20.1	" " " 16 " 100 "	41	10.5	" " .05 " " "			
20	20.1	" " " " 4 " 100 "	42	10.5	" " .05 " " "			
21	20.1	" " " 4 " 25 "	43	10.10	" " .01 " 400 "			
22	115.1	LINE RESISTOR - 120 - 38 - 38 OHMS	44	10.6	" " DUAL .05 " 200 "			

1ST I.F. TRANS.
PRI. - 14.5 OHMS
SEC. - 14.5 "

2ND I.F. TRANS.
PRI. - 14.5 OHMS
SEC. - 14.5 "

I.F. - 456 K.C.

FADA RADIO & ELECTRIC CO. LONG ISLAND CITY, N.Y.	
MODEL 1462	
DRAWN BY CHO	DATE 7-17-35
CHECKED BY FJB	APP. RFS

COMMERCIAL RADIO CONDENSERS

20X

REFERENCE BOOK

PIONEER HOME STUDY RADIO SCHOOL

NRI

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

FOREWORD

This reference work on condensers is the result of our policy to give N. R. I. men everything possible in connection with Radio. The theory of condensers is thoroughly covered in a regular lesson text—this book contains advanced formulas for condenser calculations and complete descriptions of many various types of commercial condensers.

It is not expected that you study this book as though it were a lesson—use it for reference. However, I suggest you read it through carefully now to find out what is in it—then when you want to find out something about a particular type of condenser, or want to refer to some particular mathematical formula in a hurry, you will know just where to find it.

There is much in this book that is exceedingly valuable. Learn to use it and convert the information in it to dollars in your pocket. I personally am sure that you are going to appreciate fully our policy of giving you extra help and extra cooperation through this and other reference books.

J. E. Smith.

NATIONAL RADIO INSTITUTE

WASHINGTON, D. C.

Revision 1933
1936 Edition

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Commercial Radio Condensers

CAPACITY

Capacity in an electrical device manifests itself by a tendency to prevent a change in voltage. It makes possible the storing of electricity in appreciable quantities which can be delivered almost instantly.

Condensers are the commonest capacity devices—they are designed to have capacity and nothing but capacity. Other devices, aerials, inductance coils, vacuum tubes, resistances, may have capacity, it is true, and this must be reckoned with in most problems of design. Sometimes capacity in these devices is useful, sometimes otherwise. But a condenser is built to have a certain, definite, useful capacity.

In this reference text, we are going to deal only with commercial condensers, and these are as nearly pure "capacity" devices as they can be made. A good condenser should have no inductive or resistive properties. Inductance and capacity neutralize each other, while resistance in a condenser might result in comparatively large resistance losses.

The construction of a condenser is simple—it consists of two or more metallic plates, wires, or sheets separated from one another by a non-conductive substance such as mica, glass, paper, wax, oil, even pure water or air.

A condenser can be charged by a D.C. electromotive force—as when a battery is connected across it. The amount of electricity that can be stored in a condenser is definitely determined by a simple formula: Quantity, measured in coulombs, is always equal to the capacity in farads multiplied by the e.m.f. in volts. In equation form:

$$Q = C \times V \tag{1}$$

From this it can be calculated that a condenser having a capacity of one microfarad (one-millionth, .000001, of a farad), when charged by an e.m.f. of 1,000 volts, will store one-thousandth of a coulomb (.001 coulomb). A good condenser will hold a charge for a long period of time; in fact, it is common practice to test condensers by seeing how long they will hold a charge.

When a source of A.C. e.m.f. is connected to a condenser, the action is entirely different. Then the opposite sides of the condenser are alternately charged and discharged. The effect of this is that the A.C. current *apparently* flows through the condenser. Of course, it must be remembered that no electrons pass through the insulating medium from one plate to another; it is merely the alternate charging and discharging of the plates that enables the A.C. current to flow in the circuit.

A charged condenser always has a voltage across its terminals; that is, they are of different potentials. An uncharged condenser has no voltage across its terminals.

It is possible to increase the quantity of electricity stored in a condenser by increasing the charging voltage. According to this, the quantity stored could be increased indefinitely, but there is a limit. When the charging voltage gets to a certain point, the non-conducting material between the condenser plates breaks down, or, as is commonly said, is punctured. When this insulating medium is broken down, it becomes a conductor and current flows through it, from one plate to the other, destroying the capacity effect.

In practice the charging limit is not the puncture voltage but a safe voltage far below the puncture voltage. Condensers are rated at safe "working" voltages, and these should not be exceeded.

Frequently two or more condensers are used together. Then they may be connected in parallel or in series, or, in a combination of the two, a series-parallel connection. It is essential that a Radio-Trician be able to calculate the total capacity values of any sort of a hook-up.

If there are several condensers in parallel, it is a simple matter to find the total capacity. It is necessary only to add the individual capacities. For example, a capacity hook-up as shown in Fig. 1a would be calculated from the formula:

$$C = C_1 + C_2 + C_3 + C_4 \tag{2}$$

When all the capacities are known to be identical—for example, if each condenser in Fig. 1a had a capacity of 2 mfd.—it is necessary only to multiply the number of condensers by the value of one to find the total capacity. Or use the formula:

$$C = N \times C_1 \tag{2a}$$

Where N is the number of condensers in parallel.
C_1 is the capacity of one condenser.

If seven condensers of one-half microfarad capacity were connected in parallel, the total capacity from (2a) would be:

$$C = 7 \times \tfrac{1}{2} = 3\tfrac{1}{2} \text{ mfd.}$$

When condensers are in series, computation of the total capacity is not as simple. Fig. 1b shows a series capacity hook-up. To calculate C, the total capacity, we must use this formula:

$$C = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \frac{1}{C_4}} \tag{3}$$

Again matters are simplified if all the condensers have the same capacity value. Then formula (3a) can be used:

$$C = \frac{C_1}{N} \tag{3a}$$

Thus, if 15 condensers of 2 mfd. capacity each are connected in series, the total capacity will be:

$$C = \frac{2}{15} = .133 \text{ mfd.}$$

Notice that, in series hook-ups, the total or equivalent capacity of all the condensers is much less than the capacity of a single condenser.

When condensers are in varied combinations as in Fig. 1c, each complex section as from a to b and from b to c must be calculated for its equivalent capacity and the final value computed from these results. In Fig. 1c, two series condensers of 5 mfd. and 3 mfd., respectively, are in parallel with two other series condensers of 1 and 2 mfd., respectively. This combination is in series with two other condensers of 2 mfd. each. Can we compute the value of C for the entire circuit?

Let us call the equivalent capacity of the 5 and 3 mfd. condensers in series

"C_1" and the equivalent capacity of the 1 and 2 mfd. condensers "C_2." Then:

$$C_1 = \frac{1}{\frac{1}{5} + \frac{1}{3}} = \frac{1}{.2 + .333} = \frac{1}{.533} = 1.88 \text{ mfd.}$$

$$C_2 = \frac{1}{\frac{1}{2} + \frac{1}{1}} = \frac{1}{.5 + 1} = \frac{1}{1.5} = .67 \text{ mfd.}$$

The capacity from a to b will be $C_1 + C_2$ or $1.88 + .67 = 2.55$ mfd. From formula (3a) we find that the capacity from b to c is $\frac{2}{2} = 1$ mfd.

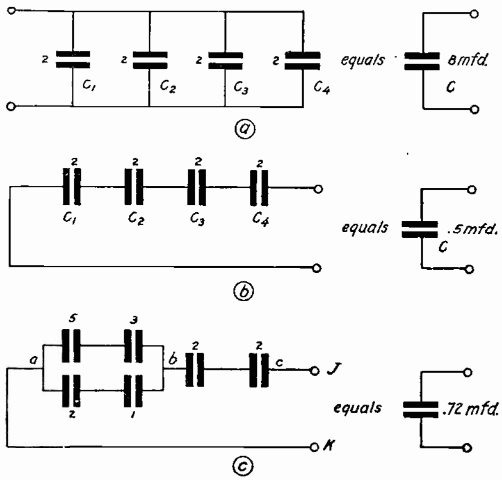


Fig. 1

Now our circuit has resolved itself to this—2 condensers in series, one of 2.55 mfd. capacity, the other with a capacity of 1 mfd. From formula (3):

$$C = \frac{1}{\frac{1}{2.55} + \frac{1}{1}} = \frac{1}{1.39} = .72 \text{ mfd.}$$

Now refer to Fig. 2. In it is shown, schematically, a multi-plate condenser. The plates are rectangular sheets of lead foil, and these are separated from one another by mica, paper, wax or glass. The plates are "w" inches wide and "l" inches long. There are in all, let us say, "n" plates (sheets of foil). How can the capacity of the condenser be determined? Look at the figure carefully; there are, in effect, six condensers in parallel—one less than the number of plates. But to find the capacity of two adjacent plates we must use a new formula:

$$C = .225 \frac{K \times w \times l}{d} \text{ micro-microfarads } (\mu\mu f.)$$

Of course, $w \times l$, width times length, is the area. So, because plates are not always rectangular and because the area is the important thing, this formula is usually expressed:

$$C = .225 \frac{K \times A}{d} (\mu\mu f.) \tag{4}$$

Where A is the area of one plate in square inches.
d is the distance in inches between surfaces of adjacent plates.
K is the dielectric constant determined from Table 1.
.225 is a number to convert the value of C to micro-microfarads.

Material	*Dielectric Strength. Kilovolts per mm.*	*Dielectric Constant. Using Air as Base.*	*Power Factor.*
Air	....	1.0	.0000
Bakelite	17.7 to 27.5*	4.5 to 9.9	.037 to .073
Castor Oil	13.0	4.67	....
Celluloid (Clear)	12 to 28	4.10	.042
Cottonseed Oil	7.0	3.10	....
Empire Cloth, Canvas	28.9	....	....
Empire Coth, Linen	54.0	....	....
Empire Cloth, Muslin	48.0	....	....
Empire Cloth, Silk	48.0	....	....
Fiber	3.0 to 16.7*	5.0	.04 to .06
Glass	8.0 to 9.0*	5.5 to 9.1	.004 to .016
Gutta-percha	8.0 to 20.0*	3.3 to 4.9	....
Linseed Oil	9.0	3.35	.012
Mica	21.0 to 28.0*	5.0 to 7.0	.0004
Micanite, Plate	37.5	....	.023
Micanite, Flexible	23.1	....	....
Mineral Oil	8.5	....	....
Paper	8.7	2.6	.024
Paraffin	11.5	2.1	.0097
Porcelain	8.0	4.4	.007
Pressboard (Oiled)	21.1 to 39.3*	5.0	....
Pressboard (Varnished)	9.5 to 26.3*	3.0	....
Rubber (Hard Ebonite)	70.0	2.0 to 3.5	.007 to .014
Shellac	....	3.0 to 3.7	.025
Sulphur	....	2.9 to 3.2	....
Water (Distilled)	....	81.1	....
Wood (Maple), Paraffined	4.6	4.1	....

* Depending on thickness; generally the thicker the material, the less the dielectric strength per unit of thickness.

TABLE 1.

The use of K in formula (4) deserves some explanation. Table 1 shows the values of K for various non-conducting materials used in condensers with air as the base or standard. From the table it will be seen that, if pure distilled water is used as the dielectric material, 81 times as much electricity can be stored in it as in a condenser of the same size having air dielectric.

K, called the dielectric constant, is the measure of the ability of a substance to help a condenser store electricity. It must not be confused with dielectric *strength*, which refers to the strength of the material used as an insulator; that is, its resistance to current flow.

This suggests a most interesting question which students frequently ask. Suppose an air dielectric condenser of 1 mfd. capacity is placed in a leakproof container and filled with castor oil (which, by the way, is often used in Radio work). Its dielectric constant, K, is approximately 5. The capacity of the condenser is now increased to 5 mfd. The condenser is charged by 1,000 volts. According to formula (1) the quantity of electricity stored is $1{,}000 \times 5 \times 10^{-6} = .005$ coulomb. Then the oil is drained off. What is the voltage across the capacity?

It must be remembered that electricity cannot be destroyed—that Q always equals $C \times V$. But when the oil is drained off, the capacity of the condenser returns to 1 mfd. So the voltage across the condenser goes up to 5,000 volts, 5 times the voltage across the condenser when the oil was in the container. The mathematical proof is:

$$Q = C \times V \quad \text{or} \quad V = \frac{Q}{C} = \frac{.005}{1 \times 10^{-6}} = 5{,}000 \text{ volts.}$$

Will the air dielectric stand a voltage of 5,000? Most likely it will break down (conduct) long before all the oil is drained off and the voltage across the terminals is 5,000 volts.

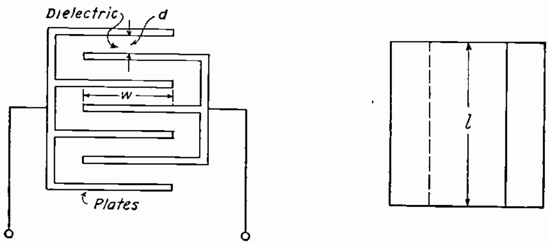


FIG. 2

The "dielectric strength" of a substance was mentioned. This is rated in terms of break-down voltages per millimeter of thickness. For the dielectric strength of various materials, refer to Table 1. Thus for thin mica it is approximately 20,000 volts per mm. ($25.4 \times 2 \times 10^4$ = about 500,000 volts per inch). Mica .002 inch thick will break down at 1,000 volts.

Now let us return to Fig. 2. If there are *"n"* plates arranged alternately, the total capacity can be calculated from this important formula:

$$C = \frac{.225\, K \times A \times (n-1)}{d} \mu\mu f. \tag{4a}$$

CONDENSERS IN A. C. CIRCUITS

Condensers play an important part in radio circuits. They may be used to block out a D.C. component, in which case the leakage resistance of the condenser must be very high. In other circuits it is used to offer a low reactance path, the purpose being to keep the signal currents out of paths which would give rise to undesirable reactions. The A.C. reactance X_c is given by the very important formula:

$$X_c = \frac{1}{2\pi f C} \text{ ohms} \tag{5}$$

Where f is the frequency of the A.C. current in cycles per second and C is the capacity of the condenser in farads.

When a condenser is associated with a resistance R, the value of the impedance of the combination will differ from the reactance value of condensers. A shunt resistance reduces the impedance, while a series resistance always increases the impedance.

For a series resistance

$$Z = \sqrt{X_c^2 + R^2} \text{ ohms} \tag{6a}$$

For a shunt resistance

$$Z = \frac{1}{\sqrt{\frac{1}{R^2} + \frac{1}{X^2_c}}} \text{ ohms} \tag{6b}$$

Condensers and coils having radio frequency resistance are used extensively in combination. When a coil having a resistance R is in series with a condenser, the net impedance is given by the formula

$$Z = \sqrt{R^2 + (X_L - X_c)^2} \text{ ohms} \tag{6c}$$

In this formula the capacity reactance is aways subtracted from the inductive reactance ($X_L = 2\,\pi f L$). If X_c is larger than X_L, then X_L should be subtracted from X_c. It should be remembered that with X_c larger than X_L, the line current will lead the line voltage. Should X_L be larger than X_c the line current will lag the applied or line voltage.

The second important coil-condenser connection is where a coil having a resistance is shunted by a condenser. For such a connection the total impedance is given by the formula

$$Z = \frac{1}{\sqrt{\left(\frac{1}{X_c} - \frac{X_L}{R^2 + X_L{}^2}\right)^2 + \left(\frac{R}{R^2 + X_L^2}\right)^2}} \text{ ohms} \tag{6d}$$

Resonance plays an important part in radio circuits. The two important circuits have been considered for any frequency. In general, resonance is obtained by balancing an inductive reactance with a capacitive reactance. In the case of a coil and condenser in series, resonance exists when $X_c = X_L$. The line current is a maximum and the impedance of the circuit is a minimum and equal to R. The current will be equal to E/R, where E is the total applied voltage.

Parallel or inverse resonance as it is sometimes called, is said to exist when the line current (not the condenser plus the coil current) is a minimum. This is the same as saying that the circuit has maximum impedance. This occurs when

$$X_c = \frac{R^2 + X_L^2}{X_L} \tag{6e}$$

When this condition is fulfilled, the resonant circuit has an impedance equal to $(R^2 + X_L{}^2)/R$ and is inductive. Dividing the line voltage by this impedance gives the line current.

Usually in radio circuits, the resistance of the coil is very small in comparison to its reactance. In this case resonance occurs when $X_c = X_L$. Remember that this is the same criterion for series resonance. Parallel resonance makes the circuit behave as resistance having a value equal to X_L^2/R or ω^2L^2/R ohms. ω equals $2\pi f$.

THE GRID LEAK CONDENSER

A good condenser is one which will not allow any current (electrons) to pass through its dielectric. This applies to both A.C. and D.C. currents, but you remember that when a condenser is in an A.C. circuit there is an *apparent* flow of current through the condenser even though no electrons move through the dielectric. But a condenser in a D.C. circuit offers infinite resistance to D.C. current flow—up to a point where too high a voltage will puncture the dielectric. This, of course, reduces the resistance to practically nothing.

In Radio, and wherever condensers are used, voltages are kept well below the danger point, so we can assume that a good condenser will have infinite resistance to D.C. current at all times.

Fig. 3a shows in diagram form a practical application of a condenser in a grid leak arrangement. Notice the resistance across the condenser. Were R not present, and the condenser a perfect one, it would hold its charge indefinitely. But with R in the circuit, the condenser will discharge rapidly, and the smaller the value of R, the greater will be the rate of discharge.

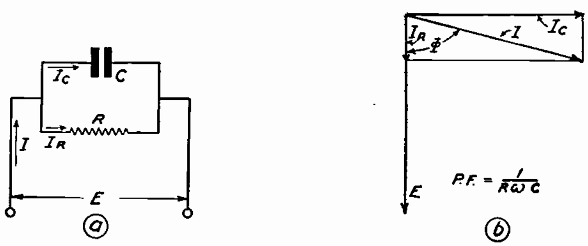


FIG. 3

The formula for determining the amount of current for any particular instant of discharge is:

$$i = \frac{E}{R}\epsilon^{-\frac{t}{RC}} \qquad (6f)$$

Where i is the current in amperes.
E is the voltage to which the condenser is charged.
R is the resistance of the leak in ohms.
ϵ is 2.72 a constant.
t is the time in seconds.
C is the capacity of the condenser in farads.

If "i" the current were calculated or measured every thousandth of a second and the values plotted as a graph, current against time, a curve as shown in Fig. 5a would result. Notice that at the beginning of the discharge, which we call "zero" time, the current "i" is at a maximum, equal to $\frac{E}{R}$. As the discharge continues, the current flow becomes less and less. Theoretically, the current curve tapers off indefinitely, so that the current reaches zero only after considerable time.

When the value of the current "i" drops to 37% of its maximum—that is $.37 \times \frac{E}{R}$—the time T will be equal to RC. This value is called the time constant of the condenser or the condenser and leak. Let us say we have a .00025 mfd. condenser and a 2 megohm leak. RC will be $.00025 \times 10^{-6} \times 2 \times 10^{6} =$ .0005 second (T). In other words, if this condenser were constantly charged, all but 37% of its full charge would leak off into R, 2,000 times a second.

Transmitters often use .00025 mfd. condensers with 10,000 ohm grid leaks. In these cases, T, the time constant, is $10{,}000 \times .00025 \times 10^{-6} = .0000025$ second.

In Fig. 5b are three curves, A, B, and C. Curve B has a smaller time constant than C, and A has a smaller T than either B or C.

POWER LOSSES IN CONDENSERS

A perfect condenser would have no leakage resistance, current flowing through or around the dielectric; no series resistance, resistance due to improper connections or using long strips as plates; no corona or brush discharge, loss due to current leaking off the sharp edges of the plates due to high voltages applied to the plates; and no dielectric hysteresis or absorption, the inability of the dielectric to return to its normal state after it has been stressed by the applied voltage. Of course, these effects exist to a more or less extent, depending on how well the condenser has been designed and how well it has been constructed.

Leakage Resistance in a well designed condenser is relatively unimportant.

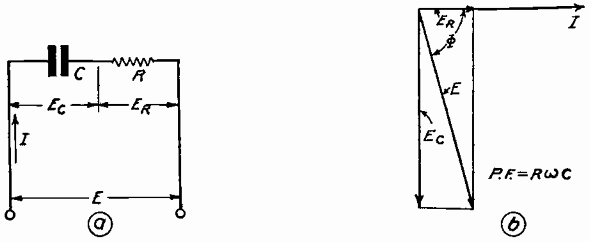


FIG. 4

In effect it approximates an ideal condenser shunted by a high resistance as shown in Fig. 3a. The shunt resistance R has the effect of making the total current I lead the line voltage E by less than 90 degrees, as shown in Fig. 3b. The value of the shunt resistance would depend on how imperfect the dielectric is as an insulator. The exposed surface becoming dirty and moist, the dielectric absorbing moisture and the surface between terminals of the condenser becoming conductive reduces the value of the shunt resistance. Condensers of the solid type are usually baked in a vacuum type furnace and impregnated with some type of insulating material to keep moisture out and have a high surface resistance. The condenser is enclosed in a bakelite, tin or other protective box and the terminals kept well apart. Thus leakage contributes a relatively small loss in the modern solid dielectric condenser.

The ratio of A.C. current through the shunt resistor to the A.C. current through the condenser will be proportional to the power factor* (p.f.) of the condenser if the p.f. is small. The power factor of an arrangement such as shown in Fig. 3a will be given by the formula:

$$p.f. = \frac{1}{\omega RC} = \frac{1}{2\pi fRC} \tag{7}$$

* Power factor is the ratio of the current or voltage in phase with the line voltage or current and the total current or applied voltage. It is always less than unity (1).

Clearly for low frequencies a large part of the line current will be shunted through the leak resistance. A large leakage resistance will reduce the shunt effect. For a given condenser, a large ratio of R to C is quite desirable for low frequency operation.

Series Resistance may introduce serious effects at high frequencies. Figure 4a shows the arrangement in symbolic form, while Fig. 4b shows the division

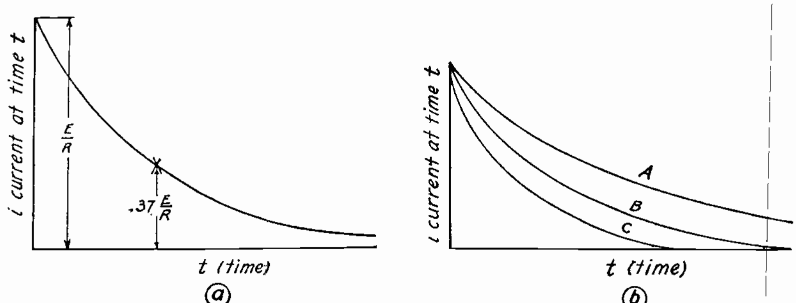


Fig. 5

of voltage across the condenser and series resistance. In this case the power factor is ωRC and the power loss will be

$$P = E^2 \omega C \times p.f. \tag{8a}$$

or $$P = E^2 \omega^2 C^2 R \tag{8b}$$

Thus at high frequencies the effect of even a small series resistance may result in large losses. The generated heat may be sufficient to heat the dielectric and make it conductive, resulting in a break-down. In fact, in a high voltage high frequency condenser, adequate cooling of the condenser is imperative.

Non-inductive type condensers, see Fig. 22, good contacts at the plate to

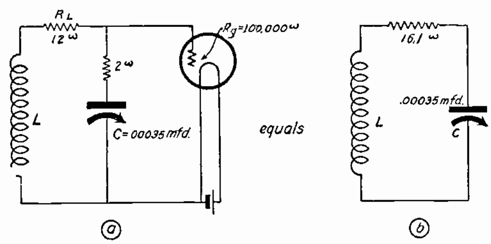
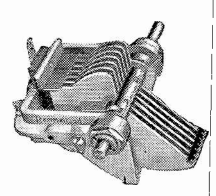


Fig. 6



COURTESY HAMMARLUND MFG. CO.

Fig. 7a

lead connection, plates made of low resistance material will prevent heat dissipation in the condenser unit. Only high grade condensers may be used in high frequency circuits where high voltages exist. Mica, air, and oil dielectric condensers are the rule.

Corona Discharge occurs only in high voltage condensers. It is only important in transmitting type capacitors. The plates must have smooth edges and air and gases which help to establish corona must be removed. In receivers the effect is essentially absent. It is worth remembering that corona losses vary as the square of the voltage.

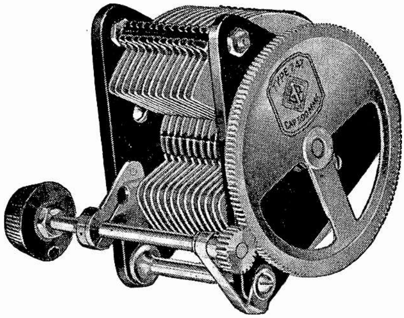
Dielectric absorption is perhaps the most serious of all the losses present in condensers. The fact that a condenser absorbs or soaks up energy which requires power to remove when used in an A.C. circuit results in heat loss. The effect of absorption is equivaent to a resistance in series or parallel with a perfect condenser. It is usually expressed as the "equivalent resistance" in *series* with a condenser.

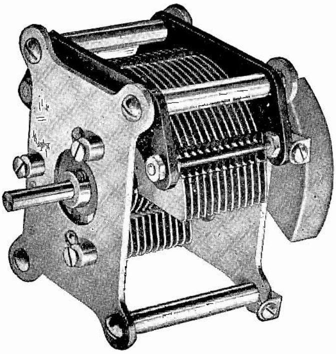
The power factor due to absorption is, in practice, independent of the condenser capacity, applied voltage or the frequency of operation. It is essentially dependent on the dielectric used. The power factor of the dielectric is an estimate of the absorption effect. Therefore, the loss is computed as in the series resistor case, having constant power factor, formula 8a. The power loss for a given condenser increases rapidly with voltage, and less rapidly with the frequency of operation.

EQUIVALENT SHUNT AND SERIES RESISTORS

Given a condenser operating at a definite frequency, voltage and temperature, the loss may be expressed as either a series or shunt resistor. In handling radio problems one may have advantages over the other.

A resistor R_{SERIES} in series with a condenser may be expressed as a





COURTESY GENERAL RADIO CO.

FIG. 7b

FIG. 7c

resistor R_{SHUNT} in shunt with the same condenser or vice versa, by means of the following formulas:

$$R_{\text{SERIES}} = \frac{1}{(2\pi f C)^2 \, R_{\text{SHUNT}}} \tag{9}$$

$$R_{\text{SHUNT}} = \frac{1}{(2\pi f c)^2 \, R_{\text{SERIES}}} \tag{10}$$

In R.F. transformer circuits where the secondary resistance is reflected into the primary (this you will learn elsewhere), it is necessary to know the total R.F. resistance in series with the coil and condenser. A typical case is shown in Fig. 6a. In this circuit the major resistance will be in the coil L and a smaller amount in the condenser C which may be expressed as a series resistor. The condenser is shunted by the grid-cathode terminals of the following vacuum tube amplifier. If the latter is an R.F. triode amplifier, the grid input resistance R_g may be any value from + 100,000 to —100,000 ohms, depending on the impedance in its plate circuit. This shunt resistance must be expressed as a series condenser resistance in order that it may be added to the others. Assuming R_g equal to 100,000 ohms (an ideal condition), the facts given in Fig. 6a and using formula *9*, we obtain:—

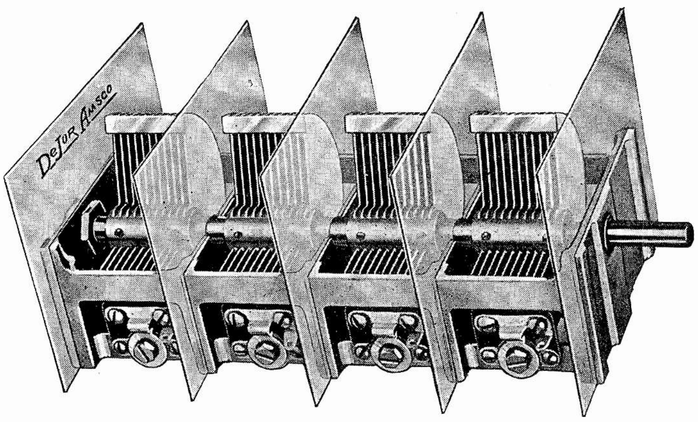
$$R_{\text{SERIES}} = \frac{1}{(2 \times 3.14 \times 10^6 \times .00035 \times 10^{-6})^2 \times 100{,}000}$$

$$= \frac{1}{(6.28 \times .35 \times 10^{-3})^2 \times 10^5} = \frac{10}{(2.2)^2} = \frac{10}{4.8}$$

$$= 2.1 \text{ ohms.}$$

This resistance should be added to the other two giving $12 + 2 + 2.1$ equal to 16.1 ohms. Should R_g have been —10,000 ohms, R_{SERIES} would figure out to be —21 ohms, giving a total series resistance of $12 + 2 - 21$ equal to —7 ohms, in which case the triode amplifier would be set into oscillation.

In practically all cases, the worth of a condenser is expressed by its power factor, computed by considering the equivalent series resistance due to all



COURTESY DEJUR-AMSCO CORP.

FIG. 7d

losses. When the power factor is given, the equivalent series resistance may be computed from the formula

$$R_{\text{SERIES}} = \frac{\text{power factor}}{2\pi f C} \tag{11}$$

VARIABLE CONDENSERS USED IN RECEIVERS

As its name implies, a variable condenser is a condenser whose capacity can be varied to suit different conditions of operation.

While variable condensers may be made with dielectrics other than air, practically all condensers of this type use air as the dielectric material. It is taken for granted, therefore, that an air condenser is referred to, unless otherwise specified, when a variable condenser is mentioned.

Variable condensers differ considerably in their constructional characteristics, the design and spacing of the plates, but they consist, essentially, of two sets of plates with air between them.

A number of different types of commercial variable condensers are shown in Figs. 7a, b, c, and d.

The one shown in Fig. 7a uses a sturdy "U" frame on which the working parts of the condenser are mounted and held in rigid alignment. Good, serviceable bearings are built into the ends of the "U" shaped frame to hold the rotor on which the "rotary" plates are mounted.

The stationary (stator) plates are mounted on a piece of bakelite material which in turn is securely fastened to the bottom of the "U" frame. The rotor is hollow, permitting the insertion of the rod to which the dial on the panel is fastened.

Two terminals are provided, one to make connection with the stationary plates of the condenser and the other for connection to the rotary plates.

The plates are made of brass which has been specially treated to maintain its rigidity and alignment. The rotary plates are soldered to the rotor shaft and are also soldered to a thin connecting strip at the ends, so there will be good electrical contact between plates with an absolute minimum of resistance. Soldering them together in this way also helps to keep the spacing of the plates accurate, and to maintain the capacity of the condenser constant at the various settings.

The individual stationary plates are also soldered to connecting strips or bars, to minimize resistance losses and to maintain accurate spacing.

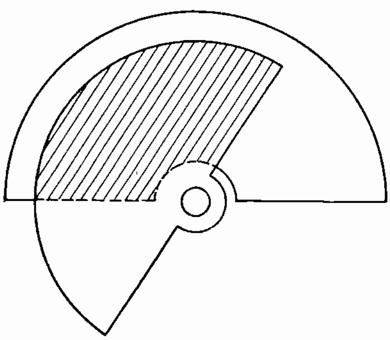


FIG. 8

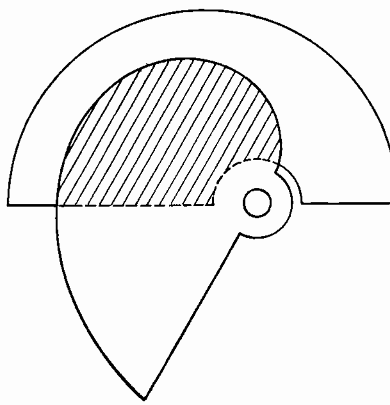


FIG. 9

The connection between the rotor plates and the frame, which serves as the terminal for the rotor plates, is made by means of a flexible spring to insure good contact at all times. There is a tiny brake mechanism at the far bearing which permits adjustment of the tension on the shaft.

A stop is attached to the rotor shaft to eliminate the strain which would be placed on the condenser plates if the condenser plates themselves were used as the stopping means at the two extremes of the condenser setting.

The comparatively small amount of material used in the frame, and the fact that it is designed so that most of the metal is some distance away from the condenser plates, serve to keep eddy current losses in the supporting framework at a minimum. (Eddy currents are induced into the frame by the flow of high frequency current in the condenser plates and leads.)

In the condenser shown in Fig. 7b, two triangular pieces of hard rubber strongly braced and held in alignment by means of separating pillars provide the framework for mounting the condenser plates, and hold them in rigid alignment.

In this condenser, brass is also used for the plates with the plates in each set of plates securely soldered to connecting strips to prevent resistance losses due to poor contact between the plates.

Accurately fitted bearings and soldered lap joints hold the plates in perfect alignment with each other and provide good contact between the rotor plates and their terminal mounted on the framework.

A fine control of the movement of the rotor plates is provided by the gear and pinion shown which permit minute changes of capacity. This is in addition to the main knob control.

This type of hard rubber endplate construction results in very small eddy current losses at very high frequencies and is particularly adapted for use in short wave receivers.

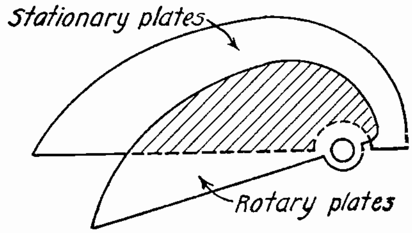


FIG. 10

The condenser shown in Fig. 7c is of the metal endplate type in which the framework of the condenser consists of two metal endplates, held rigidly in place by means of metal pillars. The advantage of the metal endplate condenser lies in the shielding effect of the metal plates which eliminates the hand capacity effects which may be produced when the condenser is mounted directly behind the panel, so that the hand is close to the plates in making adjustments. If a condenser is mounted at some distance back of the panel, so that the hand of the operator does not come near the instrument in making adjustments, this feature is not very important. On the other hand, the use of metal endplates introduces eddy current losses at high frequencies which are not met with in condensers where the metal supporting frame work is reduced to a minimum or where hard rubber endplates are used.

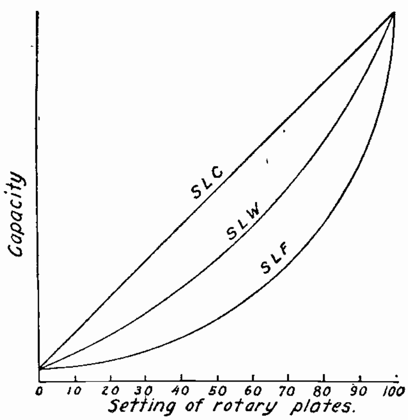


FIG. 11

The condenser shown in Fig. 7d is a standard type of ganged condenser in which several condensers are mounted on a single shaft. All of the rotor plates are connected together through the shaft, but separate terminals are provided for each set of stator plates so that a condenser of this type, having four separate units, can be used to tune four different circuits simultaneously. To permit of adjustment for any slight inequalities in the capacities of the units, small capacity "trimmer" condensers are mounted on the side of the assembly near the individual units, each of which can be adjusted independently to bring the large units into step with each other.

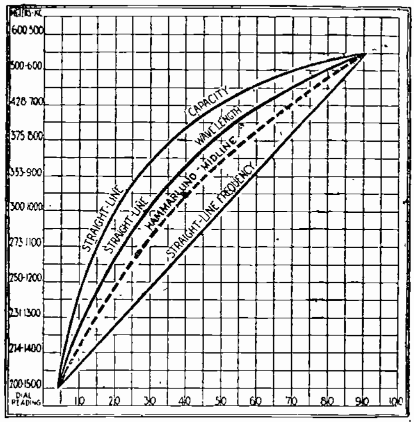


FIG. 12

CONDENSER CHARACTERISTICS

When both the stationary plates and the movable plates of a condenser are semicircular in form, as shown in Fig. 8, the change in capacity of the condenser is very nearly proportional to the angle of rotation of the dial or the number of degrees change in the setting of the rotary plates.

This type of condenser is used in measuring-instruments where it is desirable to have the capacity of the instrument or capacity in the circuit change in direct proportion to the angular movement of the condenser dial. Curve *SLC* in Fig. 11 is the curve obtained with this type of condenser when angular

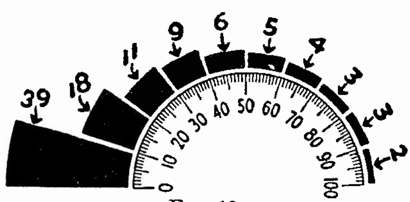


FIG. 13

movement of the dial is plotted against capacity, and explains why this type of condenser is called a "straight line capacity" condenser.

When angular displacement is plotted against frequency in kilocycles in the case where the condenser is connected to a radio frequency coil, the curve (*SLC* in Fig. 12) shows clearly why this type of condenser is not well suited for use in receiver tuning circuits. Notice that the curve is very steep at the higher frequencies (low wavelengths) and flattens out at the lower frequencies (high wavelengths). This means that in the high frequency range, stations equally spaced from each other by a given number of kilocycles will be crowded together on the dial readings, while those at the other end of the scale will be comparatively far apart.

An attempt at more equal spacing was made by designing straight line wavelength condensers to vary the capacity so that wavelengths of equal differences were separated evenly on the condenser dial.

While this type of plate design, shown in Fig. 9, relieved the crowding somewhat at the high frequency end of the tuning range, it was still not satisfactory since stations are spaced by Federal law in terms of equal kilocycle intervals from each other to prevent interference and heterodyning.

By further changing the design of the condenser and using plates shaped as shown in Fig. 10 so as to produce a slight change in capacity for a given change in angular movement at the low capacity range of the condenser, and a sharp change in capacity for a given angular movement in the condenser at the high capacity range of the condenser, a straight line *frequency* condenser was obtained.

In this type of condenser, the change of capacity for a given angular change at different parts of the dial is shown by the curve marked *SLF* in Fig. 11.

VARIOUS TYPES OF CONDENSERS

The effects of using tuning characteristics of various types on the spacing of stations on the dial are shown graphically in Figs. 13, 14, and 15 worked out by a radio condenser manufacturer.

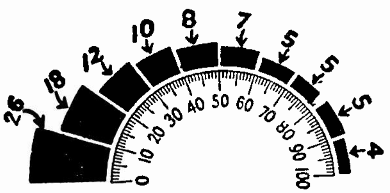


Fig. 14

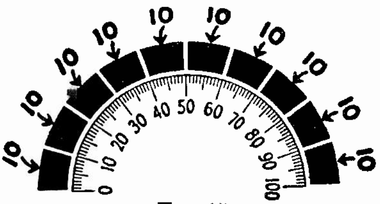


Fig. 15

There are 95 broadcasting frequency bands (10 kilocycles apart) in the broadcasting range of 1,500 to 550 kilocycles. When tuning a radio receiver with the ordinary *straight line capacity* condenser, the number of frequency bands brought in for each ten divisions on the dial are as shown in Fig. 13. This shows that almost 60% of the station frequency bands are crowded into the first 20 divisions of the dial, while the number of station bands for each of the additional 10 divisions on the dial gradually diminishes until only 2% come in on the last 10 divisions.

The *straight line wavelength* type of condenser whose tuning characteristics are represented in Fig. 14 reduces the crowding at the lower end of the scale and gives somewhat better distribution of the frequency bands over the dial scale, but there is still too much crowding at the lower end.

The straight line frequency type of condenser, however, as shown in Fig. 15, distributes the stations equally over the dial scale.

Due to the higher power of the stations at the lower frequency bands (higher wavelengths), it is desirable to have somewhat greater separation (fewer frequency bands tuned in) at the lower frequencies. See Fig. 12 for curves. The Midline characteristics represented by the dotted curve between the straight line frequency and the straight line wavelength curves are the result of a study by a prominent condenser manufacturer with a view to designing a tuning characteristic for a condenser to provide adequate spacing and eliminate overcrowding with due regard to present assignment of wavelengths.

The most important considerations to keep in mind, in selecting or designing an efficient variable condenser, are:

1. Minimum and Maximum Capacity Characteristics

Because of the capacity existing between the plates at the minimum settings, due to close relation of parts of both sets of plates and the insulation material used to mount the two sets of plates in relation to each other, a condenser with zero capacity at zero setting of the dial cannot be constructed. The minimum capacity, however, should be kept at a very small minimum. The minimum and maximum capacities of the condensers should be such as to permit tuning through the whole frequency range of the stations it is desired to tune in, when used with a coil of a given inductance. A zero capacity of 1/10th of the maximum capacity is considered good.

2. Change of Capacity with Angular Movement of Dial

It is desirable, although not absolutely essential, that means for fine adjustments be provided, that the plates be designed for a happy medium between straight line wavelength and straight line frequency characteristics.

3. Resistance Losses

It is important that resistance between plates and between their terminals be reduced to a minimum because high series resistance in a condenser results in decreased sensitivity and broad tuning in the tuned circuit.

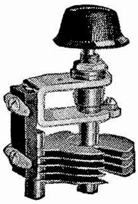
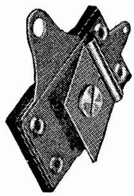


Fig. 16



COURTESY HAMMARLUND MFG. CO.

Fig. 17a

4. Leakage Losses

Low dielectric resistance and absorption losses, due to the use of poor dielectric material, or the use of large pieces of dielectric material in the strong parts of the electrostatic field, results in losses in signal strength in the tuned circuit and broad tuning.

5. Plate Material

Material used in the plates should be treated to maintain rigidity and avoid capacity changes due to bending or warping of plates. It should preferably be brass so that plates in a set can be soldered to reduce resistance. Plates should be cut clean with no fuzzy edges to give rise to *corona effects;* that is, if the condenser plates are at a high potential, the charge will leak off through the air from the sharp edges.

6. Bearings

It is important that bearings be rugged and proof against ordinary wear. Wearing of bearings, causing poor alignment and wabbling, results in uncertain settings and is especially apt to prove troublesome in ganged condensers due to individual units not lining up, thus producing low tuning efficiency.

7. Terminals

Terminals should be readily accessible for wiring and for making any necessary changes in circuit connections. Contacts to terminals should be positive so there will be minimum resistance between wiring and terminals and between terminals and plates.

8. Mounting

Mounting means provided on the condenser should be such as to permit mounting in positions which will not tend to distort the mechanism or affect the electrical characteristics of the condenser. Condensers should be mounted so that their shafts line up with the dials or adjusting means without placing undue strain on either the condenser or the dial.

The maximum capacity required in a variable condenser depends largely on the inductance with which it is to be used and the wave band which it is desired to cover.

Condensers designed for use in short-wave circuits are usually made to have maximum capacities of .0001, .00015, or .00025 mfd. Condensers for general testing designed to cover the broadcast wavelengths or frequencies with standard coils are made with maximum capacities of .000275, .00035 and .0005 mfd. Condensers having a capacity of .001 mfd. are now seldom used except in special testing instruments.

Where variable air condensers of very small capacity are required for balancing circuits or to line up several condensers for ganged or single control, miniature condensers, such as the one shown in Fig. 16 are often employed.

These units are usually made with maximum capacities of .000016, .000032, .00005, .000065 or .0001 mfd.

In recent years, small two-plate book-type condensers, using a single sheet of mica for the dielectric, mostly for protection against shorting of the two plates, have been used extensively when condensers of small capacity are required.

A condenser of this type is shown in Fig. 17a. In this type of condenser one plate is fastened to a piece of bakelite and covered with a thin sheet of mica. The other plate has a spring hinge at one end. Adjustment is made by means of the screw which passes through clearance holes in the mica and bottom condenser plates and screws into the bakelite mounting. These units are made in capacities of 35 or 70 micro-microfarads (.000035 or .00007 mfds). Fig. 17b shows another type of book condenser that may be had in ranges of .000008 to .001 mfd. maximum.

When several individual condensers must be ganged together but circuit requirements demand that they be insulated from each other, a flexible coupling as shown in Fig. 18 is employed.

This type of coupling contains two bushings, each of which can be fastened to the shafts of the condensers to be ganged together. These bushings are provided with two spiders which are connected together by insulated rivets. Because of the flexibility of this type of coupling, the separate units do not have to be exactly in line.

MICA CONDENSERS

The next most generally used condenser in circuits where a fixed capacity is required is the mica condenser. Here, again, the condenser is composed essentially of two sets of plates separated by dielectric material to give the required condenser effect.

While the mica condenser appears to be a very simple electrical unit, its effectiveness depends largely on the care and skill used in its construction and the quality of the materials used.

The plates of the condenser are made of carefully cut smooth sheets of tinfoil. The tinfoil is as thin as it can be made without being too fragile or having any considerable resistance in each leaf.

The mica used as the dielectric material is usually India Ruby Mica, which has been found to be best suited for this use because of its even thickness, ease of handling, and uniform electrical characteristics.

The mica is cut into thin sheets of the required area and each thickness is accurately gauged, inspected and tested for physical and electrical characteristics.

The alternate layers of tinfoil and mica are assembled in special jigs until a stack of the required number of layers for the particular capacity in production is obtained.

The condenser element is then thoroughly impregnated with a special compound which fills every minute cavity of the assembly to prevent the entrance of moisture which would be likely to cause change of capacity. This impregnating is done under very high pressure which presses every layer of mica and tinfoil into a practically solid mass.

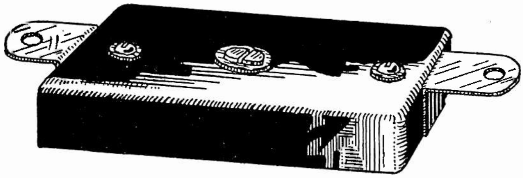


FIG. 17b

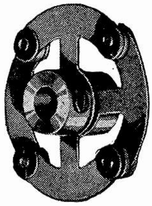


FIG. 18

In the early types of mica condensers, this element was then mounted between two slabs of rigid bakelite and the whole clamped together firmly by metal clamps, to prevent loosening of the structure, due to the mechanical stresses set up in it by the action of the current.

A condenser of this type, fitted with grid leak mounting clips, is shown in Fig. 19.

Most of the small capacity mica condensers now used generally in radio circuits are of the moulded Bakelite type. After being thoroughly impregnated and pressed together, a Bakelite case is moulded around the assembly which seals it and protects it against extreme temperatures, moisture and chemical action. The Bakelite mould also holds the element in its original form, proof against mechanical action or distortion.

Two of the most generally used types of these units are shown in Fig. 20.

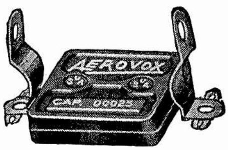


FIG. 19

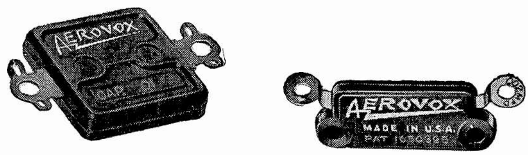


FIG. 20

Most mica condensers are made to withstand a working voltage of 1,000 volts D.C. In practically all cases they will easily withstand voltages as high as 3,000 to 5,000 volts D.C. for short periods before they break down. Since these condensers are used mostly in circuits where the voltages are seldom in excess of 100 to 200 volts, their life is practically unlimited.

Because of the constancy of the capacity of mica condensers even under various frequencies, and the extremely low losses in such units, mica condensers are often employed as standards of capacity where it is either too costly or too cumbersome to use air dielectric condensers. Condensers made for general production are usually made to a precision of 10% of the marked rating, but they can be and are often made to closer precision for receiver manufacturers who require very precise capacity values in order to keep their receiver characteristics uniform.

Because of the greater difficulty of making condensers in quantity to very precise limits, their cost is much higher than for standard production.

The standard values of capacities in which these units are available are from .00004 to .02 mfd. Higher or lower values of capacity can be obtained on special order or may be made up by properly connecting available units in series or in parallel.

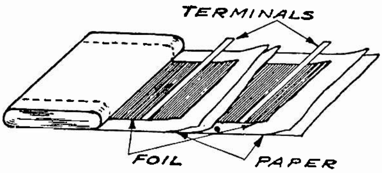
PAPER CONDENSERS

Where comparatively high capacity condensers are required, the use of air condensers is out of the question because of the great expense which would be involved in constructing condensers large enough to have a capacity of even as low as .1 mfd.

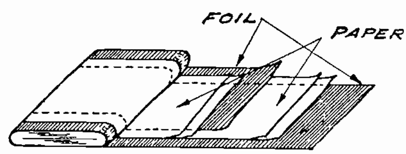
While mica condensers of high capacity can be constructed, the cost involved when units of capacities higher than about .02 mfd. are required rules out this type of condenser except in cases where very accurate condensers of very low losses are absolutely necessary and cost is not a primary consideration.

In recent years, the paper dielectric condenser has been developed to such a high degree that this type of condenser is used generally for all bypass and filter requirements where high capacities are required and where electrolytic condensers cannot be used.

A paper condenser consists of two sets of plates separated by a dielectric



Inductive Winding
FIG. 21



COURTESY AEROVOX WIRELESS CORP.
Non-inductive winding
FIG. 22

material consisting of a special grade of paper. Paper condensers may be made by stacking up layers of metal foil and sheets of paper, but the most generally used construction involves winding long strips of foil, separated by one or more layers of paper.

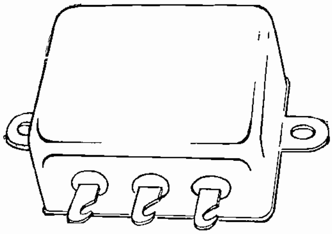
After the winding is completed (the amount of material wound on a form depends on the capacity required and the voltage to be withstood), the roll is flattened and is made ready for further treatment.

In one type of winding, the inductive type of condenser, shown in Fig. 21, the tinfoil or aluminum foil strips are narrower than the separating paper dielectric strips. In winding a so-called two-paper condenser shown in the illustration, one layer of foil is backed by two layers of the paper; then comes another layer of foil, which is completely insulated from the other layer of foil by the paper layers. This second layer of foil is then backed by another two layers of paper. When the unit is wound, it will be seen that one layer of foil is completely insulated from the other by two layers of paper through the whole process of winding. When the condenser is wound to the required capacity, the inside layer of foil is cut and a thin brass or copper strip is inserted as shown, projecting through the end of the winding to serve as one of the terminals. A length of the paper which separates the two layers of foil is allowed to project beyond the end of the inner layer of foil to insulate the two layers of foil from each other. Another thin terminal strip is then inserted to make contact with the outer layer of foil. The outer foil is then cut and a few turns of the outer two layers of the paper are wound around the section several times to protect the unit against harm.

In the non-inductive type of winding shown in Fig. 22, both layers of foil and the paper layer are of the same width. The layers of foil and paper are staggered in winding as shown, so that one layer of foil protrudes at one end while the other layer protrudes at the other end. In this type of winding, each turn of foil for each set of plates connects to the adjacent turn.

In the inductive type of winding, the elements, instead of being all capacity, also have considerable inductance because of the manner in which

FIG. 23a



COURTESY ACRACON CONDENSER CORP.

FIG. 23b

they are wound. Under certain conditions, the inductance may be of a high enough value to nullify the effects of the capacity of the condenser or to produce resonance at certain frequencies. In some cases condenser manufacturers have been known to connect the inside end of the foil winding with the outside end of the winding and call the winding a non-inductive winding. This is, of course, ridiculous, since such a connection merely results in a short-circuited coil which has a definite value of inductance.

Another bad feature of the inductive type of winding is the resistance which it introduces in the condenser. A long strip of foil has a measurable

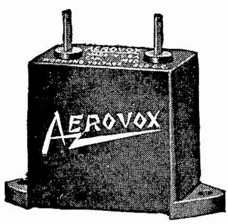


FIG. 24

resistance. If each adjacent layer of foil in a set of plates formed by the winding process is connected to the next layer so that each layer is short-circuited, as is done in the non-inductive winding shown in Fig. 22, the resistance of the layer is nil, since all the layers are connected together. In the inductive winding, however, there is an appreciable resistance between different points in the length of the foil of each layer which results in heating and losses in the condenser and consequently in the circuit in which it is used.

It will also be found that the inductive winding, while cheaper because it uses less foil for a given capacity, introduces mechanical weaknesses due to the creases resulting from pressing the terminal strip across the section and also because of the fact that both edges of the foil layers have a tendency to cut into the paper, whereas in the non-inductive winding only one edge of each foil layer lies between the paper layers.

In making high grade paper condensers great care must be exercised in the selection of the foil and the paper and the manner in which they are assembled.

While tinfoil was used almost exclusively as the plate material several years

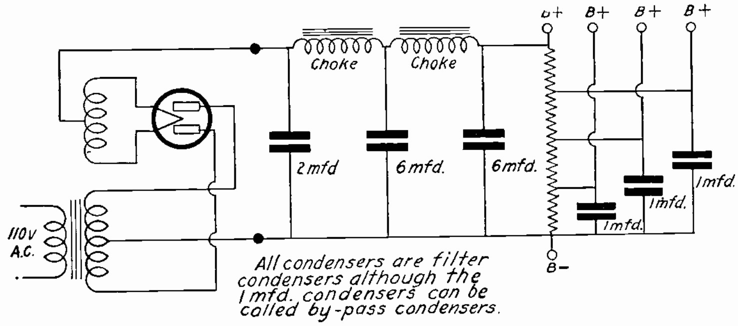


Fig. 25a

ago, due to its smoothness, uniformity, purity, workability and the ease with which terminals could be soldered to the ends of the sections, the perfection of a method for making good soldered connections to aluminum foil has resulted in a general use of aluminum foil in present day paper condensers. Aluminum foil has all the advantages of tinfoil and the additional advantage of lower cost.

The foil used in the manufacture of condensers must be free of wrinkles, uniform in characteristics, free from impurities which would tend to weaken

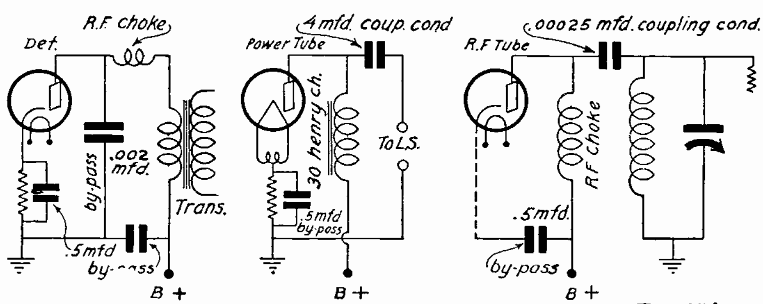


Fig. 25b Fig. 25c Fig. 25d

it and of the proper temper to "stay put" when tightly rolled, and pressed under heavy pressure.

The paper used is made especially for that purpose. It is a fine grade of pure linen paper and is very expensive as judged by the prices of other types of paper. It must be free from acid, alkali, metal particles no matter how minute, and other impurities which would tend to weaken the dielectric characteristics and life of the paper under operating conditions.

So important is it to be sure that no impurities in sufficient quantities to cause harm are contained in this paper, that representative qualities of each lot are carefully tested by quality condenser manufacturers to make sure that none but the best paper is used in the manufacturing process. Slight impurities which would seem to be of minor importance are sufficient to ruin thousands of dollars worth of condensers. If such condensers are allowed to get into a receiver, they may easily ruin the reputation of the receiver manufacturer and cause no end of trouble by breaking down in service.

After being wound and pressed together to obtain compactness and a close relation between the layers to prevent variation in capacity and mechanical movement, the sections are thoroughly impregnated by special compounds to prevent the absorption of moisture which would tend to change the capacity of the unit and produce disintegration of the paper.

INSULATION SPECIFICATIONS OF PAPER DIELECTRIC CONDENSERS

Maximum D. C. Working Voltage	Maximum A. C. Working Voltage	D. C. Retest Voltage (15 sec.)	Total Number of Papers	No. of Papers Between Plates	Thickness of Each Paper in Inches	Total Thickness of Insul. Bet. Plates
			200-Volt Series			
200	125	400	4	2	.0005	.001
			300-Volt Series			
300	175	600	6	3	.0004	.0012
			400-Volt Series			
400	250	800	6	3	.0005	.0015
			400-Volt Series			
400	250	800	4	2	.001	.002
			500-Volt Series			
500	300	1000	8	4	.0004	.0016
			600-Volt Series			
600	350	1200	8	4	.0005	.002
			800-Volt Series			
800	440	1600	10	5	.0005	.0025
			1000-Volt Series			
1000	600	2000	12	6	.0005	.003
			1000-Volt Series			
1000	600	2000	6	3	.001	.003
			1500-Volt Series			
1500	800	3000	12	3 3	.0005 .001	.0045
			2000-Volt Series			
2000	1100	4000	12	6	.001	.006
			2500-Volt Series			
2500	1300	5000	14	7	.001	.007

FIG. 26

The sections are finally assembled either in metal cans as shown in Fig. 23a and 23b or in bakelite cases as shown in Fig. 24.

Small bakelite and metal housings are used in radio or audio frequency by-passes or for any other purpose where it is desirable to prevent direct connections between terminals yet where the A.C. current must flow.

The name "condenser," of course, applies to all capacities, but usually a condenser has some other term prefixed to it in order to denote the physical location of the capacity; that is, its position in the circuit. To be exact, if the condenser is located in the plate circuit of a vacuum tube and is used to provide an easy path for the A.C. component in the plate circuit, causing the latter to flow through the condenser instead of through the other portions of the circuit, it is referred to as a "by-pass" condenser. The word "by-pass" denotes that the condenser offers a low impedance path for a particular current.

A by-pass may be used to allow an easy path for radio frequency or audio frequency currents, and we may even speak of such by-passes as a "radio frequency by-pass" or an "audio frequency by-pass." The grid bias resistance may even have a C bias condenser across it, and this is referred to as a "C bias by-pass." In all A-B-C power supplies, a condenser is used to filter out the A.C. hum or ripple and from this derives the name, "filter" condenser. If a condenser is placed across a voltage divider, it might either be called a by-pass or a filter, but the term filter condenser is more appropriate and best adapted to its use.

When two circuits must be connected together so as to allow an A.C. current to flow between them, to prevent any D.C. current from flowing, a condenser is employed. Such a condenser will either be large or small, but in this instance is referred to as a "coupling" condenser, deriving its name from the purpose; that is, coupling of the circuits. Fig. 25 shows several "hook-

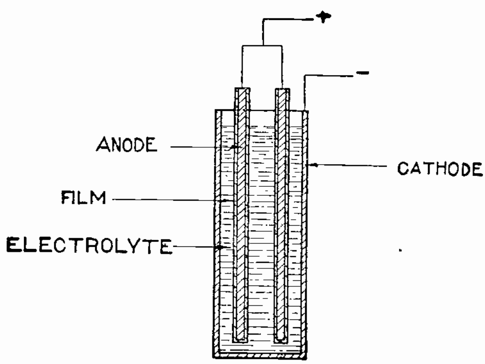


Fig. 27

ups" with condensers shown and with the proper notations of the condensers included.

When several condensers are to be used close to each other, as is the case in power supply filter units, a number of sections are mounted together in a single can with separate leads brought out through a terminal strip, with solder lugs, as shown in Fig. 23a.

In some cases it is desirable to use flexible rubber covered leads in place of solder lugs to prevent the leakage between terminals which usually occurs when a number of terminals are mounted close together on a fiber or bakelite terminal strip.

In using paper condensers it is important not only to know the capacity of the units but also their working voltage.

Just as the floors of a building must be built to withstand a given load safely, depending on the number of people and the probable weight of equipment that is to be used on the floor, so, too, condensers must be made to withstand the working voltages that are to be applied to them.

The working voltage of a condenser is determined largely by the thickness of the dielectric or layers of paper that are used between the foil plates, and the number of layers of dielectric material used between the plates.

A table showing the insulation specifications of the complete line of high grade paper condensers, giving the corresponding D.C., A.C., and D.C. retest voltages at which different types of condensers made by one manufacturer are rated and the thickness and number of layers of dielectric used between the plates, is shown in Fig. 26.

It will be noted that the thickness of dielectric is made up by using several layers of paper rather than by using a single layer of greater thickness for greater dielectric strength. This is explained in part by the fact that, due to the law of averages, weak spots in successive layers rarely coincide in position, so that there is less likelihood of having weak spots if the dielectric is laminated. It is also found that thin materials usually have greater electrical and mechanical unit strength than heavier materials.

In use, the condenser is actually submitted to considerable electrical and mechanical strain and stress so it is desirable to select a condenser that has been conservatively rated to withstand the voltages that it will be called upon to handle in actual use. These ratings are arrived at only after careful testing over long periods of time and are entirely the result of a condenser manufacturer's experience with condensers made with the materials and according to the processes he is using. It is, therefore, desirable to use condensers made by manufacturers whose experience in the field is unquestioned.

ELECTROLYTIC CONDENSERS

Certain metals, particularly aluminum for commercial purposes, when immersed in an electrolyte—that is, an alkali dissolved in water—possess the property of allowing electricity to flow in one direction and not in the other, within certain voltage limits. In this respect, the device is an electrolytic rectifier.

If a current is passed from the aluminum electrode to some other electrode, and the aluminum electrode is connected to the positive side of a D.C. supply, a film of aluminum oxide will form on the aluminum electrode. This film will be extremely thin and have a high dielectric strength, in excess of several million ohms per square inch. The usual wet electrolytic condenser makes use of this phenomenon of film formation, employing the aluminum electrode as one plate, the film formed as the dielectric and the copper can which contains the electrolyte as the other plate (see Fig. 27). The aluminum electrode is referred to as the "anode" and the copper can as the "cathode." The anode is always connected to the positive side of a D.C. circuit and the cathode to the negative side.

Realizing that the dielectric film forms only when positive potentials are applied to the aluminum, the condenser can be used only where direct potentials or pulsating direct potentials are applied. In other words, an electrolytic condenser cannot be used directly on alternating currents.*

Fig. 28 shows a Mershon electrolytic condenser which contains three condensers in a single unit. This particular battery of condensers is enclosed in a seamless copper container, approximately 4⅛ inches high and 3¼ inches in diameter. Electrolytic condensers are made in various diameters, usually 1⅜, 2½ or 3 inches, depending upon how many units are placed in one container, the capacity of the individual units in microfarads, and the design. Fig. 28 shows the cut-away of the condenser proper. You will note that the container is fitted at the open end with an insulating cover, to which the anodes of aluminum are attached. The cover serves to retain the electrolyte

* By using two electrolytic condensers in series opposing (positive to positive or negative to negative terminals) they may be used in A.C. circuits. If two similar condensers are used, the capacity is reduced one-half but the working voltage remains the same. An A.C. electrolytic condenser using tantalum for both plates is being used.

and acts as an insulating panel between the various anodes and between the anodes and the container.

The electrolyte consists generally of a solution of Borax and Boric Acid, dissolved in distilled water. The copper container provides a means of making an electrical connection to the electrolyte which forms the cathode or negative element of the condenser.

Spilling out of the liquid is prevented by a soft rubber gasket between the cover and container, and a one-way rubber expansion vent allows the gases to come out, but not the liquid. The top rim of the container is turned down against this gasket in manufacture, also to prevent the electrolyte from leaking out. This condenser is called the wet type. When the electrolyte has the consistency of syrup, the condenser is referred to as the semi-dry type; when made into a paste the condenser is of the dry type.

In the wet type condenser, the anodes generally consist of hard-drawn

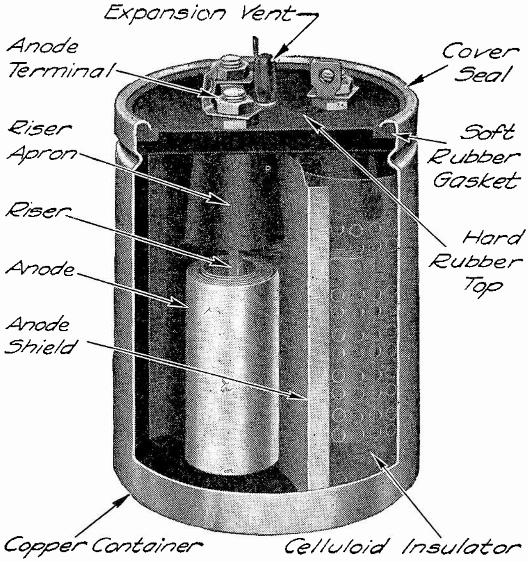


FIG. 28

aluminum strips, 2 inches wide and .010 inch thick and of a length depending upon the desired capacity in microfarads. One end of the strip is riveted and welded to a "riser," having the exposed end threaded. The strips are then rolled up and allowed to expand in such a way that practically no contact is made in the entire spiral formation. The riser is bolted to the hard rubber top and a soft rubber apron is placed directly above the aluminum anode and held firmly against the hard rubber top, thus preventing any possibility of electrical conduction from the anode over the hard rubber surface to one or the other electrode or to the cathode itself. One of the greatest problems in electrolytic condenser construction is to eliminate absorption, leakage and series resistance, in order that the device itself may work satisfactorily as a filter.

The dielectric film consists, as we have said before, of the aluminum oxide formed electrically on the anodes before the entire unit is assembled. This is done by means of a special "formation" process at the factory, by applying a definite D.C. voltage to the unit for a definite forming time.

Due to the thinness of the oxide film, very large electrostatic capacities are obtained in a small space. An approximate .125 mfd. capacity per square inch of aluminum surface is obtained between one surface of the aluminum electrode and the electrolyte. Due to the construction, both sides of the aluminum anode strip are employed thus making the capacity a quarter of a microfarad (.25) per square inch, when formed at 400 volts. The capacity per square inch varies with the formation voltage. In general, the lower the formation voltage, the thinner the film created, and the higher the capacity. However, the thinner the film, the lower the break-down voltage of the electrolytic condenser. If the film is formed at 50 volts and its capacity compared with a like anode surface formed at 400 volts, the capacity at 50 volt formation will be three times that of 400 volts.

Electrotytic condensers may be had rated at 25 to 500 volts, but for general power pack filtering use, a standard 500 volt electrolytic condenser is essential for the B voltages required in modern receivers.

The limit to which electrolytic condensers will work is not dependent entirely on the break-down strength of the film but also upon the point at which excessive leakage takes place between the anode and the cathode, through the film and the electrolyte. Excessive leakage current usually appears in standard electrolytic condensers at about 500 volts and it is not safe to employ electrolytic condensers when the peak voltage—that is, the voltage at maximum ripple—will exceed 500 volts. An electrolytic condenser designed to withstand a peak voltage of 500 volts is rated at 450 or 10 percent less volts D.C., providing, therefore, for an additional ripple voltage of 50 volts.

When an excessive voltage is placed upon an electrolytic condenser, the unit begins to conduct electricity but immediately heals itself upon the removal of the excessive voltage, providing an inherent self-repairing device worthy of installation in any A-B-C power pack. If the condenser is subjected to excessive voltage or reversed polarity for a short time, no damage will result, as, upon returning to normal condition, the film will automatically build up, restoring the unit to normal. The time required to damage the unit, of course, depends on the conditions. Excessive voltage or reversed polarity causes the electrolyte to boil, resulting in loss of electrolyte and possible excessive pressure within the container. An electrolytic condenser has an indeterminable life and will last indefinitely if the electrodes do not corrode and the electrolyte does not evaporate or dry out. Electrotlytic condensers connected to a rectifier with the can to the positive terminal may destroy the rectifier tube because an actual short exists.

Where D.C. voltages higher than 500 volts require filtering, two 500 volt electrolyte condensers may be connected in series, with a reduction of 50% in capacity. The electrolytic condenser "holds its own" at D.C. voltages having low frequency ripples. In A.C. circuits only, paper condensers alone can be used when large capacities are desired.*

The electrolytic condenser has essentially replaced the paper condenser in the filter section of the power pack of radio receivers. Large capacities are available in a small space. They are light and have a very long life. They are self-healing when surges and reversed voltages are applied. Good electrolytic condensers have three desirable characteristics.

1. As the initial current flowing when a voltage is applied to an electrolytic condenser is quite high, it is important that they have the characteristic of coming to their steady leakage current as quickly as possible. This is referred to as the *come-back* time which must be low, only a few seconds. A

---

* Sheet tantalum less than .001 inch thick as the positive foil and pure sheet molybdenum or molybdenum-tungsten as the negative foil immersed in an alkaline (ammonium borate) or acid (sulphuric) electrolyte is being used commercially where low leakage low power factor condensers are required.

low come-back time indicates low leakage, low loss and thereby reduces internal heating which drys out the electrolyte.

2. They should have a high critical voltage, the voltage above which the leakage current becomes excessive. A normal electrolytic condenser must have leakage current below .25 ma. per microfarad. The critical voltage is determined by the electrolyte and positive foil used. Borax and pure alumi-

These illustrations show electrolytic condensers in a variety of forms; a type for every need. Types *A* and *B* are the universal single section type. Types *C* and *D* are respectively the double and triple section universal types. In these types, mounting on the chassis is made by means of a clamping ring as shown in *A*. Condenser *E* is of the inverted type in which the anode connection passes through a threaded insulation piece. When mounted on the chassis the can or negative electrode automatically makes connection to the chassis. By using an insulating washer the condenser may be isolated from the chassis. Condenser *F* shows an inverted chassis mounted type, with two lug terminals situated on the cover, which is an insulator. Condenser *G* is a small size high capacity electrolytic condenser, having two right angle lugs, which permits riveting or bolting to the chassis. Dry electrolytic condensers are also made in cardboard containers. Type *H* is a two-section high voltage condenser, whereas condenser *I* is a low voltage high capacity bypass electrolytic condenser in a tubular container. Condensers in metallic cans may be of the wet, semi-dry and dry types.

num has a critical potential of 480 volts. Higher voltages may be used if the leakage is not detrimental. Usually only surges are permissible.

3. They should have a low power factor. A power factor of .1 to .15 is considered good, even though it is many times that of a solid dielectric condenser. Heat must be avoided in electrolytic condensers.

DRY ELECTROLYTIC CONDENSERS

High capacity "Dry" electrolytic condensers are based on the same principles of operation as the liquid electrolytic condensers, namely, the valve action or high resistance to the passage of current from the aluminum electrode to the electrolyte due to the formation of a thin film of oxide and gas on the surface of the aluminum electrode.

In the case of the so-called "dry" electrolytic type of condensers, however, the general construction varies from the usual electrolytic type, in that the condenser consists essentially of two aluminum plates separated by an absorbent layer which contains the electrolyte. In this respect the condenser is "dry" to the same extent that dry cells are dry. The three layers are wound in much the same way as the usual paper condenser, but the condenser is then "formed" by applying a voltage across the two aluminum plates. The application of this voltage causes the formation of the film on one of the electrodes which then becomes the positive electrode. The other aluminum layer or terminal merely becomes the means of making contact to the absorbent layer containing the electrolyte. The entire unit is then dipped and coated with wax which prevents the electrolyte from drying out.

One Commercial form of this type of condenser is shown in Fig. 29a and b.

These units are suitable for use only in low voltage circuits not exceeding about 12 volts D.C. They can be used only in D.C. or pulsating D.C. circuits and find their greatest application in "A" battery eliminator circuits when connected in suitable filter arrangements. They are also adapted for use in "A" battery eliminator circuits for operation from A.C. lines when connected through suitable transformers, rectifiers and choke units so that only D.C. or pulsating D.C. of less than 12 volts is applied across them.

FIG. 29a

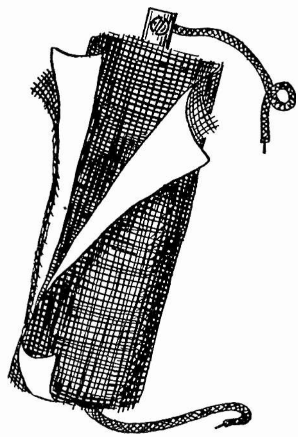


FIG. 29b

They are widely used to eliminate hum in dynamic speakers in which the voltage across the field winding does not exceed 12 volts. Their efficacy in eliminating hum in such cases is due to the filtering introduced by the high capacity of the condenser.

It is very important in using these condensers to connect the positive terminal of the condenser to the positive terminal of the circuit and the negative terminal of the condenser to the negative terminal of the circuit.

The color code usually used in connection with storage batteries, red for positive and black for negative, is used in most condensers of this type. The red lead of the condenser is the positive lead, and the black lead is the negative lead.

On page 27 there is illustrated a number of dry electrolytics. Although the containers differ, the electrolytic condenser unit is made identical to Fig. 29b. They are made to withstand peak voltages of 50 to 500 volts, depending on the initial forming voltage. The high voltage rated condensers are used as filter condensers in powers packs, while the low voltage rated condensers are ideal for by-pass condensers in audio amplifiers, particularly as C bias resistor by-pass condensers.

THE RADIO FREQUENCY AMPLIFIER AND HOW IT WORKS

20 FR-2

PIONEER HOME STUDY RADIO SCHOOL

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

THE VALUE OF REVIEW

Did you get everything you could out of the previous lesson? If you did, you will not have any difficulty with this lesson because it is practically a continuation of the last one.

Do not overlook the value of review at any time. It is a good idea to keep completed lessons handy so that you can refer to them easily. Then again, you may often want to refer to certain diagrams for one reason or another. By studying diagrams a great deal can be learned.

Whenever you have any spare time just pick out a good, complete diagram and study it. Trace through all the circuits and review in your mind the actions of the various currents and the effects of the various parts. You will find this very interesting and instructive.

J. E. SMITH.

NATIONAL RADIO INSTITUTE

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The Radio Frequency Amplifier And How It Works

ANALYSIS OF R. F. AMPLIFICATION

A review of R.F. amplification will materially aid us in our study of radio frequency design.

Let us consider for purposes of review a single stage of tuned R.F. as in Fig. 1, the voltage through the aerial and ground system being supplied by a signal and equal to E_1. It is naturally very small, about 40 microvolts (40/1,000,000 of a volt). A current flows through primary L_1 and induces by mutual induction a voltage in the resonant circuit formed by L_2 and C_2. Should this circuit be tuned to the same frequency as the incoming signal a comparatively large current will flow, building up a large voltage E_2 across L_2.

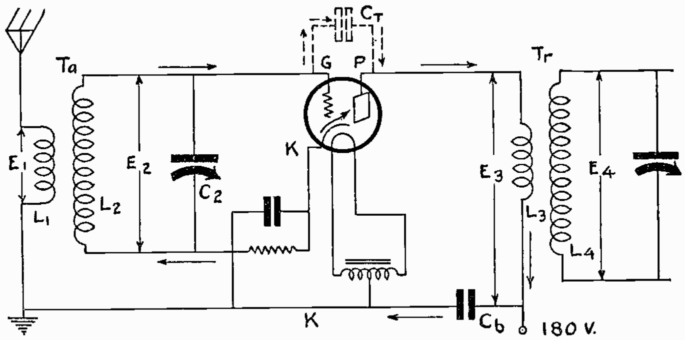

Fig. 1

Voltage E_2 is impressed across the grid (G); and the cathode (K), the grid return. The tube amplifies the voltage E_2 to μE_2. This e.m.f. creates two impedance drops, one in the tube and one due to the load impedance across L_3. The latter includes the impedance of secondary reflected across the primary. Call the drop across the primary E_3. Again by mutual inductance E_3 is raised to E_4 to an extent determined by the effective turn ratio between L_3 and L_4. The ratio of the voltages E_4 to E_2 (E_4/E_2) is what is often referred to as the voltage *gain* of the R.F. stage (R.F. gain). The ratio E_4/E_1 is the overall gain so far.

Although the tube amplification μ may be 8 for an ordinary UY-227 tube the voltage gain per stage may be more or less than 8, depending on receiver design.

It would seem a very simple matter to have one tube stage follow another until enough gain is obtained to give the detector a strong signal. But it is not so simple. Regeneration in each stage largely determines how far this *cascading* of stages can be permitted. The other factors are: side band-cutting, which we already know about; and the mechanical problem of making condensers C_1-C_2-C_3-C_4, etc., exactly alike and perfectly balanced. In fact, the problems are many and difficult for the radio engineer.

What about regeneration, which was the stumbling block for the past few years before the advent of screen grid tubes? The trouble starts right inside the tube. The grid is quite close to the plate (see Fig. 2) and there should be no doubt that because of this mechanical layout there should be a capacity between the grid and the plate. There is, and every tube has a grid-plate capacity C_T (in Fig. 1) and in the case of UY-227 it is about 8 μ.μ.f. (8 micro-microfarads) (.000,000,000,008 farads). This seems very small and it is but it offers a path for radio frequency current. In fact, its reactance will be 20,000 ohms to R.F. current at a frequency of 1,000 kilocycles and so it provides a very good path.

The voltage E_3, we know, besides acting across the inductance L_3, is also across P-K, for by-pass condenser C_b is an exceedingly low reactance for R.F. currents between P-L_3 and K. We don't have to stretch our imaginations to see that this voltage also acts across G-K through the reactance C_T which we estimated to be 20,000 ohms. If the voltage E_3 is in phase with E_2 what happens? It is again amplified by the vacuum tube and the signal further built up. So far so good. But if regeneration, for after all, this is regeneration, which we have already studied, is carried too far, the tube will oscillate and squealing will result.

At lower frequencies, that is, 550 kilocycles, the reactance of C_T will be high and at high frequencies, the reactance will be small. The result is that oscillation is more prevalent at high frequencies (low wavelengths) and hardly noticeable at low frequencies (high wavelengths). This also explains partially why ordinary radio frequency sets are more sensitive at high frequencies—because regeneration boosts a weak signal.

CORRECTING REGENERATION

When only one stage of radio frequency is employed there is not enough regeneration to be objectionable. The problem is of vital importance when two, three or four stages of R.F. amplification are employed. Radio's development clearly shows that this problem was a difficult one to master. For some time only two stages of radio were possible and it has only been in recent years that the multi-R.F. receiver was successful.

In general it can be said that the larger the tube capacity (C_T); the greater the impedance at L_3; and the greater the tube amplification;—the greater the tendency to oscillate. The capacity C_T is strictly more than just the tube capacity. It may include the capacity between wires leading to the grid and plate of the tube and there may even be capacity between the prongs of the tube or the contacts in the socket. These facts are of great importance to the serviceman.

Many valuable methods have been invented to overcome regeneration. And radio receiver performance has made great strides due to them. The methods are of extreme importance to

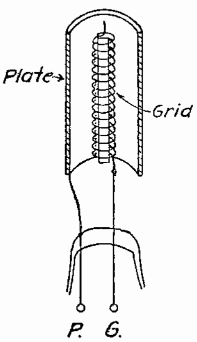

Fig. 2

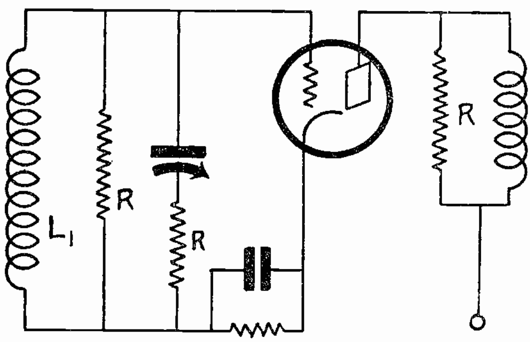

Fig. 3

Radio-Tricians as there are millions of such receivers in existence rendering perfect service but at times requiring adjustment. This is a very good reason for studying this phase of Radio.

The methods of *stabilization,* as elimination of R.F. oscillation is ordinarily called, may be divided into three main groups.

(1) Introduction of absorption to waste the regenerative power; by means of *lossers.*

(2) Counteracting the reactance of C_T; the method better known as *neutralization.* Sometimes this method is referred to as the *bridge* method.

(3) By reversing the phase of E_3 with respect to E_2 so that the signal cannot be reamplified.

A poorly made receiver or an old machine is an example of a complete losser system. For example the coils may be damp and covered with leaky material, the insulation may have spoiled, or the variable condensers may be leaky, or excessive metal may be near or inside the coils with the result that L_2, L_3 and L_4 as well as C_2 may be loaded with resistance and in that way prevent the flow of regenerative currents. See Fig. 3. Lossers of this type prevent oscillation, but their bad effects are worse than the regeneration. The selectivity and sensitivity of the machine are ruined.

The proper losser methods are shown in Figs. 4 and 5. Both these methods are now being used. In Fig. 4 the grid suppressor method is employed. The grid suppressor is the best losser method available for stabilization and is used in many radio circuits, the suppressor being placed directly next to the control grid (G).

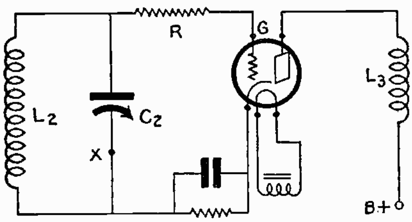

Fig. 4

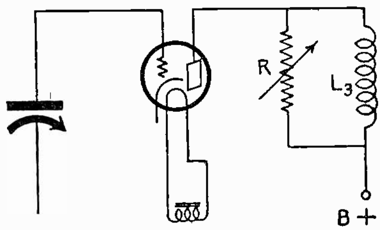

Fig. 5

A resistance at R as in Fig. 4 has exactly the same effect as a considerably smaller resistance at point X. A resistance at point X of 50 ohms is often more than sufficient to stop all oscillation at a high frequency. Why use a resistor at R when one at X will prevent oscillation? We know that regeneration is violent at high frequencies, but a resistance at X will not have materially more damping at 1500 kc. than at 550 kc. In fact a resistor at X chosen to damp out oscillation at 1500 kc. will be far too much for a frequency of 550 kc.

In action the voltage across L_3 feeds a current through the grid-plate capacity into the grid circuit in such a manner as to build up the voltage applied to the grid input. The presence of the resistor R reduces the net grid input voltage, because of its IR drop. The reactance of the grid-plate capacity decreases with increased frequency creating greater feed back or regeneration as shown by curve B in Fig. 6; but at the same time increased

I^2R loss in the grid resistor takes place as shown by curve A. By choosing a suitable value of R, a balance between regeneration (gain) and loss is obtained and more even amplification over the tuning range is realized, as well as no oscillation.

Note that a grid suppressor tends to even out amplification over the complete scale of tuning, and so is a most desirable method of oscillation control. Usually a resistance of 500 to 1,000 ohms is quite sufficient. Where several R.F. stages are used it has been found practicable to use staggered values, thus 500^{ω}, 600^{ω} and 700^{ω} in the first, second and third R.F. grid circuits. Interchangeable suppressors are best, for then the proper values may be found by experiment. If a set using grid suppression has a tendency to oscillate, it may be kept from "spilling over" by using a larger grid suppressor. If a suppressor of 1200

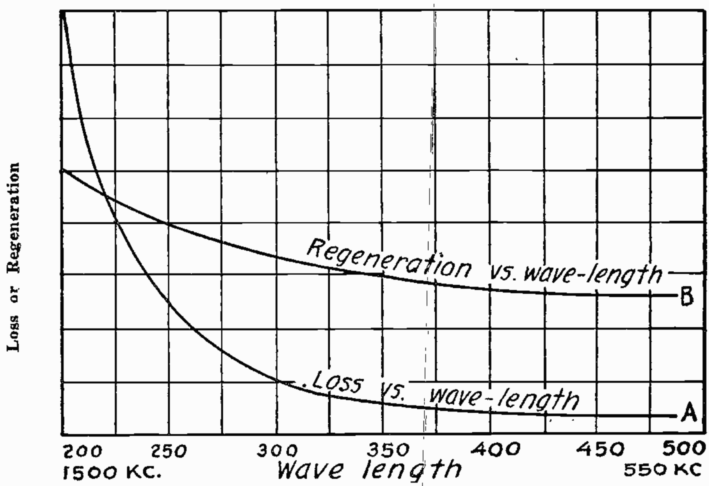

Fig. 6

ohms does not stop oscillation, the trouble is elsewhere (improper shielding; coupling between grid and plate leads; or too large a primary).

In actual practice, the smaller the grid suppressor the greater the regeneration and the more sensitive a receiver will be. Of course there is always the danger of oscillation when smaller suppressors are used.

By using a variable resistance of 0-5,000 ohms, connected across L_3 as in Fig. 5 in addition to a grid suppressor, an absolute means of controlling regeneration and volume at the same time may be had.

When this combined method of grid suppression and volume control is used, the resistance value of the suppressor should be such that when the variable resistance is at maximum, regeneration should be just barely perceptible at the lowest frequency. Then by decreasing the resistance of variable R any tendency to "spill over" at higher frequencies can be controlled as explained below. Maximum sensitivity is obtained when the R.F. tubes are just at the point of oscillation—just before they "spill over."

A variable resistance may be used without a grid suppressor (Fig. 5) but then amplification will not be uniform because this method does not level out amplification as the grid suppressor does. The action of the variable R is as follows:—Because it is a shunt load in the plate circuit, it lowers voltage E_3 (in Fig. 1). The lower this voltage is, the less e.m.f. there will be to push a current across the reactance of C_T. Thus regeneration and volume are controlled by controlling voltage E_3.

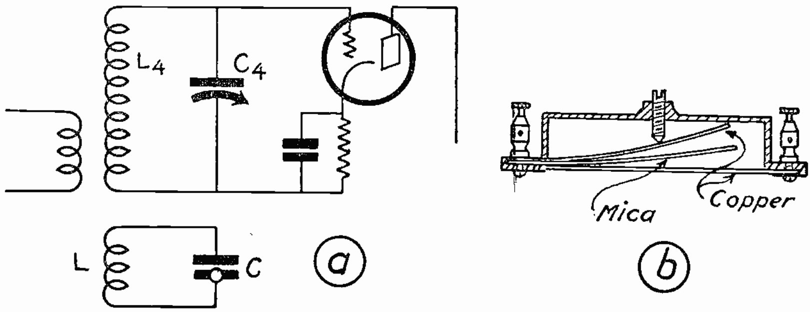

Fig. 7

A method used at times is shown in Fig. 7a. A coil L, having from ¼ to ¾ as many turns as L_4, is wound on a small tubing just large enough to slip into the tubing of L_4. The wires of L are usually bunched so there will be no capacity between L_4 and L. An adjustable capacity C, constructed as in Fig. 7b, is connected across L. Its capacity is about ½ that of the maximum value of C_4. Capacity C and inductance L form an oscillatory circuit drawing its energy from L_4 by mutual induction. If the L-C circuit is tuned to the L_4-C_4 circuit it will absorb practically all the latter's energy, a condition quite undesirable. Usually L-C is tuned to the frequency at which the receiver "spills over" most and the adjustment made at a higher frequency. In this way a fair oscillation control is available. Of course C may be a variable condenser and tuned from the panel. In this way it may even be a sensitivity and volume control. However, this method is inferior to the grid suppressor method and furthermore has the disadvantage of upsetting tuning, a serious defect when condensers are ganged.

Another method of preventing oscillation is by bringing a copper or brass plate near the coil L_4, or putting a circular disc inside the tubing of L_4. See Fig. 8. The disc acts as if it had thousands of little circuits in which currents are created by mutual induction. The currents are larger at high frequencies. These miniature circuits have resistance and a loss takes place in the form of an I^2R loss. Clearly this method would tend to prevent excessive oscillation at high frequencies and likewise would have little effect at lower radio frequencies.

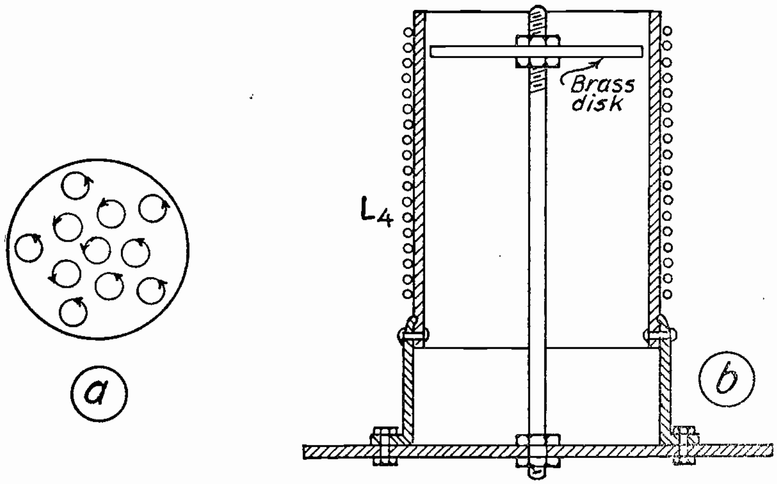

Fig. 8

Some manufacturers arranged the disc so that it could be made to slide in and out and be controllable at the panel; others arranged the disc so that it could be rotated so as to uncover the coil, with identical results. This method has the disadvantage of affecting selectivity and sensitivity, but it is not serious if not carried too far below the point of oscillation. It also affects the inductance value of L_4 and for this reason a knob control of the disc is quite often used for *"closer tuning."* This method employs "eddy current" reaction, which is important in radio shielding, a subject we shall take up soon.

STABILIZATION THROUGH "PHASE SHIFTING"

A unique method of oscillation control once extensively used by set-builders and manufacturers was introduced by John F. Rider. It is both a phase shifting arrangement and a losser system. See Fig. 9. A condenser of about .002 mfd. is placed in the plate circuit of the oscillating tube in series with primary L_3. Of course this keeps the B supply from reaching the plate. A variable resistance R of 0-10,000 is connected between the plate and the 180-volt supply to provide a path for the plate current.

If the condenser C is shorted, the voltage E_3 impresses a voltage across the grid-cathode which is in phase with E_2 and regeneration will take place. By allowing capacity C to exist in the circuit the fed back grid voltage is shifted about 90 degrees out of phase with E_2. Thus the voltage E_3 acting back through the tube capacity does not entirely aid E_2 and regeneration is materially reduced. Further decrease in regeneration may be accomplished by the losser action of R. This method although a good cure for stubborn squealing does not flatten the amplifi-

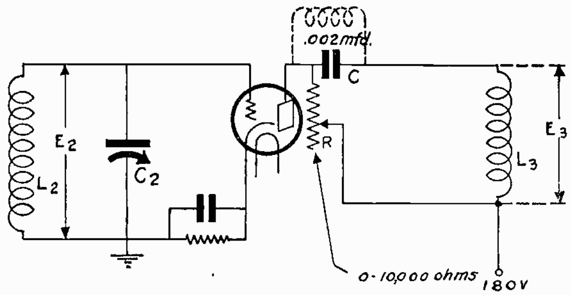

Fig. 9

cation of the receiver. However, by placing a coil of about 40 turns of No. 28 wire wound on a 1″ tube across C, the phase shifting may be eliminated for high wavelengths and the lower band of frequency actually aided by regeneration.

SUPPRESSION OF OSCILLATION BY METHODS OF NEUTRALIZATION

Patent rights have limited the greatest number of manufacturers to the foregoing methods of regeneration control but a number use one form or another of *neutralization,* introduced by Prof. Hazeltine. In the neutrodyne circuit, neutralization is accomplished by introducing into the grid circuit an e.m.f. just large enough to balance out that which may be introduced by regeneration.

Hazeltine Neutralization:

The tube capacity allows a voltage originating across the primary of the plate inductance to act back on the grid voltage in phase with it and in this manner strengthen the signal. Due to the impossibility of limiting this reverse action, violent oscillation may take place. Now the voltage across the secondary inductance is known to be 180° out of phase with the primary inductance. By tapping the secondary at a proper point, the voltage in the turns up to the tap is directed back to the grid through a variable condenser of small capacity.

Thus, in Fig. 10a, the R.F. transformer (L_3-L_4) supplies both the regeneration and the counter-e.m.f.'s. Terminals +B and –A of both primary and secondary are at the same potential when considering radio frequency current.

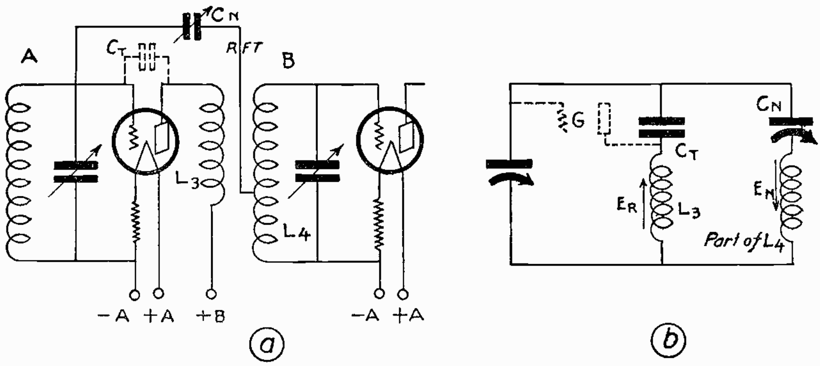

Fig. 10

The voltage across the primary feeds the grid with an "in-phase" voltage through C_T, whereas the voltage across the tap on the secondary and terminal –A feeds to the grid a voltage out of phase with the first voltage. By proper placement of the tap and by using the correct size of neutralizing condenser C_N, the neutralizing voltage can be made to balance out any tendency to oscillate. Fig. 10b will make this clear.

The position of the tap on L_4 is so chosen with relation to the capacity of C_N that the voltage fed to the grid circuit through condenser C_N is just equal and opposite to that induced into it through the internal tube capacity C_T.

Strictly speaking, if there were no capacity between the coils L_3 and L_4 when the condenser C_N was adjusted, oscillation would not occur at any frequency. However, the effective inductance of L_3 and L_4 does decrease with increased frequency and the voltage of neutralization is not 180° out of phase. Also capacity between L_3 and L_4 will vary with frequency and upset a definite setting. An approximate adjustment only is possible. It is quite essential that L_3 and L_4 be connected to the tube in such a manner that opposite voltages are present. Usually the tap is near the –A end.

Rice Method of Neutralization:

Another neutralization method that has, however, commercial draw-backs, is the Rice method. The inductance L_2 (Fig. 11) feeding the grid of the oscillating tube is center-tapped and connected to the cathode (filament). Naturally, the center of the coil L_2 becomes zero potential, that is, it is at A– or ground potential. The upper end is connected to the grid and the lower

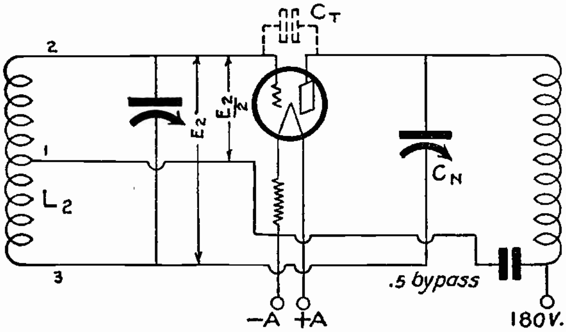

Fig. 11

end, through the neutralizing condenser, to the plate. The capacity of the neutralizing condenser is equal to the tube capacity. The voltage across 1-2 is 180° out of phase with voltage across 1-3. Thus, any regenerative voltage fed back to the grid is exactly balanced by an equal and opposite voltage. Any deviation from a condition of voltage balance will cause oscillation.

The disadvantages of this method are: that only half gain is obtained as the grid voltage instead of being E_2 as in Fig. 1 is now $\frac{E_2}{2}$, for only the voltage between 1 and 2 results in tube amplification; that ordinary ganged condensers cannot be used as the rotor is connected to the plate through C_N; that body capacity may affect operation and panel shielding may be imperative; and that a short in C_N causes the plate voltage to be shorted to the filament through half L_2.

R. F. L. Circuit:

An ingenious method of reverse voltage feed was invented by the Radio Frequency Laboratories, hence the name R. F. L. circuit. A coil of a few turns, L_N in Fig. 12, is connected by mutual induction to L_3 and may be made to create a voltage

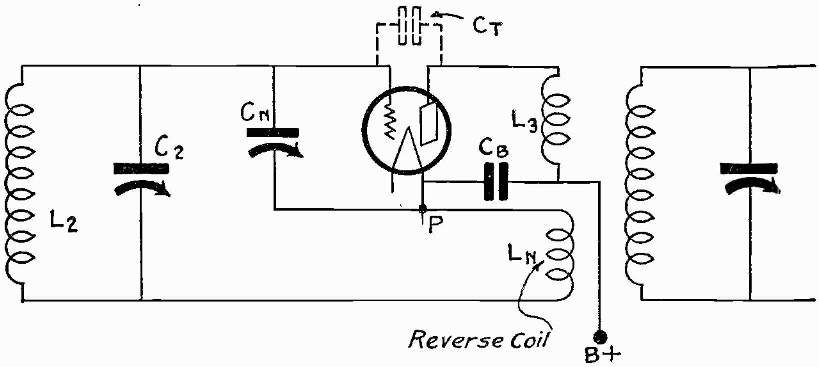

Fig. 12

either to aid or oppose oscillation. By connecting it to the grid through a neutralizing condenser C_N a counter-e.m.f. can be applied to the grid to wipe out regeneration. Capacity C_N is much larger than the tube capacity C_T. A contact between L_N and C_N is made with cathode at P. This connection, however,

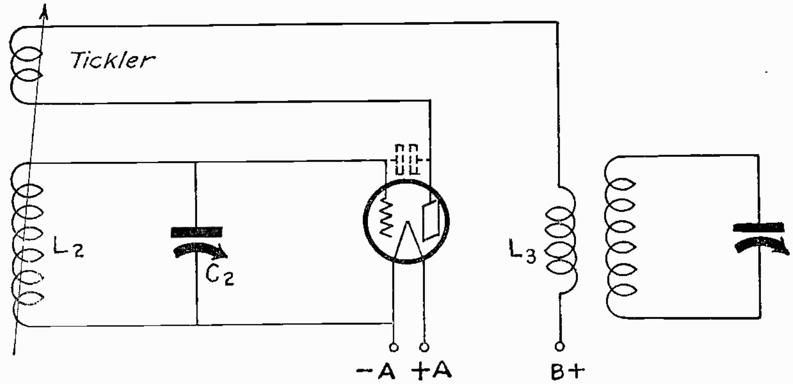

Fig. 13. Regenerative Circuit showing Variable Coupling between Tickler and L_2

may be eliminated without any change in operation, and this is usually done in A.C. receivers. C_B is a large by-pass condenser (.5 mfd.).

Reversed Feed-back Method:

If a tickler feed-back will introduce a voltage to create regeneration, by reversing the tickler an e.m.f. can be supplied to the grid so as to oppose tube-capacity feed-back of voltage. The method shown in Fig. 13 requires that tickler adjustment be made for each setting of C_2. A perfect control of regeneration is thus possible and such a control may also be used as a volume and sensitivity adjustment.

ELIMINATION OF TUBE CAPACITY

For many years, it has been the object of tube designers to develop three element (triode) tubes having extremely low tube capacity. Eight micro-microfarads for a UY-227 seems to be the lowest feasible capacity without affecting tube characteristics. The introduction of screen grid tubes revolutionized radio frequency circuits and banished the problem of feed-back stabilization by reducing considerably the tube capacity.

3 The purpose in designing the screen grid tube was to reduce the effective grid-plate capacity within the tube rather than in the circuits external to the tube. This is accomplished by the addition of a second grid, which acts as a shield or screen inserted between the usual control grid and plate of the tube.

This screen being placed at ground potential prevents the electrical charge on the control grid and plate from forming a capacity coupling. The capacity between the grid and plate, however, is not entirely eliminated, but the effective capacity of a screen grid tube compared to a triode, is reduced materially, having a value of only a few hundredths of a micro-microfarad.

ELIMINATION OF MAGNETIC STAGE COUPLING

Capacity between tube prongs, socket contacts, grid and plate leads, is of extreme importance. Unless precautions are taken, the low internal capacity of the screen grid tube is destroyed. Feed-back between coils of adjacent stages is now the chief cause of screen grid oscillation. It is a problem in the three-element tube, but a much more serious consideration in the four element tube circuits.

An inductance to be efficient and have low resistance with maximum inductance, is made in such proportion that the diameter of the coil winding is approximately equal to its length Unfortunately, such coils have magnetic fields that spread quite a distance from their sides. In Fig. 14a, the field about a short coil is shown. The coil in 14b, designed much longer, has its field close to the sides.

In the early days of neutrodyne circuits, coils were usually designed so they were 2½ inches in diameter and 2 inches long. Placing of coils to prevent magnetic induction between them was a problem. Neutrodyne receiver manufacturers used the coil placement arrangement shown in Fig. 15. The angle B was about 55°, but no hard and fast rule could be set. Too much depended on coil size and placement.

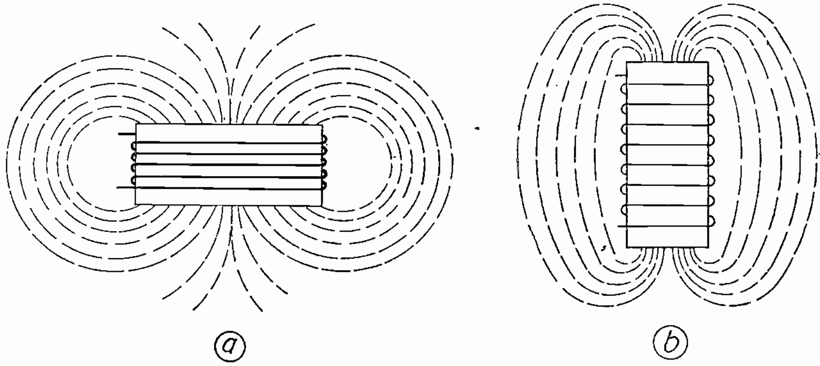

Fig. 14

Many schemes were used to prevent stray fields. The one shown in Fig. 16, proved quite effective. The coil, including primary and secondary, was wound in the shape of a doughnut, the field existing inside. Little leakage took place. However, it was by no means easy to make this kind of coil so that it would match ganged condensers.

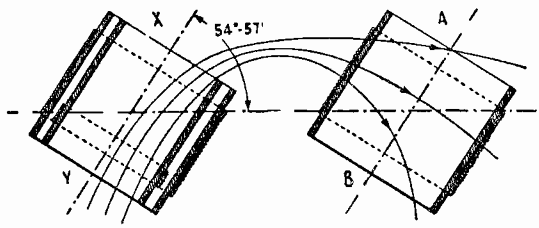

Fig. 15

A double coil arrangement as in Fig. 17, was the outcome of the ring (toroidal) coil. It approximated the effect of the latter and allowed substantial and precise construction. In fact, it held its own until quite recently. The secondary was equally distributed between the two sections and one section usually carried the primary.

After much debating, manufacturers and radio designers adopted a coil about 1¼ inches in diameter and 1¾ inches long. The secondary is usually wound with No. 30 enameled wire and there are between 60 to 90 turns per inch. Wires are always spaced one from the other for reasons we shall study soon. As precision is of utmost importance, high grade bakelite tubing about 3/32 of an inch thick is employed. The wire is wound on a thread cut in the bakelite form by a screw cutting lathe using a "V" shaped diamond cutter.

In spite of variations in tubing diameter, this last process makes all tubing exactly alike. A total of nearly 120 turns is

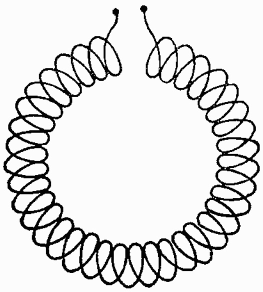

Fig. 16

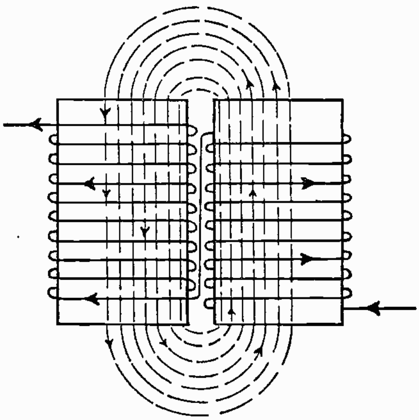

Fig. 17

generally used. Not all coil windings are like this, but in general, they are. Some manufacturers dry their coils in a furnace and dip them in moisture-proof wax of low dielectric capacity having high insulation resistance. Such a coil is shown in Fig. 8, except that the damping disc is not used in modern circuits.

This coil, being longer than wide, has a restricted side flux and so when several are used, they are usually placed perpendicular to each other as in Fig. 18. What flux does cut the wires of adjacent coils does not link with them because it does not cut the turns at right angles. Thus, whatever effect there is between coils is very weak. When the gain per stage is low, this coil arrangement possesses low *inter-stage* coupling and serves well as a coil layout.

Besides the fact that it is not possible to space coils to prevent magnetic coupling between stages altogether, there is another serious drawback to "open coils," which has caused their total disappearance in the modern receiver. You may have noticed that an old type receiver with open coils will pick up stations 50 to 100 miles away with the aerial and ground disconnected. This is because the open coils acted as small antennas. Of course a receiver that will do this is inefficient—it lacks selectivity. If used near a powerful local station it will resonate to (tune) the local over 10 to 50 out of 100 divisions on the tuning dial.

A possible remedy for this condition is to place the entire receiver in a metal box and so "shield" the receiver. Then no parts in the receiver can receive signals except through the antenna system. Of course, this does not shield one part from another—it merely shields the receiver as a whole.

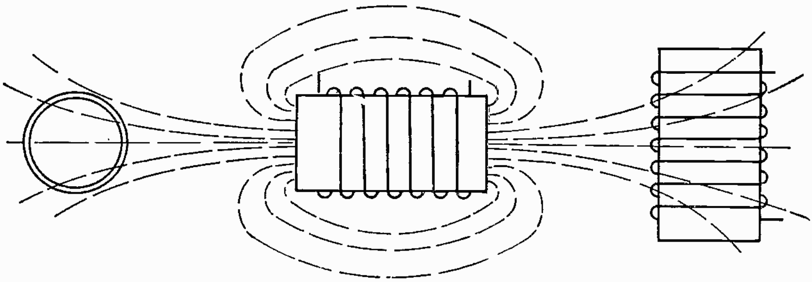

Fig. 18

SHIELDING

So much importance is attached today to shielding that the underlying principles and use of shielding must be thoroughly understood by Radio-Tricians.

We begin our study of shielding with a simple radio coil. Let's assume that it is connected to a supply of A.C. voltage, resulting in a flow of current through the coil whose inductance (L) is, let us say 250 microhenries. A magnetic field is built up about the coil whose lines of force (flux, F) flow first in one direction then in the other, in phase with the reversal in direction of the current within the coil. See Fig. 19.

If the source of e.m.f. were a battery, that is direct current, the magnetic lines of force would always be in one direction, and the flux near AB would extend out in both directions as far as it could reach. Now if a plate (S), made of copper, aluminum, bakelite or glass were placed near the coil, an instrument (X) to detect magnetic flux would show that flux actually goes through the plate and that the amount is the same whether glass, bakelite, copper or aluminum is used. These are non-magnetic materials, that is, they do not conduct magnetic lines of force. But an iron plate at S would prevent any flux from getting through because iron conducts flux and bends the lines F so as to conduct them along the plate.

Now let's see what happens when an A.C. generator is used, assuming that the effective current is the same as in the previous D.C. experiment. If the current were a 60-cycle current the magnetic flux indicator would show that practically the same amount of flux was passing through plate S but if the frequency were increased from 60 to 500, to 10,000, to 100,000 to 500,000

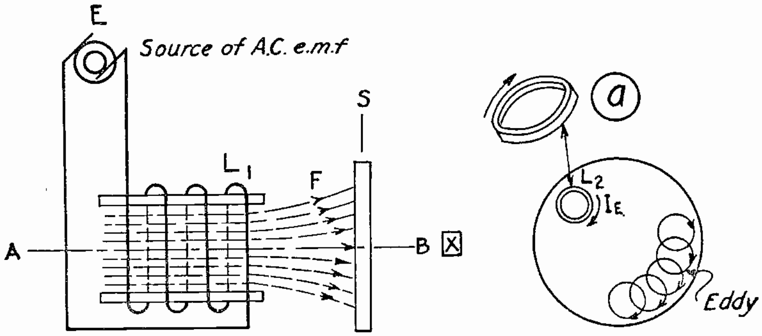

Fig. 19

cycles per second, always keeping the current constant we would find that indicator X shows less and less flux passing through a copper or aluminum plate. This same experimental set-up would show that if glass or bakelite were used, the same amount of flux would pass through constantly. It would not be affected by an increase in frequency. A simpler experiment to prove this same effect of frequency is set up in Fig. 20. Coil L_1 is placed near another coil L_2 and an A.C. voltage E_1 is placed across the terminals of L_1. An A.C. voltmeter placed across the terminals of L_2 would read a voltage E_2—because our two coils are nothing more than an air core transformer.

A glass or bakelite plate S between coils L_1 and L_2 would not change the voltmeter reading of E_2—however, the insertion of a copper or aluminum plate causes the voltage E_2 to drop and if it is possible to increase the frequency of E_1 sufficiently, the voltage E_2 can be reduced to zero.

How can this be explained? We shall have to believe what most Radio engineers accept as the correct explanation—and to understand their explanation we shall have to use our imaginations. Within the plate S there are hundreds of little circuits, all jumbled together, but for the sake of simplicity we shall assume that a single one of these tiny circuits looks like L_2 in Fig. 19-a —just a small electrical ring. Each of the many electrical rings, L_2, acts as a secondary coil to L_1. From our study of transformers we know that an e.m.f. is induced in the ring L_2. But ring L_2 is short circuited and a current I_e flows first in one direction then in the other according to flux changes. This current is called an *eddy current* because its action and flow can be compared with an eddy in a lake or river.

This changing current in L_2 has several effects which are

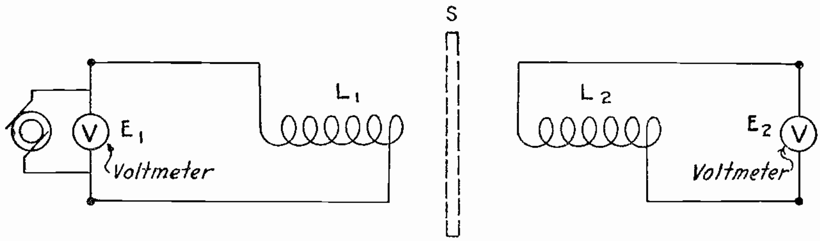

Fig. 20

of importance to us. L_2 has resistance besides its one turn of inductance and so power is lost in heat ($I^2_eR_e$). This power loss is called an eddy current loss. Of course it cannot be measured by measuring R_e and I_e—it is impossible to isolate a single eddy current and measure it. However the resistance of coil L_1 can be measured with and without S present. The increase in coil resistance is the result of eddy current loss.

It must be explained that even without plate S there may be eddy current loss. Eddy currents will be induced in some adjacent turns of the wire of L_1 by flux leakage. Of course there is resistance present in these small circuits and this resistance increases at higher frequencies—it will be greater at 1500 kilocycles than at 500 kilocycles.

Now, whether you realized it or not, we have been studying "shielding" about which so much is heard in connection with the latest receivers. Plate S is nothing more than a shield—but strange as it may seem, we have so far been considering only the detrimental effects of shielding. Eddy current loss is undesirable. Proper shielding must be able to deflect flux but eddy current loss must not be large enough to affect selectivity. So far we have learned that the magnetic shielding properties of copper and aluminum increase with frequency and for this reason shielding is always made of either one or the other. Now we can go on and learn why eddy current loss in shielding is not large enough to affect the operation of a receiver.

Copper and aluminum have low resistivity. Comparatively large eddy currents can exist in them without much power lost in heat due to low resistance. Iron, lead, tin and brass have a much higher resistivity, consequently power loss would be high if they were used for shielding.

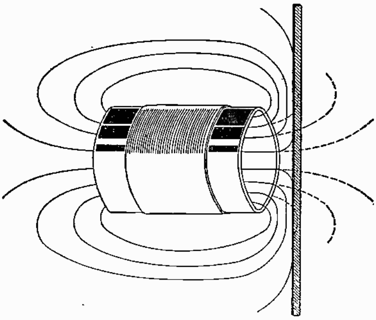

Fig. 21

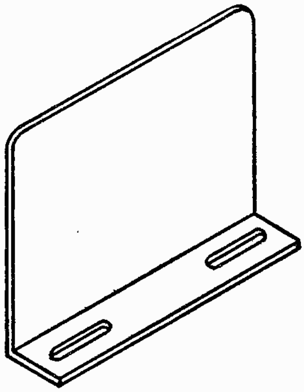

Fig. 22

But, as said before, the idea is to get maximum shielding with minimum loss. The action of the minute coil L_2 as an electromagnet has a great deal to do with efficient shielding. The current flowing in L_2 sets up its own flux in a direction opposite to F. Then whatever flux is not reduced in its attempt to get through S is bent away from plate S as in Fig. 21. However, if the plate is too thin some flux may get through, and for this reason shielding is made as thick as possible and convenient—between 1/32 and 3/32 of an inch.

If the frequency of reversals of the flux direction is increased without changing the flux strength, the voltage induced in L_2 will increase, and with it the current. The result is more effective shielding but at the cost of increased eddy current loss.

An aluminum or copper plate (Fig. 22) may be used between coils or parts in a Radio receiver but more often the coil itself is placed in an inverted aluminum or copper can, as in Fig. 23. It is important that the shield be not too close to the coil or its inductance will be reduced considerably and eddy current losses will be large enough to reduce selectivity. Modern coils are small and built longer than wide, so that a distance of ¾ of an inch between the coil and the shielding is considered ample.

In quality receivers, especially in the latest screen grid receivers where perfect isolation of one R.F. stage from the others is of the greatest importance, each R.F. stage is placed in a separate aluminum or copper box as in Fig. 24. This includes not only the coil, but the variable condenser, the R.F. choke, the by-pass and the tube. Wherever still more effective shielding is desired, the coil is shielded as a unit within the box.

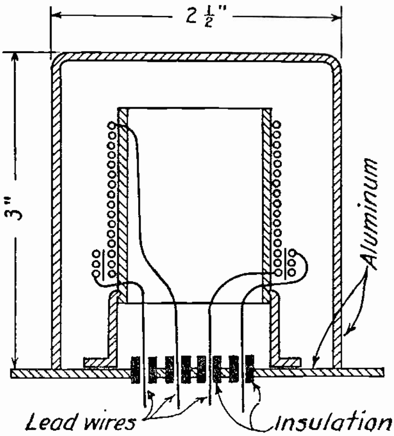

Fig. 23

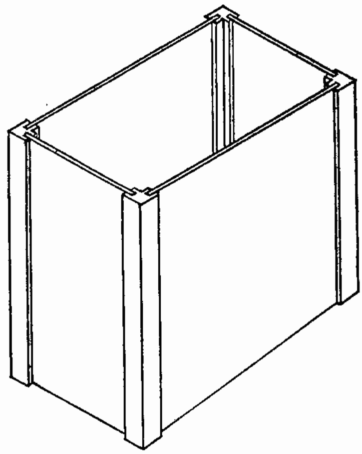
Fig. 24

Before we drop the problem of shielding, we must understand shielding of electrostatic fields as well as shielding of electromagnetic fields. Figure 25 shows two coils L_1 and L_2 in metal containers and so shielded from each other. If the cans are thick enough, there will be no electromagnetic interaction between them. We must not overlook the fact that condenser C_1 is charged and that its field, although mainly between the plates, may spread as shown and actually act between the plates of C_2. As condenser C_1 is being charged and discharged, its field is fed into C_2 and so circuit 2 will be coupled to circuit I. A current will flow in circuit 2 induced by this field. By placing a grounded metallic plate between condensers C_1 and C_2 the electrostatic lines of force can be diverted to the ground and coupling prevented.

Each variable condenser (and each section in a ganged condenser) is separated from the others by a grounded metal plate. Coils must be shielded one from the other for the same reason. By placing regular electromagnetic shields at ground or B– potential they will also act as electrostatic shields. Screen grid tubes which have very large internal elements are quite often separately shielded, as in Fig. 26, if not placed within a metal box with their other stage components.

R. F. COIL PROBLEMS—HIGH FREQUENCY RESISTANCE

From our study of resonance and selectivity, we know that if a radio frequency coil has too high resistance, the tuning

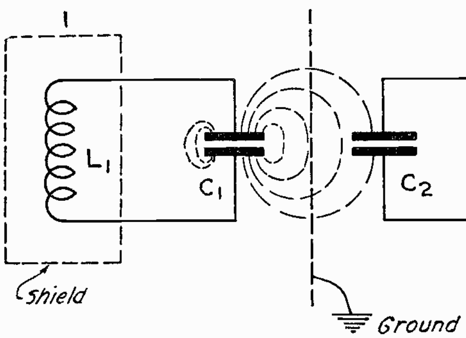

Fig. 25

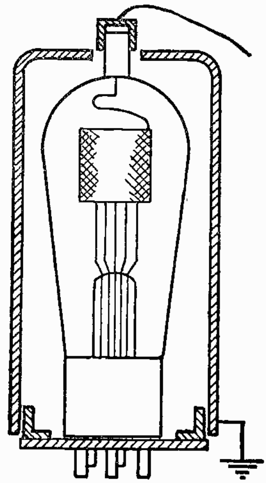
Fig. 26

within that stage will be broad and the sensitivity of the Radio reduced. A single layer coil made of No. 28 D.C.C. (double cotton covered) wire wound on a 3-inch tubing with an inductance of 300 microhenries (60 turns of wire) will have a resistance of approximately 3 ohms when direct current is flowing; a resistance of 6 ohms with an A.C. current of 500 kilocycles; 10 ohms at 1000 kc.; and 15 ohms at 1500 kilocycles.

Part of this increase in resistance is due to the eddy current loss as already explained. The use of No. 24, or larger, No. 18, wire would increase the A.C. resistance faster at high frequencies than wires above No. 24. Consequently, small wires are just as good as large wires for Radio work even though the direct current resistance is higher.

Another factor which contributes to higher frequency resistance is what is known as *skin effect.* Figure 27a represents a cross section of copper wire. When a direct current flows through it, the current passes through every portion, both the center A and the outer surface B. But at very high frequencies an action takes place at A quite similar to eddy current action, preventing a current from flowing through that portion. As a result, the current flows mainly at the surface of the wire (B). We know that as the area of B is decreased the resistance goes up. This is, in effect, an increase in wire resistance and is appreciable at high radio frequencies.

In broadcasting stations or telegraphic stations, "copper-clad" wire may be used, that is, the center A is steel, the surface B is copper. Thus a stronger and cheaper wire is had.

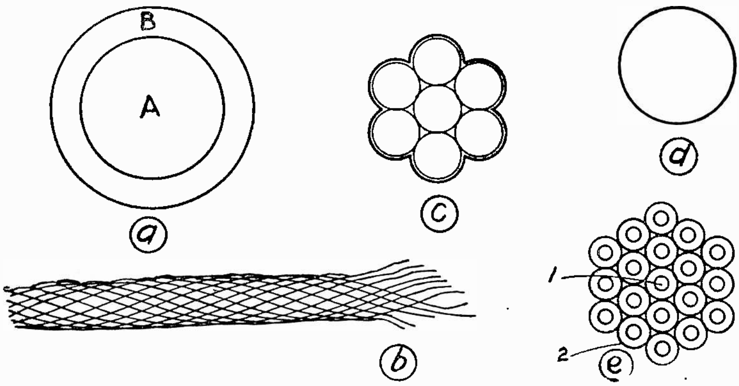

Fig. 27

A reduction of this skin effect is accomplished by braiding or twisting together a number of small wires. Thus the eddy current effect may be broken up and larger external areas for the high frequency current made available. See Figs. 27c and d. In weight, c and d are alike, but note the increase in surface area. The wire in 27c is called *stranded wire.*

7

A special stranded wire called LITZ (Litzendraht) has a very low skin-effect. This wire, shown in Figs. 27b and e is made up of a large number of small wires, each of which is enamel covered and so insulated from the others. The strands are woven in such a way that each separate strand 1, 2, etc., Fig. 27e, is on the surface of the wire for the same proportion of the total length as every other strand. Otherwise, the conductive effect would be destroyed—the same amount of current must flow in each strand.

The advantages of Litz wire are: uniform increase in resistance at increasing frequencies; comparatively small eddy current losses between turns, for they are insulated from one another. The disadvantages are that a single broken strand seriously affects the conductance of the coil in which it is used and that connections to the circuit are difficult to make because of the enamel insulation—it may take as long as an hour to clean the ends for a perfect connection. Because of these disadvantages, Litz wire is not commonly used in commercial receivers. The practical use of Litz wire is restricted to coils use below 2000 kilocycles, due to bad effects which is due to irregular weaving. At very high frequencies (especially in transmitters) copper tubing is used. In all other cases (low frequencies) regular wire is considered to be most practical.

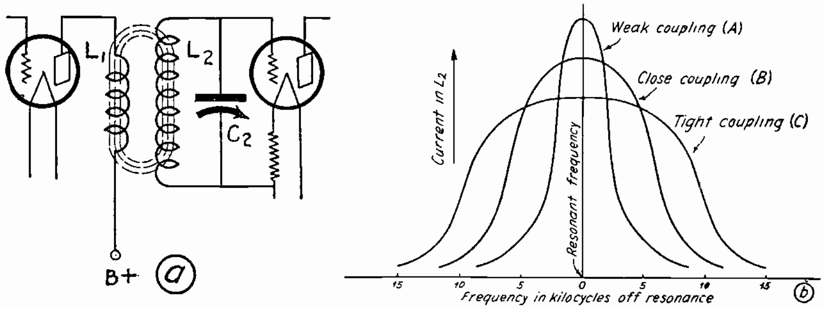

Fig. 28

RADIO FREQUENCY COUPLINGS

So far we have considered only the actual tuning inductance, the secondary, but the actual coupling between the plate of the R.F. tube and the grid of the following R.F. tube has a most important effect on a set's operation.

The most common method of coupling the plate and grid is through a radio frequency transformer, having a secondary tuned by a variable condenser. See Fig. 28a. The secondary inductance is designed so that it will be suitable to use with a variable condenser of .00035 or .0005 microfarads, both standard values for Radio receivers. Usually, the smaller condenser is used because it is inexpensive and because a greater voltage may be impressed on the grid (the smaller the capacity, the greater will be the number of turns on the secondary inductance).

Design and position of the primary are by no means easy and as in all engineering procedure, a compromise between advantages and disadvantages is necessary. Let us review what we studied in R.F. tuners in the earlier part of the course. Remember that as the coupling between the primary and the secondary is increased, the tuning becomes broader.

The primary turns may be wound over the secondary separated from it, of course, by insulation material, or the primary may be wound on bakelite tubing and slipped inside the secondary. For low capacity between primary and secondary, the primary would be wound with very fine wire with windings bunched. Where capacity is not of importance, the primary winding is usually spaced to cover the entire secondary. These represent tight coupling positions and the coupling becomes greater as more turns are added to the primary. By concentrating the primary turns and placing them on the same tubing but spaced

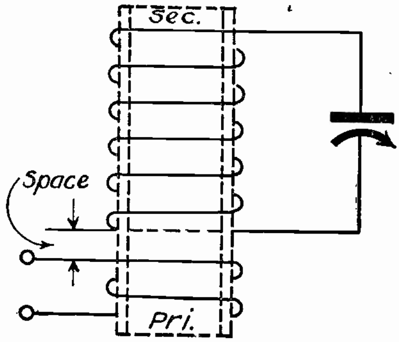

Fig. 29

away as in Fig. 29, the coupling will be made weak. The greater the space between primary and secondary, the weaker the coupling. If the primary turns are increased, the space must be increased to keep the coupling constant. In this way, too, various degrees of coupling may be obtained.

The coupling between the primary and secondary of an R.F. transformer has considerable to do with the effectiveness of the tube as a voltage amplifier and the selectivity of the tuning section. Perhaps the commonest R.F. coupling is the tuned R.F. transformer as shown in Fig. 30a, but for our present study it is redrawn as shown in Fig. 30b. The latter is the equivalent circuit of the first and is more adapted to our present study needs. It only considers the R.F. currents.

As an R.F. amplifier the circuit should produce across *a* and *b* a large voltage. If L_1 and L_2 constitute a step up transformer this will be realized when a large voltage exists across *c* and *d*

(L_1). As a voltage amplifier the impedance across the primary L_1 should be as large as possible.

Although we consider L_2 and C_2 as the resonant circuit we must not overlook the series resistance R_s which is present in the coil and condenser. Furthermore any shunt resistance, due to condenser leakage or grid-cathode resistance, or a grid suppressor resistance has the effect of increasing the value of R_s. As far as tube T_1 in Fig. 30a is concerned it has a plate load impedance across L_1 which is at resonance adjustment of C_2 practically a resistance load R_s' which depends on the mutual inductance M, the secondary resistance R_s and the frequency of the signal.* This is usually expressed by saying that the secondary resistance has been reflected across the primary. To give you some idea of this action when R_s is about 15 ohms, R_s' will be about 50,000 ohms. This reflected resistance increases when the mutual inductance, that is, the *coupling* is increased; increases with the tuned frequency and increases as the series resistance R_s is reduced.

4

All this has an important bearing on the ability of the stage to act as a good R.F. amplifier. When the reflected resistance R_s' is large the voltage across *c* and *d* will be large and then the transformer will have a large voltage to step up. Of course if the reflected resistance increases with frequency it is expected that the stage will be a better amplifier at higher frequencies. This of course is a known practical fact. The greatest amplification is obtained with R.F. transformers when R_s' is equal to the tube plate impedance. This value is not easily obtained.

If increasing R_s' tends to make the stage a better voltage amplifier why not go further and build low loss secondaries and use greater coupling. There is a limit, for although we may improve the gain in the stage we at the same time add detrimental effects. With the ordinary triode tube as an amplifier if we increase the voltage across L_1 too much, regeneration will take place. And this determines the limit for triode tube R.F. amplifiers. With screen grid and R.F. pentode tubes regeneration does not enter into the problem, in fact it is well to have a very large reflected resistance to cope with the large plate impedance of the tube. Selectivity now is the most serious problem.

Looking at Fig. 30b you will note that the tube impedance R_p is connected in the plate circuit and across L_1. In a similar

---

* $R_s' = \dfrac{39.4f^2M^2}{R_s}$ where f is in c.p.s., M in henries, R_s and R_s' in ohms.

manner it has the effect of introducing into the secondary a resistance which is in addition to R_s. If the coupling is great there will be a substantial increase in R_s. This of course means decreased selectivity. Thus gain and selectivity are oppositely

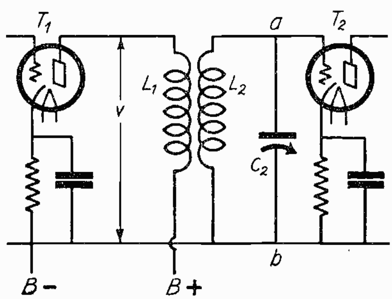

Fig. 30a

effected by coupling and resonant frequency. As a compromise the system is usually made to have a fair value of reflected R_s' resistance to get a reasonable voltage gain and several R.F. stages are employed to make up for selectivity. In this way the coil L_2 may be made with only reasonably low resistance at a reasonable cost.

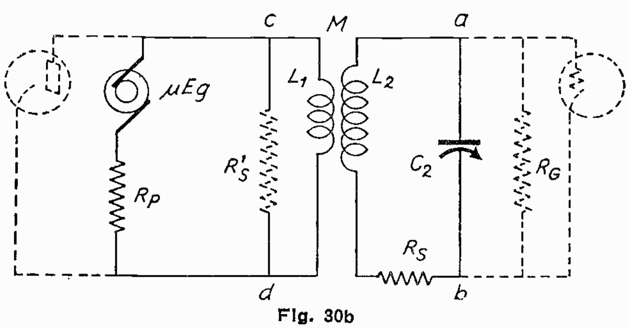

Fig. 30b

From a practical point of view the discussion is valuable. A damp coil, a dirty coil or condenser, dirt and dust at grid-cathode terminals when damp (not sufficient to create a short) will always destroy the selectivity of the R.F. amplifier. A tube worked with a low negative bias may often swing positive on strong local signals thus causing a large grid current which results in a low grid-cathode resistance R_g, grid leak-grid condenser type of detection has the same effect. In this way, too, the effective value of R_s increases and selectivity decreases.

With the advent of tetrodes (screen grid) and R.F. pentodes it became quite difficult to use circuits shown in Fig. 30a and realize sufficient amplification. This is because it was difficult to get a large effective load resistance (R_s'). Many receiver makers, especially those making superheterodynes, used the *tuned plate* circuit shown in Fig. 31a. In this case C and L at resonance act as resistance which is made extremely high by employing low loss construction. In fact the effective resistance will increase as L is made large (C of course made small to obtain resonance), increase as L is made to have a low R.F. resistance and increase as the tuned frequency becomes greater.* With proper care in design, resonant current C and L may be considered as a resistance of 70,000 to 100,000 ohms. At resonance, there-

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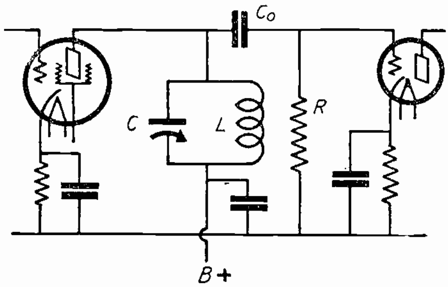

Fig. 31a

fore, circuit shown in Fig. 31a may be looked upon as an R.F. resistance coupled stage. Condenser C_o is small as at R.F. frequencies its reactance is low. Quite often C_o is a small book type adjustable condenser or merely two insulated wires from plate to grid twisted together at the ends, but not making metal contact.

A tube draw-back to this arrangement is that the grid leak R and the plate tube resistance is shunted across the resonant circuit making it difficult to get a high degree of selectivity.

A good deal of the short comings of the tuned plate R.F. system is eliminated by employing two tuned circuits, weakly coupled to each other. Such a circuit shown in Fig. 31b has considerable application on the modern radio receiver. In this case L_1 and L_2 as well as C_1 and C_2 are identical, but M the mutual inductance is exceedingly small. In fact a copper shield is often placed between L_1 and L_2 to further decrease coupling. In this

* $R_s' = \dfrac{39.4 f^2 L^2}{R}$ where R' is the equivalent ohmic resistance, f the frequency in c.p.s. to which L and C is tuned, L is in henries and R is the R.F. resistance of L.

way a high impedance load exists at the plate output and the grid input. It is possible to get a large voltage amplification, without sacrificing selectivity and the selectivity is increased as the coupling is weakened. Furthermore this circuit tends to give a flat top resonance curve which improves selectivity without cutting side band frequencies. In fact this circuit is so important in

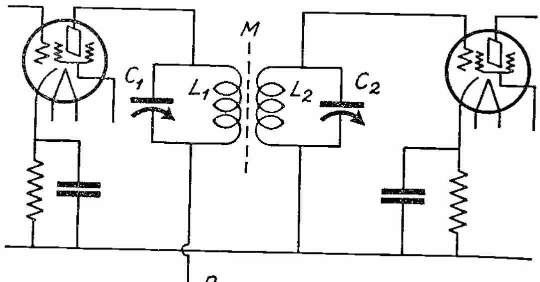

Fig. 31b

radio that we shall see it used quite often in a variety of forms. It is referred to as a band pass coupler, because it allows a definite band of frequencies to be amplified to the same degree.

Perhaps the simplest scheme of getting a high plate load with fair selectivity is shown by Fig. 31c. In this circuit L is a radio frequency choke whose resistance in the tuning range (550

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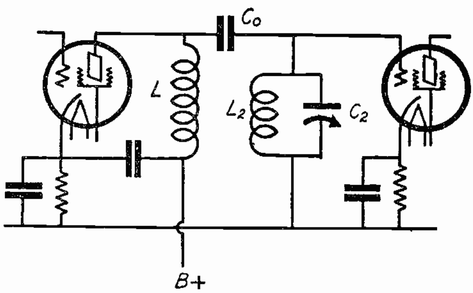

Fig. 31c

to 1500 K.C.) is comparable to the plate resistance of the tube. A value of 30 to 80 millihenries seems to be universally used. The resonant circuit (tank circuit) L_2-C_2 is at resonance equivalent to a resistance. It should be clear that in this case we have nothing more than an R.F. plate impedance coupling—selectivity obtained by using a tuned grid. Blocking condenser C_o may be any value up to .00025 mfd. The lower the resistance of L_2 and the larger L_2 is in comparison to C_2 the greater will the gain of the stage be. Quite often L by virtue of its distributed capacity is made to resonate at the low R.F. frequency thus tending to make up for the loss in gain at low R.F. values due to the fact L_2-C_2 will have a low effective resistance at low frequencies.

Quite often servicemen desire to change from triode to tetrode and R.F. pentode circuits. Where the R.F. sections are well shielded, the circuit shown in Fig. 31c lends itself to use. In this case the primary of the R.F. transformer is disregarded and only the secondary tuned by the condenser is used as shown in the circuit diagram. It is wise in this case to place a tube shield around the tube.

We should mention that L in Fig. 31c can be replaced by a 50,000 to 200,000 ohm resistor. If a noiseless type of resistor is used and the voltage supply is 2 to 3 times the rated plate voltage of the tube this scheme may be employed. As every increase in voltage means larger and more costly power supplies, it is very rarely used.

TEST QUESTIONS

Be sure to number your Answer Sheet 20FR-2.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another set ready to send in. Send in each set by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and the very best possible lesson service.

1. What is the best losser method of preventing R.F. tube oscillation?
2. How does the Neutrodyne circuit overcome regeneration?
3. Which has the highest grid-plate capacity, the triode or the screen grid tube?
4. Why is shielding necessary?
5. What two effects will a close coil shield have in a Radio?
6. How would the operation of a receiver be affected if one of the Radio frequency coils had high resistance?
7. What type of wire is used to eliminate skin effect?
8. What effect on selectivity will increased coupling have in the circuit shown in Fig. 30a?
9. Draw a diagram showing a tuned plate R.F. coupler.
10. A well shielded receiver is to be rewired from triode to screen grid tubes. Which diagram in this text would be best to follow?

THE VACUUM TUBE AS A GENERATOR IN RADIO CIRCUITS

21 FR-1

PIONEER HOME STUDY RADIO SCHOOL

NRI

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

THOROUGHNESS

There is but one straight road to success and that is merit. The man who is successful is the man who is useful. Capacity never lacks opportunity. It cannot remain undiscovered, because it is sought by too many anxious to use it.—BUHRKE COCHRAN.

NATIONAL RADIO INSTITUTE

WASHINGTON, D. C.

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The Vacuum Tube As A Generator In Radio Circuits

THE THEORY OF OSCILLATORY CIRCUITS

Regeneration and oscillation have been mentioned many times. Two simple cases have been explained in order to make clear the theory of radio frequency design. Oscillation in those cases was objectionable, but there are many times when oscillation is a useful phenomenon. Vacuum tube oscillators are used in radio transmitters to generate the high frequency carrier currents. They are used in superheterodyne receivers where a local high frequency signal is needed. Audio and radio frequency apparatus and parts are tested at their operating frequencies by vacuum tube test oscillators. A vacuum tube can be made to generate any frequency from a few cycles per second to 300 million cycles per second by properly connecting it in a circuit

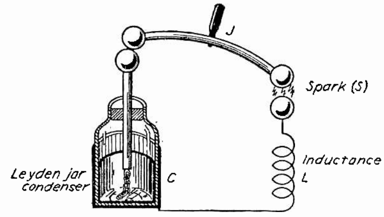


Fig. 1

consisting of coils and condensers of the proper values. The great number of uses and the flexibility of the oscillating systems make them an important subject for study.

A simple oscillatory circuit, older than Radio itself, is shown in Fig. 1. An inductance is connected to a Leyden jar condenser which has been charged with a high voltage (about 1,000 volts), and the circuit is completed by a connecting rod (J) having two round metal balls at the ends as shown. If instead of making a complete contact at "S," there is a gap of about 1/8 of an inch at S, a spark will jump across. If a high-speed motion picture camera were to take a successive run of pictures of the spark, they would show that it continued longer when the inductance L was used than without it.

Electrostatic energy was stored in the condenser and when enough voltage existed across the gap to break up the molecules in the air, by forcing each air particle to throw off an electron, leaving it positively charged, the air was *ionized.* In this condition, the gap becomes a conductor and the energy in the condenser discharges through the circuit in the form of current, storing electrical energy in the inductance, in the form of electromagnetic energy. The magnetic energy creates a voltage across the inductance, large enough to cause the gap, which has in the meantime opened, to again conduct. In doing so, the condenser is recharged but the plates are of opposite polarity. This process repeats itself and the condenser is charged to its original condition, but the quantity of electricity stored is less; some energy has been lost due to the resistance in the circuit, an I^2R loss.

The condenser and the inductance have resistance as well as the "spark gap," and we know that whenever a current flows through a resistance, energy is lost in heat. Therefore, every time a spark jumps the gap, energy is lost and the maximum

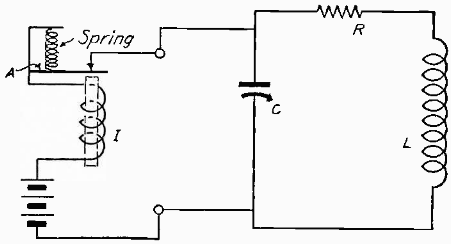


Fig. 2

current at each cycle is less. If the gap is made larger, more resistance is introduced and the spark exists only for a very short length of time. Curve (a) in Fig. 3 represents the current in the circuit when the spark gap is small. When the gap is increased, the current curve will appear as in 3b, dying out rapidly.

If the gap were closed entirely and we could consider all the resistance removed from the circuit, oscillation would continue indefinitely as in 3c. A current oscillation as in 3c is called a continuous or sustained oscillation; 3a represents a slightly "damped" oscillation; whereas 3b is a highly damped oscillation.

Regardless of the three conditions, the frequency of oscillation (the number of cycles per second) is practically independent of the resistance and may be determined by the formula,

(1) $f = \dfrac{1}{6.28\sqrt{LC}}$ where f is frequency in cycles per second, L is inductance in henries, C is capacity in farads.

which is a very important formula for oscillating circuit calculations.

After all the energy has been lost in heat, the oscillation stops and to cause another oscillation to take place requires another condenser charge. A charging method is shown in Fig. 2. Across the condenser is connected a 6-volt battery in series with a buzzer. Notice that when the iron armature A is up, a current flows through the circuit R and L storing magnetic energy in L. The magnet then pulls A down, opening the circuit and allows oscillation to take place in the L-R-C circuit. Because of R in the circuit, the oscillations are highly damped and stop quickly. Then contact is made again by the spring pulling A up into position and the battery recharges the inductance L. The oscillations controlled by a device of this kind would appear as in Fig. 3d.

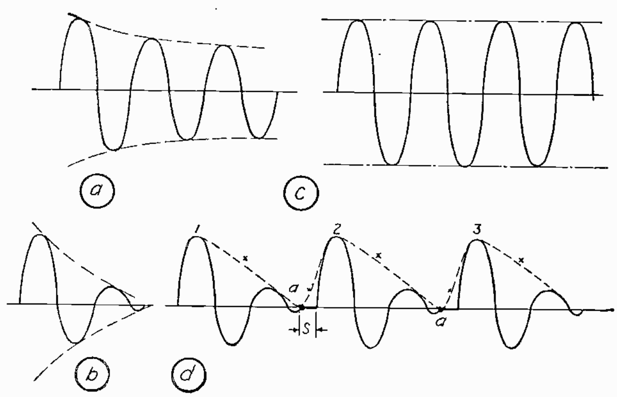


Fig. 3

Each group of oscillations is referred to as a "wave-train" and the number of trains depends on the number of makes and breaks of the interrupter I. In fact, the current in R-C-L is a modulated current whose radio frequency f is determined by formula (1). The oscillation may have stopped at point (a); then for the time S, while awaiting another charge, no oscillation is present.

The source of e.m.f. supply need not be a buzzer and battery—it could be a 60-cycle line with its voltage cut down by means of a transformer or lamp, or it might be a special tuning fork vibrator as shown in Fig. 4a which is used quite often in laboratories for a source of 1000 cycle e.m.f. The first method is used quite often by Radio-Tricians and an arrangement as in 4b is often carried in the service man's tool kit to supply a signal when a strong signal of known frequency is wanted for testing away from the work bench.

The coil L emits an electromagnetic wave which is picked up by the receiver and amplified just as though it were a broadcast signal.

A combination of L and C is nothing more than a wave-meter as is shown in 4c; an oscillatory circuit calibrated either in frequency (frequency meter) or wavelength (wave-meter).

Wave-meters are in common use today in laboratories and at the serviceman's work bench.

The value of a device of this sort is unquestionable as a part of the tool kit, but the simple signal generators mentioned give way to other more modern devices which use vacuum tubes to generate continuous or modulated continuous signals for service work.

TUBE OSCILLATORS

An R. F. amplifier as shown in Fig. 5 is often used to step up a weak R.F. supply. For example, the R.F. driver shown in

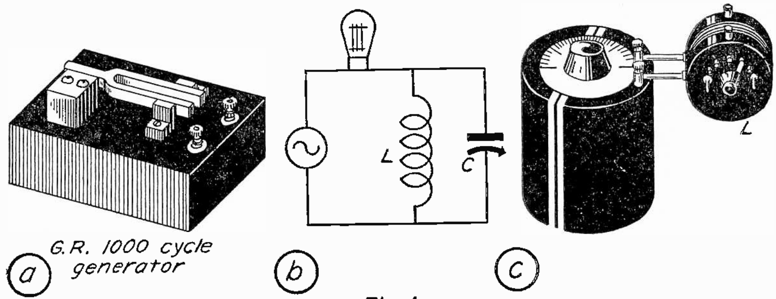


Fig. 4

Fig. 2 may be inductively coupled to L_1. If L-C of Fig. 5 is tuned to the driver frequency, a large current will flow in L as is usual with parallel resonant circuits. Furthermore, the current in L can by mutual induction feed a load as shown by L_3. This circuit is often called an externally excited generator.

2

As the vacuum tube is an amplifier, any tuned amplifier circuit may be made to act as a self excited A.C. generator. If coil L_1 is replaced by a coil L_2 coupled to the resonant circuit, the oscillation in L-C will feed a driving voltage to the grid input circuit. As the circuit is an amplifier, the output is larger than the input and it is possible to feed only a small portion of the output into the input. Any disturbance in the amplifier circuit, closing the filament circuit, will start self oscillation at a frequency determined essentially by L and C. An important condition, is that the driver voltage across *1* and *2* be 180 degrees out of phase with the voltage across L.

Tuned Grid Oscillator.—Without doubt, the simplest oscillator to build and to understand is the feed back circuit with a tuned oscillatory circuit connected to the grid, or, as it's more technically called, a tuned grid oscillator. Such a circuit is shown in Fig. 6, just as a service man would build it for bench work. Everything should be placed in a metal box for shielding and the output connections brought out at points 1 and 2.

A 201-A tube is connected to a 110-volt A.C. or 110-volt D.C. line in series with a 500-ohm, 25-watt power resistor or lamp so as to reduce the 110-volt line to 5 volts before being applied to the tube filament. Note that the resistor is on the plate side of the filament. Its terminal is connected to the positive side of the line if 110 volts D.C. is used. Thus, the filament receives 5

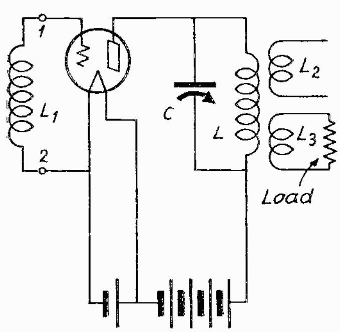


Fig. 5

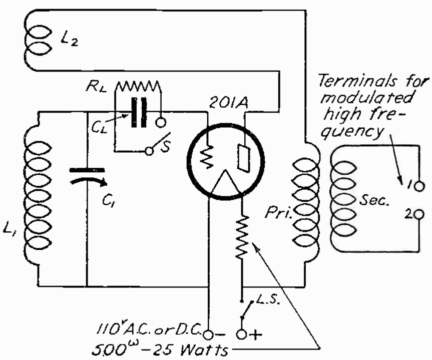


Fig. 6

volts and the plate 110 volts—continuous in the case of D.C. power—the positive half of the cycle in the case of 110 A.C. (the negative half is rectified out by the tube which acts as a diode rectifier).

If switch S is closed, a slight tapping of the tube will cause its filament to vibrate and the plate current will vary slightly. Part of the varying energy in the plate is fed back to the grid through tickler coil L_2, causing the oscillatory system of L_1-C_1 to go into action as already explained by having an e.m.f. across L_1 and C_1.* The voltage across C_1 is amplified, however, by the tube and causes the plate current to vary with the same fre-

*Coil L_1 and condenser C_1 being in parallel start to exchange energy with the result that the voltage across both oscillates, decreasing as determined by the resistance present. If it is large, oscillations will be damped out quickly.

quency as L_1-C_1. This varying current induces into L_1 a second and larger e.m.f. which aids the original induced voltage. If it were not for this second induced e.m.f., the original oscillation in L_1-C_1 would die out, because of the circuit resistance. Because this induced e.m.f. makes up for the voltage loss due to the resistance, its introduction is often referred to as adding negative resistance. This feeding back continues until the current in the plate swings from zero to a definite maximum value depending on the plate load and the supply voltages. As you know, this pulsating plate current may be considered as a D.C. component plus the A.C. signal. By introducing an R.F. coupling transformer in the plate as shown in Fig. 6, the A.C. signal may be supplied to the load.

Should the filament be connected to a D.C. power source, oscillation can be started only by tapping the tube or turning off and on, the line switch L.S. In this case, the oscillation in the plate will be sustained or continuous as in Fig. 3c.

When the switch S is opened, the rectified grid current creates a large voltage drop across R_L and C_L, thus placing a negative bias on the grid. If the resistance value of R_L is large enough, the grid bias will be sufficient to reduce or even stop the amplifying action of the tube, thus stopping the feed-back. After the tube is blocked, the energy stored in C_L gradually leaks off into R_L, which means that the bias voltage is reducing. When the bias is reduced sufficiently, the feed-back action resumes. The action repeats itself at a rate determined by the electrical values of R_L and C_L. The larger both are the slower will be the action, and the smaller both are the faster will be the interruption. Thus the oscillating signal is modulated and if a receiver is connected to the output terminals and tuned to the carrier, the modulating note will be heard.

This grid action modulates the oscillating current as shown in Fig. 3d. Again, using an A.C. source of e.m.f. at the filament terminals and closing switch S will give a 60-cycle pitch to the output and using the grid leak arrangement (switch open) will give half the pitch obtainable with a D.C. supply. By varying the capacity C_1 a carrier frequency of 1500 to 550 kilocycles can be had with a proper coil and a variable condenser. A condenser ($C_L = .00025$ mfd.) and a leak ($R_L = 4$ megohms) will give approximately a 1000-cycle modulation frequency. (See fig. 6.)

These signal generators may be calibrated by connecting an insulated wire to either terminal 1 or 2 and connecting the other end of the wire to the aerial binding post on a receiver. Tune in a broadcast signal of known frequency on the receiver, then vary the capacity of condenser C_1 of the oscillator. As you turn the dial of C_1 back and forth the receiver will squeal. If you are very observing you will note that actually two squeals can be obtained by turning dial of C_1 only a fraction of a degree, with a mid-point where no signal is heard. Note the dial reading of C_1 at this no signal point, as the oscillator is now generating a high frequency signal equal to the frequency of the station broadcasting. Choose several stations from 1500 to 550 K.C. and repeat the operation. Plot the results on graph paper and your generator is calibrated. Coupling between L_2 and L_1 can be made variable. Any large change in coupling will alter the true readings. It is best to leave the coupling fixed at a mean (average) value for precise work.

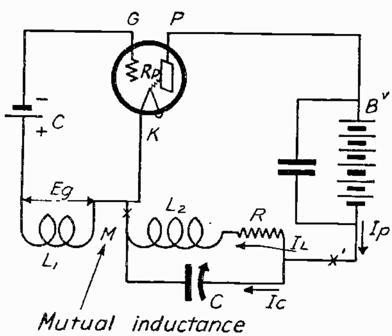


Fig. 7

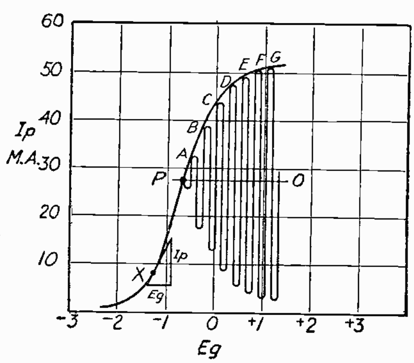


Fig. 8

3 **Tuned Plate Oscillators.**—It is also possible to create sustained oscillations in the plate circuit by having the tuned oscillatory circuit in the plate circuit as in Fig. 7. A coil L_1 is connected to the cathode K and to the grid through the C bias (C). A coil L_2 having a resistance R is shunted by a variable condenser C. Mutual induction (M) exists between L_1 and L_2 and is variable. One end of L_2 is connected to the cathode and the other end to the plate of the tube through the B battery which has a by-pass condenser across it so that the generated high frequency current won't go through the battery.

A slight vibration of the tube, or opening and closing the circuit, will cause the D.C. current (I_p) to vary. The D.C. current (I_p) passes through L_2 and causes L_2-C to oscillate, inducing in L_1 a voltage depending on the mutual inductance (M) and the value of the A.C. current I_L. The voltage induced in L_1 will appear across it as E_g and of course will be an A.C. voltage. This will add to and subtract from the "C" bias causing the plate current to vary to a larger extent than the original impulse did. The cycle of action repeats itself until the plate current varies from zero to a maximum.

Obviously the two important factors in this action are the grid voltage and the plate current. Therefore, for a closer analysis we will analyze the E_g-I_p curve, but in this case the dynamic curve. Dynamic E_g-I_p curves will be considered shortly in greater detail but for the present it will suffice to say that the circuit consists of the plate load resistance in addition to the tube resistance. When the tube is oscillating, a D.C. milliammeter in the plate circuit will read a plate current I_p (the average plate current) which is one-half the value of the maximum.

Now suppose that for a given plate voltage E_p (the battery voltage), the C bias is set so that when no oscillation takes place, for example if L_1 is shorted, the static plate current will be equal to the average oscillating I_p. Referring to Fig. 8, if the C bias was set to $-3/4$ volt, the plate current with no oscillations would be 27 ma. If the short across L_1 is removed, the slightest variation in plate current will induce a voltage into the grid and because of the amplifying action of the tube, the plate current will vary as shown between P and A in Fig. 8. During the next cycles the variation will be as shown by A, B, C, D, E, F and G until the maximum possible plate current variation exists, that is, from zero to twice I_p. This maximum current is referred to as the saturation current, for no matter how great the grid voltage became, the plate current could not exceed this value.

4 We should realize that the plate load in Fig. 7 is R and may be either the resistance of the coil L_2 or the effective load because L_2 is coupled to a load. In any parallel resonant circuit such as we have here, the resonant circuit acts as a resistance whose value is $\frac{\omega^2 L_2^2}{R}$, where ω is 6.28 times the oscillating frequency, L_2 is in henries and R in ohms. It is necessary that the value of E_g* be large enough so that when amplified by the tube, a plate current I_p (one-half the saturation value) will flow in spite of the plate and load resistance. The proper E_g is obtained by varying M, the mutual inductance.

---

*All currents and voltages are peak values. When considering power, they should be changed to effective values by dividing by 1.41.

Effect of Coupling.—If we start oscillations and then decrease the coupling between L_1 and L_2, E_g must be kept up in strength or oscillation will stop. In order to do this I_L must increase. Thus, when the coupling is loosened, but not enough to stop oscillations completely the oscillatory current actually increases to make up the loss in induced voltage due to the decreased coupling. As the tank current (as I_L is called) increases, it supplies more power to the load, and this increase must come from the power supply which is fixed by the plate supply voltage. When no more power is available for increased tank current, no further decrease in M will raise I_L and oscillations stop abruptly.

However, let us say that the coupling is again made tighter, oscillation begins and builds up to a maximum value and further increase in mutual inductance has the effect of adding more

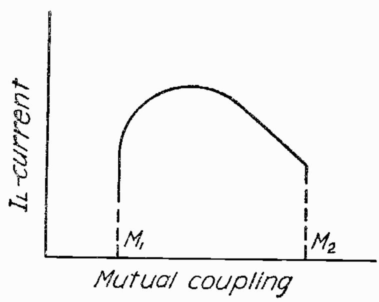


Fig. 9

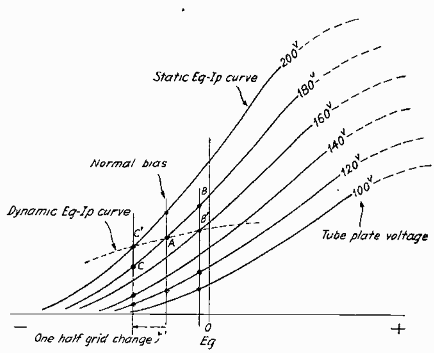


Fig. 10

resistance to the oscillatory circuit. Sufficient negative resistance cannot be supplied to this circuit and oscillation ceases. The actual variation of oscillatory current I_L is shown in Fig. 9 as the mutual induction is varied. Generally, it is best to adjust an oscillator to its maximum oscillatory current I_L, by reducing the coupling between L_1 and L_2.

Dynamic E_g-I_p Characteristic.—We mentioned that the maximum variation in plate current was determined by the plate load. We also said that for a resonant (tank) circuit, this load was equal to $\frac{\omega^2 L_2^2}{R}$, that is, if R was small the actual plate load would be very large. This load acts like a pure resistance. Suppose a given voltage (180^v) is applied to the plate of a tube. The static value of plate current will be set by the grid bias (or A in

Fig. 10). Now as the negative grid voltage decreases due to feedback, the plate current will go up, but in doing so it decreases the voltage applied to the plate of the tube because of the drop in the load. Let us say the drop is 20 volts. Now the E_g-I_p curve for 160 volts determines the plate current, that is, we have a value of B′ instead of B. When the negative grid voltage increases the same amount, the plate current will go down, the load drop will be less, more voltage will be available at the tube plate and the plate current will be larger than expected.

The current instead of swinging from C to B will vary from C′ to B′ which is less of a variation. The variation between C′ to B′ is called a "dynamic variation" and a continuous E_g-I_p curve as in Fig. 11 is called a dynamic characteristic. Therefore, dynamic E_g-I_p curves must always be considered when considering actual values. Figure 11 shows the difference between a static and a dynamic curve. A larger plate resistance load makes for a flatter dynamic E_g-I_p curve. And saturation currents should be determined from dynamic curves. Note that they will be less than the values derived from static curves. Also observe that should low plate voltage be used the saturation value will be less. Hence lower power outputs are obtained by using less applied voltage.

Effect of "C" Bias on Oscillating Current.—So far we have considered that the "C" bias causes the tube to operate in the center of its E_g-I_p curve. When oscillation starts the current oscillates between zero and the saturation current as a maximum, as determined by the dynamic curve. P is such a point on Fig. 11. If the C bias is increased so that the point of operation is A, a weak oscillation for starting will move the plate current only from A to A′ and no oscillation in L_2-C will take place because the amplification of the tube is nothing and no reinforcement takes place. If the coupling between L_1 and L_2 is increased and a forced oscillation is started in the plate, an oscillating current I_L will create a larger voltage E_g in the grid, causing E_g to swing from B to B′; oscillation will take place in the plate circuit and reinforce the oscillating circuit L_2-C.

Power Efficiency.—We should know by now that the plate load in a circuit such as shown in Fig 7 is $\frac{\omega^2 L_2^2}{R}$, where R may be increased by coupling a greater load to the tank circuit. We know that the plate saturation current is determined by the operating voltage and the plate load. Now the actual plate power is the applied voltage multiplied by the average plate current (saturation current divided by 2). This power is used to supply the plate resistance loss and the tank power absorption.

The oscillator is essentially an amplifier and we know from our study of power amplifiers that the greatest output will be obtained when the load resistance equals the plate resistance. This is true with the oscillator, and when r_p equals $\frac{\omega^2 L_2^2}{R}$ the greatest efficiency is obtained.

Now, as you know, efficiency is the useful power divided by the total power. In this case only half the power is available even under the best conditions, therefore, the efficiency is one-half or 50 per cent. This is seldom obtained and the general efficiency is usually less than 50 per cent.

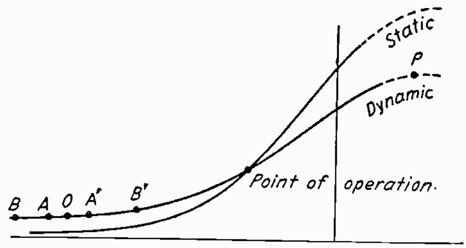


Fig. 11

In the case, however, of a very large grid bias, it is possible to get an efficiency of more than 50 per cent, but this is done at the sacrifice of a pure wave. Harmonics become quite plentiful and for this reason increased efficiency is never attempted in oscillators unless harmonics are actually wanted.

In actual power oscillatory circuits a D.C. voltmeter measures the supply voltage. A D.C. ammeter is placed in the plate circuit to measure the average plate current and an A.C. ammeter (a thermoammeter) is placed in the tank circuit, usually in the condenser lead. For a given applied voltage, maximum efficiency will be indicated when the plate ammeter reads the least and the tank meter reads the greatest. Usually this can be effected by increasing the applied load (how this is done will be shown shortly) or by varying the coupling between the plate and grid circuit. The readings are sufficient to give the actual efficiency of the oscillator. If the resistance R in Fig. 7 is known, ($I_L^2 \times R$ divided by $B^v \times I_p$) multiplied by 100 will give the plate efficiency of the oscillator. Note that the filament power is not considered.

TYPICAL OSCILLATING CIRCUITS

So far we have considered two typical circuits illustrating the principles of A.C. power tube generators—the tuned grid, and the tuned plate method—Figs. 6 and 7. We shall now study some of the variations of these two basic methods.

If instead of using two separate coils L_1 and L_2 as in Fig. 6, one coil is used and a tap P connected to the cathode as in

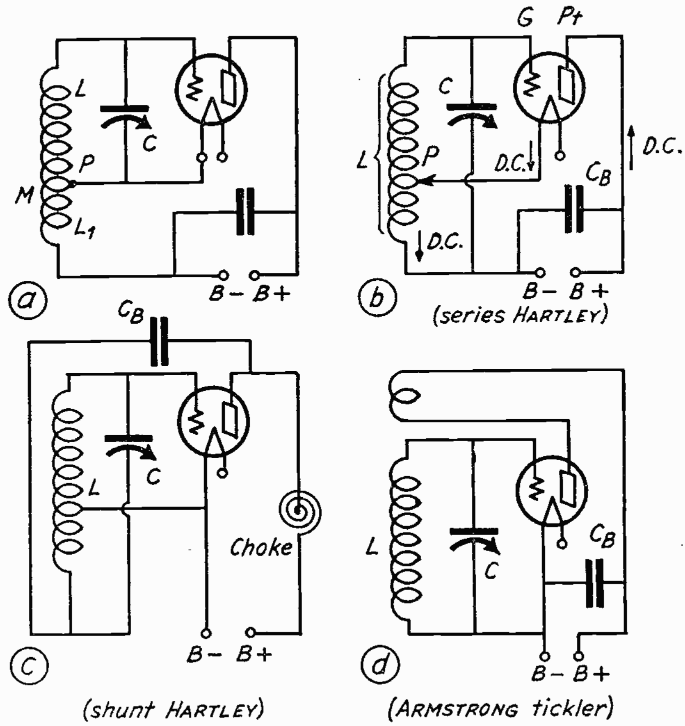


Fig. 12

Fig. 12a, a common form of tuned grid circuit is had. The feedback is accomplished by fixed mutual induction and is usually set by adjusting the number of turns in L_1 at an average value to sustain oscillation over the complete tuning scale. The frequency of oscillation as determined by equation (1) is computed by the variable value of C and the total inductance of L plus M.

A slightly different oscillator known as the Hartley (named after its originator) is obtained by connecting the rotor of the variable condenser to the B minus instead of point P, as in Fig. 12b. The point P is now variable and connected to the cathode, thus allowing various degrees of coupling. Note that the oscillatory circuit is partly plate and partly grid tuned. The plate return to the cathode is through inductance L from point P to B–. The plate D.C. voltage to reach the plate and cathode must pass through this portion of the oscillatory circuit. In other words, the plate and cathode are in series with part of the oscillatory circuit, and for this reason the plate is series fed and the circuit is known as the *series Hartley* oscillator.

Increasing the coupling by moving P toward G does not affect the frequency of generation which depends entirely on L and C. A by-pass condenser C_B is required to complete the circuit between P_t and B– to provide a better path for the A.C. component.

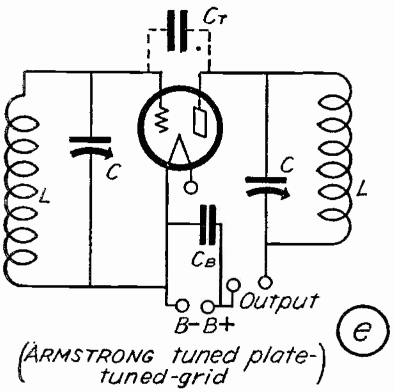


Fig. 12e.

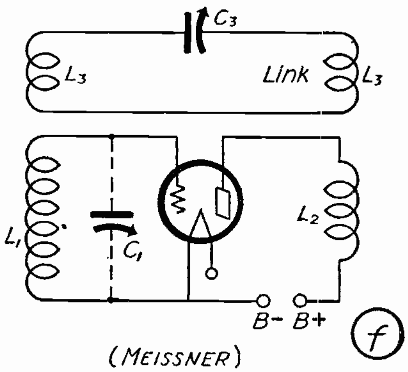


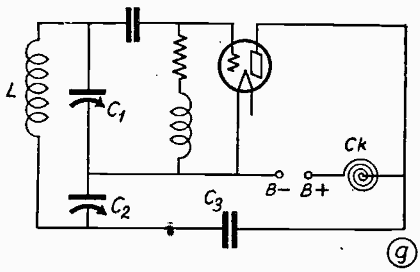
Fig. 12f.

A different form of the Hartley circuit called the *shunt Hartley* method is shown in 12c. The plate return end of coil L instead of being connected to the B– is connected by means of a plate blocking condenser C_B to the plate. Thus part of coil L is across grid and cathode and the other part across plate and cathode. In the shunt method D.C. plate voltage is fed directly to the plate and cathode and is prevented from going through lower part of L by condenser C_B. A direct plate voltage feed is a shunt feed.

The two best known oscillatory circuits are shown in Figs. 12d and 12e. They are known as the Armstrong methods of producing oscillations. Both methods have already been studied in detail. In 12d, coupling is varied by the tickler, whereas in 12e, the coupling is by means of a capacity C_T—the capacity of the tube. This is constant except when a small vernier condenser is connected across the grid-plate to increase the capacity coupling between circuits. In both cases, d and e, the frequency of oscillation is determined by L and C and in 12e, both L's and C's are alike, otherwise a heterodyne (variation in amplitude of oscillation) will take place.

In the tuned plate-tuned grid circuit, either or both of the variable condensers may be removed and the grid and plate coils coupled to each other by a tuned link circuit as shown in 12f. Without C_1 oscillation frequency is determined by the link L_3 and C_3, but with C_1 as shown, both the link and the tuned grid must be set at the same frequency.

A circuit quite often met with is shown in 12g. It is called the Colpitts shunt method. The cathode instead of being connected to a tap in the inductance coil is connected between two



COLPITTS shunt capacity control

Fig. 12g

condensers, C_1 and C_2 in series. Thus, by varying C_2 the coupling may be increased or decreased. However, every adjustment of C_2 requires an adjustment of C_1 to maintain constant frequency, as it depends on L and a new capacity value:

$$\frac{C_1 \; C_2}{C_1 + C_2}$$

C BIAS FOR OSCILLATORS

6 In any one of the circuits just studied, the C bias may be obtained by connecting a C battery or a "C" bias resistance directly in the grid-cathode circuit. A more common method, called automatic bias, uses a grid condenser and a 5,000 to 50,000 ohm grid leak resistor as shown in Figs. 12g and 13. Automatic biased oscillators are easily self started.

The principle of the automatic grid bias is best explained by studying the action of Fig. 13. Assume that the voltage across the resonant circuit e_{g1} is a sine wave as shown in Fig. 14a. During the positive alternation of the exciting voltage the grid attracts electrons, while during the negative alternation the grid attracts no electons. Current, as you know, will flow from the grid to the cathode as shown by i_g in Fig. 13. The grid current through the tube will vary from instant to instant as shown by Fig. 14b.

Now we can study the action in C and R. In the first place condenser C acts as a low reactance path for the applied e_{g1} voltage. Furthermore, the grid pulsating current through R is leveled out by its charging and discharging action, so in reality the current through R is smoothed out as shown by dotted line

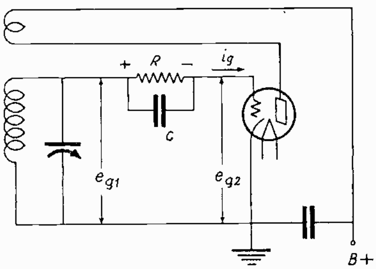


Fig. 13

in Fig. 14b, as the average i_g current. This direct current flows from the positive to the negative terminal of R, thus producing a D.C. voltage across R with the negative terminal connected to the grid as indicated in Fig. 13.

The net voltage e_{g2} applied to grid input (see Fig. 14c) will be the voltage e_{g1} less the C bias. Note that the grid is positive for only a portion of the positive cycle of e_{g1} (shaded area in Fig. 14c) and grid current through the tube only flows during this time. Plate current only flows when the grid voltage is less than the cut-off value. From Fig. 14c we can see that the plate current will exist only a slightly longer time than the grid current.

The grid bias acts like an automatic switch which turns the plate current off and on. Increasing the grid A.C. voltage merely increases the time the net grid voltage goes positive, increases the grid current, increases the C bias, increases the grid losses and only slightly increases the plate current. Increasing the bias resistor increases the bias voltage, lowers the grid current, lowers the grid losses and decreases the plate current slightly. A high bias means a high efficiency oscillator but one rich in harmonics.

The action of the automatic bias connected as shown in Fig. 12g is the same. When using a low resistor in this circuit a choke in series with the resistor is necessary if an A.C. short circuit through the resistor is to be prevented. Usually a choke is necessary only in power oscillators.

METHOD OF COUPLING LOAD

The load may be applied at any portion of the circuit where a substantial oscillating current exists, but in general, the best point is at the oscillatory inductance. Figure 15 shows several methods commonly used. By applying the load at the inductance,

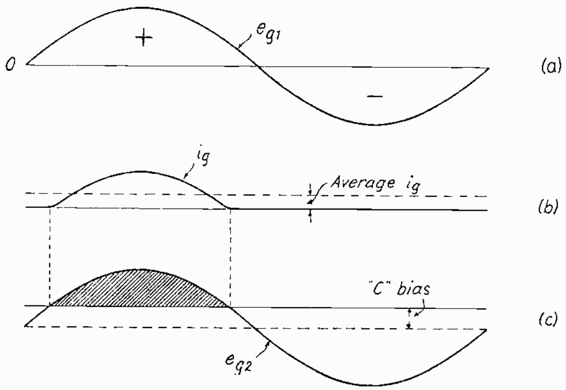


Fig. 14

either by magnetic or capacitive coupling, the effective resistance of the oscillating circuit is increased which is exactly what is needed to obtain maximum efficiency. Coupling is usually made near the plate end of the coil. If the coupling is tight the frequency of the oscillator will be altered.

MODULATION

The output energy of a power oscillator is in all cases continuous and unvarying as in Fig. 3c. For commercial purposes such a signal is of little value, although by receiving it with a regenerative receiver, the receiver can be made to oscillate at a slightly different frequency, and the difference in frequencies actually detected as an audible note. A telegraph signal can be transmitted by placing a key (sending key) at point X or X′ as shown in Fig. 7.

For broadcast transmission of speech or music, it is necessary that the oscillating frequency (R.F.) be modulated by the speech or music frequencies (A.F.). The process of modulation is nothing more than the *mixing* of two currents, one a radio frequency current and the other the audio frequency signal current. Sometimes the A.F. current is said to be *impressed* on the R.F. current. And the R.F. current is said to carry the

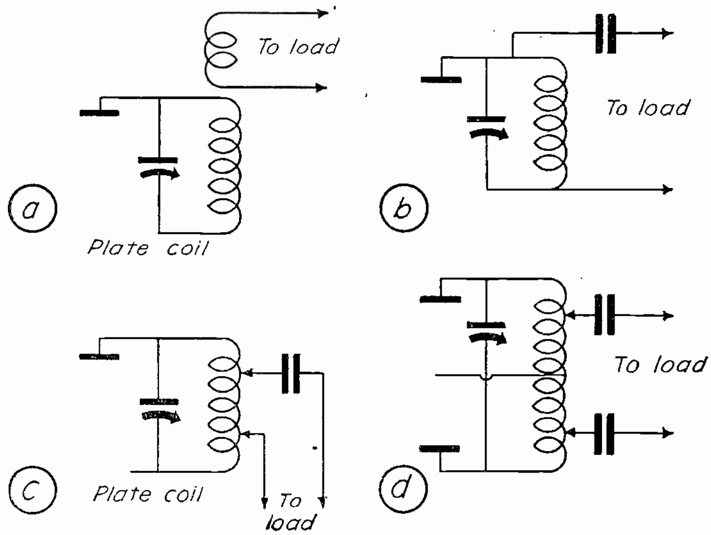


Fig. 15

audio signal. For this reason, the unmodulated R.F. is called the carrier current.

There are three ways of modulating a continuous (carrier) wave:

1. By means of a variable resistance device in the output circuit.
2. By adding the voice variations in voltage in the grid circuit of the oscillating tube.
3. By controlling the D.C. plate supply by voice variations.

The first method was formerly used in the phone transmitter but is now quite out of date. The method is schematically shown in Fig. 16. As the voice is thrown into the microphone, the resistance goes up and down in accordance with the voice vibrations. Thus, the amplitude of the oscillations is instantly increased or decreased and a modulated signal is obtained.

A simple grid method of modulation is shown in Fig. 17. Supplementing the grid bias offered by the grid condenser and low value leak, a microphone is connected to the primary of an audio transformer in series with a battery.

The secondary is connected in series with the grid return and the bias of the grid further supplemented. The average grid bias is made to follow the voice and the oscillatory current caused to change in magnitude. This method is only feasible when small power tubes are used.

Plate modulation (as shown in Fig. 18) is the common method used today in broadcast transmitters as it results in a greater degree of modulation. A power amplifying tube (modu-

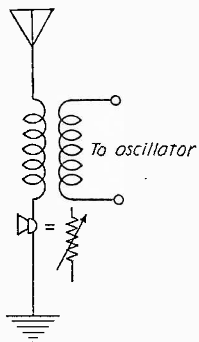


Fig. 16

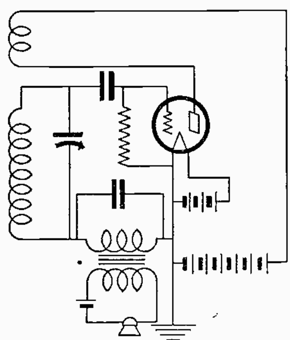


Fig. 17

lator tube) is used, connected between the oscillator and the microphone input. (In this case the Hartley shunt oscillator is used.)*

The plate currents of the oscillator and modulator tubes are fed from a common B source of voltage through an iron core choke coil CH. In a static condition, that is, when there is no voice input into the microphone, a constant current flows through CH. As the latter is a large choke it resists any current change such as would represent voice current—its magnetic field opposes the current that creates it.

A sound is impinged on the microphone and its vibrations vary the current in the primary. This varying current induces a varying voltage in the secondary of the microphone transformer

*An audio amplifier is often used between the microphone and modulator to obtain high percentage of modulation.

feeding the modulator tube. This results in a varying current (I_m) in the plate of the modulator tube. From Kirchhoff's Laws, the current to the point P equals the current away from the point, and realizing that I, the current though the choke, will not change, we know that I_g, the oscillator plate current varies as the audio current in the modulator tube varies. When one increases the other decreases.

An increase in the plate current in the oscillator tube immediately increases the oscillating current in the inductance L which is coupled to the load and a decrease in plate current causes a decrease in the oscillating current. This method of modulation is known as the Heising method of constant current

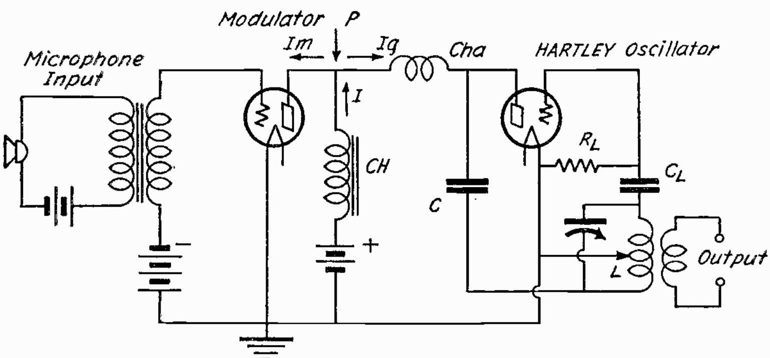


Fig. 18.—Modulated R.F. oscillator using Heising system of plate modulation.*

modulation. A choke coil Cha is placed next to the plate of the oscillator to prevent any high frequency oscillations from feeding back to the modulator.

A continuous constant amplitude oscillation is represented in Fig. 19a. This is the type of current that could be obtained from the output if no sound was "impinged" on the microphone. Curve 19b shows the variation in the oscillator plate current when a voice or a sound is directed into the microphone. This causes the amplitude of the oscillator current, Fig. 19a, to rise and fall with the result that a modulated current as in Fig. 19c, is obtained in the output.

The amount of rise and fall is an important factor in transmission and reception. If I_o represents the peak current when

*The value of CH in henries should be .008 Rp where Rp is the AC resistance of the modulator tube. This is essential for good low frequency response. For good high frequency response the value of C in microfarads is equal to 10 ÷ Rp.

"idling," and D represents the distance or value between the idle peak current and the lowest amplitude, percentage of modulation is:

$$\text{percent } M = \frac{D}{I_0} \times 100.$$

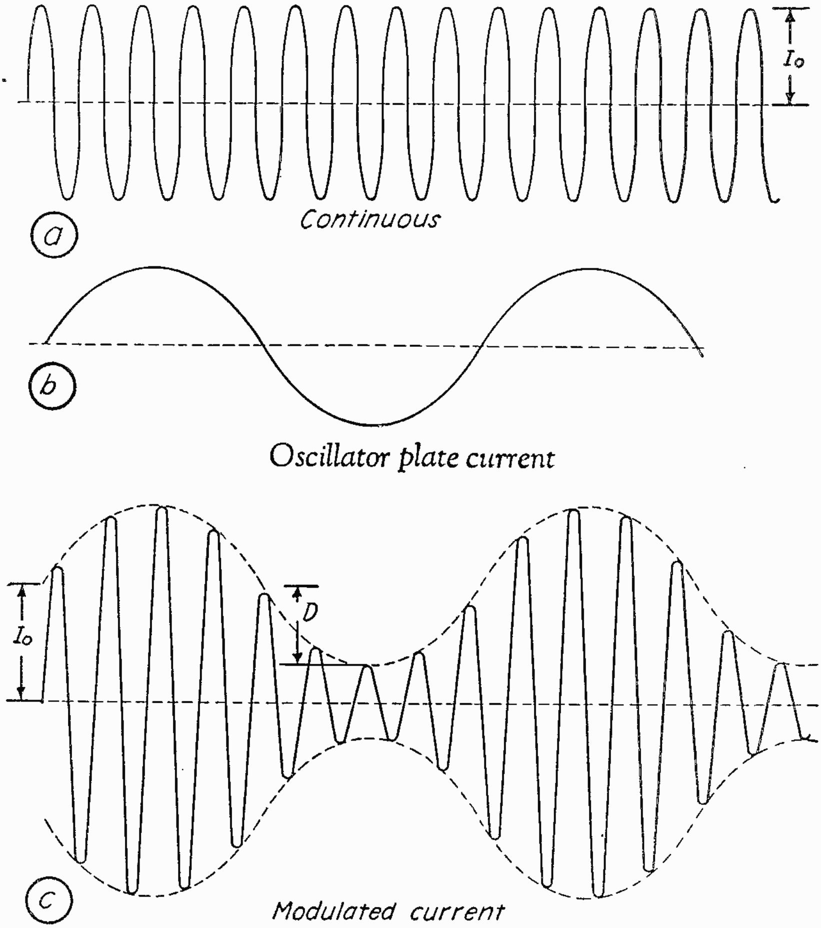


Fig. 19

When D and I_0 are equal, we have 100% modulation, which is quite common today, but is possible in practice only when the modulator tube is more powerful than the oscillator tube.

Audio Oscillator.—In much the same way an oscillator may be built which will supply oscillating current at audio frequencies. To be of any value in testing audio systems, or loudspeakers, an oscillator must be variable over a frequency range from 30 to 10,000 cycles per second. Figure 20 shows an audio oscillator capable of giving practical service. "T" is a good grade audio transformer with a 3-to-1 ratio, the leak is a variable one having very little capacity of its own and shunted by a 0.1 mfd. mica grid condenser. A 112-A tube is used as the oscillator tube. A shunt Hartley oscillator is used and the load current is taken off the plate in series with the B battery supply. The frequency of oscillation will depend on the distributed capacity of the primary and secondary and their inductance. If oscillation does not take place, reverse the primary of the transformer T. Decreasing the value of resistance in the grid leak will further increase the pitch of modulation.

Signal Oscillator for Testing Receivers.—The time has arrived when servicemen can not depend on broadcasting stations

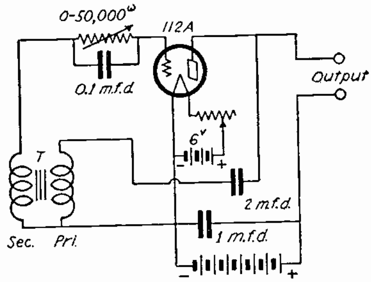


Fig. 20

for testing purposes. Most repair work is made at the bench and a variable R.F. output at varying frequencies is necessary. In this way the distance-getting and selective qualities of a machine are checked. To test the sensitivity and selectivity, the expert service man relies on his audio modulated signal oscillator, which may be like the one in Fig. 21. A phonograph pick-up may be used in conjunction with a turn-table and record to modulate the oscillator with music when desired, or an audio oscillator like the one shown in Fig. 20 may be used.

Complete information for the construction of a variable modulated signal oscillator is shown in Fig. 21. The entire device is mounted inside an aluminum box. By varying the contact P on the 100,000 ohm potentiometer, it will vary the percentage of modulation. For the broadcast band about 80 turns of double cotton covered copper wire is wound on a two inch diameter form. Tap 2 is taken off at about 25 turns from the end marked 1. This gives us the coil L.

There may be occasion when you will need lower frequencies. For example, if a 100 turn and a 200 turn honeycomb coil are connected in series aiding, the 100 turn coil replacing section 1 to 2 of coil L, the range will be approximately 90 to 250 kilocycles. You may raise the range, that is, 100 to 260 kilocycles, let us say, by removing a few turns from the 100 and 200 turn coil.

By mounting both the broadcast and low frequency coils on their own three prong base which would then be plugged into a three hole receptacle mounted within the case, a wider frequency range would be obtained. The eight turn coupling coil may be wound on a 2½ inch diameter form and secured to the three prong receptacle. Higher frequencies can be obtained from the harmonics.

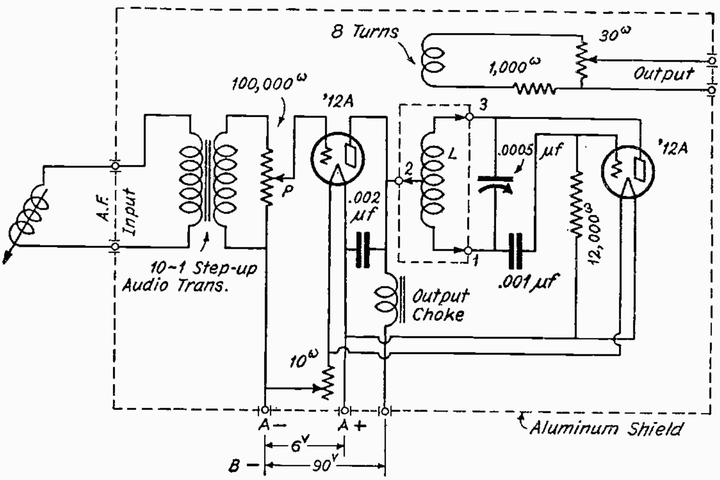


Fig. 21—Audio modulated signal oscillator (Hartly type)

HARMONICS

All oscillators in general use produce oscillations that are full of harmonics. Now what do we mean by this? Let us assume that we have a signal generator of the type just described and that its signals are being picked up by a receiver which is calibrated according to frequency and tunable over a wide band of frequencies. If the oscillator is designed to generate a frequency of 200 kc., the receiver will respond to the signal very strongly when adjusted to this frequency. Yet if we tune the adjusting dial to 400 kc., we will also receive a signal but with decreased strength. In the same way, the signal will be heard at a receiver setting of 600, 800, even 1000 or more depending on the sensitivity of the receiver. But no amount of tuning under 200 kc. will result in a signal being heard.

Radio-Tricians explain that this tuning a single signal at various dial settings is due to the presence of harmonics—a second harmonic, a third, a fourth, and so on. The "first harmonic" is the 200 kc. frequency, the original, or as it is usually referred to—the *fundamental frequency.* All the harmonics are 2, 3, 4, 5, etc. times the frequency of the fundamental. Thus $2 \times 200 = 400$ kc., the *second harmonic;* $3 \times 200 = 600$, the

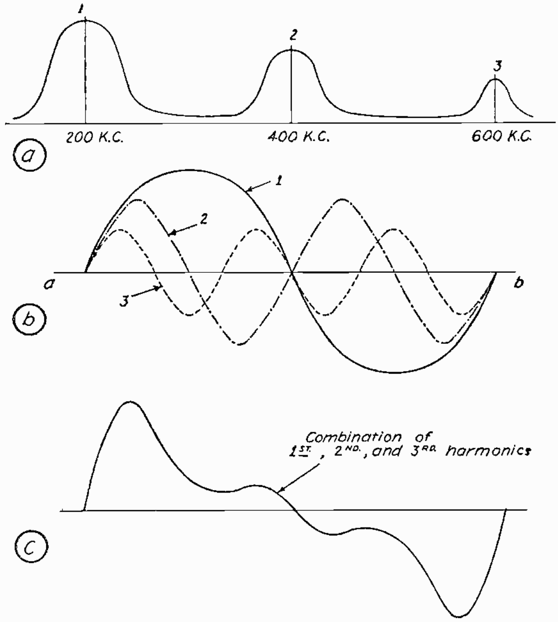


Fig. 22

third harmonic; $4 \times 200 = 800$ kc., the *fourth harmonic* and so on.

Within the generator as well as in the receiver there is only one current, of course. But the receiver is selective, that is, it is able to pick out the various frequencies—responding to one only and passing up the others. This is brought out clearly in Fig. 22a. There are three distinct points of resonance. If an oscillograph were used and photographs taken at each resonant point, the composite picture would appear as in Fig. 22b. Notice that curve 1, which represents current in the receiver when it is in resonance with the fundamental frequency (200 kc.), shows one complete cycle between a and b. But curve 2 (the 400 kc. resonance curve) shows 2 complete cycles. And curve 3 (when receiver is in resonance with the third harmonic) shows three complete cycles. Notice that each curve is a pure sine curve and that the individual amplitudes are proportionate to the resonance curves in Fig. 22a.

The oscillator did not generate three (or more) different currents, but one current in which the various harmonics ap-

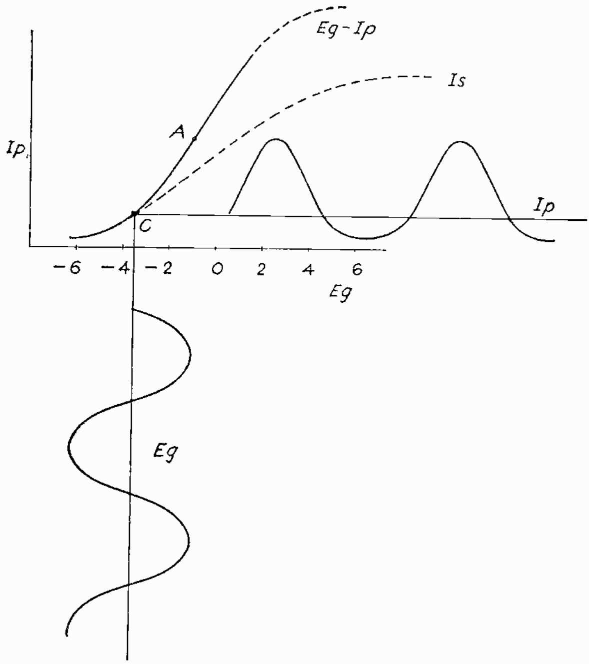


Fig. 23

peared. If an oscillograph picture were made of the oscillation current, in which the fundamental and the harmonics appear, it would look something like the curve in Fig. 22c. A curve of this sort is a distorted curve—and we know now why it is distorted—because of the presence of harmonics.

It is important to remember that any current, any vibration that has a period, that is, repeats itself time and time again should be considered as consisting of a fundamental frequency and many harmonic frequencies. This applies to oscillator signals, to Radio waves, to sound, and to audio currents. Often the reproduction of harmonics is desirable. This is particularly true in the case of music reproduction. All the audible harmonics of the original must be reproduced in the speaker, otherwise a musical program will appear distorted or flat. But in an oscillator, harmonics are undesirable and care is exercised to keep them at a minimum.

7 One method of reducing harmonics is by the use of a low C bias—another is the use of a large resistance load in the plate circuit which has the effect of making the dynamic curve more nearly straight.

Fig. 23 shows how a sine wave grid voltage E_g, sent through an oscillator tube, will result in a distorted output current when C is the bias voltage. When the plate current oscillates between zero and the saturation point, distortion will be much greater.

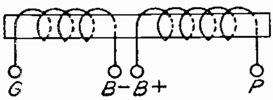


Fig. 24a

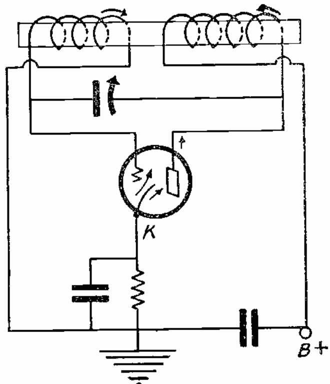


Fig. 24b

The distortion will be less if a lower C bias causes the tube to operate more nearly in the center of the straight portion of its curve, as at A. If the plate is loaded with resistance, distortion will be still less, for the effect will be to change the E_g-I_p curve as indicated by the dotted curve in Fig. 23.

This last method is often employed in super-heterodyne oscillators. In broadcasting stations the modulated current is filtered through 2 or more tuned power amplifiers, and all but the fundamental carrier frequency, modulated by the audio signals, is filtered out. This does not mean that the audio harmonics are filtered out—they are necessary for exact receiver reproduction.

OSCILLATOR CONNECTIONS

In building an oscillator, it is always wise to spend considerable time in planning the layout of wires so that no changes need be made after the circuit is wired up.

As a rule the grid and the plate coils are wound on the same form as in Fig. 24a, and usually wound as though the winding were continuous, but split in the center. The proper connections are shown in the drawing.

Sometimes, for various reasons, it may be inconvenient to employ just this arrangement. Then the proper connections can be determined very easily. Lay the circuit out on paper and trace the path of the electrons from the cathode K, in Fig. 24b. They pass from the cathode to the plate (opposite to conventional current flow). A voltage is induced in the grid coil by mutual induction with the plate coil—but this voltage is in the opposite direction (180° out of phase). Assuming that the current flow in the plate coil is in the right direction, determine the direction of current flow in the grid coil by means of the right-hand rule. The magnetic field of the grid coil is opposite in direction to the magnetic field of the plate coil.

The arrows in Fig. 24b point in the direction of electron flow. If current flows in the same direction in both coils, oscillation cannot take place. Then either the plate coil connections or the grid coil connections must be reversed to obtain oscillation.

DYNATRON OSCILLATOR

8 Secondary emission of electrons in a vacuum tube makes it possible to operate a tube as an oscillator without the usual plate-to-grid feed-back. Suppose, as is shown in Fig. 25, a screen grid tube ('24) is operated at a fixed C bias, a fixed but large screen grid voltage and the plate voltage is varied from zero to maximum. As the plate voltage (E_p) is raised, it will be found that the plate current (I_p) will increase until at a plate voltage indicated by (1) in Fig. 26 the plate current will decrease for further increases in E_p. In fact, when E_p is somewhat greater than shown by point 2, the meter I_p will start to read in the opposite direction until E_p is increased to point 4. Note that at point 3 the current will start to decrease to zero again.

This action may be explained as follows: When the screen grid is more positive than the plate, the electrons leaving the cathode will have such a large velocity that they will pass through the screen grid mesh, strike against the plate and dislodge 2 to 15 times as many electrons as originally hit against the plate. These electrons form a cloud around the plate and are attracted to the screen grid because it is at the highest positive potential. The plate is deprived of electrons and the plate circuit current therefore decreases. This decrease becomes apparent at the voltage shown by (1) in Fig. 26.

As you know, the A.C. resistance of the plate is measured by the change in plate voltage divided by the change in plate current. From points 0 to 1 the plate current increases for increases in plate voltage; from points 1 to 3 the plate current decreases for increases in plate voltage. The latter, according to our definition of A.C. plate resistance, will make r_p (plate resistance of the tube) negative. In fact, if we place a resistance load in the plate circuit, the total plate circuit resistance will be decreased by the amount of this negative resistance.

Should we introduce into the plate circuit at point X an inductance in parallel with a condenser (a resonant circuit), the slightest variation in the plate current will cause this tank cir-

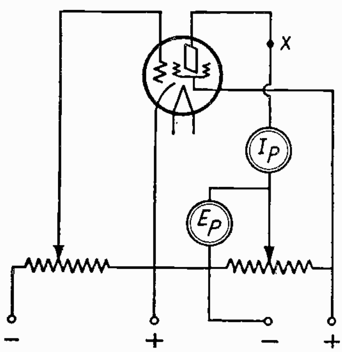


Fig. 25

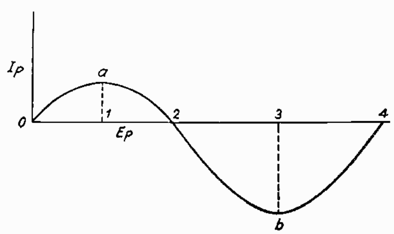


Fig. 26

cuit to oscillate at a frequency determined by its L and C. This oscillatory circuit will have a terminal resistance (provided all the resistance is in the coil) equal to $\frac{\omega\ L_2^2}{R}$. If the negative resistance is equal or less than this value, the oscillation in the tank circuit will be maintained. This should be clear when we realize that the terminal resistance of the tank circuit is in shunt with this negative resistance. The net resistance will only be negative when the above conditions exist. The most stable action is obtained when the plate voltage is set at point 2 of Fig. 26. The actual variation in plate current will be from a to b and accordingly, the tank current variation will be much greater (in a parallel circuit the line current is much less than the current in either the condenser or coil.) The amount of A.C. current in the plate and of course in the tank circuit may be controlled by varying the C bias on the control grid. The greater the C bias the less the A.C. signal.

Quite often when a modulated R.F. signal is desired, an A.F. and R.F. parallel resonant circuit are connected in series and inserted at point X of the circuit shown in Fig. 25. Under these conditions, the sum of the series resistors (impedance of both tank circuits at their respective resonance points) must be greater than the negative resistance of the tube. In such a condition, practically 100% modulation is obtained and the essential sine wave carrier and modulation wave form is realized.

For testing and servicing purposes a variable modulated carrier is desirable and for this purpose the circuit shown in Fig. 27 is quite valuable. In this circuit a '24 screen grid tube is used.

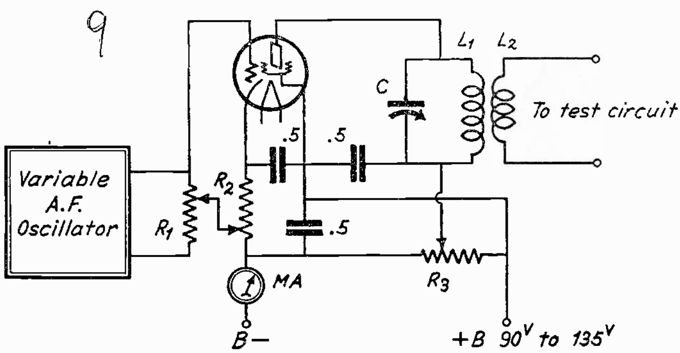


Fig. 27.—Dynatron oscillator circuit in which the percentage of modulation may be varied.

The audio oscillator may be of any design; for example, the one shown in Fig. 20. A microphone or magnetic phonograph pickup may be used. R_1 is a 500,000 ohm potentiometer, R_2 a 2000 ohm potentiometer and R_3 a 100,000 ohm potentiometer. If the test oscillator is to be used for testing in the broadcast range of 550 to 1500 kc., C may be a .00035 variable condenser, L_1 a 250 microhenry coil (76 turns No. 24 D.C.C. wire on a 2½ inch diameter tube) and L_2 about 20 turns tightly coupled to L_1. Adjust R_2 and R_3 with the A.F. input not in operation until maximum R.F. output is obtained. (This may be obtained by connecting a radio receiver to the oscillator output and the receiver output noted.) The value of the 0-10 milliammeter reading should be noted and thereafter the oscillator adjusted to this indication.

TEST QUESTIONS

Be sure to number your Answer Sheet 21 FR-1.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and the best possible lesson service.

1. Name three uses of vacuum tube oscillators.
2. What is the primary reason that makes a vacuum tube suitable for use as self excited A.C. generator?
3. Briefly explain the fundamental difference between a tuned grid and a tuned plate oscillator.
4. Where would you apply a load in an oscillator circuit?
5. What method of modulation is most commonly used at the present time in broadcast transmitters?
6. How is an oscillator tube automatically self-biased?
7. Assuming you had built an oscillator, name two ways you would keep down the harmonics generated to a minimum.
8. What electron action in a vacuum tube makes it possible to operate it as a dynatron oscillator?
9. Draw a circuit diagram showing how a dynatron oscillator is A.F. modulated when it is desired to vary the percentage of modulation.
10. What effect does increasing the plate resistance load have on the dynamic E_g-I_p characteristic?

TUNERS AND WAVE FILTERS

22 FR-1

PIONEER HOME STUDY RADIO SCHOOL

NRI

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

SINCERITY

We are often told that a man must rely on himself for success. In one way this is perfectly true—but it is not true that a man can become successful in any line of work without the cooperation of others.

Were it not for the fact that we are all, individually, as a group, living together in associations of various kinds, there would be no point in striving for success, or in being successful.

For this reason, men who desire to become successful can not ignore other people, they can not ride rough-shod over the feelings of others, they must be considerate, courteous, fair, honorable.

Of course, there are some men who have become seemingly successful without having developed these qualities. They have merely acquired a superficial smoothness, with which they are able to impress people for a time, until their true qualifications for success are found out and they lose what they have gained.

In other words, they try to lubricate the road to success with "banana oil," not realizing that all might go smoothly until they strike a hill in the road and then they will surely slide backwards as easily as they slid forward before.

Be considerate of others, be honorable in all your associations with your fellowman, be courteous, be just.

Possibly we can sum all this up in two words — be sincere. If you are really sincere, you will be honest, fair, kind and considerate.

All truly successful men are sincere. Success built on insincerity is not success—it can not last, nor is it complete and satisfying. Only merited success is complete and satisfying. Be sincere—if you want the kind of success that brings happiness. J. E. SMITH.

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Tuners And Wave Filters

SIMPLE RESONANT CIRCUITS

As we learned in a previous lesson there are several requirements that must be fulfilled to a satisfactory degree if a radio receiver is to be considered worth using. These are, simply:

(a) It must be sensitive;

(b) It must be capable of reproducing the sounds entering the microphone at the transmitter with a fair amount of fidelity;

(c) It must be able to discriminate with a fair degree of success between the many broadcasting stations within its receiving range.

The first two requirements have been discussed in this course. The main purpose of this lesson is to discuss the third requirement (c), but the first two requirements must be brought into the picture insofar as they are intimately concerned with item (c).

Item (c) may be briefly referred to as SELECTIVITY. The radio receiver must be capable of *selecting*, from a number of broadcast signals, only the one which the operator desires to receive, and it must be able to do this without permitting any other signals to come through to the listener's ears. In other words, no two stations must be permitted to "overlap." It is obvious that when we tune, for example, to WJZ we do not wish to hear music emanating from WOR. The intermingling of two programs would certainly spoil reception.

Selectivity is a serious and difficult problem to the designing engineer. Just consider for the moment how great a problem it really is. All radio broadcast signals are in a frequency band which has a lowest frequency of 550 kilocycles and a highest frequency of 1500 kilocycles. In other words, the broadcasting "range" is 1500 – 550 or 950 kilocycles (950,000 cycles) wide. The Federal Communications Commission allocates frequencies 10 kilocycles apart; this means that the tuning range of the receiver can accommodate 950/10 or 95 stations. Now, with 100 divisions on the dial of a straight line frequency tuning system, there will be a station for almost each division on the dial.

Anyone who has ever tuned a radio receiver knows what this means; it is possible to separate completely two adjacent stations (on the dial) only when both stations are fairly weak or distant. Local stations may sometimes be powerful enough to "spread" over the dial by as many as 15 or 20 dial divisions, depending upon how powerful or how near the station is.

Even many distant stations spread out considerably on the dial, especially when the receiver has a fair amount of amplification. The greater the amplification of the set, the greater will be the signals in the later R.F. stages, so that these will be likely to cover somewhat more than a division or two on the dial even when the stations being received are quite distant. There is generally a conflict between selectivity and sensitivity, as we shall see as we proceed in this lesson, and furthermore, there is also generally a conflict between *fidelity* and selectivity. This means that when extreme selectivity is desired some fidelity must be sacrificed and vice versa.

In order to understand properly the principles of selective circuits we must first start with the simplest. It consists of a generator supplying an alternating voltage to a circuit which contains a resistance, an inductance, and a capacity, all in series. Such a circuit is shown in Fig. 1. This may not at first look very much like a circuit in a radio receiver, but as we shall see later on, it is the form of circuit which occurs most often in a radio receiver.

The generator supplies the circuit with an alternating voltage *e*, which causes an alternating current to flow. Suppose we place somewhere in the circuit, as at *I*, a current-measuring device. The A.C. generator is, of course, driven by a motor. Suppose we are able to vary the speed of the generator by controlling the speed of the motor driving it. By so doing we will be able to vary the *frequency* of the generated voltage and current. Let us start with the generator turning slowly. The frequency will be quite low, and the generator will supply a certain small amount of current to the circuit.

Now let us speed up the generator somewhat, and increase the frequency. We shall find that the current in the circuit will increase somewhat, even if we are careful to adjust the generator field so that the generated *voltage remains the same as before.*

Now, let us go through the same performance again. We find that the current increases again; and so, continuing the process we eventually arrive at a frequency at which the current supplied to the circuit is quite great, even though we have not changed the generator voltage at all. In other words, we changed *only the frequency*. If we should plot a curve showing the relation between the current and the frequency, we should obtain one like the solid curve in Fig. 2. We started at the frequency f_1 and had a current equal to a. Then we increased the frequency to f_2 and obtained a current b. Finally, we increased the frequency to f_3 and the current increased to c. But now, if we increase the frequency further, we find that the current decreases; for example, by making the frequency equal to f_4 the current drops to d.

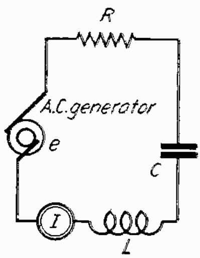

Fig. 1

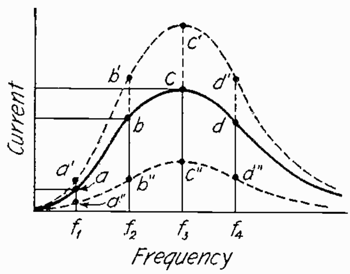

Fig. 2

At the frequency f_3 the current had its greatest or maximum value. This frequency is known as the FREQUENCY OF RESONANCE, or simply, the RESONANT FREQUENCY. Now, let us go through the entire performance once more, but this time let us decrease the resistance (R) in the circuit a trifle; we obtain another curve similar in shape, but somewhat more peaked; the curve is the broken curve a', b', c', d', in Fig. 2.

Note particularly that the peak of this curve occur exactly at the same frequency as the peak of the former curve. Now, in order to complete our story about this series resonant circuit let us make the resistance R greater than it originally was. Then we obtain the lower broken curve a'', b'', c'', d''. The peaks still occur at the same frequency; but note how flat the curve becomes. The peaks become flatter and flatter as we increase R.

Since the peaks always occur at the same frequency, regardless of the value of the resistance, it is clear that the frequency at which resonance occurs depends only on the inductance and capacity.

If we performed another set of experiments in which we allowed the resistance to remain fixed, while we changed either the inductance or capacity, we should find that we could vary the frequency at which resonance occurs. An increase of capacity or of inductance lowers the resonant frequency, and vice versa. All this we have studied many times before, but it is reviewed here as it will be a stepping-stone to a complete understanding of selectivity.

In radio receivers we have exactly the condition shown in Fig. 1. The resistance R is the resistance of the tuning circuit, i. e., of the coil and condenser and the wiring of the circuit. *Tuning* is done by adjusting the tuning condenser. We use the word *tuning* to mean adjusting the circuit to resonance. When we want to "tune in" a certain broadcasting station we adjust the tuning condenser so that the circuit is in resonance at the frequency of that particular station. We can't change the frequency of the broadcast station as we did that of the generator in Fig. 1, so we change the receiving circuit instead. We usually do this in radio receivers by varying only one part of the circuit, invariably the condenser.

The circuit in Fig. 1 is the fundamental circuit of the tuned stages in any receiver. The generator e may represent the voltage induced in the antenna circuit by a passing radio wave. The capacity C may be the capacity of the antenna, the resistance R may be the resistance of the antenna circuit, and L may be the inductance coil in the antenna circuit, which is generally *coupled* to another circuit or to a tube.

Now, let us see what this has to do with selectivity. Suppose we have two or more signals, from which we wish to select a certain one. This is illustrated in Fig. 3, where we have two generators, e_1 and e_2, each supplying a voltage to the circuit, but of different frequencies, f_1 and f_2. Suppose also that we can vary the condenser C. As we vary C we find that we can tune the circuit first to one generator and then to the other. If the frequencies were not too close together we should find that we would be able to obtain two distinct *peaks* of current, such as are shown in Fig. 4. The value of these current peaks would depend upon the voltages supplied to the circuit by two generators, and the two peaks would occur at condenser settings C_1 and C_2, which make the circuit resonate to the frequencies f_1 and f_2, respectively.

This is a true example of selectivity; we can tune the circuit to either generator frequency. If the two generators were broadcasting stations, we could easily tune in one or the other station. In other words, we could make the circuit *select* the desired signal.

However, let us suppose we adjusted our condenser to a point C_3, somewhere between the two peaks of Fig 4. What is happening? We can explain this by first supposing that we shut off the generator e_1. The current supplied to the circuit by the generator e_2 is shown by the broken curve *o-a-b-h*. In other words, at the setting C_3 we should have a certain amount of cur-

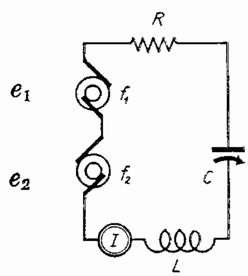

Fig. 3

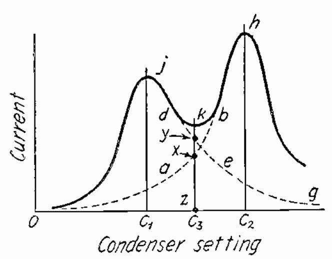

Fig. 4

rent in the circuit from generator e_2, which is represented by *z-x*. Now, if we shut off e_2 the current supplied by e_1 being represented by the curve *j-d-e-g*, we should have at the setting C_3 the current *z-y* supplied by generator e_1. With both generators going, it is clear that at the setting C_3 we should obtain a fair amount of current from each generator simultaneously,* and we should have what we call *interference*. It is this sort of interference we get in a radio receiver which is not sufficiently selective. The two signals interfere with each other and the interference will depend on the values of *z-x* and *z-y*.

We can decrease this interference by making the curves more *peaked*, and this can be accomplished by making the resist-

*As the currents are of different frequencies, the meter *I* does not measure the sum of the two currents, but a value somewhat less. This explains why line *kz* in Fig. 4 is shorter than a line representing the sum of *zx* and *zy* would be.

ance of the circuit less. In other words, if we made the resistance so small that we obtained curves like those shown in Fig. 5, there would be only a very small amount of current due to either frequency when the condenser is tuned half-way between the two resonant frequencies. For example, at "*a*," Fig. 5, the signals are too weak to be noticed. At "*b*," the signal "*A*" is so much greater than the signal "*B*," that the latter is "drowned out"; the reverse is true at "*d*." This is the principle of obtaining satisfactory selectivity. The desired signal intensity must be very large compared with the undesired signal, so as to "drown" out the latter. In other words, the ratio of the desired to the undesired signal intensity must be very great for any setting of the tuning condenser.

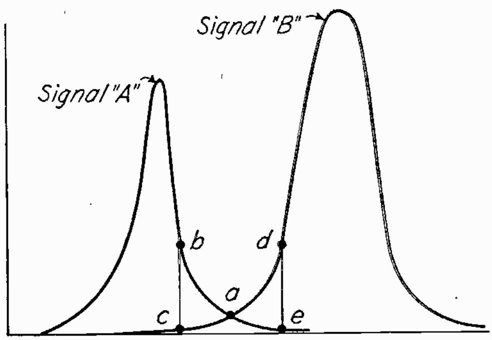

Fig. 5

COUPLED CIRCUITS

Now we are prepared to go on to the study of coupled circuits. Fig. 6 shows a tuning circuit placed between two tubes, such as we have in R.F. amplifiers of radio receivers. The output of tube T_1 feeds into a coil L_1, called the primary, which by mutual induction induces an alternating voltage into the secondary coil L_2, of the resonance transformer. This secondary voltage causes a current to flow in the circuit consisting of the coil L_2, the resistance R_2 and the variable condenser C_2, all in series. As the current flows through the condenser C_2 it establishes a drop of potential, or a voltage, across the terminals of C_2, which acts on the input circuit of the tube T_2, which amplifies it.

In Fig. 7 we have the equivalent of the circuit in Fig. 6. The plate resistance of the tube T_1 is represented by R_p and the voltage e represents the voltage of the signal in the plate circuit of T_1. You will note in the description given above that we were careful to state that the secondary voltage works into L_2, R_2 and C_2, all *in series*. The secondary must always be regarded as being in a *series* circuit.

As a matter of fact, we may regard the entire transformer circuit as a series circuit. Let us see how. Let us put a box around part of the system, leaving only the generator e and the condenser C_2 exposed. This is represented by the broken box in Fig. 7. We have then a generator e supplying current to a load C_2 through some kind of electrical network hidden in the box. The simplest way in which to consider this network is to regard it as a simple series circuit. In other words, we could sketch it as shown in Fig. 8, if we pleased.

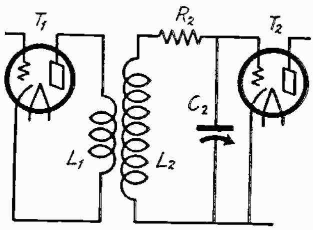

Fig. 6

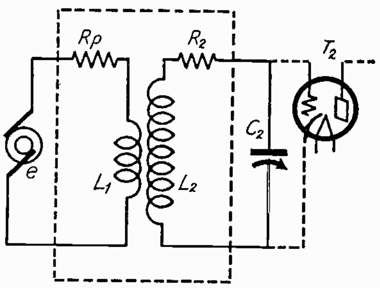

Fig. 7

We still have L_2, R_2 and C_2 in series. But now we have two new quantities, R_p' and L_1' in series with these. These quantities represent the *effect on the secondary* circuit of the constants of the primary circuit. In other words, it is known that the resistance and inductance of the primary circuit have an effect on the current in the secondary; so we say that these are the reflected values. Furthermore, we know that there is a change of voltage in the transformer due to its stepping-up or stepping-down action, so when we consider the generator voltage as applied directly to the secondary circuit we must assume that its value has been changed. Therefore, we write e' instead of e, in Fig. 8.

This explanation is a little different from previous explanations, but if you once get it straight you will be able to understand clearly the action of coupled circuits. Let us sum it all up again.

We are going to change a resonance transformer circuit into a simple series circuit without changing any secondary values. If the transformer has a step-up action then we must regard the voltage as if it were increased when operating directly into the secondary. If the transformer has a step-down action, then vice versa. The effect of the primary resistance and inductance is likewise transferred through the transformer, so if we consider these as acting directly *in* the secondary circuit, we must also regard them as having altered values—the reflected values. So we have a simple series circuit instead of the resonance transformer circuit.

The question that now arises is, "How do these reflected values vary with the different conditions?" Without going deeply into the matter we may simply state that the greater the

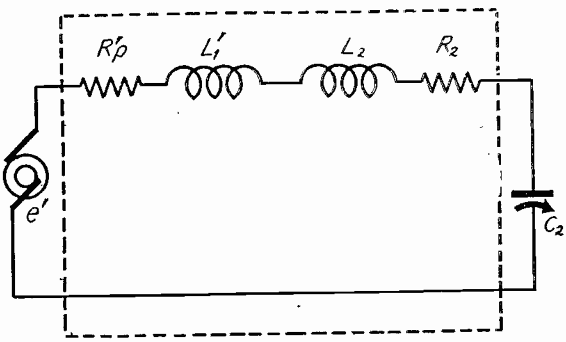

Fig. 8

mutual inductance between the two windings of the resonance transformer, the greater is the effect of the primary circuit constants on the secondary. That is, the greater M (the mutual inductance) is, the greater will be the reflected resistance R_p'. The same is true of L_1'. It is clear then that if this is so, the greater M becomes, and the greater the reflected resistance becomes, the poorer will be the selectivity. In other words, by
3 making R_p' greater, we do the same thing that we did in Fig. 2 when we made R (of Fig. 1) greater. We made the resonance curve of this circuit flatter, and spoiled the selectivity.

However, we may not have made the curve drop lower; as a matter of fact, we may have actually raised it. For example, suppose we started with a curve like *a* in Fig. 9. By increasing the mutual inductance M we increase the reflected resistance R_p' and expect the curve to take the form of *b* in Fig. 9. However, as we increase M, up to a certain point, the voltage step-up of the transformer increases also, so that we have a much greater voltage acting on the secondary circuit. Consequently, the curve takes the form of *c* in Fig. 9, which, although higher than the curve *a*, has a much flatter top, that is, it shows reduced selectivity.

It is now clear why selectivity and sensitivity are always at odds with one another in simple coupled circuits like this. But before going further, we mention the fact that since L_1' is also reflected into the secondary circuit, the inductance in the primary circuit can also influence the *tuning* in the secondary. For,

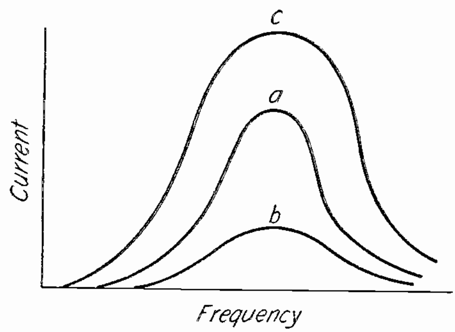

Fig. 9

since L_1' increases when we increase M, this has the same effect as if we added a small amount of inductance to the secondary circuit, and it is clear, of course, how this would affect the tuning of that circuit. However, when the primary resistance R_p is quite large, the reflected effects are made quite large, so that in ordinary circuits where the primary resistance is the high plate resistance of a tube, all the reflected effects are quite large.*

The advanced student will find the following of interest.

* The R.F. voltage amplification of a circuit such as Fig. 7 is $\dfrac{(2\pi f)^2 ML_2\mu}{R_2R_p + (2\pi fM)^2}$ where M is the mutual inductance between the primary and secondary circuits, and R_2 is the effective secondary circuit resistance. This formula is very nearly correct for the condition of secondary resonance. *f* is the resonant frequency.

This is especially true when screen-grid tubes are used, because their plate resistances are so high.

So far we have considered systems in which only one circuit is tuned, the secondary. In Fig. 6 and 7 there is no condenser in the primary circuits so that these circuits are not tuned. However, if we include a condenser in the primary circuit we have a condition that requires further study.

Let us consider a simple antenna coupling circuit like that shown in Fig. 10. The circuit which is equivalent to this is shown in Fig. 11. C_a represents the antenna-ground capacity; R_a represents the resistance of the primary or antenna circuit. The rest of the circuit is the same as before. You will note that the only way in which Fig. 11 differs from Fig. 7 is that we have added a condenser to the primary circuit. Figure 12 shows the equivalent circuit, which differs in form from that of Fig. 8

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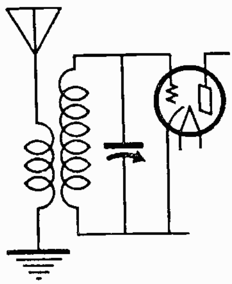


Fig. 10

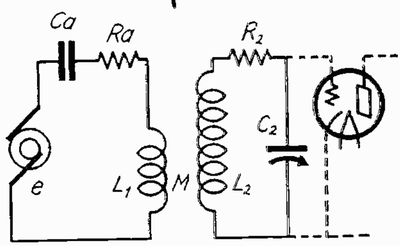


Fig. 11

again only in the addition of the condenser C_a'. The voltage e' is the reflected voltage in the antenna caused by the passing wave; C_a' is the reflected antenna capacity; R_a' is the reflected antenna circuit resistance.

Now we must begin to consider the reactances of the circuits. So far, our only concern in tuning the circuits to resonance was to make the reactance zero. In Fig. 1 the current was greatest when the reactance was made zero by adjusting the frequency to the proper value. In Fig. 3 we made the circuit reactance zero at either frequency by adjusting C. In Fig. 8 we adjusted the *equivalent* circuit reactance to zero by adjusting C_2. Now, however, we must focus our attention for a moment on the antenna circuit proper as its resonant current exerts an influence on the secondary. This is represented by the small box drawn around C_a', R_a' and L_1', in Fig. 12.

As shown in Fig. 11 the primary (or antenna) circuit is a distinct circuit. It has its own reactance, independent of the secondary circuit. Consequently a great deal depends on the frequency of the voltage in the antenna. Suppose this frequency is lower than the resonant frequency of the primary cir-

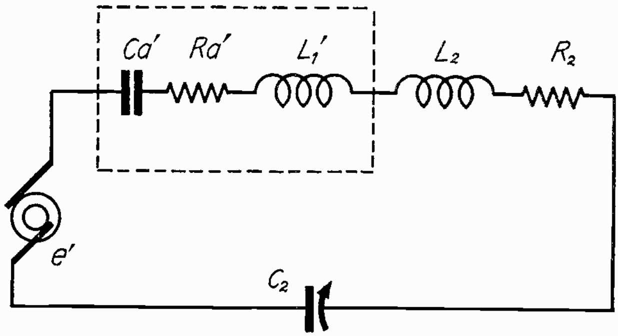


Fig. 12

cuit proper. Then the primary reactance is capacitive; i. e., the antenna circuit acts like a condenser. If the frequency is higher than the resonant frequency of the primary, then the reactance of the latter is inductive and the antenna circuit acts like an inductance.

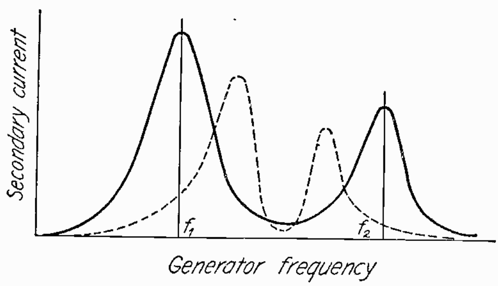


Fig. 13

In other words, for the high frequency, we have the boxed-in portion of Fig. 12 acting like an inductance, adding to L_2 since it is in series, and for the lower frequency we have it acting like a condenser, in which case it may be regarded as adding to the capacitive reactance of C_2, since it is in series with it. It is clear then, that there are two resonant frequencies to the system, or, looking at it the other way, it is possible to tune the circuit two different ways in order to make it resonate to a given signal.

This effect is shown in Fig. 13. If we keep C_2 fixed and change only the generator frequency, we will find a maximum of current in the secondary at two different frequencies. The peaks will not have the same value, but there will be two peaks nevertheless. By changing the constants of the primary circuit, either the capacity or the inductance, we can change the location of the peaks. If we decrease the mutual inductance M, we can bring the two peaks closer together (and vice versa), as shown by the broken line in Fig. 13.

On the other hand, if the frequency of the signal is fixed and we vary the secondary condenser C_2, we obtain the effect shown in Fig. 14. The signal is tuned in at two different condenser settings, C_1 and C_2.* If the primary circuit did not exert any

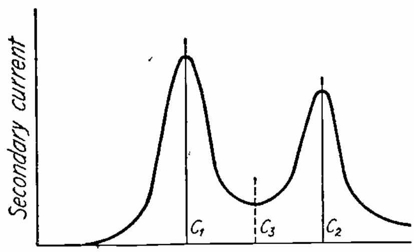


Fig. 14

influence on the secondary, that is, if only the secondary constants L_2 and C_2, determined the tuning, the secondary condenser when tuned somewhere between the settings at which the two peaks are obtained, as at C_3 in Fig. 14 would result in a single peak resonance at C_3. Again, the spacing of the peaks can be adjusted by varying the mutual inductance. If the mutual inductance of the coil in Fig. 11 is reduced sufficiently, the two peaks will disappear and a single peak will be obtained as shown in Fig. 2.

You will note that in this lesson we have not used the term "coupling," nor have we mentioned the expression "degree (or

* Set builders who have made their own coils, with excessive mutual inductance between P and S often experience this. Reducing the M even with attending decrease in sensitivity is absolutely necessary.

coefficient) of coupling." The reason for this is that the expression is usually used very inaccurately, and for our purpose it is not necessary. The coupling between the primary and secondary circuits of a transformer coupled system is generally taken to mean the closeness of the primary and secondary windings of the transformer. This is not the whole story, however, for the coupling between the circuits depends not only on the closeness between the coils (i. e., the mutual inductance), but upon the other constants of the two circuits as well, as, for example, the self-inductance of the primary and secondary circuits.

EQUALIZING SELECTIVITY AND SENSITIVITY

It is our ultimate purpose, in this lesson, to study the theory and practice of band-pass filters and the side-band theory, which has an important bearing on the use of band-pass filters, but be-

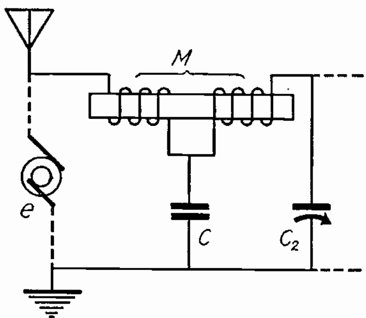


Fig. 15

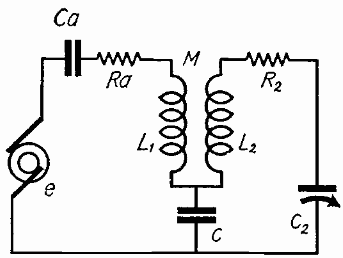


Fig. 16

cause there are several variations of the simple coupled circuit shown in Fig. 6 and Fig. 10, it is advisable to study these variations first. All coupled circuits are similar in general theory, in spite of the apparently great differences in circuit arrangement. Fig. 11 shows the fundamental coupled circuit. In order to transform it into any of the variations it is only necessary to replace the primary of the transformer by a condenser, or a simple coil or a combination of these.

For example, in Fig. 15, the antenna coupling between e and C_2 is a combined inductive and capacitive coupling. The condenser C forms part of the coupling between the primary-secondary circuits. This circuit has often been used for coupling the antenna to the first R.F. amplifier tube. In actual use the circuit appears as shown in Fig. 16 in which the resistance R_a is the resistance of the antenna and primary coil, and R_2 is that of the secondary. The mutual inductance M, between the two coils, is generally made small.

It is well known that in the ordinary transformer coupled circuit the coupling effects increase as the frequency increases.* In tuning from one end of the dial to the other, i. e., from 550 kc. to 1500 kc., as the frequency increases the voltage step-up increases very rapidly and we have a large amplification at the high frequencies with but very little at the low frequencies. It would be of considerable advantage to decrease the gain at the high frequencies, as we generally have more than we need, and increase it at the low frequencies, where the gain is generally not sufficient.

In Figs. 15 and 16, it is clear that if we short-circuit C there will be no coupling between the two circuits except through the transformer. So, if the condenser C is large enough, at high frequencies it acts as a virtual short-circuit, because its reactance is practically zero, and the only coupling between the circuits is that which is due to the small mutual inductance between the coils. We purposely make this small so that the gain will not be too great.

As we tune to lower frequencies (longer wavelengths) C becomes less and less of a short-circuit, since the reactance of a condenser becomes greater with decreasing frequency, and it begins to act as a means of coupling the two circuits together. On the other hand, while the effectiveness of C as a coupling device is increasing, that of the transformer is decreasing, because the inductive coupling effect (through M) decreases as the frequency decreases. So, whereas ordinarily there would be very little gain through the transformer, at the lower frequencies, there is considerable coupling due to the condenser, and it becomes possible to hold up the gain at the low frequencies.

It would seem possible to replace the coupling condenser C by a small inductance, but there would be no advantage in doing this because an inductive coupling of this sort has characteristics similar to those of a transformer; its effectiveness as a coupling device increases with frequency—the same as the transformer—and it would not afford a means of equalizing the gain over the whole frequency band.

*The secondary voltage (e_2) is equal to $2\pi fIM$ where I is the primary current, f the frequency e and M the mutual inductance.

The action of the coupled circuit shown in Figs. 15 and 16, like all coupled circuits, is based upon the ability of this circuit to resonate to two different frequencies. In practice the circuits are so designed that the two resonant frequencies are quite far apart, so far apart, in fact, that no trouble results from double tuning. This is the case only where the coupled systems are used for equalizing the gain of the system.

Another circuit used for equalizing the gain of an R.F. amplifier is shown in Fig. 17. The coils L_1 and L_2 constitute a regular R.F. transformer. The coil L is a small bobbin wound coil which is coupled quite loosely to L_2 and wound opposite to L_1.* Coil L is shunted by a condenser C of such size as to make the circuit LC resonate to a frequency somewhat lower than 550 kc., the lowest frequency to which the set may be tuned. Being

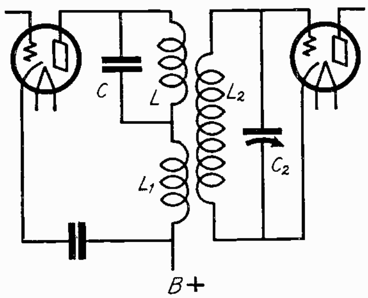


Fig. 17

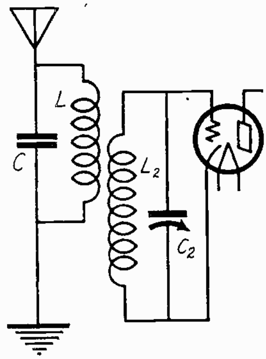


Fig. 18

nearly resonant at the low frequencies, coil L carries a large signal current and effectively transfers power to the secondary, thus keeping up the gain at the low frequencies. As the frequency increases, that is, as we tune to signals of higher frequencies, C becomes a virtual short-circuit across L and most of the signal power is transferred from L_1 to L_2 as in the usual resonance transformer. The gain is thus held up at the high frequencies, as well, and by proper design this circuit can be made into quite a successful equalizer. Note, however, that this circuit is adapted for inter-stage R.F. coupling rather than antenna coupling. Note, too, that there will be a double peak current in the L_2-C_2 circuit.

* At high frequencies the current through C and L_1 is nearly in phase, but the current in L will be 180 degrees out of phase with the current through C. To make the effects of L and L_1 add, either coil is wound or connected in opposite directions.

In Fig. 18 is shown another form of antenna coupling, consisting of a small bobbin like L in Fig. 17, shunted by a condenser C. The bobbin L and the condenser C are designed again, to resonate at a frequency somewhat lower than 550 kc., thus holding up the gain at the lower frequencies. By combining the circuits of Fig. 17 and Fig. 18, a receiver can be designed to be almost perfectly equalized, that is, to have about the same gain at all frequencies in the broadcast band.

In Fig. 19 there is shown a drawing of a bobbin that can be successfully used in the circuit of Fig. 17. On a diameter of $3/8$ in. there are wound 400 turns of No. 36 D.S.C. wire, the width of the winding being 3/16 in.

The same bobbin can be used as the antenna coil of Fig. 18 if it is provided with a tap at the middle; that is, at the 200th

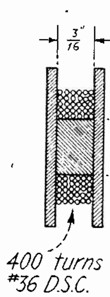


Fig. 19

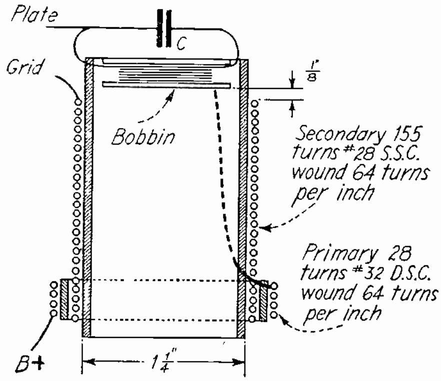


Fig. 20

turn. Only half of the winding is then used, one-half operating as a dead-end of the coil and furnishing the shunt tuning capacity. Of course, a coil of only 200 turns may be used if shunted by a small condenser.

The construction of the entire tuning coil is shown in Fig. 20. On a form $1\frac{1}{4}$ in. outside diameter, there are wound 155 turns of No. 28 S.S.C. wire, 64 turns per inch. The secondary winding is started about $\frac{1}{8}$th of an inch below the bottom of the bobbin, which is inserted in the upper end of the tubing. The secondary winding goes all the way to the bottom of the tube, and at the bottom, two layers of thin empire cloth are placed, upon which the primary coil of 28 turns of No. 32 D.S.C. wire is wound. The spacing of the turns of the primary is the same as that of the secondary, 64 turns per inch. The condenser which tunes the bobbin is connected directly across it, as indicated in Fig. 20, and has a capacity of .000050 microfarad, or 50 micro-microfarads. The entire coil is placed in an aluminum or copper

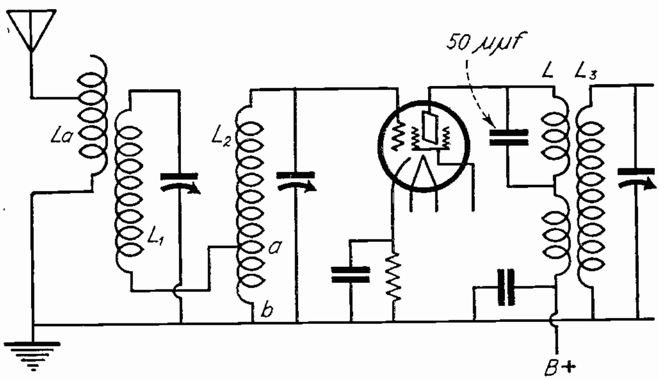


Fig. 21

can at least 2½ inches in diameter and 4 inches high, closed at all points except for the leads.

The circuit arrangement for such a system of equalized R.F. gain is shown in Fig. 21, where a double tuning system is shown coupled to the antenna as a pre-selector circuit. L_a is the antenna bobbin, which is the same as the bobbin L, except that it is tapped at the middle.

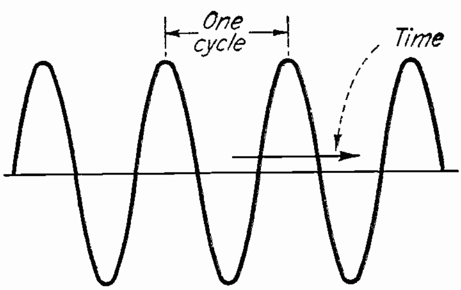


Fig. 22

The secondary coils L_1, L_2 and L_3 are all alike in design except that coil L_2 has a tap which is located four turns from the bottom, at the point a in Fig. 21. The small section a-b, of the coil L_2, acts as the coupling inductance between the first and the second tuned circuit of the pre-selector. No condenser is used across the bobbin in the antenna circuit.

There are various forms of pre-selectors (band selector circuits) and complicated coupled circuits, all designed to provide equalized R.F. gain, and in addition, some are designed to assist in overcoming the effects of side-band cutting. Most modern circuits are complicated because of these essential additions, but if you will reduce each circuit to the essential tuned circuit and gain and selectivity aids, you will understand the reason why they are used.

R.F. BAND-PASS CIRCUITS

It is quite well known that a radio wave which is broadcast from a station is very complex. First, let us suppose that the station is operating, but that no sound waves are being sent into the microphone. The wave that is radiated from the antenna

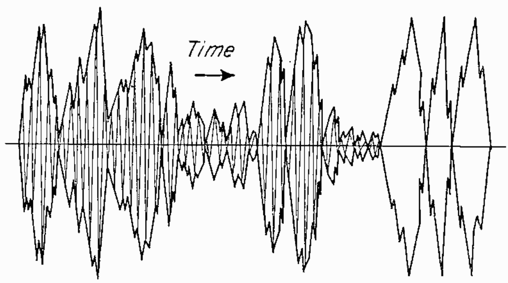


Fig. 23

is then simply a pure radio frequency wave, which is continuous and which always has the same amplitude. Such a wave may be represented by the curve of Fig. 22.

Now suppose a sound is impinged on the microphone. The sound waves are converted into audio frequency electrical currents which are combined with the radio frequency current and cause the latter to become distorted into a very complex form, which might at some instant have the form shown in Fig. 23. This illustration is exaggerated in order to show the variations which take place over a considerable portion of time. The boundary line (the envelope) of the upper, or the lower side of the complex wave represents the form of the sound wave going into the microphone.

Without going very deeply into the theory, it can easily be understood that we have a mixture of frequencies radiated from the broadcasting antenna, and, of course, these arrive at the receiving antenna and must be tuned in. It is quite important that the entire wave is tuned in and the equivalent radio current *equally amplified* in the R.F. amplifier, otherwise the sounds that emanate from our loudspeaker will not sound very much like the sounds that originally went into the microphone.

Instead of having a complex sound wave sent into the microphone, let us suppose a very pure single 1,000 cycle note is being sent into it, and let us also suppose that the radio frequency wave of the transmitter is 1,000,000 cycles per second. This is the carrier wave. In the transmitting set the 1,000 cycle wave mixes with (modulates on) the 1,000,000 cycle wave and produces two

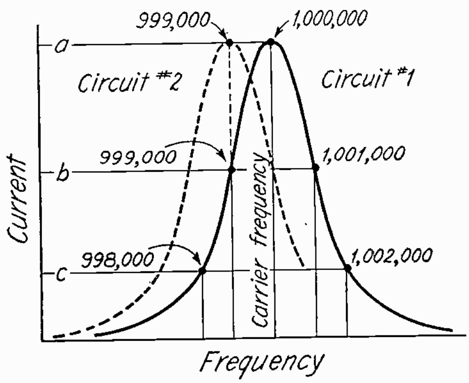


Fig. 24

additional waves, having the frequencies 1,001,000 and 999,000 cycles. In other words, one wave has the frequency 1,000,000 *minus* 1,000 and the other has the frequency 1,000,000 *plus* 1,000 cycles. Now we have *three* waves radiated by the broadcaster and received by the receiver, viz., 1,000,000 cycles, 1,001,000 cycles and 999,000 cycles. The 1,000,000 cycle wave is called the *carrier wave* and the other two the side-waves or *side frequencies*.

Now let us see what relation this bears to the selectivity of the receiver. Suppose the tuning circuits of the receiver have selectivity curves (or resonance curves) such as shown in Fig. 24, and suppose we tune our circuits accurately to the 1,000,000 cycle carrier wave. The carrier wave will cause a current to flow in the circuit having the value "*a*," Fig. 24. But, we will notice that the two side frequencies only produce a current equal to "*b*" in Fig. 24, because the tuned circuits are not accurately tuned to these frequencies.

Let us go a step further. Suppose we now have a note of 2,000 cycles sent into the microphone. The condition would be still worse, because our side frequencies would now differ from the carrier frequency by 2,000 cycles instead of 1,000 cycles, and the current produced in the tuned circuits would only be equal to "*c*," Fig. 24. The higher the frequency of the sound the more does the side frequency differ from the carrier frequency, to which the set is tuned, and the farther away from resonance will be the receiver. In other words, the effect of selectivity is to cause a loss in the higher audio frequencies.

The group of side frequencies on either side of the carrier frequency are called the side-bands. There are two side-bands, an upper and a low side-band, one formed by adding the audio frequencies to and the other by subtracting them from the carrier. Both of these side-bands pass through the R.F. amplifier and are converted into a single audio frequency wave in the
5 detector. The maximum side frequencies which are important in radio reception are about 6,000 or 7,000 cycles above and below the carrier frequency (known as side-bands). Consequently, it is necessary to design the receiver that all frequencies in this band (12,000 to 14,000 c.p.s. wide)* are equally amplified as far as it is possible, in order that good fidelity of reproduction may be obtained. This is the purpose of some of the band-pass selector circuits used in radio receiving sets.

The simplest band-pass circuit, and one which has been used for a long time, is formed in the following manner: Suppose the resonance curve (solid line) of Fig. 24 applies to the first R.F. circuit of a certain R.F. amplifier. Now, suppose we arrange the second tuned circuit of this amplifier so that instead of being tuned to the same frequency as the first circuit, it is tuned 1,000 cycles lower. In other words, circuit *2* would be tuned to 999,000 cycles when circuit *1* is tuned to 1,000,000 cycles. The effect would then be that although the combined amplification of the two circuits would not be as great as the sum of each, the amplification that we do have would be more nearly equal at the two frequencies. In other words, referring to Fig. 24, the gain of circuit *2* at 999,000 cycles would be the same as the gain of cir-

*(6000 + 6000 and 7000 + 7000).

6

cuit *1* at 1,000 kilocycles. Likewise we could arrange the third R.F. stage to tune accurately to 1,001,000 cycles and so obtain a band-pass filter that would amplify rather equally quite a range of frequencies, and reduce considerably the falling off at the upper audio frequencies which generally results when the circuits are all tuned alike. As a matter of fact, it is quite fortunate that, even when we do not intentionally adjust an R.F. amplifier in this manner, it is so difficult to align three or four tuned circuits exactly that there is nearly always enough mis-tuning to provide at least *some* band-pass effect.

The main difficulty with systems of the sort just described is that it is difficult to keep the separate R.F. stages peaked at these small differences in frequencies as we tune from one end of the tuning range to the other. There is always a tendency for

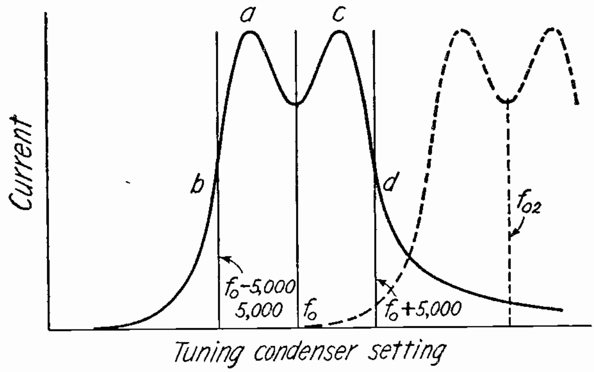


Fig. 25

the difference to be small at the long wavelengths (low frequencies) and large at the short wavelengths (high frequencies).

Another method of producing a band-pass effect is to use several coupled circuits, as was described in connection with Fig. 14. If we have two circuits coupled together closely enough, it will be remembered under these conditions the circuits will be resonant to widely different frequencies, and that we can make these two frequencies as far apart or as close together as we please by designing the circuits properly. So, if we take a circuit like those shown in Figs. 11 to 21, and arrange a coupling, a response to any wave will be obtained which will always have two peaks. The effect created is shown in Fig. 25, which is similar to the effect we tried to get in Fig. 24 by staggering the tuning of the several tuned circuits. There are innumerable circuit arrangements by means of which the curve of Fig. 25 can be obtained, but they all have the disadvantage that the peak frequency difference between the peaks varies with the frequency to which we are tuning. An inductively coupled circuit causes the peaks to separate at the high frequencies; a capacitively coupled circuit causes them to separate at the low frequencies. Sometimes a combination of inductive and capacitive coupling can be used satisfactorily, so that the frequency separation between the peaks remains substantially uniform throughout the tuning range.

Before we pass on to other matters, it will be of interest to point out that band-pass selectors such as we have been discussing have very steep-sided curves in comparison with the ordinary selectivity curves. That is, referring to Fig. 25, the sides of the

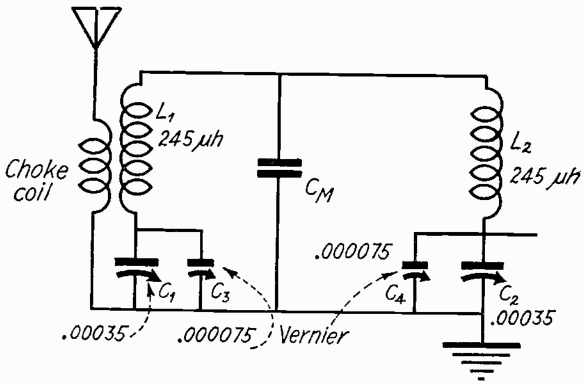


Fig. 26

curve, *a-b* and *c-d*, are very steep, and a very sharp *cut-off* is obtained. For example, if in Fig. 25, f_o represents a definite carrier frequency and the curve becomes very steep at a frequency 5,000 cycles away from f_o, then we say the curve cuts off sharply at a side frequency of 5,000 cycles. Frequencies below 5,000 cycles are reproduced fairly well, but frequencies higher than 5,000 are hardly reproduced at all. The advantage of having a sharp cut-off can be understood when we consider its value in connection with separating two stations. In other words, band-pass filters or selectors assist not only in maintaining the good quality of reproduction but also assist in the ordinary process of separating stations. If the broken curve of Fig. 25 is the resonance curve for a second carrier frequency, in an adjacent channel, we can easily see that as the sides of the curves are steep the separation between two stations will be well-defined, and the over-lapping of the curves will occur only way down where the amplification or current values are small.

In Fig. 26 and 27 are shown two forms of band-pass pre-selectors which have been quite popular. One of these is capaci-

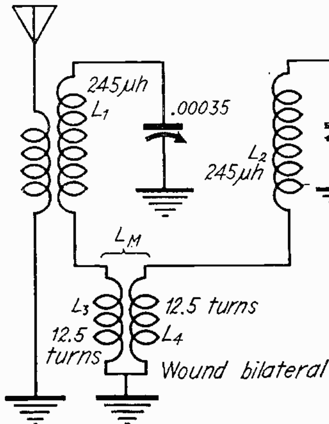


Fig. 27

tively coupled and the other inductively coupled. Figures 15 and 16 show a combination coupling to obtain constant band width over the entire tuning range.

In all coupled circuits some kind of coupling device is required. In some cases, it is a condenser; in others it is an in-

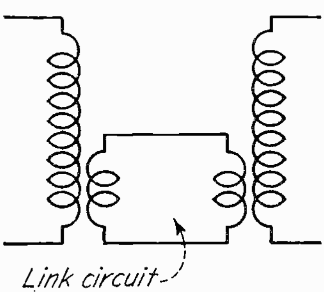


Fig. 28

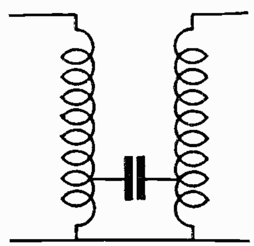


Fig. 29

ductor; in still others it may be a combination of the two, and finally, sometimes we have what is called a *link circuit.* A link circuit is nothing more than small local circuit which acts as a coupling circuit between two other circuits. Fig. 28 shows a link circuit coupling together two coils. The link circuit windings are generally very small, consisting of only a few turns of wire, the sole purpose being to transfer power from the one circuit to the other. The link circuit is also generally untuned. Fig. 29 shows another form of link circuit in which the coupling is done by a very small condenser.

AUDIO FREQUENCY FILTERS

Band-pass circuits are used quite widely in audio frequency transmission circuits, such as telephone lines, in broadcasting circuits, and in motion picture sound reproduction. They are also sometimes used for controlling the quality of reproduction in radio receivers in which case they are called line equalizers.

The simplest type of band-pass filter is the low-pass filter, two sections of which are shown in Fig. 30(*a*). It is used to allow only low frequencies to a certain value to pass through. Each section consists of two series inductors L and shunt condenser C. The variation of current output from the filter is as shown in the graph accompanying the diagram. At very low frequencies the inductors have very little reactance and the condensers have high reactance. Consequently all the low frequency current passes through the circuit. As the frequency becomes higher, however, the inductive reactance increases, retarding the flow of current, and the lowered reactance of the condenser permits it to short-circuit whatever current does get through the inductors. Consequently, the passage of high frequency current flow is prevented whereas low frequencies are permitted to get through. It must be remembered that any number of sections can be used in the filter in cascade as shown by the dotted lines and the greater the number of filter sections and the lower their resistance, the sharper will be the cut-off.

Fig. 30(*b*) shows a high-pass filter. It will pass all currents whose frequencies are greater than the cut-off frequency. The condensers have high reactance to low frequencies and very little current appears in the output. The inductance has low reactance to low frequencies. At high frequencies the capacitive reactance is low and current passes through very easily while the inductive reactance is quite high and has no by-passing effect.

By making the band-pass filter sections more complex we can obtain various characteristics for the filter. For example, in Fig. 30(*c*) we have shown the circuit of a *single-band* pass filter. By properly arranging the circuit values we can make the upper and lower cut-off frequencies anything we please, therefore the function of a band-pass filter is to allow only the desired range of frequencies to pass. For example, we may arrange the circuit to pass frequencies lying between 3,000 and 4,000 cycles,

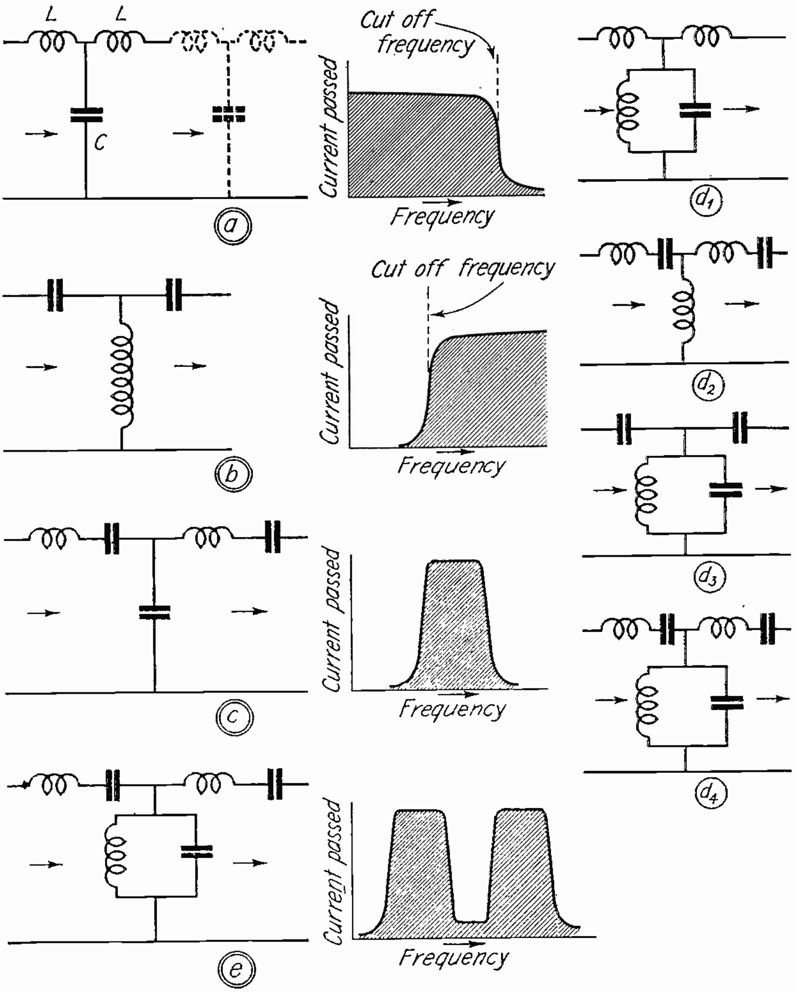


Fig. 30

or, between 50,000 and 60,000 cycles. Such circuits have a wide use in carrier current (land line) systems where it is desired to transmit several communications over the same wire system without permitting them to interfere with each other.

In Fig. 30 (d_1 to d_4) we have other forms of single band-pass filters, whereas in Fig. 30(e) we have the circuit of a *two-band filter.* Although some of these circuits appear identical in form, the manner in which they operate depends upon the values of the inductances and condensers used in them.

The low-pass filter, for example, is widely used in power-packs designed to furnish the voltages for radio receivers. However, because they are made to filter out a wide range of ripple frequencies in the rectified current coming from the rectifier tube, it is not necessary to design them to have sharp cut-offs like that shown in Fig. 30(a). Furthermore, the inductances (choke coils) have to be so large that they have considerable resistance, which makes it impossible to obtain a sharp cut-off. Consequently, the low-pass filter used for this purpose is simply a "brute-force" filter. By making the choke coils and shunt con-

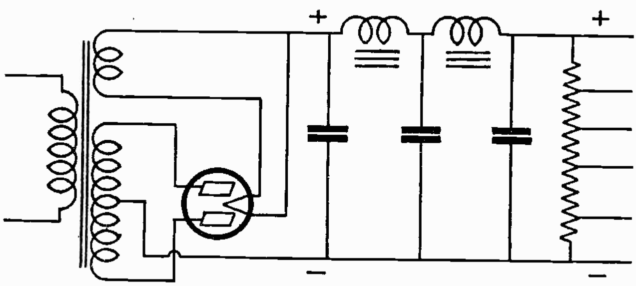
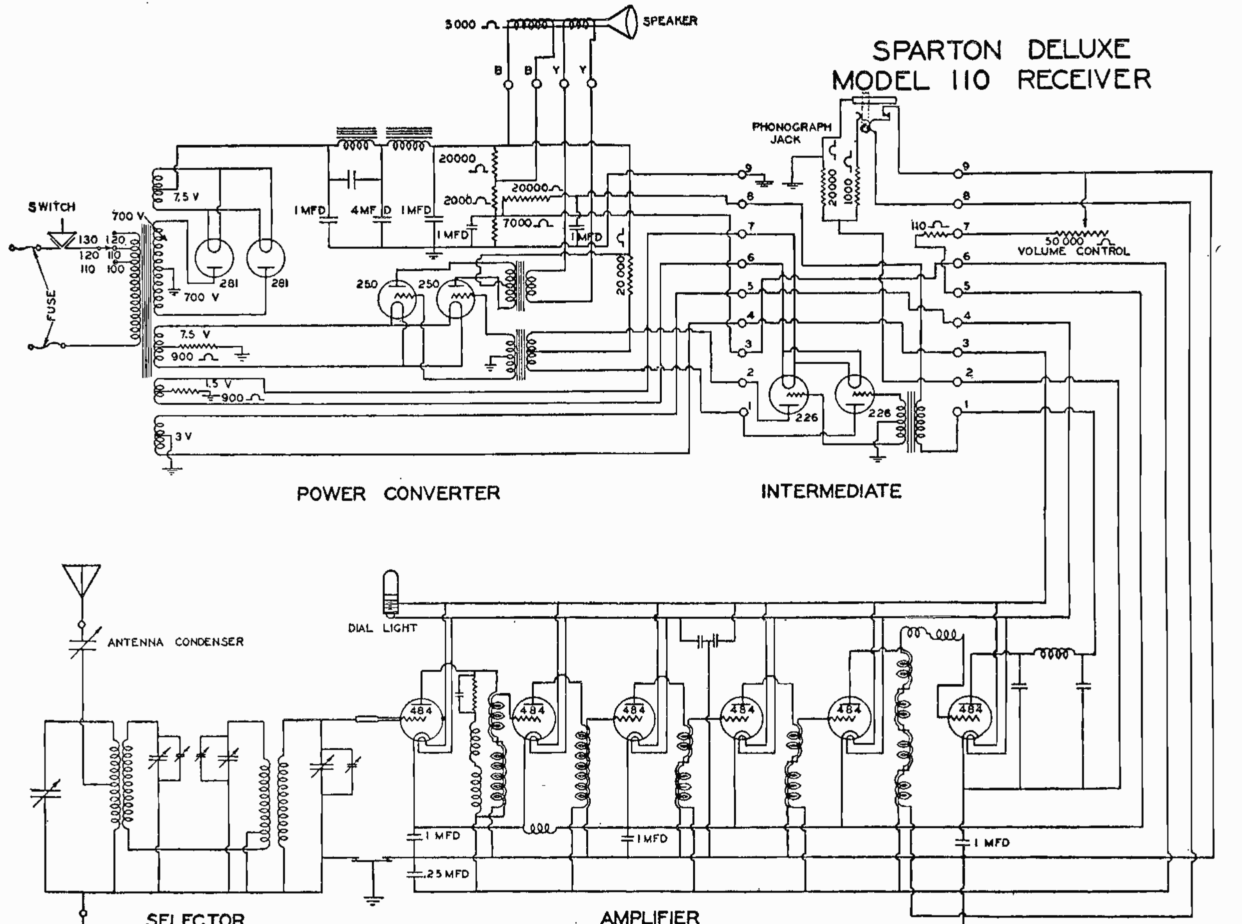


Fig. 31

densers large enough, we can make the filtering action just as satisfactory as we please, depending upon how expensive we want to make the job. The circuit is shown in Fig. 31.

The output of the rectifier tube consists of a number of pulses all in the same direction and by using a combination of condensers and choke coils as shown in Fig. 31, we cause these various pulses to overlap and form a more or less continuous current always flowing in the same direction. However, this unidirectional current has a lot of ripple which must not get into the audio amplifier, otherwise the ripple will be amplified and come out of the loudspeaker as a "hum." These ripples are composed of various frequencies, of which, in the full-wave rectifier shown, the lowest frequency is 120 cycles, when we connect the set to a 60 cycle line.



Circuit diagram of a typical receiver employing a band-pass filter tuning system before the fixed R. F. amplifier and showing the filter unit in the power supply system.

It is necessary therefore, to filter out the 120 cycle wave. More than this, there are plenty of harmonics in the wave, that is, frequencies which are exact multiples of 120, for example, 240, 360, 480, 600, etc. The high frequencies are sometimes difficult to filter out because the ear is quite sensitive to high frequencies and can hear them in the loudspeaker even when the electric currents producing them are quite weak.

However,* by loading up the filter circuits with inductance and capacity, the inductance is made to choke back the ripples, the condensers short-circuit the ripples that get through the inductances, and eventually a practically ripple-free unidirectional current is obtained which furnishes the voltages for the radio receiver. The design of the rest of the circuit is of little importance in this lesson. The output resistor and power transformer are discussed elsewhere in this course.

In the practical design of the filter, however, there are certain practical features which should be borne in mind. It is uneconomical to use choke coils greater than about 50 henries. It is better practice to use smaller coils and more sections. The same is true of the condensers. The filtering action is improved very slightly when we increase the capacity beyond 4 microfarads. However, a very great improvement in the filtering action can be obtained by increasing the number of filter sections from, let us say, two to three. And finally, a very important feature in connection with the design of hum filters (for that matter all filters) is to prevent coupling between the various choke coils. Each coil should be well shielded in iron, and considerable attention should be paid to the ground circuit. A very great reduction in hum can often be obtained by properly grounding the shield of the coils, this prevents coupling between the coil and some other part of the circuit.

* The student might ask, "Why not use a high-pass filter from 60 c.p.s. and up?" Inspection of such a filter (Fig. 30(*b*)) shows that the condensers would not allow the desired direct current to get to the voltage divider.

TEST QUESTIONS

Be sure to number your Answer Sheet 22 FR-1.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will able to work together much more closely, you'll get more out of your Course, and the best possible lesson service.

1. What effect does increasing the resistance in a series resonant circuit have on the resonance curve?

2. What relation must exist between the intensity of a desired signal and undesired signal for satisfactory selectivity?

3. How will increasing the mutual inductance (M) between the primary and secondary of a resonance transformer affect selectivity?

4. Draw the circuit of an antenna coupling designed to have a combined inductive and capacitive coupling.

5. What are side-bands?

6. What is the function of a band-pass filter?

7. If the incoming carrier is modulated by audio frequencies up to 7000 cycles, how wide must the R.F. band-pass filter be in order not to cut any of the side frequencies?

8. Draw the circuit of a high-pass filter.

9. How can increased sharpness of cut-off be obtained in a low-pass audio frequency filter?

10. Why is it unnecessary to have a sharp cut-off in a low-pass filter used in power packs?

HOW TO START A SPARE TIME RADIO BUSINESS

22X

REFERENCE BOOK

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WASHINGTON, D.C.

FOREWORD

The National Radio Institute Course has been written for men who desire to make money in Radio —who want cash returns just as soon as possible.

Radio lends itself well to the plan. The small amount of capital required enables you to start in a spare-time business early in your training period. Frequently students make several times the price of the tuition, before they complete the Course, and having gotten such a good start they step out into a full time Radio business as soon as they complete the training.

N. R. I. wants you to obtain spare-time Radio work, not solely for the advantage of the earnings, but for the valuable practical experience you will obtain in doing the work.

Of course, there are some types of Radio work which we suggest you not attempt until after graduating as the proper training for this work is received later in the Course. Tackling advanced jobs too soon may have a bad reaction in loss of confidence in yourself and dissatisfied customers.

But there are literally hundreds of jobs you can do. And these are the jobs which make spare-time money and give confidence—cultivating experience. Get them!

NATIONAL RADIO INSTITUTE

WASHINGTON, D. C.

Revision 1933

1936 Edition

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How To Start a Spare Time Radio Business

WHAT TO SELL

The Radio-Trician, seeking spare-time work, is by reason of his special N. R. I. training, particularly fitted for three general fields:

1. Radio Service
2. Radio Receivers Sales
3. Sales of Household Electrical Appliances

Radio Service

Service of Radio Receivers offers a fine opportunity for quick returns. Every person in your community who owns a Radio is a prospect for your services. Radios are everywhere. Your neighbors have sets; so have your friends and acquaintances. The corner barber shop has one—or should have—likewise the restaurant down the street. All these sets will need fixing sometime. The jobs belong to the man who sells his services.

Radio Receiver Sales

There are sufficient people still without Radios to make Radio receiver sales a very worth-while proposition. While the returns may not be so rapid as in the service field, this is offset by the size of the individual earnings. Receiver sales works in well with service work.

The Radio Man doing a spare-time business will naturally not be interested in stocking receiving sets in an effort to demonstrate and sell them.

In the first place, by devoting only part time to his business, his capital would be tied up in his sets too long. Secondly, a store or adequate showroom, which the spare-time Radio man seldom has available, would be required.

However, it is a proven fact that the spare-time service man will quite frequently run into a set sale opportunity and he will naturally wish to be in a position to take advantage of the occasion to make some money.

Therefore, it is a good plan to make arrangements with a good live wire dealer to sell sets for him on a commission basis. You may make a deal with him whereby he will pay a slightly higher commission than he ordinarily pays his salesman, you in turn agreeing to relieve him of the installation and all service in connection with the set.

While the spare-time Radio serviceman may occasionally run across a prospect for a custom built receiver, it is not recommended that he solicit such jobs until he has received all the training N. R. I. can give him. Remember, also, that custom built Radio jobs nowadays quite frequently call for having the sets "built in." Therefore, on such jobs sufficient leeway should be allowed in the estimate to pay where you can still give good service, for the larger it gets the more rapidly it will grow. As soon as you find it impossible to do this, get another Radio-Trician to help you. Dealing with so many people will enable you to buy your accessories in larger quantities, at a better price. This will keep your bank account growing.

An important class of business is new sets under guarantee. Don't pass these people up and forget about them. Experience has proved that the majority of dealers are more interested in sales than in giving service. You cash in on their mistake.

When you visit a set owner who gets free service from a Radio store, find out all you can about the transaction. If possible, see the set, get the date of purchase. By careful inquiry, you can figure out just when this free service period expires.

Copy down the information you obtain on a card and file it away as valuable business possession. Arrange this file to be under your close observation every day. At the time of the expiration of the free period sell your service contract before someone else beats you to it.

Don't figure too strongly on the payment of the contract price as your chief source of revenue. It is merely an incidental expenditure which you require of the customer to keep him dealing with you. Your chief source of income will be in the service and parts which are found necessary from time to time. You can reasonably figure to make a profit of 40 per cent on the parts and tubes which you install. But do not overcharge. Remember you must keep your customer.

The price charged may range from $3 to $10 a year, depending on conditions and service given. It will not take you long to get the routine of your business worked around to a point where you will find it a simple matter to handle from three hundred to four hundred service contract customers, making two calls a month on each, and still have time to be on the lookout for new business.

Wholesaling Radio Service

Still other service men adopt what is generally termed the "Wholesaling Service" system. They do not contract the set owners as a general policy, but solicit, on contract, the service work of dealers, large and small, who do not care to operate their own service departments.

Two classes of Radio organizations offer the Radio-Trician the best market in the Wholesale Radio Service Field.

One class comprises Radio Sales Organizations, which do not care to handle service, not having space, time, nor personnel to render efficient work. The other class includes the small dealer who cannot afford to operate his own service and installation. Whether these dealers like it or not, service is a necessity—demanded by purchasers of their products.

The far-sighted Radio-Trician will soon have as many of these firms as possible under contract for all their service work. This, in short, is what is meant by Wholesaling Radio Service.

Usually the service wholesaler will not handle the sale of any Radio set. In this way he is looked upon more favorably by his dealers; he is not acting in competition to them. On his service calls he endeavors to keep the individual customers of these dealers sold on Radio and on the store from which they bought. He must often be a diplomat in this respect.

He conceals the fact that he is the "wholesaler" or the "wholesaler's service man," as the case may be. He acts as the direct representative of the store which sold the receiver in the first place.

He must never show partiality to any receiver. To the customer they must all be good. At least one case is on record where the representative of a wholesale Radio service company lost his firm the account of a large department store, and lost himself a good job by criticizing the set owner's selection of a particular Radio.

It will not be possible to stick to any "cut and dried" contract arrangement. You may find it necessary to make a slightly different deal with each of your dealers. The essentials will be the same, naturally, and governed by the business policy you set out to follow, but the details will be altered to the mutual satisfaction of yourself and the dealer.

For instance, in the matter of replacement material for service work, you can either supply it at cost, plus 10 per cent, or allow the store, whose work you contract, to furnish it. The former plan is preferable. It saves time and gives you an added profit, but it must be remembered that it also necessitates carrying parts in stock, ordering, and other details.

Rates usually run at $1.50 per hour flat unless the set must be brought to your shop. In that case make a $2.50 charge for the regular service and a shop charge of $1.50 per hour with a minimum shop charge of $1.50, making the total minimum $4. Of course, to large customers—those giving several hundred service calls a year, for instance—a special price of 1.25 or even $1 per hour should be offered. These rates, however, are only tentative and must be governed more or less by the standard rate for Radio service work in the particular locality in which you are operating the business.

When the size of your business permits, a special "aerial crew" can be used—to save time for the more experienced service man. Give a good aerial job and don't try to make a big profit on it. For about $6 you can afford to give two ten-foot metal poles, lightning arrester of the best type, wire, lead-in, etc., carried to the aerial binding post of the receiver. Add approximately 40 per cent of this price if the aerial installation is to be on a peaked roof.

A profitable side-line to this service, for those having a car or truck, is to maintain a delivery service for sets sold by the dealer. You can charge fifty cents a delivery for a midget, seventy-five cents for a console, and $1 for a highboy model. It stands to reason that your man has to go to the job to install the Radio anyhow—it's a simple matter to have him call on the dealer on his way, pick up the set—and in that way the dealer pays you for the trip your car or truck has to make.

Your business depends on the amount of sales your dealers get. Work with the dealer. If he is in competition for a sale, it's a good idea to have a special "wooden pole aerial job" you can offer for $4.50, or some other such scheme which will allow him to meet the competition of price. But, on the whole, be wary about cutting prices. You may educate the dealer to expect it. If you find the competition for a sale is between two of your "customer-dealers," play safe and let them fight it out. Don't cut prices for either. You'll get the job anyway, regardless of who sells the set.

THE SELLING JOB

Start out by making a list of all your friends who have sets. See each of them. Explain your ability to service receivers. Your local printer will make you up business cards at a reasonable price. Distribute these among your friends.

Ask these same friends for the names and addresses of persons who have receivers. Add these new names to your list and call on them immediately. Perhaps they have no work to be done right away, but leave your cards and ask for more names. Keep a card file of all prospects, noting information on the cards which may be useful later, 3″ x 5″ index cards are fine for this purpose and can be purchased at the local 5 and 10 cent store.

This first work may seem slow—almost useless—but you've never yet heard of a building being constructed without the foundation being laid first. You are building your foundation; you are making business acquaintances; you are constructing a list of prospects which will grow rapidly and be valuable to your business, if the above system is worked diligently.

Keep a close watch on persons whom you know to have recently purchased sets. The dealer will service his sale for a short time; after that you'll find, generally, he pays little or no attention to the customer. The dealer is interested in sales. It's up to you to get after the service.

Personal Solicitation

Various types of advertising can assist the service man in building up his business, as will be shown later, but no amount of advertising will offset the value of personal contact. The service man must obtain a lot of his prospects, and incidentally his business, by a systematic solicitation of residents of his community. He must spend a large portion of his available spare time in canvassing.

Canvassing constitutes making calls at the homes or offices of all persons in a given locality in an effort to secure business. The value of this plan has been proved in the experience of some of our largest sales organizations. And bear in mind, yours is a sales organization. You are selling services.

The Territory

It is well to lay out a territory for yourself and confine your activities to that section when you first start out. In some cases, where your city is small, you may decide upon the whole town as your territory. But in the larger cities it is well to make your selection carefully. Then work that territory thoroughly until it is fully covered, before spreading out your field.

If the community in which your home or shop is located offers good possibilities, you should lay out your territory nearby. This saves time in traveling to and from jobs. By intensively working a small territory you will become well acquainted with the residents, which is very helpful. Soon they will know you by sight and point you out to their friends.

Our advice to sticking close to your territory and working it well must not be construed to mean that you must never take work elsewhere. Through your friends and acquaintances you will frequently

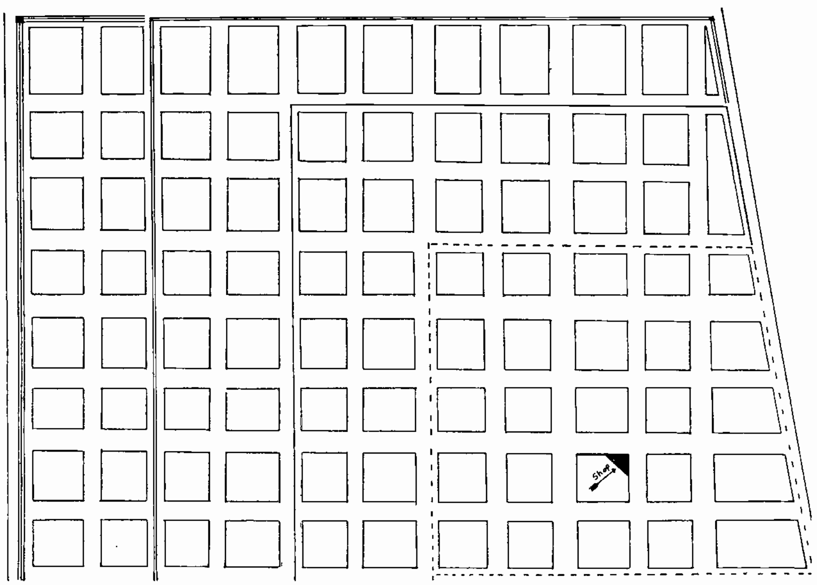


FIGURE 2

obtain jobs in different parts of the city. Take these jobs whenever you can get them. It may even be a good plan to canvass the whole block after you've done such a job.

Fig. 2 shows a diagram of a community and the location of a student's Radio shop. This student laid out twenty-five square blocks as his original territory, shown by the dotted line. After this had been worked to his entire satisfaction he enlarged his territory as indicated by the single line, pushing his boundary two blocks north and two blocks west. This practically doubled his territory. Subsequent extensions are indicated by the double and triple lines. This territory was handled in a very business-like manner.

Every home in your territory should be considered a potential source of income for you. Of course, how much work you get out of the district will depend on how much you put in. A territory is much like a garden. It will only produce if properly cultivated.

Plan to visit, systematically, every home on every street. When you do this, jobs are bound to result.

However, you cannot merely push door bells, stammer through a few words of introduction, say good-bye—and get business. You must prepare your visit in advance, know exactly what to do and say, plan to meet and overcome objections. When this is done you may expect the law of averages to do the rest.

The Attitude

As you go into your territory to begin work, you are a salesman. You are the sales manager of your Radio business. Do not worry about the immediate earnings. They should take care of themselves. Consider the fact that you want to make a sale of your services of secondary importance. Primarily you are building up a business.

Consider that you are bringing your customers a worth while service—a service which will mean pleasure and enjoyment to the homes. If you cannot take such a view of your service, it is better not to sell it. Such an attitude will not be accomplished over night. It must be cultivated, but it will win you favor with your customers. It will take much of the commercial sting from your dealings.

The Approach

It is doubtful if any two men, canvassing for business, use exactly the same approach. Some like one method; others find an entirely different plan effectual.

Another thing, a different approach will be required in starting out to develop a territory than later on in making future calls.

We know of a case of a young man who successfully worked up a Radio business and from whom we have obtained his original method of approach.

As he did not want his name used in this connection, we'll call him Bill Jones. Jones selected the block for his morning's work, walked up to the first house, and rang the door bell. As the door was opened he removed his hat and said: "This is Mrs. Perkins, I believe." (He had already determined the names of the residents on the whole block by reference to the city directory.) "Mrs. Perkins, I have just opened up a Radio shop, right near your home, to render prompt and efficient Radio service to the residents of this community. I'd like to leave my card with you and have you call me any time your Radio isn't working just as it should." Mrs. Perkins thanked him and he left. He made a very favorable impression, first, because he didn't try to high pressure Mrs. Perkins into buying something; second, because he was neat and courteous; third, because he was rendering a service which Mrs. Perkins felt might some time in the future be of value to her.

By this approach, and by a sales talk which was short enough not to take up a lot of his prospect's time, the young man succeeded in becoming very well known in his territory. Incidentally, we understand that he picked up quite a few jobs, even on that first, introductory canvass. In these cases, when he mentioned that he was in the Radio business, left his card and was about to depart, the occupant of the house prolonged the conversation by stating that she had a Radio which was giving a little trouble and asked if he would step in and look at it. These jobs more than paid for the time required for this preliminary canvass. Later on in this book we will show how this young man worked his follow-up canvass on these people and built himself a nice Radio business. He reports that, three days after his first canvass started, he got a telephone call and business began picking up from that time.

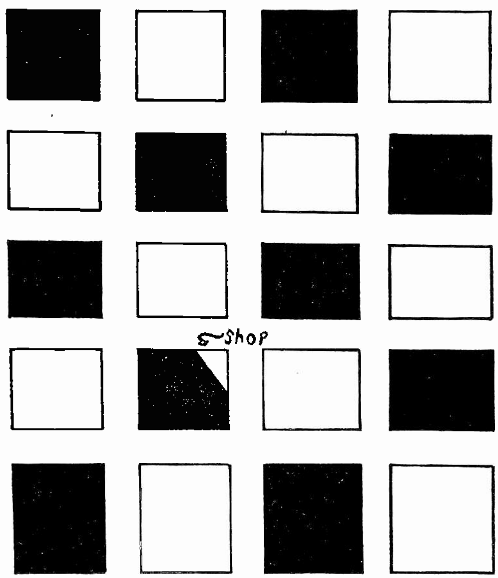


FIGURE 3

The Square Block System

In canvassing, your purpose is to see and place your message before as many persons as possible. It must also be remembered that there are a number of canvassers who may work in your territory, some of whom, by high-pressure methods, have become a nuisance. Housewives do not like to talk to such men, and it is a good plan to show the people in the territory, right at the outset, that you are not that type. Keep away from high-pressure methods.

Having become aggravated by numerous solicitors of the type mentioned, the resident will frequently refuse to answer the doorbell, if she has seen someone canvassing the block. Therefore, the Radio-Trician, desiring to see every one in his territory, will do well to utilize the "Square Block" system of canvassing.

This entire plan may be summed up by the simple rule: "Never canvass both sides of the same street on the same day."

The reason is, while you are canvassing the North side of the street, the occupants of the homes on the South side can see you going from house to house. They don't know what you have to offer; consequently, they label you as just another salesman, and you'll find very few answers to your knock when you start canvassing the South side of the street.

The accompanying chart, Fig. 3, shows the ease with which this difficulty may be eliminated. Consider that the blocks in black and white represent the city blocks in your territory. Never cover a black and a white block in the same day.

The Time To Call

Next in importance to saying the proper thing when making your canvass calls is calling at the proper time. The canvasser's day is short, so he must work rapidly, consistently, in the few hours which he may logically use.

No calls should be made before 9:30 in the morning, nor later than 11:30 a.m. Be considerate of the prospect's time. She may have children who must be dressed and sent to school; she has breakfast dishes to get out of the way. Give her time to do this before you arrive. After 11:30 and until 1:00 in the afternoon she is in the midst of lunch routine. She doesn't want to be annoyed. Your afternoon work can go on from 1:00 until about 4:30 p.m. No later. So you really have only five and a half hours in which to canvass during the day. Of course, you may not have any of this time available, by reason of some other job you are holding. In that case you must make your calls at night.

Call Backs

You'll run across a number of homes where both the man and his wife are away during the day. You must record these cases and arrange to call back on them until they can be seen. Night—between 7:00 and 8:30—is a good time. These people are usually good prospects for Radio work. They most likely have incomes above the average by reason of more than one member of the family being employed.

There is a tendency among most canvassers to pass up this class of business because it entails night work. Don't make that mistake. It is an important angle of your Radio business.

In making call backs at night there are several things which must be guarded against. It would be very serious, for instance, to call while the prospect is entertaining company. Business calls in the day time are more or less expected and are not considered as out of the ordinary, but discretion must be used on night calls or your prospect may be antagonized.

As you are about to make your call, but before you ring the door bell, listen carefully a few seconds. If you hear any unusual sounds which might indicate a party in progress, or company being entertained, make your call the next evening. The evening following such a party or gathering is usually a safe time to call. The resident will most likely not entertain two nights in succession. Then again, the Radio may not have acted so well before the company, embarrassing the host and hostess. That makes them good prospects for Radio repair work.

Apartment Houses

Of course a large number of residents of apartment houses depend upon the programs furnished by loudspeakers, connected to the apartment house set, for their entertainment. Nevertheless, there are many apartment residents who have their own sets. Their business should not be overlooked.

Regulations in some apartment houses prevent canvassing on the premises. It is sometimes possible to get around this by making friends with the building superintendent, by repairing his set free of charge.

At least one Radio-Trician we know of built up a fine business in buildings of this kind. He would call on the building custodian and offer to repair his set whenever called upon, free of charge, to prove his merit. Then he would request that this gentleman, or lady, recommend him to the residents who might then or in the future need Radio service.

Our friend Bill Jones, whom we referred to previously in this book, tells us that, failing to obtain permission to canvass in an apartment house, he would list the names shown on the mail boxes, then return to his shop and make his canvass by phone. Once he obtained permission from a prospect to call, no one could keep him out of the building.

Some apartment houses have all the mail delivered to a clerk's desk, in which case it is impossible to get the names from the boxes. In such a case Jones made the acquaintance of a schoolboy who resided in the building and gave him a dollar for as many of the names of Radio set owners in the building as the boy was able to obtain. Then he made his phone canvass from this list, with the aid of the telephone directory.

City directories, which are available in libraries and most public buildings, will help a lot in this work, but they cannot be relied upon solely, as apartment house dwellers are usually more transient than other classes, and many discrepancies will therefore appear in a list constructed purely from this directory.

If there are apartment houses in the territory you lay out for yourself, find some way to contact the occupants. It may require some ingenuity, but you're setting out as a business man now and you must find a way.

The Sales Talk

If you've ever talked with a good salesman, you probably marvelled at the ease with which he presented his plan—how he first gained your favorable attention, then created an interest—carried your interest into a desire for his product and then obtained your order.

Of course, as you listened to the man's talk you were not aware of these individual processes. You were conscious only of an easy flow of conversation, but those elements of salesmanship were present, nevertheless.

And when you asked questions you were impressed, probably not consciously, at the quick, well phrased answers, which overcame any objections you might have had. Has it occurred to you that the salesman knew exactly what questions you were going to ask and had his answers all ready for you? Furthermore, he probably made you, by leading remarks, ask those very questions so that his reply would make a deeper impression.

He was merely practicing good salesmanship in his sales talk.

You should build a sales talk around your own product or service, incorporating the sales elements of attention, interest, desire and action. Write it out carefully. Check and correct it. Then rehearse it in the privacy of your home until you know it by heart. Change it where occasion demands.

You remember the first time you drove an automobile. You shifted gears with your mind on each particular operation. Later you did it without thinking—in a purely mechanical manner. So it is with your sales talk. At first you will find it requiring conscious effort; later it will become more or less mechanical.

No two men, selling a product or service, will use exactly the same sales talk. Neither will they prepare them in similar manners. Let's get back to our old friend Bill Jones and see how he developed his sales talk.

First, he listed all the items connected with his business, which could be considered as sales points. He then struck from his list those of lesser importance and rearranged the list until he had the following:

Expert Radio Service
Training—Experience
Equipment
24 hour Service
Centrally located—Prompt service

Around these points he built his story. He then considered every possible question a prospect might ask and framed the proper answer. He took into consideration any objections which might be raised in the course of conversation and had his replies to these prepared as well.

It must be remembered that Jones had already made an introductory canvass of his territory, frequently referred to in salesmanship as missionary work, and had done some Radio service work in it prior to starting his second round of calling on his prospects. This gave him an opening or what is termed in salesmanship as entree. The following is one of his standard talks built around the sales point which he had listed:

"You probably remember me, Mrs. Brown. I called about two weeks ago to see you about your Radio and tell you about our Expert Radio Service. Is your set working just the way it should?

"I know you have quite a bit of money invested in your set and naturally you want the best reception possible from it. By the way, Mrs. Brown, what kind of set do you have?

"I have done quite a bit of work on the ———— receivers. In fact, I had special training on them while studying Radio. I like the ———— set very much. I think you were very wise in purchasing that particular brand.

"Do you get all of the distant stations that you would like? Do you get out of town stations without interference from the locals? How is the tone quality? Are you getting deep, clear reception on the bass notes?

"The manufacturers who made your set are fine engineers and they intended this set to give you about the best possible in Radio reception. If you are not getting it, there is a possibility that something is slightly wrong and needs to be remedied. Possibly it's just a tube. Or it may be that the set needs cleaning. These sets are open in the back, you know, and you just can't keep dust from getting in them. And a little bit of dust will sometimes throw your set out of perfect order.

"Suppose you let me take a look at your set, Mrs. Brown, and make a test with my Radio set analyzer which I have right with me. You will be absolutely under no obligations and it won't cost you a cent. With these scientific testing instruments I can tell you, in a few minutes, just what the condition of your set is.

"Don't forget, Mrs. Brown, our shop is centrally located, right here in your neighborhood, to render you prompt, efficient service. Give us a ring any time, day or night, and we'll be on the job to serve you."

It is not always necessary to go through your entire sales talk to get an opportunity to work on the set. And it is seldom possible to go through a complete sales talk in just the manner given above, because if the person is interested at all she will ask questions which must be answered before you can proceed with your sales story.

The sales talk of Bill Jones which we have printed for your information is not given you with the idea that it is perfect. It probably could be greatly improved upon, but the point is this—it got business for Bill Jones, and a similar sales talk should get business for you. Change your sales talk whenever you see room for improvement.

Talking Their Language

An important point taken into consideration is the class of people with whom you are dealing. Folks like to do business with people on their own plane. If you are operating in a territory where the residents are well educated, be particularly careful of your grammar and manner of speech, and if, as frequently is the case, the conversation should drift away from the subject of Radio, talk about something which will interest that class of people. If the neighborhood is populated by a different class, it may be well to talk the way those people talk.

To emphasize this point, let us cite an example of an insurance salesman of our acquaintance who was selling in a farming community. For a long time this gentleman was only partially successful until he happened to overhear a conversation in the country store where he was referred to as "that dude insurance salesman from the city." It didn't take him long then to learn to talk about things which interested farmers: weather, crops, planting, harvesting, farm machinery, etc. It is not unusual—now—to see him perched on a fence in conversation with a farmer about a tractor, or discussing the digging of a well. He learned what interests his clients, he talks their language, and it helps him sell insurance to farmers.

It is well to learn from your prospects, as early in the conversation as possible, the nature of the Radio programs in which they are particularly interested. A record can be kept of this information, as it will always make interesting conversation on later visits. Know the various Radio programs and their contents so that you will be able to discuss them intelligently with your customer.

Do not attempt to use Bill Jones' sales talk as your own. Build your sales talk for the people of your territory. It is to be expected that you will know enough about the locality in which you are going to work, and the people in it, to work up a presentation which will meet their approval and result in business for you.

ADVERTISING

Advertising, good will and business go hand in hand. We once heard of a man who obtained publicity for his business which resulted in a number of sales by selling a Radio to a church which was giving a fair. The Radio was sold below actual cost. The set was kept on exhibition in the church hall for several months, prior to being raffled off at the fair, and it bore the card and the address of the Radio man in full view of all those who inspected the set. Needless to say, the congregation of the church was appreciative of his assistance. Good will and sales were the results. Later, this same man obtained a lot of service work by donating, free of charge, to another church five certificates—each of which entitled the owner to free Radio service for a year. These certificates were raffled off for the benefit of the church. The cost to the dealer was slight, but think of the number of people who heard about him and his Radio service while the tickets were being sold. Cooperation with clubs and lodges can also result in a lot of good business for the wide-awake dealer.

You will develop many prospects by direct canvassing. You will contact other prospects whose names have been given you by friends. No amount of advertising you do through newspapers, letters or other methods will ever take the place of those two methods.

But you'll probably want to do some advertising, not as a substitute for those methods, but to supplement them—make them more productive.

There are several methods of advertising, generally used by Radio service men. Each will be covered separately. It should be understood that no one method of advertising can be considered best, until it proves so in your particular case. In some localities one form pays well; in others another method gets most results. Frequently certain combinations will pay dividends. But, regardless of the scheme of advertising decided upon as best suited to your purpose and location, *canvass your territory.*

Newspaper Advertising

If you live in a large city there will be a number of large daily newspapers. There may also be one or more community papers.

Where community papers are published, they make good advertising media enabling you to cover, with your ad, particular territories.

> FREE SERVICE COUPON
>
> Clip this ad and bring it to our store with your Radio Tubes. It will entitle you to a free inspection service by experts. We use only the most modern testing equipment. This offer is good this week only.
>
> BLAND RADIO SERVICE
>
> 1234 Summer Street
>
> A

FIGURE 4

One question generally arises, when more than one daily newspaper is available: *"In which paper shall I advertise?"*

An eminent authority on the subject claims the best way to solve the problem is to watch the ads in the papers and see if firms handling Radio Servicing use the paper consistently. He states that this is a good indication that the paper has pulling power; otherwise the Radio firms would not continue their ads.

Courtesy Radio-Craft

FIGURE 5

A combination of publicity and advertising with small space "bullets," frequently repeated.

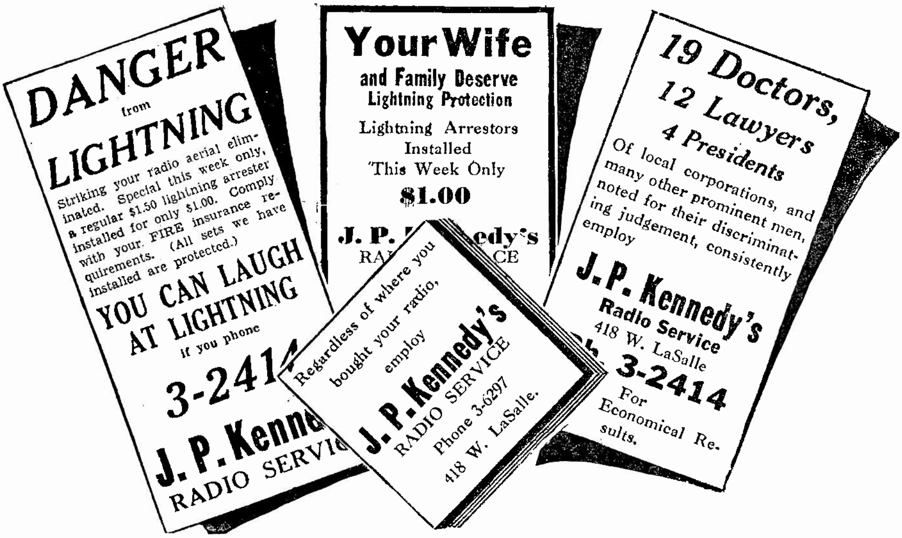
But another way of looking at the problem is that these firms may not pay much attention to the results of their ads, merely accepting what comes from them as a matter of course. This is a condition all too prevalent among Radio stores.

One service man solved the problem for himself by running an ad similar to the one pictured in Fig. 4, so he could test the reader interested in his ads—one paper against the other. These ads were identical in both papers—run at the same time, one week in each daily. By requiring the ad to be presented to get the free service and by having a key letter on the bottom of the ads he could tell which paper gave him most returns.

Small ads repeated frequently serve to keep your name before the public. They are usually better than large ads run at longer intervals.

A lot of good free publicity can be obtained for your business if you can get the editor of your paper to let you run a Radio Question Box as a regular feature of the paper. In this column you can discuss various phases of Radio, answer questions, and, by the use of your name, keep your business in the eye of persons interested in Radio.

Fig. 5 shows pictures of actual newspaper ads which were run to the financial advantage of the advertiser. At the extreme right and



Courtesy Radio-Craft

FIGURE 6

A group of larger newspaper ads which paid dividends.

left in this group are parts of a "Question" column, edited by the Radio man. To create interest in such a column, at first, it may be necessary to make up the questions and then supply the answers.

One must not expect too much from his newspaper advertising right at the start because a lot of persons, reading the ad, may not need service at the moment. The advertising value is in having readers become familiar with your name. It may be months before their Radio needs attention. In other words, it is quite possible for advertising to work for you, even when it is not producing definite, tangible results.

In Fig. 6 is reproduced another group of ads from newspapers. It has been reported that the ad at left, while using practically the same appeal, was less successful than the one in the center. This goes to prove the necessity of putting the "human interest" touch in advertising copy. These ads and those appearing daily in the papers will give you good ideas for your own advertisements. And your newspaper has an ad man who'll be glad to work with you in preparing them.

If pictures, cartoons, etc., are to be used in your newspaper ads, your newspaper office will be glad to tell you where cuts may be obtained locally.

Phone Book Ads

Every Radio man going in for service business will find it necessary to install a phone to take calls and make solicitations. When this is done it may be advisable to pay a little more and have an ad inserted in the classified section of the phone book.

KENNEDY'S J. P. RADIO SERVICE

PERSONAL
HIGH QUALITY SERVICE

Reasonable
Rates

418 W LaSalle................3-2414

Courtesy Radio-Craft

FIGURE 7

An advertisement in the classified telephone directory attracts attention at the right moment.

While large ads may serve to pull in more business than small ones, telephone book advertising operates on the same basis as newspaper advertising under what is known as the principle of decreasing returns. By this is meant that if the size of an ad is increased four times, the returns will not be four times that of the smaller ad—and so on.

Therefore, the Radio man operating in a small way may be content with an ad in the phone book similar to the one in Fig. 7. There is no doubt that these ads serve a useful purpose, otherwise they would not be in such general use.

Business Cards

To the Radio-Trician, business cards have a very important use. They are an inexpensive method of advertising and, if properly distributed, can help secure a lot of business.

They can be used to advantage when canvassing, left with the housewife, they serve as a reminder when the Radio needs fixing.

In soliciting service work from a dealer who does not maintain his own service department, they are useful. Ask him to attach one to the front cover of his phone book so he can call on an instant's notice.

Ask each of your friends to carry one in his billfold. He may run across some one who needs Radio work done. You'll find any number of other uses for your business cards.

Fig. 8 shows some business card forms picked at random from those used by Radio men. The form really makes little difference so long as it has the essentials of a good card, which include your name, address, and nature of business, and that the card be neat and easy to read.

Business cards are printed in many sizes. They are also printed in many color schemes. But it has been found that a card 3⅜ inches long by 2 inches wide is most popular because it is handy to carry and fits a standard billfold well. The cards preferred by most Radio-Tricians are white, printed in black, dark blue, or dark green ink.

RADIO SETS AND AERIALS INSTALLED
ADJUSTED, REPAIRED

LEON WHITE
Member of National Radio Institute
Washington, D. C.

278 Berriman St. Brooklyn, N. Y.

Sales—RADIO—Service

THOS. R. BROWN
Conduit Road
BRENTWOOD, ALABAMA

Member N.R.I. Phone—14F

GUARANTEED RADIO SERVICE
MAIN 2843

WHITE'S RADIO SHOP
2614 Albertson St.
WEST VALE, NEBRASKA

Member National Radio Institute

Telephone 3-2414

J. P. KENNEDY
418 West LaSalle Avenue
SOUTH BEND, INDIANA

J. P. Kennedy's Radio Service

FIGURE 8

Some, however, go in for more expensive cards printed in two colors. The extra expenditure, we feel, is not justified.

Any printer can supply these cards. When you are ready to order them, make a rough layout of just what you want; take it to a local printer and he will be glad to quote you a price. In one color ink, the job should be run between 75c. and $1 per hundred; in two colors, about $1.25 to $1.50 for the same amount. Of course, printing costs vary in different localities. In larger amounts the cost per hundred cards is considerably lower.

Direct Mail Advertising

Radio service men frequently find it advisable to use what is known as "Direct Mail" Advertising in conjunction with other plans

ROBERT B. GUBBINS, JR.

RADIO SERVICE AND CUSTOM SET BUILDING
STANDARD ACCESSORIES

3855 N. HAMILTON AVE.

BUCKINGHAM 0813

NORTH SHORE RADIO COMPANY
TELEPHONE GREENLEAF 4900
1703 SHERMAN AVENUE
EVANSTON, ILLINOIS

COMMUNITY RADIO AND NOVELTY STORE
15015 East Warren Avenue at Wayburn
Phone Lenox 9727
DETROIT, MICHIGAN

Authorized Hammarlund Roberts Service Station **Set Building, Repairing and General Service.**

HENRY H. CREWS
RADIO SERVICE
TELEPHONE 3255-W.
315 Pine Street

BALL · RADIO · SERVICE
Service and Supplies
Connersville, Ind.

OVIE B. BALL
Graduate of
Natl. Radio Inst.

531 W. 19th Street
Phone 1721
"Real Radio Service"

ELECTRIC APPLIANCES
PHONE 3594
22 SAN GORGONIO AVENUE

BRUNSWICK
RADIOS--PANATROPES--RECORDS
RADIO SERVICE

The Radio Shop
of
L. L. BOSWELL
Banning, California

Reiss-Central Radio Service Company
3015 REGENT STREET
EAST ST. LOUIS, ILLINOIS
CONSULTATION SERVICE
CUSTOM BUILDING
SERVICING

FIGURE 9

for getting business. Direct Mail Advertising constitutes placing your sales message before a list of prospects, by use of letters, post-cards or other literature, sent through the mail. It is so called because your message goes *direct* to the person for whom it is intended rather than broadcast to a great number, some of whom are not prospects for your service, as in newspaper advertising. It is in this direct mail plan that the list of prospects you have compiled will be particularly valuable.

Direct Mail in this case can be described in a few words. A form letter is carefully written, telling the prospect of your ability to render good Radio Service. Check and recheck the letter for errors, as well as for possible improvements. When you are satisfied that it will meet the favor of *your particular prospect list*, then have it multigraphed (or typed if the list is small) and mailed.

A modification of this plan is to prepare the letter, then type on the envelope "Personal to Mr. ——————." These letters are then

> Is your Radio working like it was the day you bought it? It should be.
>
> Even the best Radio set will deteriorate. It should be inspected by an expert and corrected before the condition becomes serious.
>
> I'll look over your set—regularly, or when called—keep it in tip-top condition. The cost of this service is very small—it more than pays for itself in satisfaction alone.
>
> My technical experience and knowledge of Radio are unreservedly at your call.
>
> Simply mail the postcard which I am enclosing (no obligation whatever). I'll gladly call and discuss the matter with you—any day or hour to suit your convenience. May I hear from you?

FIGURE 10

This letter produced good results for the Graduate who developed it. (*Courtesy National Radio Institute Alumni Assn.*)

slipped under the door at the home of the parties addressed. In this way you save the postage otherwise required for mailing. Follow up direct mail efforts by a personal call as soon as possible after the actual mailing.

Many persons in the Radio Service business try direct mail advertising and give it up as a bad job because it fails to produce as rapidly and the volume expected. One cannot expect to place several hundred letters in the mail and receive an equal number of replies. In fact, large mail order houses are pleased if mail selling efforts pull 1 to 3 per cent returns.

Of course, some letters are more productive than others. There are numerous factors which enter. Letter writing, just like Radio, is an art in itself. No attempt will be made here to delve into the intricacies of letter writing for the simple reason that in the short space allowed for the subject we would be doomed to failure.

However, a few of the most necessary rules for writing a letter will be given, which, together with the sample forms pictured, should enable you to prepare such letters as you need.

You should have a neat letterhead and envelope to match. Your local printer is an authority on the subject. Consult him. Some sample letterheads used by Radio-Tricians appear in Fig. 9. In addition to their use in direct mail work, letterheads are valuable in writing to manufacturers, etc., for literature, samples and discounts. They give a businesslike atmosphere to the request.

I don't sell Radios!

I'm not like the barber who gets you in his chair and then tries to sell you something out of every bottle on his shelf. My business is servicing Radio equipment. It is my job to make your Radio work when you call on me—not to tell you how bad it is—or how obsolete it has become, with the idea of selling you a new set. I'd rather make a set work—and work properly, just the way it did when you first bought it, than anything I know.

So when you call on me to repair your set—feel confident that I'm going to make it like you want it—like the manufacturer of that set intended it to be. I couldn't sell you a Radio if I wanted to—because I'm a Radio Serviceman first and last and *I don't sell Radios.*

Don't put up with improper Radio reception—what sounds like a big trouble in the set may only require a few minutes of an expert's time to correct. Is your Radio just the way you want it? If not—a phone call to Blake's, Main 2476, is all that's necessary.

Cordially yours,

FIGURE 11

An unusual letter, used satisfactorily by an N. R. I. graduate who wished to stress "SERVICE."

For your purpose the letter need not be over one page in length. It should be neatly typewritten or multigraphed. Multigraph companies listed in your phone book will give rates on this work.

The letter should be simple and clear. Use small words, fairly short sentences and short paragraphs. This makes it easy to read. The best letters are written in unstilted phrases, very much like a person would talk.

Open your letter with a sentence (be sure it deals directly with your message) which will get attention and make the reader want to go further into its contents.

After gaining attention in the opening paragraph, state your proposition clearly in the body of the letter so as to create a desire for your services, then endeavor to use closing paragraphs which will get the action you desire on the part of your prospect.

This action may be to call you on the phone, to send you a card to call, to give you an order for some special work, etc. In case they are supposed to mail you a card, a government post-card should be enclosed for their convenience. This should be mentioned in the closing paragraph, or, if they are to call you, give your phone number as a reminder.

Use care in grammar, spelling, and punctuation. Errors in these matters are unpardonable. If you are not quite sure of your letter's value, ask the representative of the multigraph company which you engage to go over it for you. He is familiar with letters.

Fig. 10 is a letter used in direct mail campaign by an N. R. I. graduate. He reported very favorable results.

> Here comes Old Man Winter!
>
> A few years back he brought only the holidays, sleigh-riders, turkey dinners. Now, he brings seven months of *Good Radio Reception.*
>
> Beautiful, inspiring Christmas and New Year's music from the mighty organs of the grandest cathedrals in the country; the sporting and political events—music, drama for every mode—all brought to your fireside—free—if your Radio is operating as it should.
>
> Give your Radio a chance and it will bring you every note of the organ recital—every word of the world-famed lecturers. This wonderful Radio of yours brings the world to your home—give it a chance to do its best.
>
> Give it a little cleaning—a little adjustment by an expert—possibly a new tube or two and it's at your service again. Let me look over the little "wonder cabinet" free of charge and make you an estimate to put it in "NEW" condition.
>
> Act now before the rush is on—don't take chances on missing anything. When may I call?

FIGURE 12

A letter taking advantage of the Christmas season to solicit service work.

In Fig. 11 a letter is shown which is slightly out of the ordinary. In order to get attention the service man has used a startling opening. However, as the open fits in well with the balance of the letter, it is perfectly permissible from a point of letter writing.

Timeliness is a keynote of direct mail advertising. To tie up your mailing with a coming event of importance—a season, a special series of broadcasts—is to make that mailing more to the point and consequently more productive. In Fig. 12 the Radio-Trician ties up his copy with the Christmas season. By slight changes this letter could be used for World Series baseball, college football, political campaigns or any series of Radio broadcasts which have a strong appeal to the listening public.

Five hundred letterheads and an equal number of envelopes, printed, will cost between $8 and $12. Multigraphing that amount of one-page letters should cost around $5 or $6.

The reverse side of this half contains the address of the prospect.

Dear Radio Owner:

For a limited time we are offering a *free inspection* of all Radios in the neighborhood. This is being done so that we may get acquainted. We want you to know our company.

Though your set is in perfect order it should be checked periodically—just to make sure. Physical examinations help people keep fit—and Radios are like that, too.

As we said before, this service is free—there's no obligation. With our modern testing equipment we'll give you an accurate report on the condition of your set.

Just mail the attached card telling us when our expert may call.

John Murphy Company,
Radio-Tricians.

John Murphy Co., Radio-Tricians,

3823 Broad Street,

Miami, Florida.

FIGURE 13

The reverse side of this lower half contains a form for the prospect to fill in the name, address, and time for the Radio-Trician to call.

The sample shown above is smaller than your card should be. Make your card 5½ inches wide by 3¼ inches deep.

The inside of a double postcard. The top half carries the message. The lower section is the return form. The card is folded and the open ends sealed together with a one cent postage stamp which carries it through the mail.

A very popular form of mail advertising among Radio Service men is the government post-card. This is due to the small expense involved.

One side of the card contains the prospect's address; the other side carries the Radio-Trician's message. The messages can be multigraphed, printed, or typed. Multigraphing or typing is preferable.

Great use is made of these cards to pave the way for an inspection or canvass call. Copy similar to the following is frequently used:

"Our representative will call on you in the next few days to test your Radio free of charge;" or "Our representative will call to tell you about our new service plan," etc.

These cards are also used to induce the prospect to call you on the phone and request service.

A modification of the plain government post-card mailing plan is the use of the "double post-card" system. In this plan a double size post-card stock is used. The set-up is that of a mailing card and a return card attached. See Fig. 13. This card may be sealed at the bottom by a one cent postage stamp. (It is well to inquire at your post-office about rates on mailings before any literature is prepared, as these rates may change from time to time.)

A post-card mailing, to prospects, single or double, once every several weeks, is an inexpensive method of keeping your name and business before them. All mailings should be followed as soon as possible by a personal call. Change the message frequently on your mailings.

WHAT TO CHARGE

It is not possible to make any hard and fast rule regarding the charges to be made by the Radio Service man. The standard price charged in the locality in which you are doing business will have a lot to do with your charge for Radio Service work.

Then, also, the method in which you are operating your business will have a decided bearing on your charge. Naturally, if you are operating on the service contract plan your scale of charges will be different than if you were working on the wholesale service business. In other words, charges will depend upon the service to be rendered.

The Minimum Charge

There is no doubt that every service organization operating on the "Call" basis should make a policy of having a minimum service charge. By that is meant that, regardless of the reason for the call, regardless of the work necessary upon the arrival of the service man, there should be a certain fixed charge which the customer will be required to pay. This minimum service charge is necessary, even though the work you will be required to do is of a trivial nature; nevertheless, it was necessary for you to spend your time going to and from the customer's home, expenses of driving your car. street car fare, etc.

Minimum charges used by service men and dealers all over the country vary from $2.50 down to 50c. Both of these extremes are wrong. One is too high; the other too low, for a proper minimum service charge. But when we take an average of a large number of minimum charges, we find that the figure is $1.25, which makes a very fair price for a minimum service charge.

Miscellaneous Charges

Watch your jobs very closely at first, especially those jobs requiring some construction work like antennas and ground. Keep an accurate record of all the items which go into such a job, including time, labor, material, and in this way know just exactly the cost at which you can do the work and still make a good margin of profit. Whenever a job is obtained on aerial or ground work, it is safest to make no estimate, no quotation, until you see the job, look it over carefully, and know just what you may expect. Numerous service organizations make a policy of doing aerial and ground jobs on a time and material basis. Figure an extra charge for an aerial job if it is on a sloping roof. It will require more time. In connecting up a set to an old aerial always first inspect the job thoroughly. The old antenna may not be satisfactory and may cause trouble for which your installation may be held responsible. Improperly installed or inferior lightning arresters and grounds can cause no end of difficulty for the set owner. Inspect them carefully.

Just as lining up new customers is important to the Radio Service man, so is it important to retain old customers. It is advisable to contact the persons for whom jobs have been done at regular intervals. A phone call, a post-card or a personal call will do. Let them know you are interested in how the job turned out and if the set is working satisfactorily.

ADDING PERSONALITY TO YOUR EQUIPMENT

In addition to tools and testing equipment the Radio Service man can well add additional equipment. This is personality.

Personality is something none of us have enough of; there is room for improvement in the best of us.

It is easy to improve personality and it is advantageous to do so regardless of business or position, but the chief difficulty lies in making any person realize that he is not perfect along the lines of personality.

To improve personality we must analyze our personal habits, decide frankly those traits or personal habits which need improvement, then strive for perfection in each instance where we find ourselves below par.

Read over the following list of questions. Answer each of them with one of two words, "YES" or "NO." Be frank with yourself; you can afford to be because no one will know the answers but you. If your answer is "NO," then you must strive for improvement. Write your answer in pencil in the space provided. Then, once a month, check up on yourself, go over the entire list and strive until you know positively that your answer is "YES" in every case. You'll find it will pay dividends. Some of these questions are very personal—but one has to be personal to improve personality.

PERSONALITY IMPROVEMENT CHART

Question	*Answer*
Do I keep my clothes clean, my suit well pressed, my shoes shined?	______
Do I select my clothes carefully so they are not the extremes in style or color?..	______
Do I practice cleanliness of body? Are my face and hands clean, my nails well cared for? Is my hair neatly combed?.........	______
Am I doing all in my power to keep healthy? Do I care for my teeth, eyes, and digestion? Do I get sufficient sleep and exercise?	______
Am I friendly, pleasant, dignified; at ease before strangers? Do I meet problems as they come, solve them myself without shunning responsibility and looking to someone else for guidance?	______
Do I put in a real day's work? Do I start early, quit late? Do I put in as much time when working alone as when working under supervision?.......................................	______
Am I careful with my method of speech? Do I avoid slang as much as possible? Do I talk the language of the persons with whom I am dealing?.................................	______
Do I plan each day's work in advance and follow out the plan? Do I aim to have each day carry me a step nearer my ultimate goal?..	______
Do I please each customer? Do I make sure of satisfaction in every transaction? Do I charge properly, consider the customer's welfare, and avoid shady transactions?...............	______
Do I keep my temper, always?...............................	______
Is my word to be relied upon?...............................	______
Am I loyal to my friends?...................................	______
Do I pay my bills promptly and thereby improve my credit?...	______
Do I strive to improve my memory?..........................	______
Do I continually conduct myself so as to improve my standing in my community?...	______
Am I trustworthy in little things?............................	______
Do I keep appointments?.....................................	______
Do I establish my reliability as thoroughly as my ability?.......	______

When you can conscientiously answer "YES" to every one of the above questions you will find yourself a bigger, better man in your own estimation and in the regard of others. You will have passed an important milestone in your march to Success.

CREDIT

While being a good Radio-Trician will go a long way in helping you to success, as a business man you must consider the phases of business practice which have a definite bearing on your Success.

Good credit is a necessary foundation for Success.

Credit is like a frail flower. It flourishes in the sunlight of truthful dealings. It withers and fades when individuals make promises they are unable or unwilling to fulfill.

It is estimated that 70 per cent of all business today is conducted on credit. Everything from daily newspapers to international warfare is operated on the deferred payment plan.

No one should hesitate to buy on credit, but, before buying, definite plans should be made for paying for the merchandise or services received. And there is no disgrace in asking a bank for a loan for business purposes; in fact, it is good business to do so.

Suppose a man has several hundred dollars due his creditors at a certain time and doesn't see his way clear to pay them. If his credit is good, he should be able to borrow the money at from 6 to 10 per cent, pay off his bills, and take advantage of discounts for prompt payment.

J. Pierpont Morgan, the outstanding financier of the last generation, says that the best security for a loan is character. And a big factor in any man's good character is his willingness and ability to meet his bills and obligations on time. Good credit is little more than reputation for reliability.

The man who insists on your making your payments on time is doing you a big favor. He is helping you maintain a most valuable asset—your credit.

Modern business has established an elaborate system of individual credit ratings. Every town of any size and consequence has its trade association. These associations maintain Credit Information Bureaus, which supply credit information not only locally but maintain reporting services to other bureaus all over the country.

Apply for credit in a store or business house of any kind and your application is referred to the Credit Agency. If they have no unfavorable reports from merchants or other credit bureaus, you get what you want. Otherwise, you pay cash.

Excuses don't go with these fellows. They are not interested in a hard luck story. With them it is a case of *"Do you pay, or don't you?"* They feel that a man should analyze conditions far enough in advance to know when and how he can meet his credit obligations.

Employers frequently check up on the general character of a man before they hire him. A man who is conscientious in paying his bills is usually straightforward in his dealings with his employer.

To the man in business for himself, good credit is a most valuable asset. He can get along on a small capital if he has good credit, but if not, as soon as his capital is invested in equipment, etc., he has no place to turn for additional capital.

I have in mind the case of a man who made $15,700 in his business in three years. Then came a period of depression. He lost it all and $4,300 besides. That was a big hole to climb out of, but he did it. He had a reputation for paying his bills promptly; consequently, very liberal credit. Right now he is well on his feet again, but he wouldn't be if his credit hadn't been good.

The best rule for establishing a credit standing is to never buy anything you can't pay for and to pay all bills promptly as they fall due.

THINGS TO DO

The wise Radio-Trician is he who searches for every opportunity to make money with his knowledge. This is a list of some of the things the Radio-Trician can do to cash in. You'll probably think of many more. Check over the list to see if you are passing up any opportunities.

Repair Radio receivers.

Charge batteries—particularly in rural sections.

Remodel old sets.

Install or improve aerials and grounds.

Install interference eliminating circuits and grounds.

* Locate and remedy minor interference cases.

Install sets for dealers.

Sell and install lightning arresters.

Clean Radio sets.

Replace tubes, sell spare tubes.

Sell sets on commission for dealers.

Sell service contracts.

Wholesale the service of dealers.

Contact dealers and garages for automobile Radio Installation and service work.

Install new chassis in expensive cabinets, removing old chassis.

Install new chassis in special cabinets, walls, etc.

Install tone controls on old receivers.

Electrify phonographs and install pick-ups where Radio has pick-up jacks already built in the circuit.

Modify sets for phone pick-up.

Build and install short wave converters.

Install additional speakers.

Construct and install wave traps.

Install automatic line voltage controls.

Build and rent small public address systems for public gatherings of many sorts.

Install and service sets on boats and yachts.

Add remote control to sets.

Sell on commission all sorts of electrical appliances, such as electric clocks, Radio lamps, irons, vacuum cleaners, etc.

It is well to carry a midget set along on service calls. A customer may complain about noises in a set which are beyond the power of the service man to remedy. When this condition arises, connect up

---

* The elimination of interference often offers a splendid opportunity for the Radio Service man to make money. In the ordinary household are usually numerous electrical appliances which may cause Radio interference. Set owners frequently blame the poor reception in such instances to improper functioning of the set. They will usually authorize you to correct the trouble, particularly when it is explained that they may be interfering with their neighbor's reception as well as their own.

However, the more complicated interference jobs, especially those involving commercial apparatus, should not be tackled by the service man until he is a full-fledged graduate Radio-Trician, as his more advanced lessons will be a big factor in enabling him to carry the job through successfully.

the small set; let the customer listen to the reception. If the noises persist in the midget, it will satisfy him that his Radio and service are not to blame.

It is a nice gesture to leave a midget with a customer whose set must be taken to the shop for repairs. Remove the chassis and leave the midget on top of the cabinet for his entertainment until his set is returned.

You'll find children very favorably impressed by midget sets. Possibly because of the size, they compare them to toys. In many cases a midget, left while the large set is being repaired, can be sold for the children's room.

Ask the housewife if she wouldn't like an inexpensive midget on top of her kitchen cabinet.

NOW YOU MUST ACT

Your N. R. I. training and the hints given in this book have fitted you to go out, right now, and make spare-time Radio profits.

The same training you have received, up to this point in the Course, has enabled thousands of N. R. I. students to make fine profits in their spare time. What they can do, you can do.

Up till now you have been studying, reading, thinking. Now you must act if you want to make your start for a successful Radio Business of your own!

All ideas in this book, while written primarily for the spare time Radio worker, can be elaborated and used successfully by a man in full-time Radio.

THE MODERN SUPERHETERODYNE RECEIVER

23 FR-1

PIONEER HOME STUDY RADIO SCHOOL

NRI

NATIONAL RADIO INSTITUTE

EST. 1914

WASHINGTON, D.C.

BE WISE

I am sure this lesson on Superheterodyne Principles is going to make you realize more than ever that a single reading of a lesson is really insufficient. I know that some students are going to read this lesson three and four times—and they are wise, because it is "brim full and running over" with practical information on a subject which at the present time is of the greatest interest to sincere Radio students.

Soon after you have read a few pages of this text book you will realize why the following subjects were taken up in previous books; Side Bands, Modulation and Demodulation, Regeneration, Fixed and Tuned RF Circuits, Oscillators, Harmonics, Band Pass Circuits and why the Federal Radio Commission assigns frequencies 10 kc, apart to broadcasting stations.

Should you have any trouble understanding any of these things when you meet them in this lesson, I advise you to refer back to your previous books and refresh your memory on the principles involved.

Recent developments are proving the supremacy of the Superheterodyne Principle. Set manufacturers have let their engineers loose on the problem of perfecting the "Super." And the last few years have seen the "Super" come into its own. For many reasons, this lesson should be considered one of the most important in the Course.

J. E. SMITH.

NATIONAL RADIO INSTITUTE

WASHINGTON, D. C.

Revised 1932, 1933, 1934,
1936 Edition

WPC3M7336

Printed in U.S.A.

The Modern Superheterodyne Receiver

SUPERHETERODYNE PRINCIPLES

Broadcast Radio receivers can be divided into several classes according to the circuits used: (1) The regenerative receiver, which is no longer considered efficient enough and is no longer popular; (2) The tuned radio frequency receiver having its R.F. stages stabilized; (3) The fixed R.F. receiver with its R.F. stages preceded by band-pass filters for selectivity; (4) The super-regenerative receiver (although this circuit is not much used in commercial receivers, and (5) The superheterodyne.

In the field of broadcast reception, it is safe to say that the tuned R.F. and the superheterodyne receivers are the most important types of machines. It is further interesting to note that the superheterodyne is now made almost exclusively by all set makers, although there are countless T.R.F. sets still in use to be serviced. The change in receiver design is the inevitable result of giving radio receivers buyers a better machine for their money.

Tuned radio frequency circuits have serious drawbacks and limitations that are quite baffling to the set designer. Poor selectivity is the rule at high frequencies and poor gain at low * frequencies. If a tuned R.F. circuit is made selective the audio quality suffers by the cutting off of side bands, and even modern T.R.F. receivers suffer from this defect. Many schemes have been evolved to remedy these defects, but they involve complications which are not desirable in commercial receivers. Some of the methods of obtaining uniform amplification over the 1500 to 550 kc. band are far too costly for a production product. The superheterodyne does away with many of these troubles in one sweep, but do not think for a moment that the "super" is an easy machine to design, or repair. Its action is complex and each section must be exactly right.

Theoretically the superheterodyne seems to have every advantage, but in practice the limitations present real problems.

* Increased R.F. amplification is obtained at high frequencies due to regeneration. The reversed condition is true if regeneration is removed.

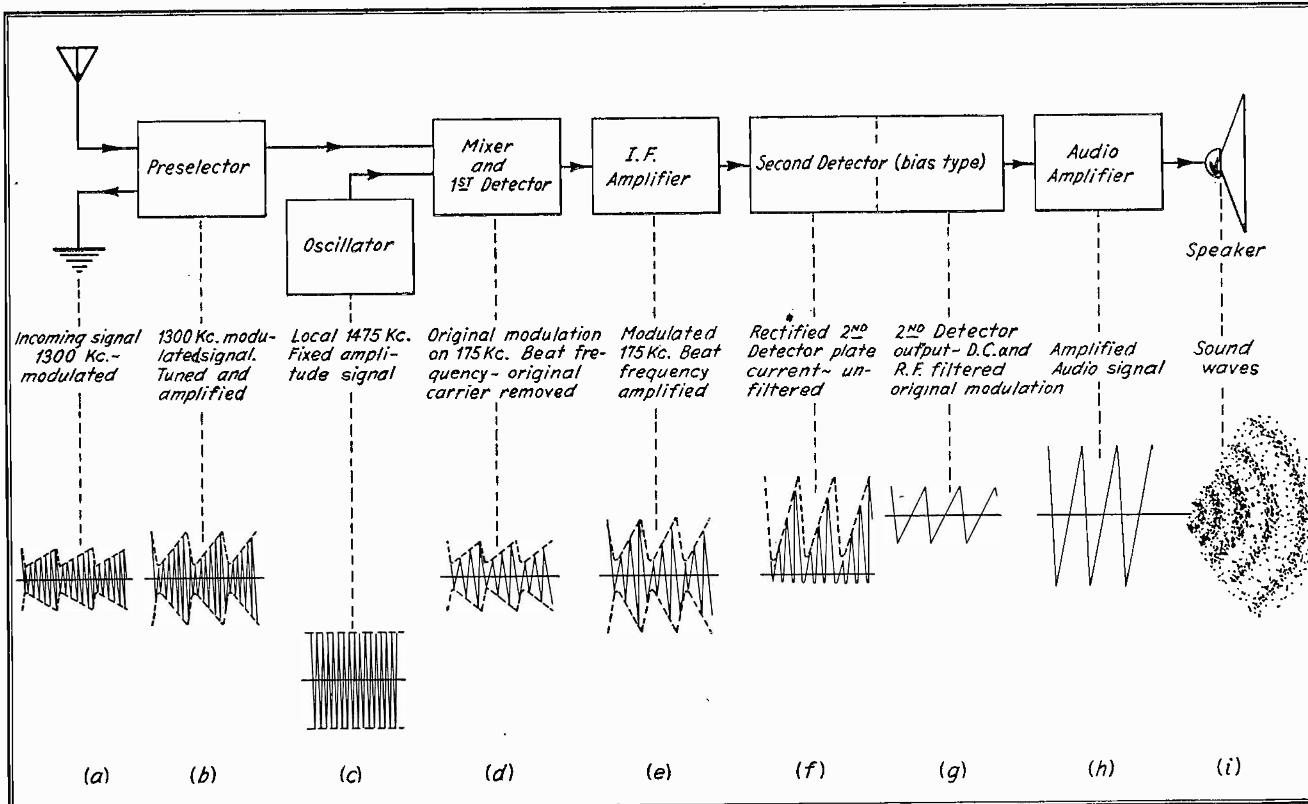


Fig. 1.—Sketch showing the various parts of a typical superheterodyne receiver and the changes which occur in the signal voltage in each part.

With more manufacturers working on this circuit it will eventually reach its height of performance. Now what are the underlying principles of superheterodyne circuits?

A superheterodyne employs a system whereby the incoming signal frequency of 1300 kc. for example, is reduced to a lower frequency of let us say 175 kc. and this in turn amplified and filtered to the desired degrée, which seems simple to say the least. Any other incoming signal frequency between 1500 and 550 kc. is likewise reduced to 175 kilocycles and amplified by two or more stages of fixed T.R.F. amplifications of tremendous gain and constant band width in what is called the intermediate frequency amplifier. But how is this reduction of frequency accomplished?

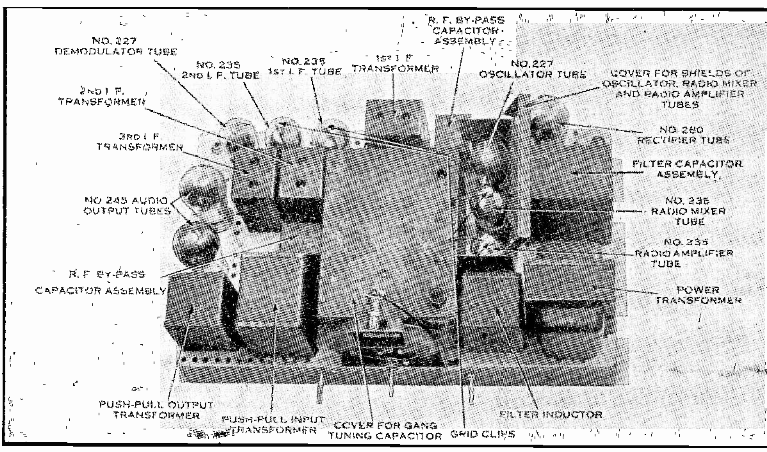


Fig. 2.—Top view of the chassis of a typical superheterodyne receiving set, showing the tubes in place. Just as it would look when taken out of the cabinet.

We have already learned that if a signal of 1100 kc. is received in a regenerative receiver and the tickler feeds back to the grid circuit an oscillation of 1105 kilocycles, a note will be heard in the loud speaker equal to the difference, 5,000 cycles (1105 minus 1100 kc.). This is known as the phenomenon of beats.

If we were to build two oscillators, one capable of generating a 3000 cycle frequency and the other a 4500 cycle frequency and each were connected to a loudspeaker, the ear would hear three frequencies:* (1) the 3000 cycle note; (2) the 4500 cycle note; and (3) the difference, a 1500 cycle note. It would no

* Actually a fourth note will be generated, the sum of the two original notes, 3000 + 4500 or 7500 c.p.s. This frequency is of little importance in radio work and is disregarded here for simplicity.

doubt appear as a rising and falling squeal which swings between the two main frequencies.

It is possible to separate the 1500 cycle note from the other two and in the super heterodyne receiver it is done by what is called the "first detector." If one of the original frequencies, for example, the 3000 cycle note generated by the oscillator, were modulated by a 75 cycle audio frequency, the beat note of 1500 cycles would appear with a 75 cycle modulation.

Returning to actual Radio conditions in a superheterodyne receiver: An incoming signal of 1300 kilocycles modulated of course with music of 30 to 5000 cycles (audio frequency) is received by the antenna and ground system. A local oscillator is adjusted to generate a frequency of 1475 kc. The *local signal,* as the frequency of the oscillator is referred to, is combined,
2 "mixed," with the incoming signal. This will result in a beat note or intermediate frequency equal to 1475-1300 or 175 kc. per second.

In effect, the high frequency signal is modulated with 175 kilocycles. By passing the combined incoming and local oscillator signals through the first detector, the signals are rectified leaving
3 the 175 kilocycles. Since the original incoming signal was modulated with voice frequencies, the 175 kc. intermediate frequency appearing in the plate of the first detector will also be modulated with these same voice frequencies. It is important to remember that the mixer tube is also a detector, because it converts the combined signal and oscillator frequencies to the intermediate frequency.

Refer to Fig. 1, the incoming modulated signal is at a frequency of 1300 kc. per second as in (a): It is then tuned and amplified by the pre-selector (b) or pre-tuner as it is sometimes called; the locally generated frequency is 1475 kc. per second as in (c). When both the received and local frequencies are mixed, and the result demodulated by the first detector, a modulated beat frequency of (1475 minus 1300) 175 kc. per second appears as in (d). The dotted line represents the original modulations.

The modulated beat frequency of 175 kc. is then sent through several stages of fixed R.F.—known as the Intermediate frequency amplifier—(e), which is tuned to exactly 175 kc. and with such selectivity that it shuts out any radio frequency signal above 180 and below 170 kc.

When sufficient R.F. amplification and selectivity are obtained through two to four intermediate frequency stages, the amplified signal is sent through a second detector (demodulator) as in (f), and the beat frequency is removed, leaving nothing but the original audio frequency (g)—original modulation. This in turn is amplified by one or more stages of audio frequency amplification as in (h) and then it is fed by the output tube of the receiver to a loud-speaker.

The upper part of Fig. 1 shows the entire procedure in block form. STUDY IT IN DETAIL.

It is clear that as the receiver must be made to tune to any frequency in the 550-1500 kc. band, and as the intermediate frequency is fixed the oscillator frequency must be variable. In modern practice, the oscillatory circuit is so designed that the frequency is always greater than the incoming carrier frequency by the amount of the intermediate frequency. If the latter is

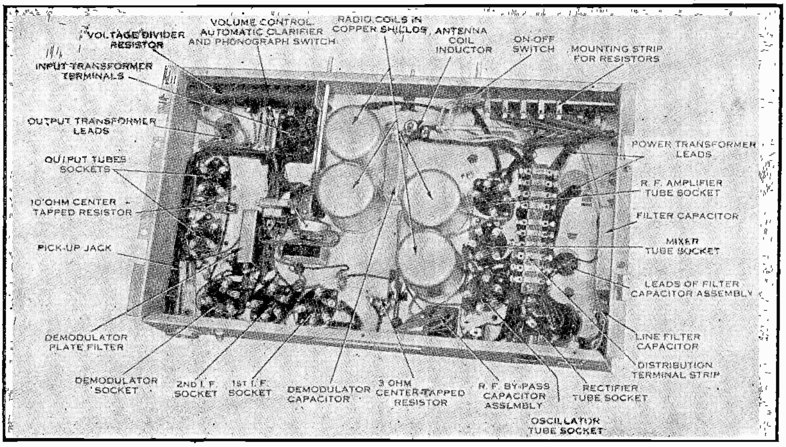


Fig. 2 (a).—Bottom view of the chassis of a typical superheterodyne receiving set with the cover removed.

175 kc., the oscillator has to be designed to generate frequencies from 550 + 175 or 725 to 1500 + 175 or 1675 kc.

So far we have been considering only an I.F. of 175 kc., but it must not be assumed that this is the only I.F. possible or practicable. While 175 kc. is the favored I.F. at the present time, other intermediate frequencies have been and still are in use.

Now that you have learned that one function of the superheterodyne is to reduce the incoming carrier frequency to one of a
4 lower value, you will no doubt ask why such a system is of value. It is well known that R.F. amplifiers at frequencies of 30 to 500 kc. are comparatively more effective than from 550 to 1500 kc. We shall go on to this shortly, but for the present, let it suffice to say that at lower carrier frequencies, increased selectivity and sensitivity may be obtained in the same number of R.F. stages.

And before we drop the subject of the required oscillator frequency, let us consider another intermediate frequency.

Now suppose we have an incoming signal of 1300 kc. a local oscillator signal of 1475 or 1125 kc.; this will also result in a beat frequency of 175 kilocycles. The beat will be the difference of the original two frequencies. In one case it is 1475 minus 1300 or 175 kc., the other 1300 minus 1125 or 175 kc. The 175 kc. frequency is the intermediate frequency and the intermediate fixed R.F. stages are designed to have maximum efficiency at 175 kc. The local generator is always adjusted to give a beat frequency equal to the preadjustment of the intermediate. It may be either the sum of the I.F. (intermediate frequency) and the received signal frequency or the difference between the signal frequency and the I.F., but the former only is used in broadcast superheterodyne receivers.

Now let us assume we have an intermediate frequency of 480 kc. and that a 1500 kc. signal is received. What is the required local frequency? Either 1500 + 480 = 1980 kc. or 1500 minus 480 = 1020 kc. Take the other end of the broadcast band, 550 kc. What is the required local frequency in this case? Either 550 + 480 = 1030 kc. or 550 minus 480 = 70 kc. A local oscillator that would generate frequencies controllable at will from 1980 to 1030 kilocycles would reduce a 1500 to 550 range of frequencies to 480 kc., the intermediate amplifier frequency. Likewise an oscillator producing a local signal of 1020 to 70 kilocycles may result in 480 kc. beat frequencies.

It was stated several times that an oscillator is always made to tune to a frequency above the received signal by the frequency of the I.F., amplifier. That is, from 725 to 1675 kc. instead of 375 to 1325 kc. for a 175 kc. I.F.) and from 1030 to 1980 instead of 70 to 1020 kc. (for a 480 kc. I.F.). The reason for this is not difficult to explain. Most oscillatory circuits will only tune down to a frequency one-third of their maximum tunable frequency because the variable condenser generally has a minimum capacity one-ninth that of the maximum value. Although it might be possible to tune from 375 to 1325 kc., it would not be possible to tune from 70 to 1020 kc.

PRESELECTORS

Of prime importance in a superheterodyne circuit is the selecting circuit intended to resonate the radio energy collected from the aerial and ground system before it is mixed with the local oscillation. The importance of this part of the circuit is being realized more and more. It is essential that the "preselector" (a band selector circuit or filter system preceding or incorporated with a R.F. amplifier) select one and only one signal from the many that are radiated through the "ether."

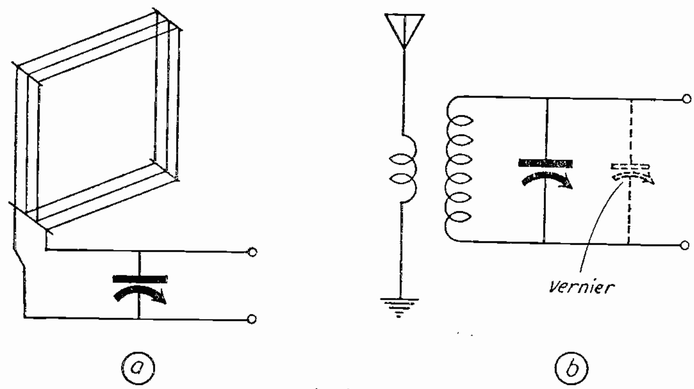


Fig. 3 a, b

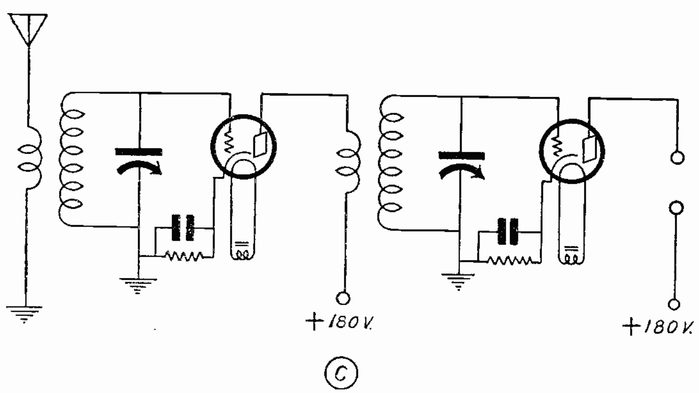


Fig. 3c

Although modern supers are one dial receivers, from the service man's point of view the modern super can be considered to have several tuning controls. These multi-controls, however, instead of being located on the front panel, are in the chassis in the form of trimmers and are used for purposes of adjustment.

First we shall consider the action of the preselector and oscillator as they are tuned individually. Note the troubles that appear in these circuits and how they are eliminated, and finally, how the preselector and oscillator condensers are ganged together.

Because of the tremendous sensitivity of this type of receiver, the loop antenna (a large coil of wire wound on an open form) has been extensively used for the pick-up system. The coil antenna, see Fig. 3a, is tuned by a .0005 or .00035 mfd. variable condenser. The advantage of this antenna lies in its inherent directional pick-up properties and if two stations are operating at very nearly the same frequencies, but the signals originate from different directions, the undesired station may be tuned out by turning the loop.

Loops of large sizes are used in commercial stations, but these are hideous contraptions for home use and so they are being replaced by an antenna and ground system as shown in Fig. 3b. A regular R.F. coil is used, the primary side connected to the collecting system, the secondary tuned by a regular standard variable condenser. Even if the antenna is small, this pickup system tunes quite broadly. For example, if the intermediate amplifier operates at 175 kc. and the signal to be received is 1200 kc., the oscillator must be adjusted to 1375 kc. to obtain the required beat (1375 — 1200 or 175 kc.). Should the preselector not be selective—see Fig. 3d—a strong signal from 1250 to 1150 kc. will get through. Thus, in tuning the oscillator alone (varying from 1425 (1250 + 175) to 1325 (1150 + 175) kc.) and without adjusting the preselector, we may hear as many as 10 stations, if all are 10 kc. (1250 — 1150 ÷ 10 = 10 kc.) apart as permitted by Federal ruling, which is undesirable to say the least.

The natural thing to do in such a case is to build the preselector so sharp that only one carrier frequency can get through. For example, if a preselector, having two R.F. stages as shown in Fig. 3c, is used instead of the one shown in 3b having only one R.F. stage, it would be possible to get at least 20 kc. separation before mixing. Let us see what would happen if we used such a preselector tuned to 1200 kc. When the oscillator is adjusted to 1375 kc. (1200 + 175), the desired signal will be fed to the I.F. amplifiers. But as the preselector is only 20 kc. sharp, at oscillator settings of 1365 and 1385 kc., signals of 1190 and 1210 kc. will get through to the I.F. stages.

Suppose we tuned the oscillator to 1025 kc. We would find that the 1200 kc. station was received again. With what we know already, we can explain why this happens—1200 — 1025 = 175 kc. and this beat frequency will be amplified by the I.F. amplifier. Of course, when the oscillator is tuned to 1015 and

1035 kc., the receiver will receive the two side signals of 1190 and 1210 kc. The important fact to remember is that in any two dial superheterodyne (the preselector and oscillator independently controlled) no matter how selective the preselector is made for every setting, there are two positions of the oscillator at which the same station will be received. These are referred to as the *repeat* points.

Now let us consider the case where the oscillator is fixed at 1375 kc. and the preselector is varied. When adjusted to 1200 kc., a 175 kc. beat will be obtained and the desired signal received. If signals of 1190 and 1210 kc. get through the preselector, a beat frequency of 185 kc. and 165 kc. will be obtained

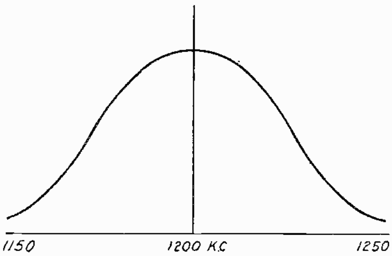


Fig. 3d

Preselector Tuned to 1200 kc.
Oscillator Varied from
1325-1425 kc.

Signal Getting Through Preselector	Oscillator Setting Giving a 175 kc. I.F. Signal
1150	1325
1160	1335
1170	1345
1180	1355
1190	1365
1200	1375
1210	1385
1220	1395
1230	1405
1240	1415
1250	1425

TABLE 1

and if the I.F. amplifier has 10 kc. selectivity, they will not get through the set.

Now if the preselector is tuned to 1550 kc. and a station is broadcasting on that frequency, it will be received because 1550 minus 1375 will give a beat frequency of 175 kc. The frequency of this signal is called the *image* frequency. And here the important fact to remember is that if the oscillator is set to a given value and the preselector is varied, a signal will be obtained at two points—one at the desired frequency and the other at the image frequency which is above the desired frequency by twice the I.F. frequency. The importance of this phenomenon will be brought out as soon as we consider one more condition.

It would be natural to say that if there is so much confusion in tuning due to repeat points and image frequencies, why not gang together the preselector and oscillator so that the oscillator will always be 175 kc. (the I.F. frequency) above or below the preselector setting? Up to the present time this has been a difficult procedure, but now due to good design, which we will consider shortly, this can and is being done. In addition to ganging the preselector and oscillator, the oscillator tuned circuit is always set above the preselector frequency by the value of the I.F., thus eliminating a *repeat* point and greatly reducing *image* frequency interference.

Unquestionably such a procedure eliminates repeat points. Suppose, however, that the preselector is not sharp enough and a station gets through at 350 kc. (twice the I.F. frequency) above the preselector setting. Clearly there will be *image interference.* With a selective I.F. system there could be no interference from any other signal frequency.

There is one exception to the last interference which requires further comment. Should two stations be broadcasting whose frequency difference is equal to the I.F. frequency (175 kc. in the case we are considering), they will create a beat in the preselector without the oscillator, pass through the first detector and be amplified by the I.F. amplifier.

Let us consider two cases. First, if a 1100 kc. and a 1275 kc. are both induced into the antenna system of a preselector, a beat of 175 kc. (1275 — 1100) will be modulated on one of the carriers which will pass through a broadly tuned preselector and get into the I.F. amplifier. More than likely it will not be exactly 175 kc. and in the I. F. stage it will again beat with the desired 175 kc. signal and result in a whistle interference. Perhaps the most frequent cause of interference of this type is beating between the desired signal (1200 kc.) and a signal above and below the desired signal by the I.F. frequency, that is, 1375 kc. (1200 + 175) and 1025 kc. (1200 — 175). When either the 1375 or 1025 kc. broadcast is present in addition to the desired broadcast, a 175 kc. beat will be obtained which will give rise to interference.

But you probably have noticed that the Federal Communications Commission do not assign stations having 1275, 1025 and 1375 kc. carrier. Quite true. If we had made the I.F. frequency 180 kc. (some value in multiples of ten as 160, 170, 180, 260, or 480), a signal of 1280, 1020 and 1380 could be present and interference would take place. This should explain to you why an I.F. frequency ending in 5 (as 135, 265, 175) is desirable, for with a sharp 10 kc. wide I.F. amplifier this interference will be eliminated.

Then two things are essential in superheterodynes—first, and this is quite a problem, the preselector must be so sharp (no side-band cutting) that there will be no image interference; and second, the I.F. amplifier must be so sharp (no side-band cutting) that should any signal in the channel adjacent to the one that is desired happen to get through, its beat, which will be greater than the I.F. frequency, cannot be amplified by the I.F. amplifier.

The amount of image interference in a superheterodyne is expressed as the *image ratio* which is found in this simple way. A superheterodyne is set to a given frequency and the voltage fed to the aerial and ground measured in microvolts is applied to give a definite output measured in milliwatts. Then the signal

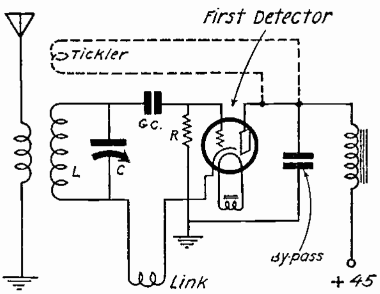


Fig. 4

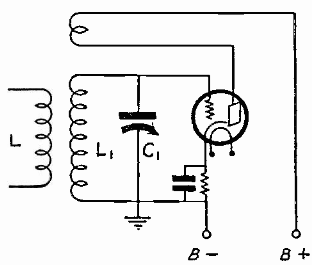


Fig. 5

is changed to a frequency twice the frequency of the I.F. value *plus* the frequency to which the set is tuned and the input voltage increased until the output (in milliwatts) of the set is identical to the original. The second input signal (in micro-volts) is then divided by the first to give the *image ratio* and the larger the value the less will be the interference possibilities.

The cascade stages of tuned R.F. may employ the regulation three-element tube or the screen grid tube depending entirely on the design of the receiver. Any of the methods of tuned R.F. known may be employed. They may embody band-pass filters as is done today in a well engineered popular make. They should not be too sharp or the fidelity of the receiver will be impaired at the start. It goes without discussion that the T.R.F. stages must be stable and properly shielded from local pick-up.

Regardless of what type the preselector may be, the R.F. output is led at once to a detector; in the superheterodyne, a *first* detector (often called the *modulator*). The simplest case is shown in Fig. 4, that of an antenna circuit feeding directly into a grid leak-condenser detector (condenser G.C. and leak R). The grid input circuit has a pick-up link, which gathers the local signal from the oscillator. Without local oscillation present the signal received would pass through the first detector and result in an audio signal at the plate output. This audio signal would be of no value as the following I.F. stages could not amplify it.

The presence of the local high frequency induced into the circuit therefore results in a doubly modulated carrier, that is,

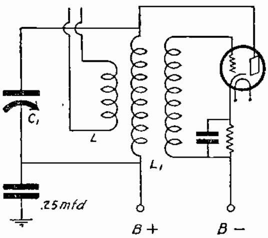


Fig. 6

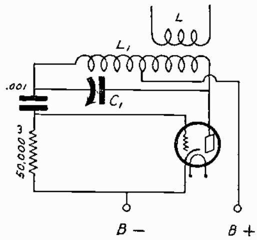


Fig. 7

first the high frequency of the local signal modulated by the beat frequency and second, the latter modulated by the audio signal carried by the original incoming carrier frequency. Only the beat frequency modulated by audio signal appears in any degree in the plate load of the first detector. Chokes and by-passes need not be used as in the detector plate circuit.

The first detector will feed into a tuned R.F. transformer and because it is set to the I.F. the original R.F. signal will be negligibly amplified. In Supers using a high I.F. the first I.F. coupler should be sharply tuned.

Regeneration is always possible to amplify the preselected signal further, as R.F. exists in the detector plate. A feed-back tickler is shown in dotted lines in Fig. 4. The choice of grid leak and condenser or grid bias detection is a matter for the engineer to decide. Where the preselected signal is strong either because of R.F. amplification or the nearness of the broadcasting station grid bias is most desirable. Where weak pretuned signals are received the grid leak-condenser method is preferred.

The local oscillator signal has the peculiar property of increasing the strength of the incoming signal. If the incoming signal, let us say, has been preamplified to 1000 microvolts, the local generator can also supply a signal of 1000 microvolts. Then when combined, 100% modulation will take place and the resultant beat frequency will swing 2000 microvolts.

With a tickler used to reinforce the incoming signal, the local oscillator *may* be dispensed with. If the coupling between the tickler and the tuned input is made great enough oscillation may take place. If the incoming signal is 1000 kc. and L and C are tuned to 1040, a beat (squeal we called it before) will appear in the plate circuit of the first detector, having a fre-

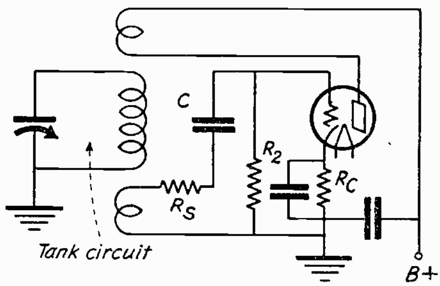


Fig. 8

quency of 40 kc. and modulated with the original audio signal. Thus we make the first detector section act as the preselector, oscillator and modulator. A superheterodyne of this kind is referred to as an "autodyne" circuit because the signal is automatically preselected, mixed and detected by its self-oscillation. However, every conceivable weakness in supers is present and this method of creating local oscillation is not used in modern broadcast receivers.

Our previous study of oscillators will help us to understand the types used in regular "super-hets." Any type of oscillator can be used to generate the local signal, but a simple one is usually employed. The tuned grid, the tuned plate and the Hartley oscillators are in common use. The prime function of the oscillator is to generate a local constant frequency with as few harmonics as possible. It must be variable so as to produce the required beat frequency over the entire broadcast band, the 1500 to 550 kc. spectrum of frequency. For modern superheterodynes an oscillator that will cover this band without any adjustment other than tuning condenser adjustment is of utmost importance. The plate voltage, the coupling between the grid and the plate circuits, and the filament current should need no adjustment other than the first one.* For the present we shall consider the oscillator coupled to the first detector grid circuit by the link as in Fig. 4.

Some oscillators are better than others and a study of the few used in "supers" will show why. Fig. 5 is the common tuned grid oscillator using a 227 tube which is an ideal oscillator tube for superheterodynes. This method has the advantage that the control side of the variable condenser can be grounded, which is desirable for stable and simple operation. Body capacity † shows up quickly when the condenser is not grounded.

Fig. 6 illustrates the tuned plate method, grounded through a .25 mfd. condenser to prevent hand capacity and is an excellent oscillator.

Fig. 7 shows a form of the Hartley circuit used frequently in superheterodynes. A single coil acts as both the grid and the plate inductance. A tap near the center is connected to the B supply. The tuning condenser is connected across the whole coil forming the oscillatory circuit. Coupling is quite tight. A .001 mfd. mica condenser serves to isolate the B voltage from the grid, and serves to feed the grid with regenerative voltage. A 50,000$^{\omega}$ leak maintains a constant negative bias when the circuit is oscillating. As an oscillator it is good—simple to construct and to operate. Special precaution in shielding is needed to prevent the effects of body capacity.

With the importance of the oscillator recognized, designers are turning to types which can be better controlled. Many have found the Meissner (isolated tank circuit) shown in Fig. 8, to be very good. To prevent total isolation of the tank circuit, the rotor may be grounded. The exact amount of feed from the plate to the tank circuit and the tank circuit to the grid input of the tube is adjusted by separate link coils.

In a few modern midget receivers it has been found desirable to have a combined oscillator-mixer-detector. The dynatron oscillator shown in Fig. 9 has been used successfully. Here the oscillator tank circuit is shown in the plate circuit of a '24 tube

* In a completed receiver the strength of the oscillator signal may be reduced by cutting down the plate voltage fed to the oscillator tube.

† The electrostatic capacity which exists between parts of a person's body and radio circuit apparatus.

with the screen grid connecting to the I.F. transformer to a higher potential than the plate. Mixing takes place within the tube, which also rectifies the beating by a proper choice of C bias.

6 Local oscillators should produce a signal voltage the intensity of which should be at least as large as the strongest received signal delivered to the mixer tube. Furthermore, its signal should be free from harmonics. Perhaps the best scheme used for this purpose can be explained by reference to Fig. 8. The amount of plate voltage for a given tube will determine the available signal strength and the C bias which will cause the tube to operate in the center of its dynamic E_g-I_p curve will create minimum harmonic generation. Therefore the values of R_c and B+ are carefully chosen. What harmonics are generated will be suppressed by R_s in the grid circuit. As the grid is isolated by condenser C, leak R_2 is required. By choosing a low enough leak resistance, the frequency

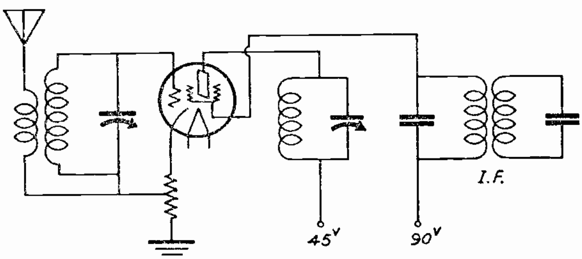


Fig. 9

of the oscillator may be made to vary but little from the time it is turned on through continued operating action.

The importance of having an oscillator free from harmonics cannot be over-emphasized, especially where the preselector consists of only one resonant circuit. If the intermediate amplifier operates at 175 kc. and a 600 kc. signal is received the oscillator must operate at 600 plus 175 or 775 kilocycles. Thus the oscillator's second harmonic will be twice 775 or 1550 kc. If a nearby station having a frequency of 1550 minus 175 or 1375 kc. gets through the preselector this station will create 175 kc. beats which will be heard along with the signals from the original desired station. More of this difficulty will be considered when we consider mixing.

We may state in general that an oscillator for a superheterodyne receiver must have the following characteristics: (1) It should generate a constant frequency regardless of its setting; (2) it should deliver a reasonable signal; (3) the signal voltage should be constant over the entire tuning range within 30%; (4) its output must have little harmonic content; (5) it must be well shielded so it will not radiate; (6) it should be coupled loosely enough to the mixer circuit so it will not detune it.

PADDING

In modern superheterodyne receivers, the oscillator must track the selector—always above the preselector frequency by the amount of the I.F. This is quite a problem for both must be controlled by the same tuning dial.

Of course it is a simple matter to use a slightly smaller inductance in the oscillator tank circuit than in the preselector circuits but the difficulty is that the difference in frequency be-

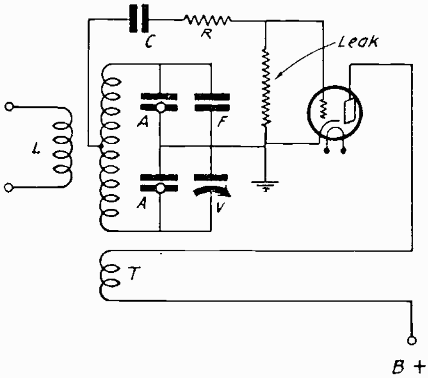


Fig. 10

tween the oscillator and preselector will not be the same at all settings of the tuning condenser.

The solution to the problem lies in the use of a padding system as shown in Fig. 10. Notice the arrangement of condensers, across the oscillatory inductance—A and F, in parallel, in series with A and V in parallel. Condensers marked A may be adjusted. These condensers are not variable condensers in the ordinary sense, but are small compact mica adjustable condensers. This is indicated in the diagram by the circle and straight line instead of the curved arrow used to represent the rotor plates. F is fixed and V is the main tuning condenser. By proper selection of condensers, V can be ganged to the preselector condensers and operated successfully by a single control. This is done by adjusting A across F at a low frequency and adjusting A across V at a high frequency.

MIXING

The oscillator is the "heart" of the superheterodyne and as long as it "beats" the receiver is "alive." A clear picture of the various schemes for producing local oscillation should be had by now. If the incoming signal is preamplified as well as preselected the intensity of the signal delivered to the first detector
7 will depend largely on the *intensity* of the local oscillation.

Sensitivity hinges directly on the method of coupling the oscillator with the grid of the first detector (modulator). If the coupling is tight the sensitivity of the machine is good, if weak the sensitivity is reduced. The methods of coupling the oscillator and the modulator are varied although in common practice the link coil used for previous illustration is the most common method. However, there are other means well worth knowing.

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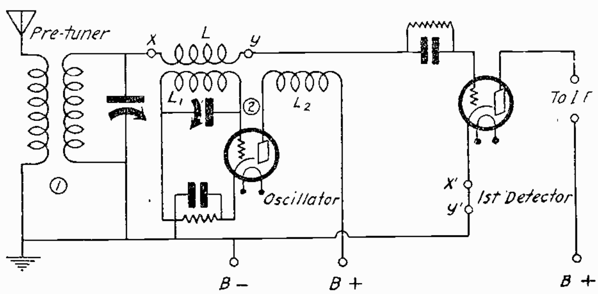


Fig. 11

A complete assembly of a typical preselector, oscillator and modulator is shown in Fig. 11. Coupling between the modulator and the local generator is through coil L by mutual induction. This system is used more than any other. The link L need not be directly in the grid feed at X and Y but may be in the grid return at X' and Y'. L_1 should be coupled loosely to L and still more loosely to L_2 to prevent too much of a load being placed on the oscillator thus preventing any considerable transfer of harmonics, and preventing the preselector from having any effect on the tuning of the oscillator.

In an earlier lesson it was pointed out that volume in screen grid sets could be controlled by increasing or decreasing the screen grid voltage because the plate current in a screen grid tube is sensitive to screen grid voltage changes. One method of coupling the oscillator to the modulator makes use of this phenomenon. Refer to Fig. 12. It shows a tuned grid oscillator with its oscillatory inductance linked with the screen grid and the 75-volt B voltage. The local signal is introduced via the screen grid, whereas the received signal is fed to the modulator by the control grid G. Harmonics are usually present in the plate circuit hence L_1 and T should be very weakly coupled. The modulator is shown as a grid bias detector and its plate current feeds directly into the I.F. stages.

Another scheme used extensively in commercial receivers is to wind the mixer and oscillator tuning inductance on the same coil form. In this way inductive coupling for mixing may be obtained. The separation between the two coils determines the amount of coupling.

Now let us give some attention to troubles that arise in the mixer circuit. To begin with, the tube is essentially a detector and its prime purpose is to rectify the combined local and signal

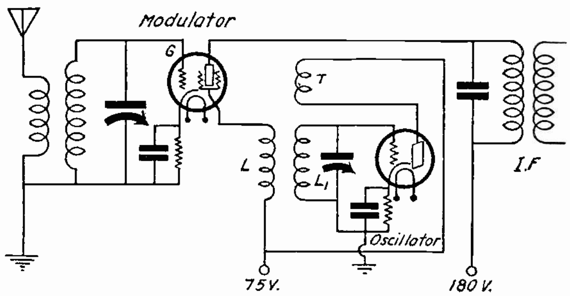


Fig. 12

frequencies. As a detector, it will introduce harmonics and they will be harmonics of the original frequency, the oscillator frequency and the beat frequencies. The latter are important. For example, the second, third, fourth, fifth and sixth of the 175 kc. beat will be 350, 525, 700, 875 and 1050 kc. respectively. They will be present regardless of the setting of the receiver dial as the beat frequency is always 175 kc. Suppose the receiver is tuned to a 700 or 1050 kc. station and it is not exactly on its assigned frequency. You would naturally expect the incoming signal to beat with the harmonics of the I.F. frequency giving rise to a whistle. Thanks to the efforts of the Federal Communications Commission to keep the broadcast stations on their assigned frequency to within 50 cycles and to the fact that C bias detectors can be used where the harmonies over the third are negligible, this defect is becoming less bothersome.

INTERMEDIATE FREQUENCY AMPLIFIER

If the oscillator is the heart of the super, the I.F. stages are the "brawn." They determine the sensitivity and the selectivity of the machine. It should be tuned to a definite, predetermined frequency and for perfect selectivity and freedom from side band cutting it should receive equally well, 5 kc. each side of the resonant point. This is illustrated in Fig. 13 by the square top resonance curve; a signal of 194 or 206 kc. would not go through the I.F. amplifier tuned to 200 kc. But signals of 195 to 205 are amplified. Then all audio signals up to 5000 cycles would pass through without any side band cutting. The round top curve is more like the actual operating curve and will allow amplification 20 to 30 kc. on each side of the resonant point. Each successive stage of tuned I.F. permits sharper selection of the beat frequency, but from a quality viewpoint selectivity should not be

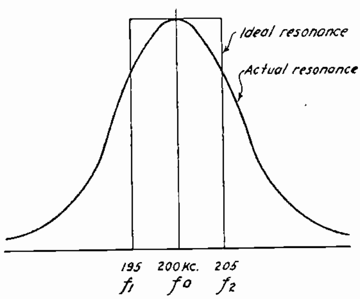


Fig. 13

excessive. Where fixed R.F. is used in the I.F. section it should be preceded by a single stage of very sharply tuned T.R.F. or a band pass filter section.

The matter of coupling systems in the intermediate frequency amplifier is an important subject for study. The method of amplifying depends on the intermediate frequency. This may be anywhere between 30 kc. and 500 kc. for the broadcast receiver. Now let's see what types of I.F. coupling devices are commonly used.

In the earlier developments of superheterodynes low I.F.'s were used, between 30 and 75 kc. Transformers were the common coupling systems, but they were of the iron core type because air core inductances would have to be so large that their distributed capacity would render them worthless at those frequencies, to say nothing of the cost of such bulky devices. Iron core transformers, see Fig. 14a, were universally used and the eddy current and hysteresis losses were reduced by using a special core made of pulverized iron filings. These transformers tuned broadly and so a single air core tuned stage was essential. Band pass filters could have been used, but early types of band pass filters were extremely bulky.

A resistance coupled amplifier, shown in Fig. 14b, was often used in earlier "supers" where the I.F. was below 50 kc. Precautions were necessary to prevent I.F. amplifier stage noises

Data for Intermediate Frequency Transformers on 1.5-inch diameter Coil Form.

IF kc	*Secondary L mh*	*Secondary C mfd*	*Layers of Wires*	*Wire*	*Secondary Turns*
50	10.12	.001	4	#32	610
75	4.5	.001	4	32	337
100	2.53	.001	3	32	253
125	3.24	.0005	3	32	300
150	2.25	.0005	2	32	278
175	1.664	.0005	2	32	224
200	1.266	.0005	2	32	184
250	.810	.0005	1	32	182
300	.563	.0005	1	32	140
400	.316	.0005	1	32	91
500	.202	.0005	1	32	68

Ratio of Secondary to Primary—Loose Coupling.

Tubes	*(Sec/Pri)*
'27	3.5/1
'99	2/1
'24	1.4/1

Example:—For 175 kc. I.F. using '24 tube:
secondary has 224 turns
primary " 224/1.4 = 160 turns

TABLE 2

which are bound to appear in ordinary resistance coupled stages. An iron core transformer can be built to a peaked resonance (show resonance effects) but a resistance coupled I.F. can show no resonance. In either case a good circuit before or after the I.F. stage was essential.

As higher and higher intermediate frequencies were used air core transformers found their place in this section of the receiver. The common type of primary-secondary transformer was used. Because the I.F. frequencies are comparatively low, little care was required to prevent regeneration and oscillation provided that no magnetic connection existed between stages. These coils were wound in multi-layers (so called bank winding, or lattice winding to keep down distributed capacity) and a step-up ratio as in Fig. 14c was the proper practice. A table of primary-secondary turns is shown in Table 2 together with the values of proper secondary shunt condensers.

When the screen grid tube appeared, it was necessary to increase the primary turns so that a larger load impedance could be placed in the I.F. tube plate circuits. This is shown symbolically in Fig. 14d.

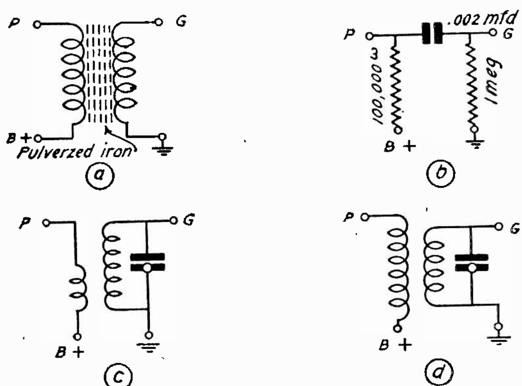


Fig. 14 a, b, c, d

Quite often condensers adjusted to resonance were used in intermediate stages on the plate (primary side of the R.F. transformers), see Fig. 14e, to excellent advantage, but more often across both the plate and grid windings as in 14f. In the latter case (14f) by adjusting the coupling between primary and secondary it is possible to have a double peaked resonance. Then by greatly weakening the coupling the ideal flat top resonance can be approached. Most commercial supers of today use this arrangement. In some machines the primary is approximately tuned to resonance and the secondary accurately adjusted afterward by modulated signal generators. Some machines even attempt to neutralize the I.F. stages where great gain per stage is desired. Combinations of various methods have been attempted in some machines, as experience with this type of receiver will show you.

Screen grid tubes are ideal low frequency amplifiers. Naturally tuned plate impedance or tuned grid impedance is used with these tubes. See Fig. 14g and h. Especially valuable are these methods in those modern superheterodyne receivers whose I.F. is 480 kc.

By this time you should have a fair idea of I.F. amplifiers. But don't let it go at that. These various basic methods that you have been introduced to, as it were, are important. So become thoroughly familiar with each system, study the diagrams carefully so that you can recognize at a glance what sort of I.F. system is used in a particular "super." You should be able to look at a diagram and determine immediately the type of oscillator, what method of preselection is used and what I.F. system is used.

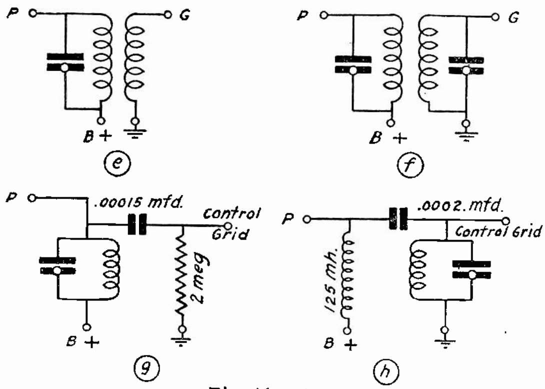


Fig. 14 e, f, g, h

Chokes and by-pass condensers are, of course, used in all the intermediate frequency tube supply circuits.

CHOICE OF INTERMEDIATE FREQUENCY

Although we chose 175 kc. as the I.F. frequency to illustrate the theory of superheterodynes, it must not be assumed that this is the only frequency, even though it may be the most desirable. If we say that we are only interested in the beat which is produced by the incoming frequency minus the oscillator frequency, and the latter is always greater than the received signal, the I.F. frequency may be any frequency up to the lowest received signal. Therefore in broadcast receivers, any value from 30 to 540 kc. will work even though every one may not necessarily be satisfactory. By the same reasoning, in a short wave superheterodyne tuning from 1500 to 30,000 kc., the I.F. frequency should be less than 1500 kc.

Then too, the I.F. amplifier must be selective but yet it must not cut side bands, that is, the resonance characteristic of the I.F. amplifier should be flat over a range of 10 kc. It is a well known fact that low frequency R.F. amplifiers are more selective than high frequency amplifiers. Perhaps you have noticed in old tuned R.F. receivers that the set is more selective at the low frequencies. Figure 15 shows the respective resonance curves for 100, 300 and 500 kc. circuits. These curves were drawn on the basis that resonance current in each circuit is the same. Note that the 500 kc. circuit is less selective than the 300 kc. circuit. Naturally the resonance curve for 1500 kc. would be much flatter.

Suppose a 1000 kc. signal is received in a tuned R.F. set. The signal should be tuned out 5 kc. off (1005 kc.), that is, 0.5%

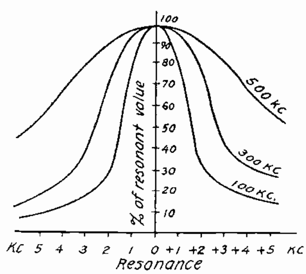


Fig. 15

off the carrier ($100 \times 5 \div 1000$). In a 175 kc. I.F. amplifier the signal should be tuned out at 180 kc. or 2.88% ($100 \times 5 \div 175$) of the I.F. carrier. That is, the I.F. amplifier need not be as selective as an R.F. set.* We may say that if the resononce curves, similar to the ones shown in Fig. 15 but for 1000 kc. and 175 kc., were alike, the latter would be 5.8 times more selective. This is known as the *arithmetical selectivity* of supers. And as the lower frequency stages are easier to make selective, it is desirable to use low I.F. amplifiers.

On the other hand if a low frequency I.F. amplifier is used to take advantage of the selectivity of the I.F. stages, we know that image interference is bound to be troublesome. In a two dial superheterodyne the repeat points will be too close to one another, causing endless confusion in tuning.

---

* The selectivity of an R.F. stage may be measured by considering the two off resonance frequencies which both reduce the signal by a definite percentage. The ratio of the difference divided by the carrier frequency is a measure of selectivity.

For a two dial set, no repeat points in the entire tuning range should be present, that is, it should have, as it is called, one spot tuning. The I.F. value in this case should be approximately one-half the difference of the frequency range, that is, ½ of 1500—550 (950 ÷ 2) or 475 kc. and the oscillator should tune from 1025 (equal to 475 + 550) to 1975 (equal to 475 + 1500). Of course, a greater I.F. could be used but not greater than 540.

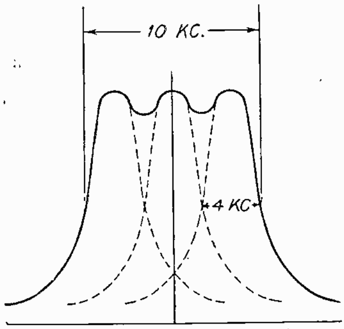
However, as most sets are single dial controlled there is no need to use such a high I.F. If the oscillator tracks the preselector, that is, always tuned above the preselector by the I.F., lower intermediate frequency values may be used and still not have repeat points. The problem is then a question of image frequency suppression. The I.F. value should be low for selectivity and sensitivity and high for image frequency suppression. Code stations should not broadcast on the frequency chosen, else they will come through if poor shielding prevails and cause interference. Engineers differ on the exact value for the I.F., as 125, 130, 175, 180 and 260 have been used. It generally is conceded that an I.F. value of 175 kc. is most desirable for reasons we have already considered.

Not all the selectivity inherent in a "super" is in the I.F. amplifier—the preselector contributes its share to station separation. In more modern receivers the pretuner, besides having amplification, includes one or two band pass sections and makes possible 10 kilocycle separation. The over-all selectivity of a super is the accumulated selectivity of the two sections, namely, the preselector and the I.F. stages. And the designer of supers must take both into consideration.

We have repeatedly stated that the R.F. stages, whether they are in the preselector or I.F. amplifier, should be highly selective but must not cut side bands. By this we mean that the response characteristic should be rectangular with no or little amplification 5 kc. above and below the received carrier and uniform amplification in this 10 kc. band. How may this be accomplished? Two methods have been used.

One method, where three stages of R.F. amplification are employed in the preselector or I.F. amplifier, is to use highly selective stages and tune one stage slightly above and the other slightly below the carrier. This is illustrated in Fig. 16. From an efficiency point of view, this method is not desirable as it is difficult to accomplish in production of radio receivers and even more difficult to service with the usual tools of the Radio-Trician. Secondly, the full over-all amplification of the stages is not realized.

The second method, now universally used, is to employ a tuned band-pass selector in the preselector or a similar type of circuit in the I.F., usually in the latter. A form of band-pass circuit is shown in Fig. 14f. Here the primary and secondary are tuned individually to the carrier frequency and when both are coupled loosely to each other, a response characteristic as shown in Fig. 17 results. In practice, the secondary and then the primary condenser would be adjusted for maximum set output and a response as shown by the dotted line would be obtained. Then the capacity of the secondary condenser would be



Over-all resonance curve when one R.F. stage is adjusted slightly above, and one slightly below resonance.

Fig. 16

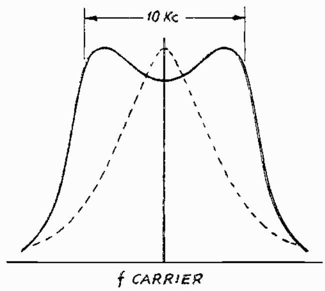


Fig. 17

slightly increased and the primary condenser slightly decreased. In many midget supers, the second band-pass adjusting step is not attempted, which results in greater sensitivity at the sacrifice of fidelity.

Of course, a suitable volume control is necessary in a superheterodyne and as the I.F. stages contribute most of the gain, the control is placed in this section of the receiver. With the advent of variable mu and R.F. pentode tubes, a variable C bias type of volume control came into use. Where automatic volume control is used in superheterodynes, and this now seems to be universal, the volume control is generally placed in the input to the grid of one of the A.F. tubes.

The second detector receives a tremendous grid swing. Linear grid bias detection is advisable. Where the swing is sufficient a power detector may be used feeding directly through a suitable audio transformer to the power output tube, or push-pull arrangement. The detector and audio stages are the same as those used in modern, sensitive, powerful T.R.F. machines.

Each section of a super should be well shielded from the others and of course from local disturbances.

The limit of amplification in a super depends definitely on the "noise level." That is, static always exists in the air and there is tube or circuit noise, ready to be amplified. If the signal is weaker than this static (below the noise level) further sensitivity in a super is worthless.

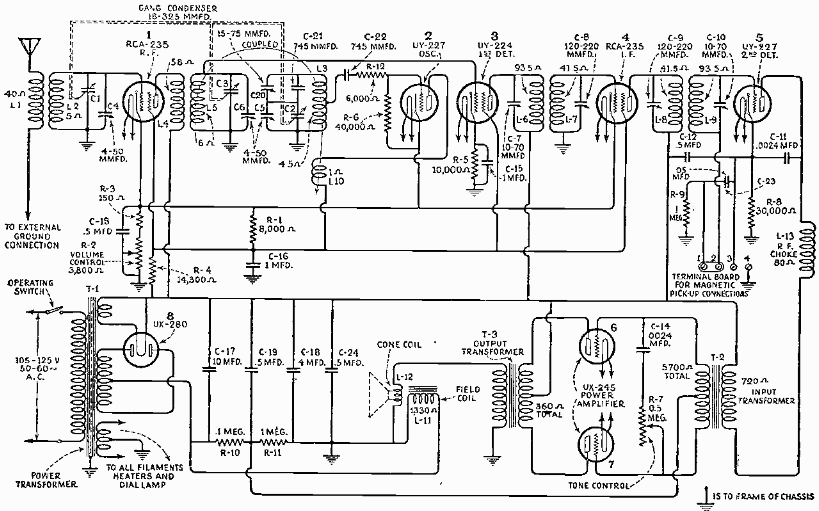


Fig. 17 (a).—Schematic wiring diagram of a typical superheterodyne receiver showing preselector and R.F. amplifier, oscillator, first detector, I.F. amplifier, second detector, push-pull power amplifier and power supply.

A superheterodyne is sometimes called a "double detection" receiver, naturally because of its two detectors. The I.F. amplifier amplifies frequencies higher than audio frequencies, therefore a super uses the "supersonic" principle.

The oscillator should generate as few harmonics as possible, yet only the simple methods of producing oscillation are commonly desirable.

By changing the coils in the preselector and the oscillator, the super may be made to operate at low or high wavelengths.

A super demands good parts, careful design and exceptional care in construction. Otherwise failure to operate satisfactorily is certain.

SUPER-REGENERATION

A peculiar characteristic of the simple regenerative circuit, particularly the one employing a tickler feed-back, led to the discovery of the principle known as super-regeneration. You most likely have noticed when operating a simple regenerative circuit with a variable tickler, that if the coupling between the tickler and the tuned grid circuit is increased, the signal increases in intensity, to a remarkable degree, just before the system spills over (oscillates). The principles of super-regeneration involve a scheme whereby the tube is prevented from breaking into oscillation by a local oscillator and regenerative action

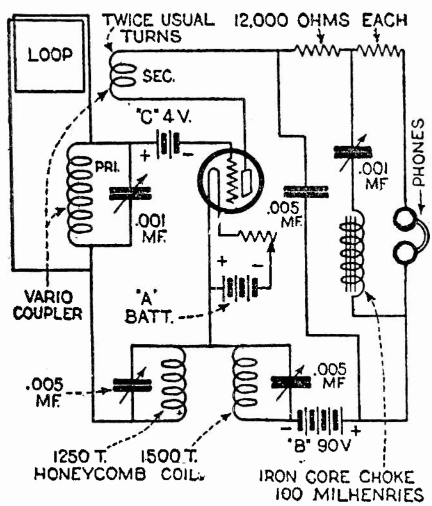


Fig. 18

is kept *just at* the point of maximum signal reception at all times.

The oscillatory circuit, that is, the tuned grid circuit, has resistance. The tickler feeds back energy, which we have said is equivalent to providing negative resistance. As more negative resistance is added to the tuned grid, the plate signal current increases in intensity. At the point where the negative feedback resistance balances the resistance in the tuned circuit, the oscillatory grid voltage swings between extremely wide limits, causing the entire system to oscillate. If we could place a variable resistance in the tuned grid circuit which would increase automatically when the point of oscillation was reached, this disturbing effect would be eliminated.

Let us assume that we have a regenerative detector, its plate operating at a definite voltage. If at the point of zero resistance in the grid circuit, that is, the point where the negative resistance feed-back equals the resistance of the tuned circuit or, we can say, the point where oscillation is just ready to start, the plate voltage is instantly reduced, the negative feed-back resistance will also be reduced and an absolute means of oscillation prevention will be had.

Figure 18 shows how this is accomplished in a super-regenerative circuit in which the detector tube serves three purposes; it is, of course, a detector of R.F. current; it is an amplifier due to the regenerative action of the tickler in the tuned grid circuit; and it is an oscillator in the oscillatory circuit formed by the two honey-comb coils and their condensers.

The tube, therefore, is an oscillator. The plate oscillatory circuit is in series with the plate voltage supply and when in a state of oscillation, it automatically builds up and decreases the plate voltage. The frequency of the local oscillator must be super-audible for telephonic purposes and a frequency near 30,000 cycles is usually chosen. This particular oscillator, we can say, has the property of causing the plate voltage to go from 91 down to 89 volts. The regenerative portion of the system is adjusted so that the circuit will break into violent oscillation at 91 volts.

A received signal is automatically built up by virtue of regeneration. But when the plate voltage reaches 91, oscillation will take place. Just as the plate voltage reaches the maximum 91, the local oscillator cuts down the plate voltage, the regenerative action of the detector decreases and oscillation is prevented. At the next instant, but at a frequency which is inaudible, the regenerative action is allowed to build itself up again almost to the point of oscillation where the plate voltage is again automatically cut down and oscillation controlled. Thus it is possible to maintain regeneration at its maximum peak value without audible oscillation.

At first sight this super-regenerative hook-up appears extremely efficient and one might wonder why commercial receivers never made use of this principle. The fact of the matter is that a circuit of this kind is very critical and is most difficult to maintain in proper operation due to the impossibility of keeping the average plate voltage exactly constant. Another disadvantage is that a circuit of this type is a very powerful radiator and is capable of creating a great deal of interference. However, in the hands of experts this circuit is being used to good advantage, particularly for telegraphic short wave work.

TEST QUESTIONS

Be sure to number your Answer Sheet 23 FR-1.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and the best possible lesson service.

1. Explain how a beat frequency is obtained.

2. What two signal frequencies are combined to form the intermediate frequency signal in a superheterodyne receiver?

3. What is the function of the first detector?

4. What is the advantage of reducing the incoming signal to a signal of lower frequency?

5. What *two* interferences are eliminated or greatly reduced by ganging together the oscillator and preselector?

6. How large should the intensity of the signal voltage be from the local oscillator, compared to the strongest received signal delivered to the mixer tube?

7. How would you reduce the signal output of an oscillator in a receiver brought in for repairs?

8. Draw the circuit of a simple pretuner, oscillator and first detector where mixing (modulation) takes place in the control grid lead to the first detector.

9. Why are tuned band-pass filters used in the preselector and I.F. amplifier stages?

10. What is the purpose of the oscillator in a super-regenerative receiver?

10 CIRCUIT DIAGRAMS EACH WITH TESTING INFORMATION

23SS

SERVICE MANUAL

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

FOREWORD

This booklet is one of a series of service manuals which contain service sheets giving typical information on radio receivers. Each service sheet shows the circuit diagram in the usual symbolic form for that radio receiver. Many of the service sheets will contain such special service information as space will permit.

By studying each service sheet, you will gradually develop the ability to read any diagram or manufacturer's service manual and learn the usual methods of set adjustment. Enough typical receivers have been selected to give you quickly a good insight to the entire radio problem.

In reading a circuit diagram, learn to trace independently the power supply and the signal circuits. Then locate the special control circuits, such as the automatic volume controls, tuning indicators, manual volume controls, etc. Detailed information on power, supply, signal and control circuits, as well as set servicing, is given in the course, to which reference should be made.

J. E. SMITH.

WPC3M5536

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RADIO-TRICIAN
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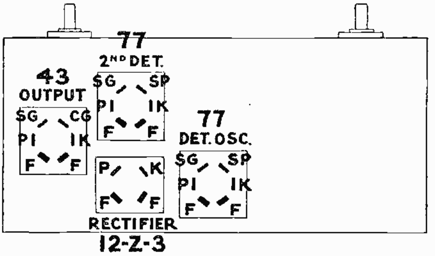
Service Sheet
Compiled Solely for Students and Graduates
NATIONAL RADIO INSTITUTE, WASHINGTON, D. C.

PHILCO MODEL 53

The Philco Radio Model 53 is a four tube superheterodyne, employing the new Philco high efficiency tubes with pentode output and a permanent Field Dynamic Speaker. The set uses a Philco Type 77 tube as a first detector and oscillator, a Type 77 tube as second detector, a Type 43 tube as output, and a Type 12-Z-3 as a rectifier. The set will operate universally on either alternating or direct current, 105-125 Volts. The intermediate frequency for tuning the I.F. transformer is 450 kilocycles. The power consumption on both A. C. and D. C. is approximately 45 watts.



F	Filament	SG	Screen Grid	K	Cathode
P	Plate	CG	Control Grid	SP	Suppressor Grid

Fig. 1—Tube Sockets, Under Side of Chassis

Table 1—Tube Socket Data*—A.C. Line Voltage 115 Volts

Circuit	Det. Osc.	2nd Det.	Out-put	Recti-fier
Type Tube	77	77	43	12-Z-3
Filament—Total 49.9 Volts A.	C. Refer	to Note.		
Plate Volts—P to K........	95	15	94	112
Screen Grid Volts—SG to K...	94	34	102	....
Control Grid Volts—CG to K..	7	4	4	...
Cathode Volts—K to F... ...	18	12	10	112

NOTE:—Refer to Fig. 3. Due to filaments in series, test with suitable A. C. voltmeter across the two points indicated.

*All of the readings above in Table 1 were taken from the under side of chassis, using test prods and leads with a suitable A. C. voltmeter for filament voltage and a high resistance, multi-range D. C. voltmeter for all other readings. Volume control at maximum and station selector set for 550 KC. Readings taken with a radio set tester and plug-in adapter will not be satisfactory.

Table 2—Tube Socket Data*—D.C. Line Voltage 120 Volts

Circuit	Det. Osc.	2nd Det.	Out-put	Recti-fier
Type Tube	77	77	43	12-Z-3
Filament—Total 51 Volts D.C.	—Refe	r to Note.		
Plate Volts—P to K...	95	14	94	10
Screen Grid Volts—SG to K...	93	34	100	....
Control Grid Volts—CG to K..	8	3	4	....
Cathode Volts—K to F.......	7-14	6-12	3-26	58-73

NOTE:—Refer to Fig. 3. Due to filaments in series, test with suitable D.C. Voltmeter across the two points indicated.

*All of the readings above in Table 2 were taken from the under side of chassis, using test prods and leads with a suitable high resistance, multi-range D. C. voltmeter for all readings. Volume control at maximum and station selector set for 550 KC. Readings taken with a radio set tester and plug-in adapter will not be satisfactory.

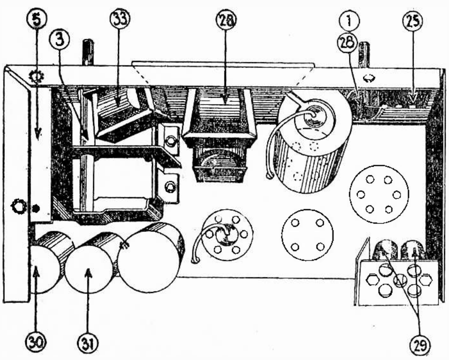


Fig. 2—Top View of Chassis, Showing Parts

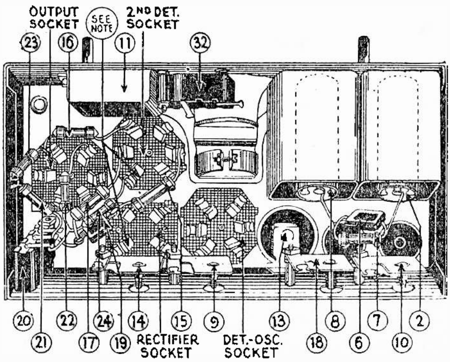


Fig. 3—Bottom View of Chassis, Showing Parts
NOTE:—Place test prods across the two points indicated to test filament voltage.

Model 53

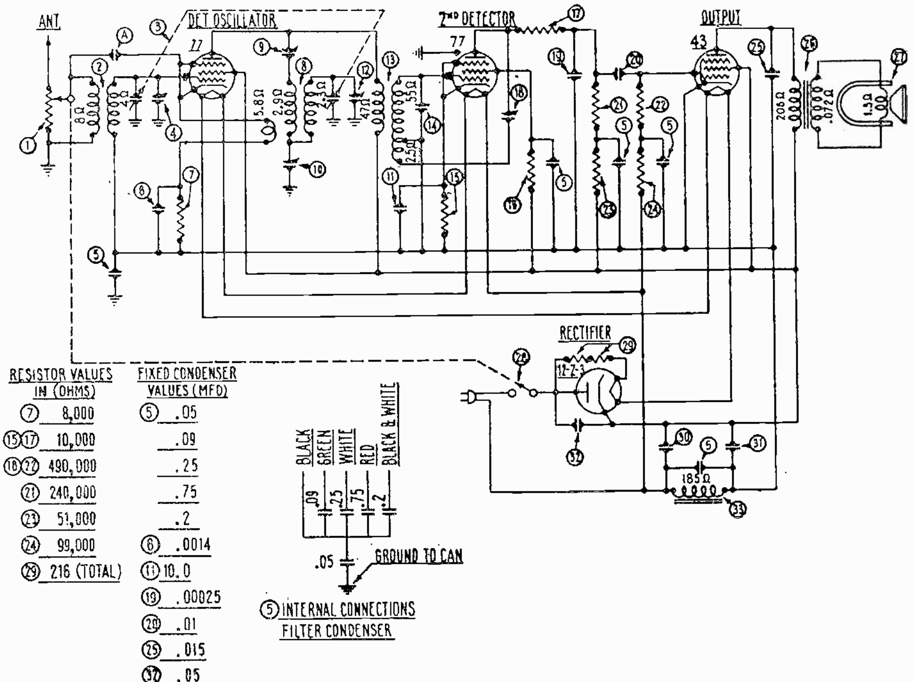


Figure 4—Schematic Wiring Diagram
NOTE Ⓐ—This capacity obtained by pair twisted wires

Replacement Parts for Model 53

No. on Figs. 2, 3 and 4	Description	Part No.
①	Volume Control	33-5001
②	Antenna Transformer	32-1000
③	Tuning Condenser Assembly	31-1000
④	Compensating Condenser (Part of Tuning Condenser Assembly)	
⑤	Filter Condenser Block (.05-.09-.25-.75-.2 Mfd.)	30-4000
⑥	Condenser (.0014 Mfd.)	7007
⑦	Resistor (8,000 ohms) Gray-Black-Red	5838
⑧	Oscillator Transformer	32-1001
⑨	Compensating Condenser (I.F. Primary)	04000-A
⑩	Compensating Cond. (Low Frequency)	04000-S
⑪	Condenser (10.0 Mfd.)	7440
⑫	Compensating Condenser (Part of Tuning Condenser Assembly)	
⑬	I.F. Transformer	32-1002
⑭	Compensating Cond. (I.F. Secondary)	04000-A
⑮	Resistor (10,000 ohms) Brown-Black-Orange	4412
⑯	Resistor (490,000 ohms) Yellow-White-Yellow	4517
⑰	Resistor (10,000 ohms) Brown-Black-Orange	4412
⑱	Compensating Condenser (Regeneration)	04000
⑲	Condenser (.00025 Mfd.)	3082

No. on Figs. 2, 3 and 4	Description	Part No.
⑳	Condenser (.01 Mfd.)	3903-AM
㉑	Resistor (240,000 ohms) Red-Yellow-Yellow	4410
㉒	Resistor (490,000 ohms) Yellow-White-Yellow	4517
㉓	Resistor (51,000 ohms) Green-Brown-Orange	4518
㉔	Resistor (99,000 ohms) White-White-Orange	4411
㉕	Condenser (.015 Mfd.)	3793-S
㉖	Output Transformer	32-7000
㉗	Voice Coil and Cone Assembly	36-3000
㉕	A. C. Switch (Part of Volume Control Assembly)	33-5001
㉙	Resistors (2 Wire Wound-108 ohms each)	33-3000 33-3001
㉚	Electrolytic Condenser (8 Mfd.)	30-2000
㉛	Electrolytic Condenser (8 Mfd.)	30-2000
㉜	Condenser (.05 Mfd.)	3615-E
㉝	Filter Choke	32-7000
	Tube Shield	7172
	Knobs (Both Controls)	03064
	Four Prong Socket	7544
	Six Prong Socket	7547
	Pointer for Station Selector	28-1019
	Dial	28-1021

RADIO-TRICIAN
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NATIONAL RADIO INSTITUTE, WASHINGTON, D.C.

PHILCO MODEL 81

The Philco Radio Model 81 is a four tube superheterodyne receiver combining Standard broadcast and police reception and employs the new Philco high efficiency tubes with pentode output and electro dynamic speaker. The same superheterodyne circuit is used for Standard broadcast and police reception. The intermediate frequency for tuning the I. F. transformer is 460 kilocycles. The power consumption of the Model 81 is 46 watts.

Table 1—Tube Socket Data*
Power Line Voltage 115 Volts

Circuit	Det. Osc.	2nd Det.	Out-put	Rec-tifier
Type Tube	77	77	42	80
Filament Volts–F to K	6.3	6.3	6.3	5.0
Plate Volts–P to K	240	75	240	425
Screen Grid Volts–SG to K	85	40	250	..
Control Grid Volts–CG to K	5.6	.6	2.3	..
Cathode Volts–K to F	24.5	16	16.2	..

Table 2—Power Transformer Data

Terminal	A. C. Volts	Circuit	Color
1–2	105–125	Primary	White
3–5	6.3	Filament	Black
6–7	5.0	Filament of 80	Blue
8–10	630	Plates of 80	Yellow
4	..	Center Tap of 3-5	Black-Yellow Tracer
9	..	Center Tap of 8-10	Yellow-Green Tracer

*All of the above readings were taken from the underside of the chassis, using test prods and leads with a suitable A. C. voltmeter for filament voltages and a high resistance multirange D. C. voltmeter for all other readings. Volume control at maximum and station selector turned to low frequency end. Readings taken with a radio set tester and plug in adapter will not be satisfactory.

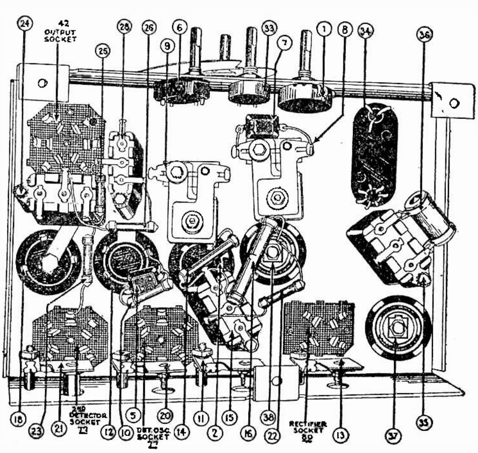


Fig. 1—Parts Diagram

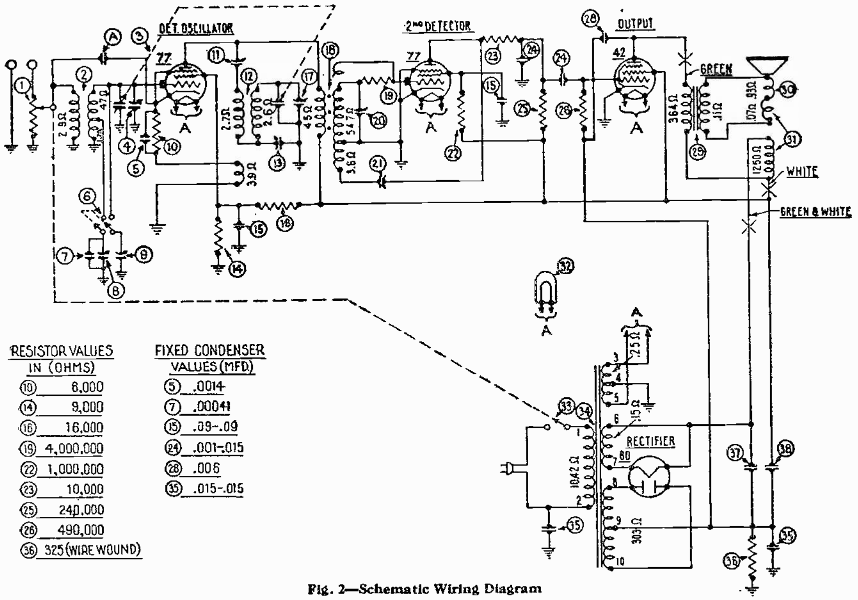
77 Sockets

42 Socket

80 Socket

Terminal Arrangement of Tube Sockets Viewed from Under Side of Chassis.

PHILCO MODEL 81



RESISTOR VALUES IN (OHMS)	
10	6,000
14	9,000
16	16,000
19	4,000,000
22	1,000,000
23	10,000
25	240,000
26	490,000
36	325 (WIRE WOUND)

FIXED CONDENSER VALUES (MFD)	
5	.0014
7	.00041
15	.09-.09
24	.001-.015
28	.006
35	.015-.015

Fig. 2—Schematic Wiring Diagram

Note A—This capacity obtained by pair twisted wires.

REPLACEMENT PARTS MODEL 81

No. on Figs.	Description	Part No.	List Price
1	Volume Control*	33-5002	.75
2	Antenna Transformer	32-1030	.50
3	Tuning Cond. Assembly	31-1006	
4	Compensating Condenser (Part of 3)		
5	Cond. (Red and Black)	7007	.25
6	Frequency Switch	42-1000	
7	Cond. (Orange and Yellow)	30-1000	.20
8	Compensating Condenser	04000-S	.25
9	Compensating Condenser	04000-X	.16
10	Resistor (Blue-Black-Red)	7352	.25
11	Compensating Condenser (I.F. Primary)	04000-A	.12
12	Oscillator Coil	32-1031	.75
13	Compensating Condenser (Low Frequency)	04000-S	.25
14	Resistor (White-Black-Red)	7501	.25
15	Condenser	4989-B	.22
16	Resistor (Brown-Blue-Orange)	7500	.40
17	Compensating Condenser (Part of 3)		
18	I.F. Transformer	06100	1.25
19	Resistor (Mounted on I.F. Transformer)	6010	.25
20	Compensating Condenser (I.F. Secondary)	04000-D	.10
21	Compensating Condenser	04000	.16
22	Resistor (Brown-Black-Green)	4409	.25
23	Resistor (Brown-Black-Orange)	4412	.25
24	Condenser (Double)	7762-B	.20
25	Resistor (Red-Yellow-Yellow)	4410	.25
26	Resistor (Yellow-White-Yellow)	4517	.25
28	Condenser	7625-B	.12
29	Output Transformer	2660	1.25
30	Voice Coil and Cone Assembly	02861	.60
31	Speaker Field and Bucking Coil (with Pot)	02667	2.00
32	Pilot Light	6608	.14
33	"On-Off" Switch*	6416-W	.40
34	Power Transformer—50-60 Cycles	7421	2.75
	Power Transformer—25-40 Cycles	7422	4.00
	Power Transformer—50-60 Cycles, 250 Volts	7423	2.75
35	Condenser (Double)	3793-R	.25
36	Resistor (Wire Wound)	7465	.12
37	Electrolytic Condenser (8 Mfd.)	7558	1.25
38	Electrolytic Condenser (4 Mfd.)	7467	1.25
	Bezel	7417	
	Tube Shield	7172	.12
	Knob (Large)	03063	.08
	Knob (Small)	03064	.06
	Knob Spring	5262	.35 per C
	Grid Clip	4897	.30 per C
	Four Prong Socket Assembly	5026	.08
	Six Prong Socket Assembly	6417	.10
	Chassis Mounting Screw	W-567	2.40 per C
	Chassis Mounting Washer	W-315	.40 per C
	Pilot Lamp Shield	5760	

*On later production (run No. 3 and above, rubber stamped in a star on back of chassis) volume control 1 and on-off switch 33 was combined. This new volume control and on-off switch is Part Number 7439.

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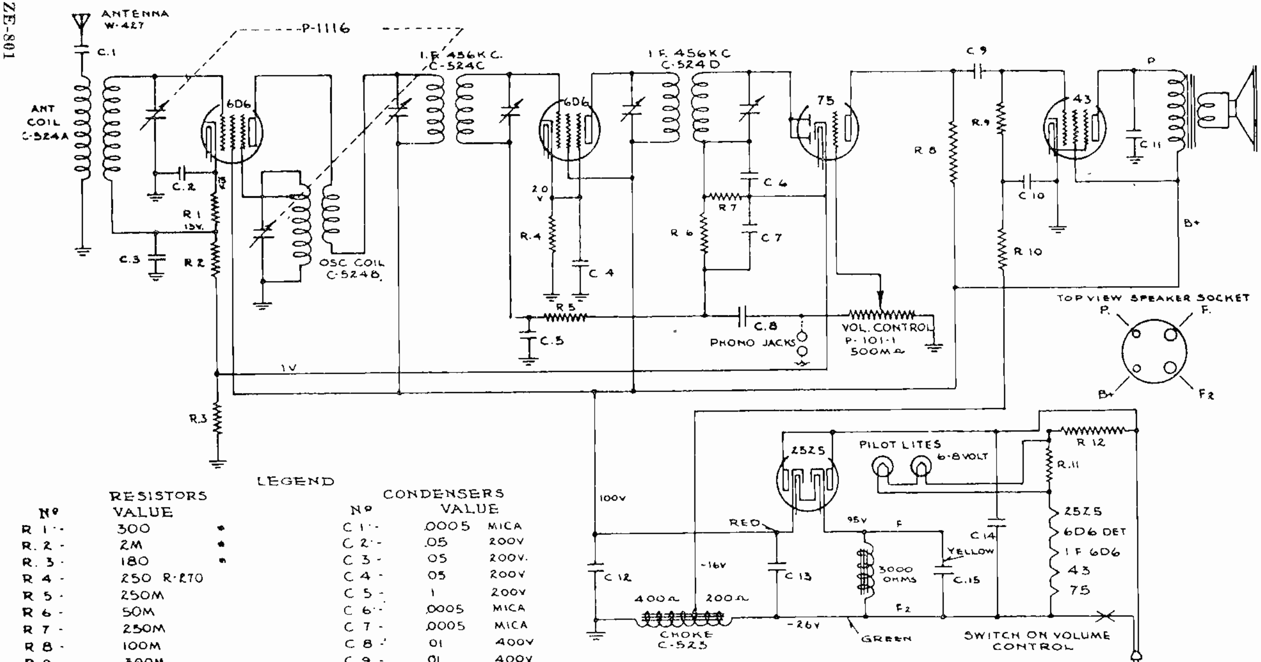
ZENITH MODEL 801



LEGEND

RESISTORS

Nº	VALUE	
R 1	300	*
R 2	2M	*
R 3	180	*
R 4	250 R-270	
R 5	250M	
R 6	50M	
R 7	250M	
R 8	100M	
R 9	300M	
R 10	250M	
R 11	40Ω 300MA. 0 36W P 106-1	
R 12	126 IN CORD P107-1	

CONDENSERS

Nº	VALUE	
C 1	.0005	MICA
C 2	.05	200V
C 3	.05	200V.
C 4	.05	200V
C 5	.1	200V
C 6	.0005	MICA
C 7	.0005	MICA
C 8	.01	400V
C 9	.01	400V
C 10	.1	200V
C 11	.025	300
C 12	50MFD	C-525D
C 13	25 0MFD.	*
C 14	.1	400V
C 15	5 0MFD	*

- NOTE -

* R 1, R 2 & R 3 IN ONE UNIT PART NUMBER R-268.
* C. 13 AND C 15 IN ONE UNIT PART NUMBER C-525-C
NUMBERS PREFIXED BY LETTERS ARE PARTS.
VOLTAGES TAKEN FROM POINTS INDICATED TO CHASSIS GROUND. VOLUME CONTROL ON FULL MEASURED ON A C CURRENT.

ZE-801

SERVICE NOTES

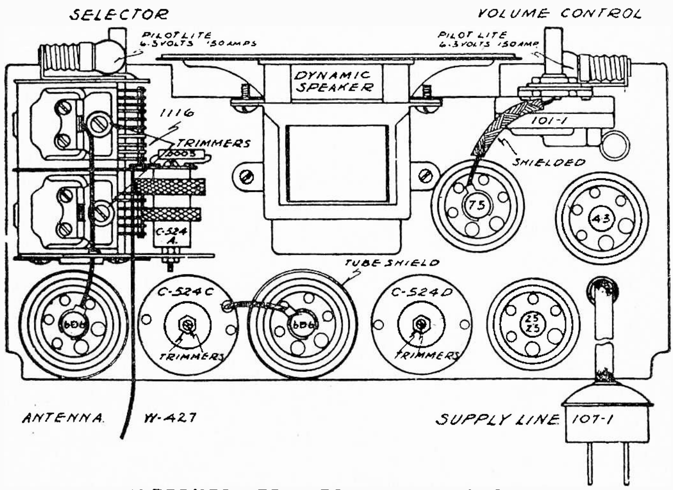
Should it be at any time necessary to rebalance this set, the correct procedure is as follows:

1. Volume control on full during all alignment.
2. Variable condenser in minimum capacity position, plates open, at start of all aligning.

I.F. ALIGNMENT.

1. To peak I.F. transformers, connect oscillator set at 456 kilocycles to the grid of the 6D6 tube directly in back of the variable condenser and adjust the trimming condensers of the I.F. transformers to resonance (Maximum deflection on an output meter connected across the primary of the speaker input transformer).

Each I.F. trimmer has two adjustments, one nut and one screw, both of which are adjustable from the top.



INTERMEDIATE FREQUENCY 456 K. C.

SERVICE SUGGESTIONS:

NOTE—CONNECTING CORD OF SET GETS WARM IN NORMAL OPERATION. DO NOT BECOME ALARMED.

Make sure that all tubes are pushed firmly in their proper sockets and that the clips are securely fastened to the caps on the tops of the tubes.

That the aerial is stretched out and that the connections to an outdoor antenna (if used) are good

If necessary to change tubes or service chassis, UNDER NO CIRCUMSTANCES REMOVE BACK OR CHASSIS WITHOUT FIRST REMOVING PLUG FROM LIGHT SOCKET.

To remove chassis from cabinet, pull off knobs from front, remove back (held with screws to case). Remove four mounting screws, then chassis can be slipped out of case.

BROADCAST BAND ALIGNMENT.

1. Disconnect antenna wire and connect oscillator in series with a 75 mmfd. condenser to the antenna coil. With the variable condenser set at its minimum capacity position, at the extreme right of its rotation, and with an oscillator output adjusted to 1720 kilocycles, adjust trimmer of oscillator section of variable condenser (rear section) to resonance (maximum deflection on an output meter connected across the primary of the speaker input transformer). Next adjust the trimmer condenser of the front section of the variable condenser to resonance.
2. Check alignment at 1400-1200-1000-800-600-530 kilocycles, bending the slotted plates of the front section of the variable condenser only if absolutely necessary.

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NATIONAL RADIO INSTITUTE, WASHINGTON, D.C.

MAJESTIC AUTO RADIO—MODEL 114

ALIGNMENT

It will be necessary to use a special chassis container can that has had holes drilled in it to permit reaching the aligning condenser with the aligning tool. The bale should be removed before inserting the chassis in the special container can as it covers the two first I. F. aligning screws.

1. Completely connect the receiver as for operation with the volume control in maximum position. It will be necessary to connect the cathode of the G-85 tube to ground to stop the inter-station noise suppression action while aligning the receiver.

2. Supply a 175 kc. signal to the grid of the G-38 first detector tube and align the three I. F. aligning condensers for maximum output. (Two are located on the first I. F. transformer, and one just below the G-85 tube.)

3. Supply a 1500 kc. signal to the grid of the first detector tube and adjust the gang condenser for maximum output.

4. Supply a 1500 kc. signal to the antenna post and align the two trimmers on the gang condenser for maximum output.

5. Turn the gang condenser to approximately maximum capacity position (completely meshed) and supply a 550 kc. signal to the antenna post. Adjust the series aligning condenser, which is located just below the first I. F. transformer, for maximum output. For each adjustment of the series aligning condenser there will be a different gang condenser setting which gives maximum output. The combination of gang setting and series condenser adjustment which gives maximum output, disregarding setting, is the correct adjustment. Be sure to remove the ground from the G-85 cathode after completing alignment.

INTER-STATION NOISE SUPPRESSION

Noise suppression is obtained by the use of the resistor R-5 in the G-85 cathode circuit. There is a voltage across this resistor due to the space current of the triode portion of G-85, hence the ground end of R-5 is more negative than the cathode end, and R-3 is more positive than ground. A certain signal voltage must, therefore, reach the diode plates before the diode plate end of R-3 attains a voltage below ground potential. This is similar to the usual delayed A. V. C. while the condition of no signal exists, the grids of the G-39's tend to be positive, and are prevented from being actually more positive than their cathodes by the fact that they draw grid current through the resistors R-6 and R-1. The fact that these tubes are drawing grid current prevents them from giving the full amplificatoin of which they are capable under proper voltage conditions. When, however, sufficient signal reaches the diode plates to produce a bias of three volts across the resistor R-3, the G-39 tubes attain their full mutual conductance and the entire system works as a normal A. V. C. circuit.

CONNECTION FOR NEGATIVE GROUND ON BATTERY

The "B" eliminator on the Model 114 as supplied from the factory is connected for operation in automobiles which have the positive terminal of the battery grounded. When an installation is to be made in a car having the negative terminal of the battery grounded, it is necessary to reverse the two leads that come out of the generator near the choke and connecting assembly.

In some of the first sets made, it may be necessary to splice the wire that is now grounded so that it will reach to the terminal on the ½ mfd. condenser. Be sure to use wire that is large enough to carry the current required to run the motor.

TABLE OF VOLTAGES

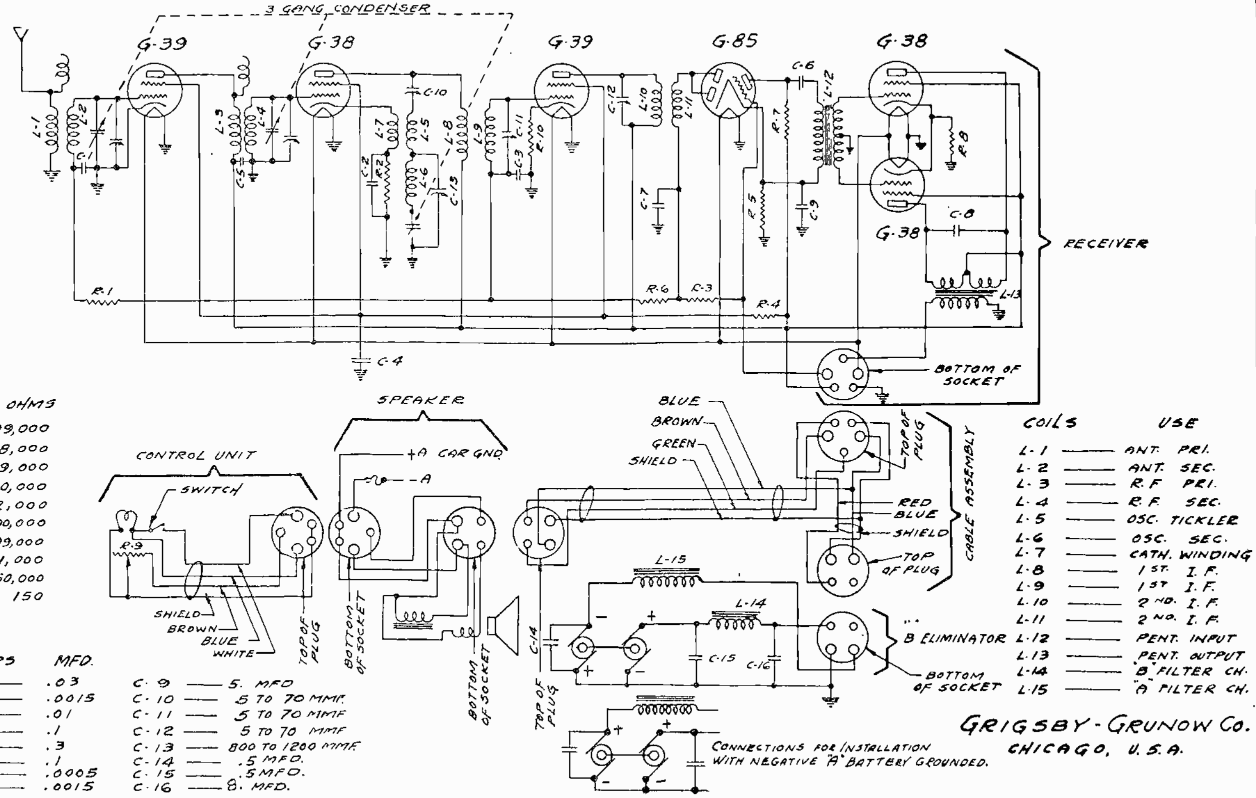
Tube	Purpose in Circuit	Plate Voltage	Screen Voltage	Cathode Voltage
G-39	R. F. Amplifier	180	85	0
G-38	First Detector Oscillator	180	85	15
G-39	I. F. Amplifier	180	85	1.1
		A. F. Plate		
G-85	Second Detector and First Audio Amplifier	50	..	2
G-38	Power Amplifier	170	180	17
G-38	Power Amplifier	170	180	17

NOTE: Measurements made with a 1000 ohm per volt, 300 volt range, D. C. voltmeter, all tubes in their sockets and receiver connected to a storage battery supply delivering 6 volts at the cable terminals, under load.

Tubes should be previously tested to assure that they are in good condition.

Readings to be taken from designated points to ground, with the condenser gang fully meshed and with no signal supplied to the receiver.

SCHEMATIC DIAGRAM OF MAJESTIC AUTOMATIC VOLUME CONTROL SUPERHETERODYNE AUTOMOBILE RECEIVER MODEL -114



RESISTORS	OHMS
R-1	99,000
R-2	8,000
R-3	99,000
R-4	30,000
R-5	2,000
R-6	500,000
R-7	99,000
R-8	1,000
R-9	250,000
R-10	150

CONDENSERS	MFD.
C-1	.03
C-2	.0015
C-3	.01
C-4	.1
C-5	.3
C-6	.1
C-7	.0005
C-8	.0015
C-9	5. MFD
C-10	5 TO 70 MMF.
C-11	5 TO 70 MMF
C-12	5 TO 70 MMF
C-13	800 TO 1200 MMF
C-14	.5 MFD.
C-15	.5 MFD.
C-16	8. MFD.

COILS	USE
L-1	ANT. PRI.
L-2	ANT. SEC.
L-3	R.F. PRI.
L-4	R.F. SEC.
L-5	OSC. TICKLER
L-6	OSC. SEC.
L-7	CATH. WINDING
L-8	1ST. I.F.
L-9	1ST I.F.
L-10	2ND. I.F.
L-11	2ND. I.F.
L-12	PENT. INPUT
L-13	PENT. OUTPUT
L-14	"B" FILTER CH.
L-15	"A" FILTER CH.

GRIGSBY-GRUNOW CO.
CHICAGO, U.S.A.

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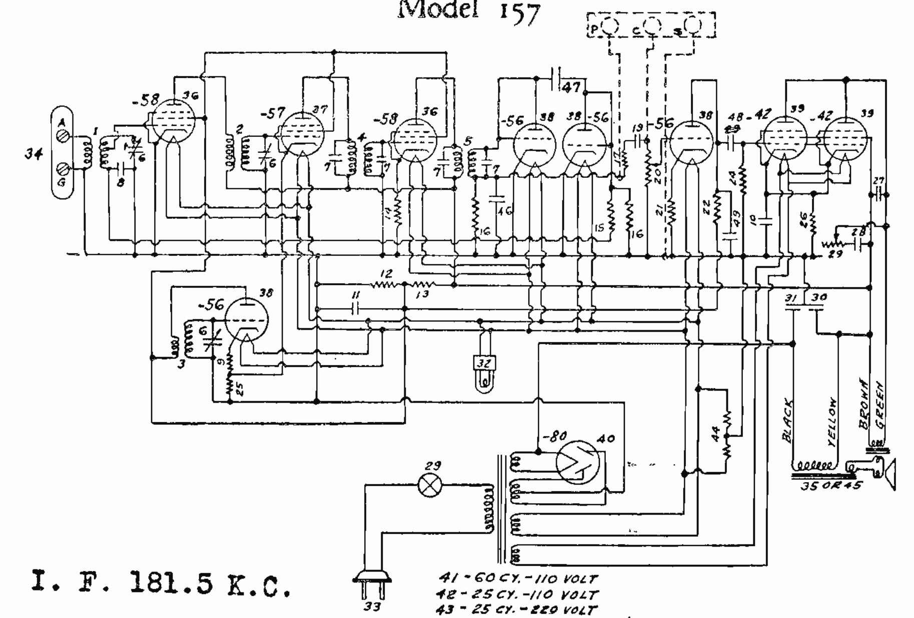
CROSLEY MODEL 157

Model 157

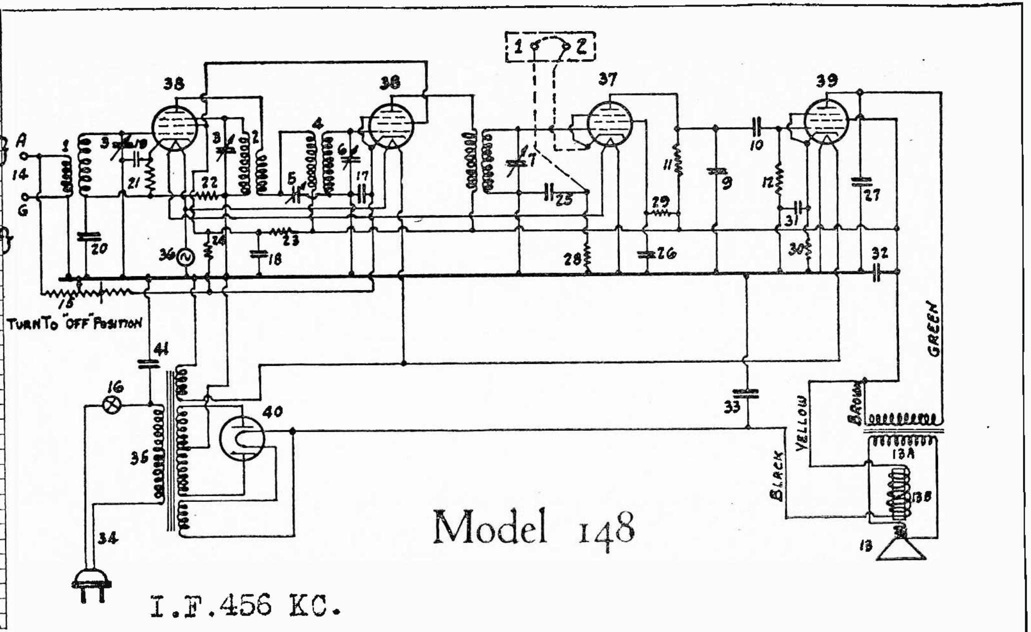


I. F. 181.5 K.C.

Tube	Position	Plate	Screen Grid	Voltages Supp. Grid	Bias	Fil.
-58	R. F. Amplifier	240	110	0	0	2.5
-57	1st Detector	240	110	0	6.0	2.5
-56	Oscillator	110			20.0	2.5
-58	I. F. Amplifier	240	110	0	2.8	2.5
-56	Detector	0				2.5
-56	AVC Rectifier	0				2.5
-56	A. F. Amplifier	40			2.0	2.5
-42	Parallel Output	250	260		17.5	6.3
-42	Parallel Output	250	260		17.5	6.3
-80	Rectifier	350				4.8

1	G7-24995	ANTENNA COIL
2	G2-25968	INTERSTASE COIL
3	G14-24996	OSCILLATOR COIL
4	G5-24065	FIRST I.F. TRANS.
5	G10-24065	SECOND I.F. TRANS.
6	C-26442B	TUNING CONDENSER
7	G3-25948	I.F. TUNING CONDENSERS
8	W-27203	0.02 MFD.
9	W-22180	1650 Ω
10	W25857	8 MFD.
11		8 MFD.
12	W-25970	15,000 Ω
13		10,000 Ω
14	W-25937	275 Ω.
15	W-22215	3-MEGOHMS
16	W-21454	1-MEGOHM
17	W-21455	300,000 Ω
18	~~W-26152~~	~~TWIN 0.0001 MFD.~~
19	W-26559	0.006 MFD.
20	W-25666	LEVEL CONT. 3-MEG.
21	W-23013	2,000 Ω
22	W-21237	60,000 Ω
23	~~W-27203~~	~~0.02 MFD.~~
24	W-21455	300,000 Ω
25	W-22514	750 Ω
26	W-22873	220 Ω
27	W-25517	0.008 MFD.
28		0.05 MFD.
29	W-25594	TONE CONT. & SWITCH 80,000 Ω
30	W26118A	8 MFD.
31		8 MFD.
32	W-22221	2.5V DIAL LIGHT
33	B-21491A	CORD & PLUG
34	LW-20264	ANT. GND. POST
35	27869	337-4 SPEAKER-8"
36	G24-26614	-58 SOCKET
37	G23-26614	-57 SOCKET
38	G18-26614	-56 SOCKET
39	G25-26614	-42 SOCKET
40	G6-26614	-80 SOCKET
41	G10-25669	POWER TRANS. 60 CY.
42	G11-25669	POWER TRANS. 25 CY.
43	G12-25669	POWER TRANS. 220 V.
44	W-22417A	10 Ω - 10 Ω
45	27870	337-5 SPEAKER-10"
46	W-27932	.0001 MFD.
47	W-27932	.0001 MFD.
48	W-25537	.03 MFD.
49		.001 MFD.
50		
51		
52		
53		
54		
55		
56		
57		
58		
59		
60		
61		
62		

1	W-27474	ANTENNA COIL
2	W-27475	OSC. COIL
3	B 27425	A-56 VAR. COND.
4	W-24203-D	I.F. TRANS. COIL
5	GL-25948	I.F. TRANS. COND.
6	W-25008-A	I.F. TUNING COND.
7	W-25008-A	I.F. TUNING COND.
8	G7-25448	I.F. TRANSFORMER
9	W-25537	.0006 MFD. COND
10	W-25537	.03 MFD. COND
11	W-21456	300,000 Ω RESIS.
12	W-23788	500,000 Ω RESIS.
13	27610	SPEAKER
14	W-20264-E	5-9 TERM. BOARD
15	W-26573	5-55 VOLUME CONTROL
16	W-26573	SWITCH
17	W-25438	.1 MFD. COND.
18	W-25438	.1 MFD. COND.
19	W-25438	.1 MFD. COND.
20	W-25438	.1 MFD. COND.
21	W-25937	275 Ω RESIS.
22	W-26690	4500 Ω RESIS.
23	W-27120	8500 Ω RESIS.
24	W-27120	25000 Ω RESIS.
25	W-24784	.25 MFD. COND.
26	W-25517	.05 MFD. COND.
27	W-25517	.008 MFD. COND.
28	W-21483	40,000 Ω RESIS.
29	W-26577	3 MEG. RESIS.
30	W-28807	750 Ω RESIS.
31	W-27488	8 MFD. COND.
32	W-27488	8 MFD. COND.
33	W-23701-A	7 MFD. COND.
34	B-21491	CORD & PLUG
35	G1-23559	POWER TRANS.
36	W-4099A	DIAL LIGHT GV.
37	623-27456	'57 SOCKET
38	624-27456	'58 SOCKET
39	625-27456	'42 SOCKET
40	66-25456	'80 SOCKET
41	W-27540	.0005 MFD. COND.



Tube	Position	Plate	Screen Grid	Voltages Supp. Grid	Bias	Fil.
-58	Osc. Detector	230	110	33	2.7*	2.5
-58	I. F. Amplifier	255	140	0	3.0	2.5
-57	Detector	180	40	0	5.8	2.5
-42	Output	240	255	0	17.0	7.0
-80	Rectifier	330				4.8

*Across 275 ohm resistor in cathode circuit.

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PIONEER HOME STUDY RADIO SCHOOL

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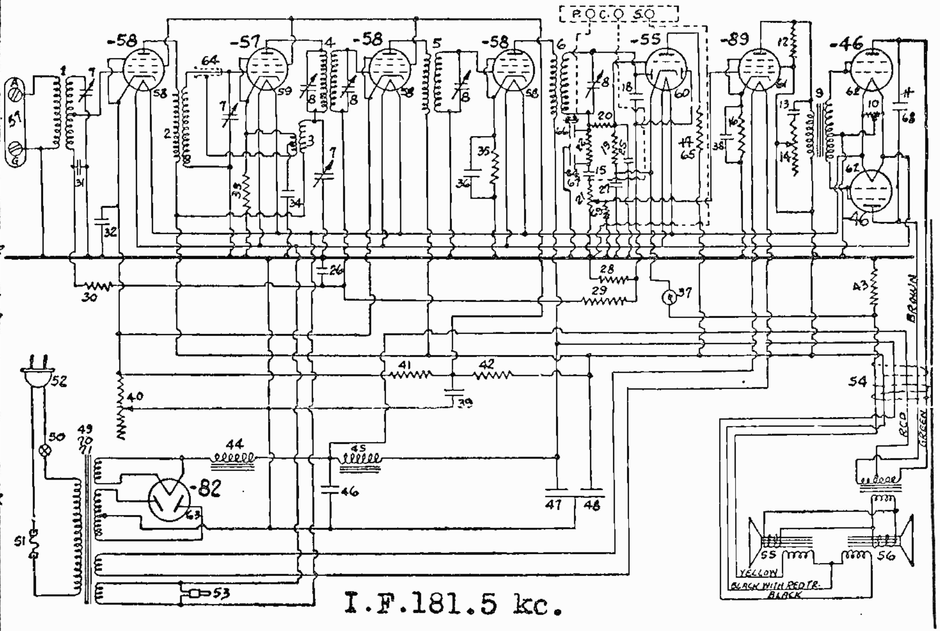
CROSLEY MODEL 146-1



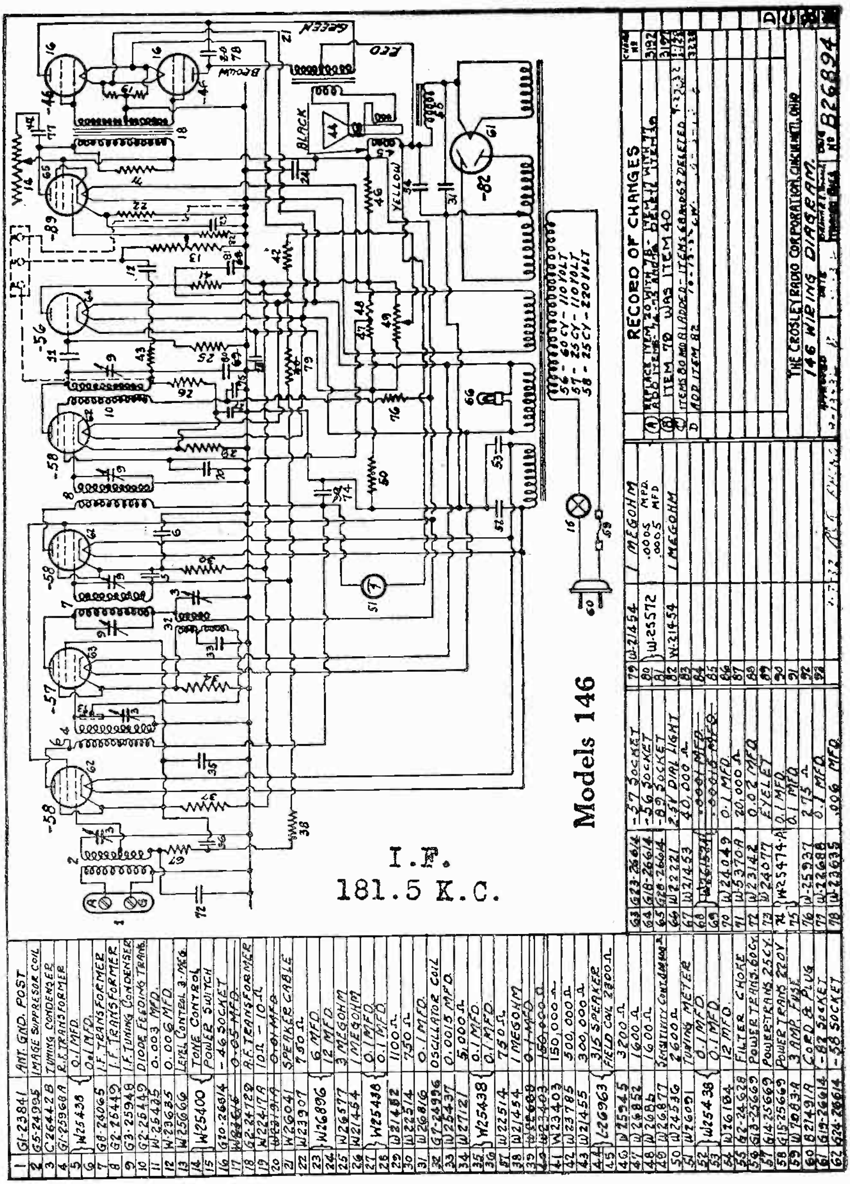
I.F. 181.5 kc.

1	G5-24995	ANTENNA COIL
2	G1-25968	R.F. INTERSTAGE COIL
3	G1-24996	OSCILLATOR COIL
4	G8-24065	1ST I.F. TRANSFORMER
5	G2-25449	2ND I.F. TRANSFORMER
6	G2-25449	3RD I.F. TRANSFORMER
7	C-26442B	VARIABLE CONDENSER
8	G3-25948	I.F. TUNING CONDENSER
9	G2-24729	A.F. TRANSFORMER
10	W-22417A	10-10 Ω FIL. POTEN.
11	W-23191	.01 MFD. CONDENSER
12	W-22196	20,000 Ω RESISTOR
13	W-23615	.05 MFD. CONDENSER
14	W-25594	80,000 Ω TONE CONTROL
15	W-23635	.006 MFD. CONDENSER
16	W-23907	750 Ω RESISTOR
17	W-25540	15,000 Ω RESISTOR
18	W-25435	.003 MFD. CONDENSER
19	W-23403	150,000 Ω RESISTOR
20	W-21454	1-MEGOHM RESISTOR
21	W-25666A	3-MEGOHM LEVEL CONTROL
22	W-21455	300,000 Ω RESISTOR
23	W-25538	.0015 MFD. CONDENSER
24		.0015 MFD. CONDENSER
25	W-25438	.1 MFD. CONDENSER
26		.1 MFD. CONDENSER
27	W-23142	.02 MFD. CONDENSER
28	W-21454	1-MEGOHM RESISTOR
29	W-21454	1-MEGOHM RESISTOR
30	W-21454	1-MEGOHM RESISTOR
31	W-25438	.1 MFD. CONDENSER
32		.1 MFD. CONDENSER
33	W-27121	5000 Ω RESISTOR
34	W-25437	.0015 MFD. CONDENSER
35	W-22514	750 Ω RESISTOR
36	W-23142	.02 MFD. CONDENSER
37	W-26091	TUNING METER
38	W-25857A	8 MFD. CONDENSER
39		8 MFD. CONDENSER
40	W-25573	4500 Ω SEN. CONTROL
41	W-27120	25,000 Ω RESISTOR
42		8500 Ω RESISTOR
43	W-25945	3200 Ω RESISTOR
44	G2-24628	1ST. FILTER CHOKE
45	LW-23213	2ND. FILTER CHOKE
46	W-26194	12 MFD. CONDENSER
47	W-25542	8 MFD. CONDENSER
48		4 MFD. CONDENSER
49	G13-25669	60~ POWER TRANS.
50	PART OF W-25594	POWER SWITCH
51	W-7983A	3 AMP. FUSE
52	B-21491A	CORD & PLUG
53	W-22221	2.5V. DIAL LAMP
54	W-26600	SPEAKER CABLE
55	L-26109	328-4 SPEAKER 5500 Ω FIELD
56	L-26999	327-4 SPEAKER 650 Ω FIELD
57	G1-23841	ANT.-GND. STRIP
58	G24-26614	-58 SOCKET
59	G27-26614	-57 SOCKET
60	G29-26614	-55 SOCKET
61	G28-26614	-89 SOCKET
62	G20-26614	-46 SOCKET

63	G19-26614	-82 SOCKET
64	W-24077	EYELET CONDENSER
65	W-4921	10,000 Ω RESISTOR
66	W-26152A	.0001 MFD. CONDENSER
67		.0015 MFD. CONDENSER
	W-23635	.006 MFD. CONDENSER
	W-21454	1-MEGOHM RESISTOR
	G14-25669	25~ POWER TRANS.
	G15-25669	220V. POWER TRANS.
72		
73		
74		
75		
76		
77		
78		

Model 146-1

Tube	Position	Plate	Grid Screen	Voltages Grid Supp.	Bias	Fil.
-58	R. F. Amplifier	310	130	0	4.5	2.5
-57	Osc. Detector	290	130	0	6.0	2.5
-58	1st I. F. Amplifier	310	130	0	4.5	2.5
-58	2nd I. F. Amp.	310	130	0	6.0	2.5
-56	Diode Detector and A. V. C.	80				2.0
-89	A. F. Amplifier	250	255		28.0	6.0
-46	Class B Output	365			0	2.5
-46	Class B Output	365			0	2.5
-82	Rectifier	380				2.5



Model 146

Tube	Position	Plate	Screen Grid	Voltages Supp. Grid	Bias	Fil.
-58	R. F. Amplifier	195	62	0	2.5*	2.5
-57	Osc. Detector	195	132	0	9.0	2.5
-58	1st I. F. Amplifier	200	62	0	2.0*	2.5
-58	2nd I. F. Amp. and Diode	0	105	200	5.0	2.5
-56	A. V. C.	60			70.0	2.5
-89	A. F. Amplifier	180	200	0	20.0	6.0
-46	Class B Output	350			0	2.5
-46	Class B Output	350			0	2.5
-82	Rectifier	380				2.5

* Measured across cathode resistors of each tube.

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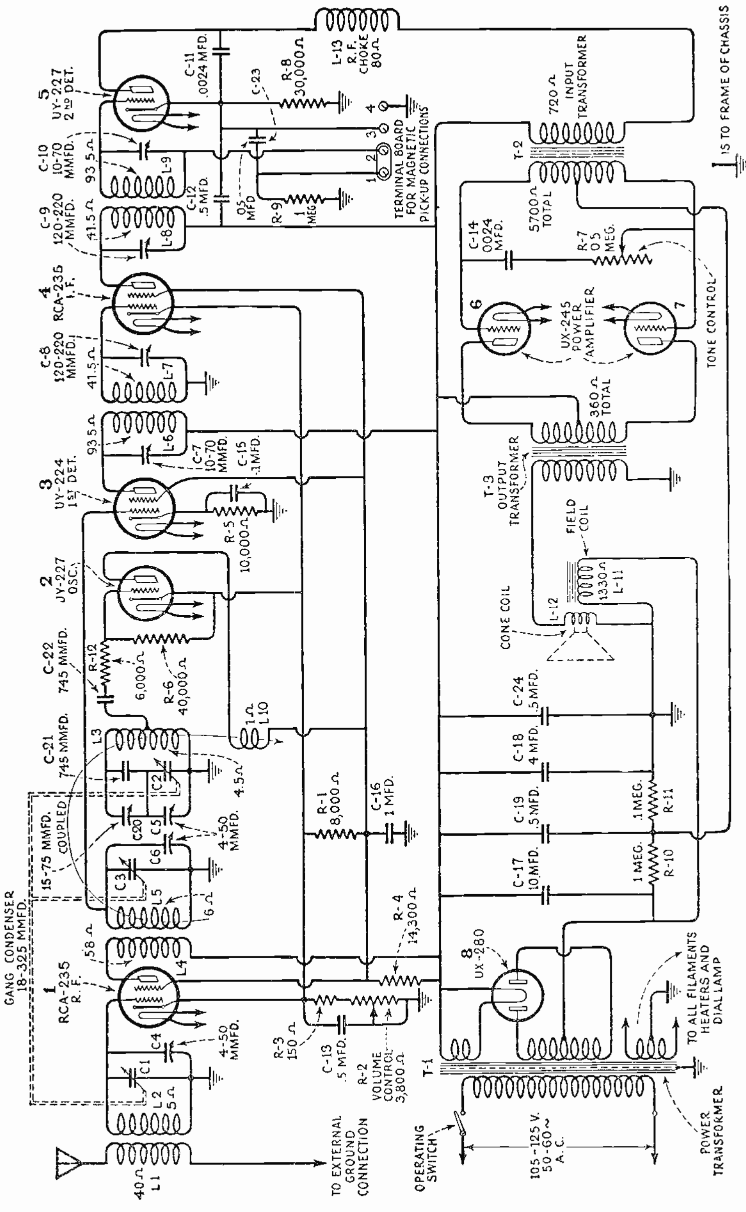
NATIONAL RADIO INSTITUTE, WASHINGTON, D. C.

GENERAL ELECTRIC S-22 AND VICTOR-RADIOLA SUPERETTE



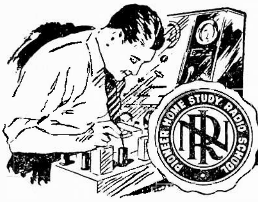
Schematic Wiring Diagram

The wiring diagram is also used in the following receivers: Graybar No. 8 Midget; Westinghouse No. WR-10 Columnette; and General Electric Models G. E. Jr. No. S-22, G. E. Jr., with clock, No. S-22-X and G. E. Jr. Console S-42.

VOLTAGE READING SERVICE DATA CHART

VOLUME CONTROL AT MAXIMUM

VOLTAGE CHARACTERISTICS	1 R. F.				2 OSC.			3 1st DET.				4 I. F.				5 2nd DET.			6 PWR. A. F.			7 PWR. A. F.			CAUSE OF INCORRECT READING
	C.G. Volts	S.G. Volts	Plate Volts	Plate M.A.	Grid Volts	Plate Volts	Plate M.A.	C.G. Volts	S.G. Volts	Plate Volts	Plate M.A.	C.G. Volts	S.G. Volts	Plate Volts	Plate M.A.	Grid Volts	Plate Volts	Plate M.A.	Grid Volts	Plate Volts	Plate M.A.	Grid Volts	Plate Volts	Plate M.A.	
Normal	3.5	70	240	5.0	0	65	5.5	5.0	70	235	0.5	3.5	70	240	5.0	5.0	220	0.5	30	245	25	30	245	25	
No C. G. Voltage on Tube No. 1	0	70	240	9.0																					Open Secondary of R. F. Transformer L-2
No C. G. Voltage on Tube No. 3								0	70	235	1.5														Open 1st Det. Grid Coil L-5
No C. G. Voltage on Tube No. 4												0	70	240	9.0										Open Secondary of 1st I. F. Transformer L-7
No C. G. and Low Plate Voltage on Tube No. 5																0	70	5.5							Open Sec. of 2nd I. F. Trans. L-9 or 1 Meg. Res. R-9
Low Voltages on All Tubes	2.0	35	150	2.5	0	35	3.0	3.0	35	140	0.5	2.0	35	150	2.5	5.0	100	0.25	0	140	80	30	150	0	Open One-Half Secondary of Interstage Transformer T-2
Low Voltages on All Tubes	2.0	35	150	2.5	0	35	3.0	3.0	35	140	0.5	2.0	35	150	2.5	5.0	100	0.25	30	150	0	0	140	80	Open One-Half Secondary of Interstage Transformer T-2
No Voltages on Tube No. 2					0	0	0																		Open Oscillator Plate Coil L-10
No Plate Voltage on Tube No. 1	3.5	60	0	0																					Open R. F. Plate Coil L-4
No Plate Voltage on Tube No. 3								4.0	70	0	0														Open Primary of 1st I. F. Transformer L-6
No Plate Voltage on Tube No. 4												3.5	60	0	0										Open Primary of 2nd I. F. Transformer L-8
No Voltages on Tube No. 5																0	0	0							Open R. F. Choke L-13 or Primary of Transformer T-2
No Plate Voltage on Tube No. 6																			20	0	0				Open One-Half Primary of Output Transformer T-3
No Plate Voltage on Tube No. 7																						20	0	0	Open One-Half Primary of Output Transformer T-3
No C. G. Voltage on Tubes Nos. 1 and 4	0	70	240	9.0								0	70	240	9.0										Shorted 0.5 Mfd. Condenser C-13
No C. G. Voltage on Tube No. 3								0	70	240	4.0														Shorted 0.1 Mfd. Condenser C-15
No C. G. or S. G. Voltages on Tubes Nos. 1, 2, 3 or 4	0	0	240	0	0	0	0	0	0	235	0	0	0	240	0										Shorted 1.0 Mfd. Condenser C-16
Low Voltages on All Tubes	1.0	20	100	1.0	0	20	1.5	1.0	20	100	0.25	1.0	20	100	1.0	5	60	0.5	+8	80	50	+8	80	50	Shorted 0.5 Mfd. Condenser C-24
No. C. G. Voltage on Tube No. 5																0	180	30							Shorted 0.5 Mfd. Condenser C-12
Low Plate Voltage on Tube No. 5																0	60	1.5							Shorted 0.05 Mfd. Condenser C-23
No Plate Voltage on Tube No. 5																25	0	0							Shorted .0024 Mfd. Condenser C-11
Low Plate M. A. on Tubes Nos. 6 and 7																			50	260	10.0	50	260	10.0	Shorted 100,000 Ohm Resistor R-10
Low Voltages on All Tubes	1.5	25	100	0.25	0	25	0.5	1.5	25	100	0.25	1.5	25	100	0.5	5.0	100	0.25	0	100	40	0	100	40	Shorted 100,000 Ohm Resistor R-11
High C. G. Voltage on Tubes Nos. 1 and 4	200	0	0	0	0	0	0	20	200	215	0	200	0	0	0										Open Volume Control R-2 or 150 Ohm Resistor R-3
High S. G. Voltages	7.0	160	210	25	0	100	12	14	160	200	2.0	7.0	160	210	25										Open 8,000 Ohm Resistor R-1
No C. G. or S. G. Voltage on Tubes Nos. 1, 2, 3 and 4	0	0	250	0	0	0	0	0	0	240	0	0	0	250	0										Open 14,300 Ohm Resistor R-4
No Voltages on Tube No. 3								0	0	0	0														Open 10,000 Ohm Resistor R-5
No Plate Voltage on Tube No. 5																20	0	0							Open 30,000 Ohm Resistor R-8



RADIO-TRICIAN
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NATIONAL RADIO INSTITUTE, WASHINGTON, D.C.

CLARION SUPERHETERODYNE MODELS 80 AND 81

Poor Sensitivity

This might be due to a high resistance connection in antenna coil, first detector, intermediate, second detector or oscillator primary or secondary windings, short circuited turns in these windings or grounds due to loose strands of wire or excess solder or poor contact at control grid cap and at tube prongs, should be looked for.

Poor Selectivity

This condition may arise from the same causes and appear simultaneously with poor sensitivity. Where tuning is usually broad and the local broadcasting station is not causing the trouble, it is a good idea to check for high resistance in the grid circuits.

A high resistance connection in an r.f. circuit need not run to thousands or hundreds of ohms, especially in the oscillatory circuit, i. e., the circuit comprising the variable condenser and secondary, or tuned primary winding, and tests with a continuity meter may not give sufficient indication of the poor connection. In a case of this type where the connections are suspected, a practical remedy would be to go over these connections with a hot soldering iron. An improvement should be immediately apparent.

Oscillation

It should be remembered that with an intermediate frequency of 175 k.c., a heterodyne whistle, similar to oscillation, will be picked up at 700 k.c. This is due to the fourth harmonic of the receiver's oscillator frequency beating with the carrier frequency of the broadcasting station to produce an audio note in the loudspeaker. However, this condition has been minimized in CLARION receivers and the intermediate frequency of 175 k.c. has been selected by all manufacturers as the one intermediate frequency having most advantages and least disadvantages.

In addition, oscillation may be brought about by a poor ground, or no ground at all being used. High line voltage may also cause oscillation. Omission of tube shields aggravates this condition. "Hot tubes" will seldom cause oscillation in a superheterodyne due to the wide tolerance shown by this circuit.

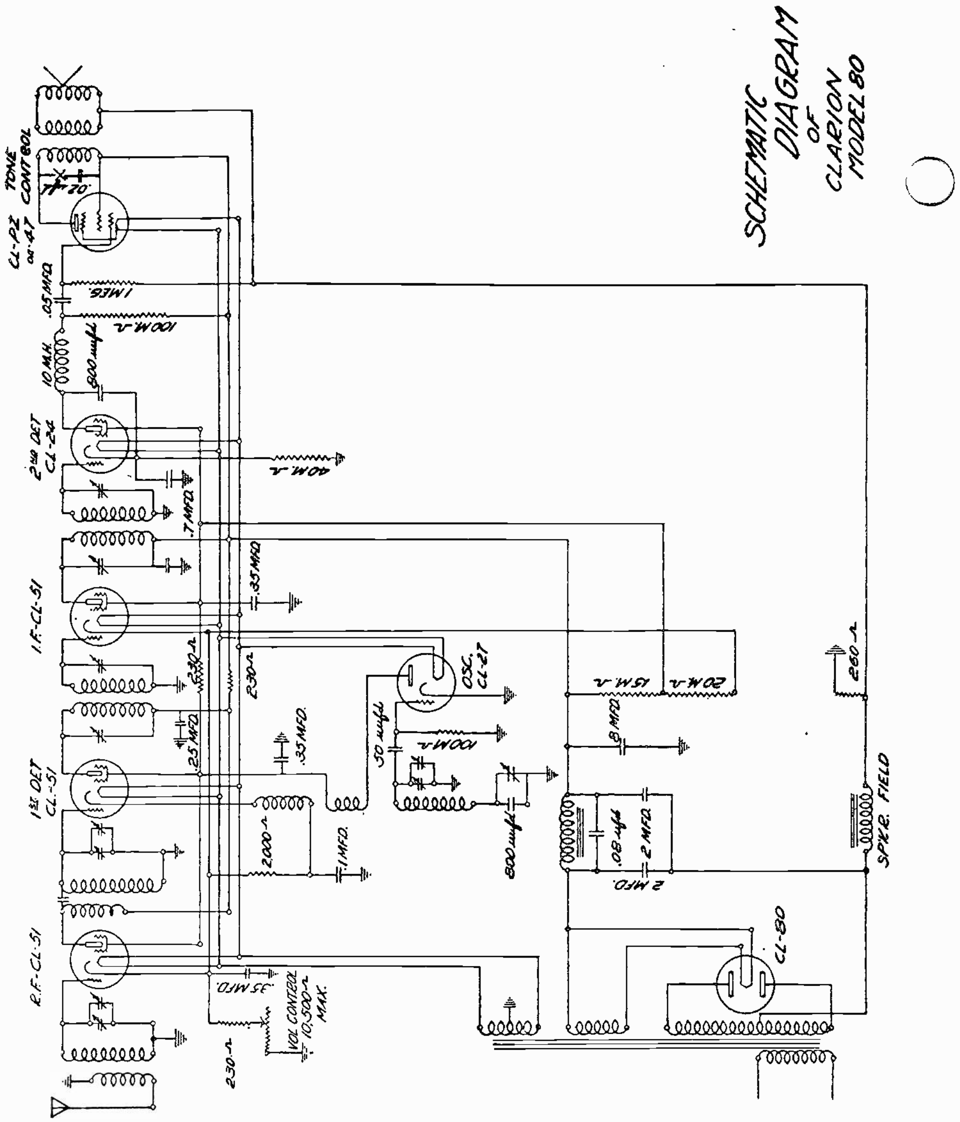
(1) An open screen grid by-pass condenser.
(2) An open r.f. cathode by-pass condenser.
(3) An open det. cathode by-pass condenser.
(4) Poor ground at the installation.
(5) A high resistance connection in series with a by-pass condenser.
(6) Tube shields removed and high line voltage.

Noisy Operation

Due to its extreme sensitivity, the superheterodyne may appear a trifle noisy on distant reception. However, it will be found that in turning down the volume on any station to equal that of a tuned radio frequency receiver, the superheterodyne will perform as quietly, and possibly more quietly, than the tuned radio frequency set does.

Other than this, loose connections causing intermittent open circuits or short circuits are probable causes. Ninety percent of noisy operation arises in location, installation or 110-volt supply. Tubes are the most common source of noisy operation, but we are assuming, of course, in all these texts that everything external to the chassis and speaker are known to be good.

Where loose connections are suspected, go over all connections with a wood or fiber stick, moving each connection firmly BUT NOT ROUGHLY, listen for clicks or rasping noises from the speaker. A vibration at a particular tone occurring repeatedly during the playing of music generally is due to a loose or vibrating part on the speaker and roughness or rasping at all tones is usually due to a rubbing voice coil. A rattle may develop if the tube shields bear against one another.



Voltage Table of Clarion Model 80

Position	Tube	Fil. Volts	Plate Volts	Grid Volts	Screen Grid Volts	Cathode Volts	Normal Plate M.A.
R.f.	CL-51	2.2	233	3.	66	3.	5.
1st Det.	CL-51	2.2	233	7.	73	7.	2.3
Osc.	CL-27	2.2	80	0	0	0	4.
I.F.	CL-51	2.2	233	3.	77	3.	5.
2nd Det.	CL-24	2.2	162	6.2	73	7.2	.5
Output	CL-PZ	2.2	228	15.	233	0	27.
Rect.	CL-80	4.8	300	0.	0	0	50.

Volume control position Full. Line Voltage 115.

Note: Since resistance tolerances in the sets are plus or minus 10%, and tubes may vary over 20%, your readings may disagree with the above by plus or minus 30%. CL-PZ is also known as CL-47, the latter being the final type number.

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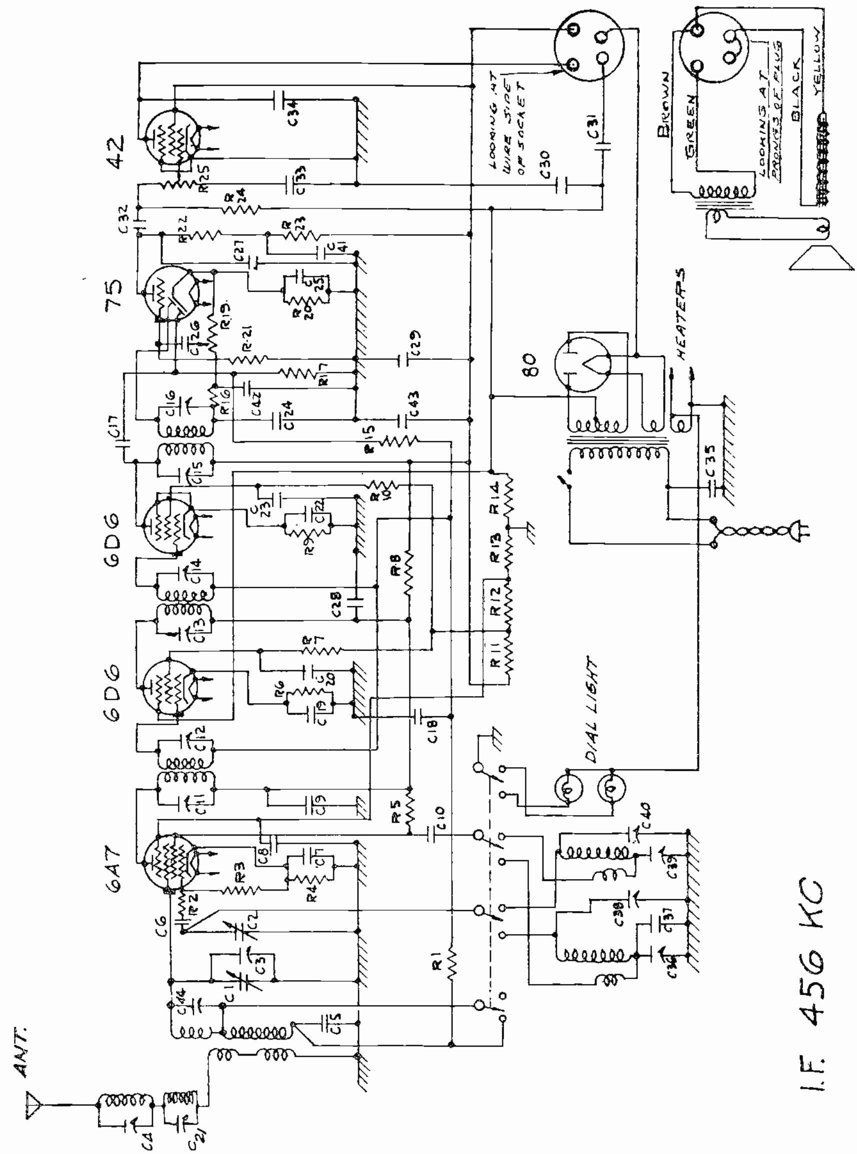
NATIONAL RADIO INSTITUTE, WASHINGTON, D.C.

WESTINGHOUSE DUAL-WAVE RECEIVERS MODELS WR-28-29



WESTINGHOUSE DUAL-WAVE RECEIVERS MODELS WR-28-29

Symbol Number	Description	Part Number
C-1, C-2, C-3	Variable gang with trimmer	WR-07256
C-4	600 mmf. variable	WR-07238
C-5	.05 mf - 2 ply	WR-06386
C-6	.0001 mf - mica	WR-06417
C-7	.05 mf - 2 ply	WR-06386
C-8	.05 mf - 2 ply	WR-02493
C-9	.05 mf - 3 ply	WR-02492
C-10	.02 mf - 3 ply	WR-02504
C-11, C-12	Part of I.F. coil	WR-07247
C-13, C-14	Part of I.F. coil	WR-07248
C-15, C-16	Part of I.F. coil	WR-07249
C-17	.001 - mica	WR-06417
C-18	.05 mf - 2 ply	WR-06386
C-19	.05 mf - 2 ply	WR-06386
C-20	.05 mf - 2 ply	WR-06386
C-21	10 to 55 mmfd.	WR-07842
C-22	.05 mf - 2 ply	WR-06386
C-23	.05 - 2 ply	WR-06386
C-24	.0001 mica ...... part of	WR-07249
C-25	.5 mf - 2 ply	WR-02499
C-26	.005 mf - 3 ply	WR-03659
C-27	.001 mf - 4 ply	WR-06403
C-28	8 mf - electrolytic	WR-07239
C-29	4 mf - electrolytic	WR-06665
C-30	20 mf - electrolytic	WR-06665
C-31	8 mf - electrolytic	WR-06665
C-32	.005 mf - 3 ply	WR-03659
C-33	.001 mf - 4 ply	WR-06403
C-34	.01 mf - 4 ply	WR-03695

Symbol Number	Description	Part Number
C-35	.01 mf - 4 ply	WR-05931
C-36	425 mmf. variable	WR-07241
C-37	1500 mmf. mica	WR-07422
C-38	Trimmer condenser	WR-07237
C-39	425 mmf. variable	WR-07241
C-40	Trimmer condenser	WR-07237
C-41	.05 mf - 3 ply	WR-02492
C-42	.001 mica	WR-06417
C-43	.05 mf - 3 ply	WR-02492
C-44	4-40 mmf. variable ... part of	WR-07246
R-1	.1 meg. 1/4 watt	WR-05278
R-2	50 ohms 1/4 watt	WR-05255
R-3	50,000 ohms 1/4 watt	WR-05276
R-4	500 ohms 1/4 watt	WR-05264
R-5	20,000 ohms 1/2 watt	WR-00813
R-6	1,000 ohms 1/4 watt	WR-05267
R-7	5,000 ohms 1/4 watt	WR-05249
R-8	1,000 ohms 1/4 watt	WR-05267
R-9	1,000 ohms 1/4 watt	WR-05267
R-10	5,000 ohms 1/4 watt	WR-05249
R-11	11,200 ohms	WR-07236
R-12	1,800 ohms	
R-13	12,000 ohms	
R-14	300 ohms	
R-15	1 meg. 1/4 watt	WR-05281
R-16	50,000 ohms 1/4 watt .. part of	WR-07249
R-17	1 meg. 1/4 watt	WR-05281
R-19	.5 meg. variable	WR-05562
R-20	2,000 ohms 1/4 watt	WR-05245
R-21	1 meg. 1/4 watt	WR-05281
R-22	75,000 ohms 1/4 watt	WR-05277
R-23	50,000 ohms 1/4 watt	WR-05276
R-24	.25 meg. 1/4 watt	WR-05279
R-25	.25 meg variable	WR-07250

Stage	Tube	Filament	Plate	Screen	Cathode
Rectifier	80	4.85	382		
Power Output	42	6.1	234	245	18
2nd Detector	75	6.1	126		0.87
1st I. F.	6D6	6.1	236	99	5.6
2nd I. F.	6D6	6.1	245	96	5.6
Oscillator	6A7	6.1	236-136	87	4.7

Note: These values are readings of a high resistance voltmeter from each socket terminal to ground, with the exception of the filament voltages.

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NATIONAL RADIO INSTITUTE, WASHINGTON, D.C.

ZENITH MODELS 811-862-865-866-1162

SOCKET VOLTAGE READINGS

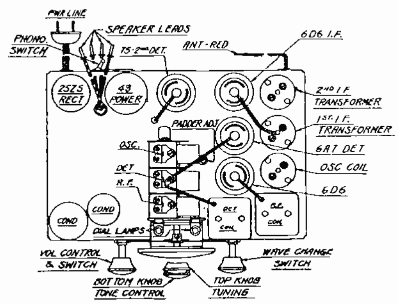
TUBE	POSITION	Ef	Ek	Eg1	Eg2	Eg3	Ep
6D6	R.F.	5.8	3		98	3	98
6A7	1st Det.	5.8	2.5		60	-	98
	Osc.			-1	-	-	90
6D6	I.F.	5.8	3		98	3	98
75	2nd Det. A.V.C 1st Aud.	5.8	.5		-	-	30
43	PWR.	26	13.5	0	98	-	90
25Z5	Rect.	26	-30 -28	-	-	-	-

Line Voltage 112 — Antenna and Ground Disconnected

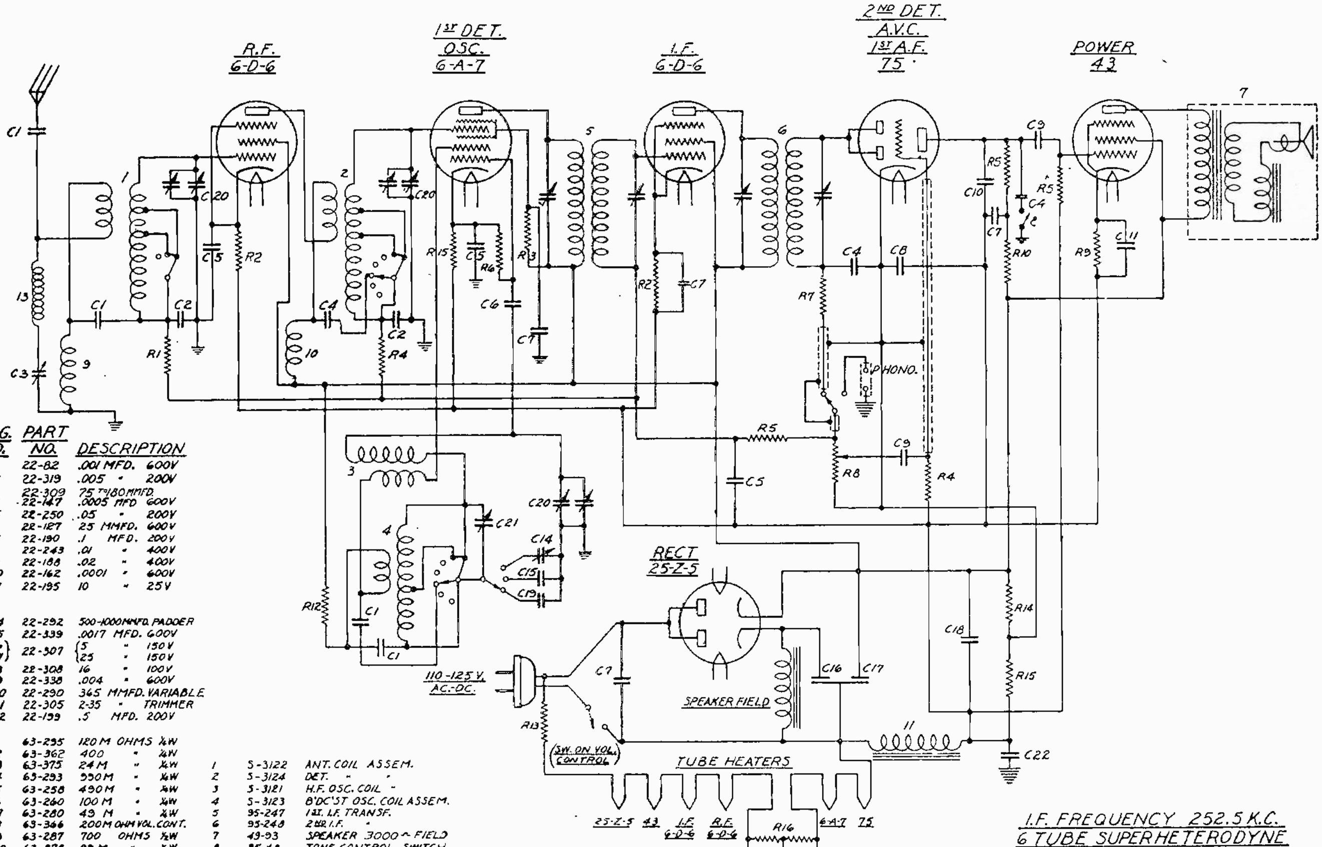
F - Filament; K - Cathode; g1 - Control Grid; g2 - Screen Grid; g3 - Suppressor Grid; p - Plate

Alignment

1. Balance intermediate transformers at 252.5 K.C. with service oscillator connected to grid of 6A7 and chassis ground.
2. Adjust wave trap padder (located underneath chassis at rear right side) for weakest signal with 252.5 K.C. service oscillator connected to antenna and ground.
3. Turn wave-band switch clockwise to the highest frequency band. Set service oscillator at 15 M.C. - still connected to aerial and ground. Balance oscillator trimmer on gang condenser for correct dial reading at this frequency.
4. Turn wave-band switch counter clockwise to standard broadcast position. Adjust broadcast oscillator trimmer (located underneath chassis at right - center) for correct dial reading at 1400 K.C. and adjust R.F. and first detector trimmers on gang condenser for loudest signal.
5. Set service oscillator at 600 K.C. Adjust oscillator broadcast padder through hole in top of chassis, simultaneously rocking the dial back and forth for loudest signal.



Tube Position



DIAG. NO.	PART NO.	DESCRIPTION
C1	22-82	.001 MFD. 600V
C2	22-319	.005 " 200V
C3	22-309	75 TO 180 MMFD.
C4	22-147	.0005 MFD 600V
C5	22-250	.05 " 200V
C6	22-127	25 MMFD. 600V
C7	22-190	.1 MFD. 200V
C8	22-243	.01 " 400V
C9	22-188	.02 " 400V
C10	22-162	.0001 " 600V
C11	22-195	10 " 25V
C14	22-292	500-1000 MMFD. PADDER
C15	22-339	.0017 MFD. 600V
C16	22-307	5 " 150V
C17	22-307	25 " 150V
C18	22-308	16 " 100V
C19	22-338	.004 " 600V
C20	22-290	365 MMFD. VARIABLE
C21	22-305	2-35 " TRIMMER
C22	22-199	.5 MFD. 200V
R1	63-295	120 M OHMS ¼W
R2	63-362	400 " ¼W
R3	63-375	24 M " ¼W
R4	63-293	990 M " ¼W
R5	63-258	490 M " ¼W
R6	63-260	100 M " ¼W
R7	63-280	49 M " ¼W
R8	63-366	200 M OHM VOL. CONT.
R9	63-287	700 OHMS ½W
R10	63-278	99 M " ¼W
R12	63-326	4 M " ¼W
R13	11-9	90 OHM RES. CORD
R14	63-372	50 M OHMS ¼W
R15	63-244	500 " ¼W
R16	63-374	50 " 2W

1	S-3122	ANT. COIL ASSEM.
2	S-3124	DET. " "
3	S-3121	H.F. OSC. COIL "
4	S-3123	B'DC'ST OSC. COIL ASSEM.
5	95-247	1ST. I.F. TRANSF.
6	95-248	2ND I.F. "
7	49-93	SPEAKER 3000 ~ FIELD
8	85-48	TONE CONTROL SWITCH
9	20-71	ANT. CHOKE
10	20-76	R.F. PLATE IMPEDANCE COIL
11	95-249	POWER FILTER CHOKE
12	85-57	BAND CHANGE SWITCH
13	20-75	WAVE TRAP

MODELS 811-862-865-866-1162

I.F. FREQUENCY 252.5 K.C.
6 TUBE SUPERHETERODYNE
CHASSIS NO. 5609 A.C.-D.C.

ZENITH RADIO CORP.
CHICAGO ILL.

HOW TO SELECT A GOOD RADIO RECEIVER

24 FR

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

HONESTY

In the course of your life you have possibly heard the expression "Honesty is the best policy," thousands of times. The statement stands undisputed in the business world of today. In fact, as most business depends to a large extent on repeat business, honesty is not only a good policy, it is an absolute necessity.

As far as the individual is concerned, absolute honesty is essential to his peace of mind and to his happiness. It isn't enough to be honest within certain limits or to be absolutely honest in some respects but not quite so honest in others.

For example you might be legally honest if you refuse to live up to a verbal agreement on the ground that you have forgotten the agreement or that the other party to the agreement has nothing to show in writing. But you are not being honest with yourself when you do this and what you may gain in this way will never bring you any real satisfaction or happiness.

Or you might overcharge a customer for whom you did a Radio repair job. You may have figured up the cost of the parts you used very scrupulously, but when it came to charging for labor, you allowed yourself a little leeway—you charge two hours service whereas you know you didn't spend more than an hour on the job. Or you may have figured the time exactly and over-charged for the parts.

In either of these cases, no one could very well accuse you of dishonesty, but you know, deep down in you, that you are not playing the game. And eventually you will regret it.

So for your own sake, for the sake of the real Success and Happiness you want to be honest—scrupulously honest. Let your spoken word be as good as your signature on a legal contract. Expect and ask for a fair return on your labor.

Then your reputation will take care of itself and what is even more important you will have the great satisfaction of knowing that you are upright and honorable and that you can look any man in the eye, fearlessly.

J. E. SMITH

NATIONAL RADIO INSTITUTE

WASHINGTON, D.C.

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How To Select A Good Radio Receiver

RECEIVER CHARACTERISTIC CURVES

You have already become very familiar with the use of characteristic curves of vacuum tubes and you have seen how valuable they are to anyone working in the field of Radio. In this lesson we are going to study the characteristics of complete radio receivers. These characteristics are represented in the form of curves, just as tube characteristics are.

Radio has become a standardized industry. Most of the guess-work has been taken out of it. Manufacturers can no longer sell their receivers with no more behind them than the imagination of their sales managers. Today, when claims are made for a receiver, they must be backed up by a set of characteristic curves.

Even the buying public is demanding more and more that manufacturers' claims be substantiated—and characteristic curves for various receivers are appearing in several popular radio magazines.

It should be perfectly obvious from this that the modern Radio-Trician must thoroughly understand the use of these curves, and not only that, he should understand how they are made. In this lesson, after reviewing the main characteristics by which receivers are judged, we are going to see how the various characteristic curves are made and what they mean. Then later we are going to consider typical characteristic curves of several commercial receivers.

As we know, the performance of a receiver is dependent on its sensitivity, selectivity and fidelity characteristics. It is so important that you understand the meaning of these that we are going to define them again before going on.

Sensitivity is that property of a radio receiver which enables it to respond to a small input voltage, in other words, to signals from a weak or distant station. It is measured in terms of input voltage required to give a definite output power. Remember that the input voltage is a modulated high frequency e.m.f. and that the output is audio power which is used to operate a loudspeaker. The input voltage is ordinarily measured in microvolts and sensitivity is measured in terms of the microvolts required for a definite standard output (usually considered as 50 milliwatts). The sensitivity characteristic of a receiver is represented as a curve made by plotting the input voltages required to provide an output of 50 milliwatts at various frequencies in the broadcast band.

Selectivity is that property of a radio receiver which enables it to tune out signals from all stations except the desired station. In receivers having poor selectivity characteristics, there is continual station interference. As we say, two or more stations overlap on the dial. On the other hand, a receiver that permits 10 kilocycle separation of stations is considered very selective.

The *fidelity* of a receiver is a measure of its ability to handle signal voltages without distorting the audio signal in any way. Perfect fidelity would be obtained if the sound output of a receiver were an exact duplicate of the audio signals impressed on the microphone in the transmitting studio. This of course assumes that the signal was not distorted in any way during transmission.

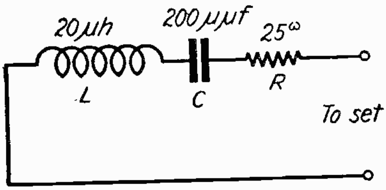


Fig. 1

In making fidelity measurements, the loudspeaker is not taken into consideration. It must be assumed that a loudspeaker is used that will respond faithfully to the audio signals fed to it from the receiver.

Having considered briefly the three main characteristics of a radio receiver, let us consider a few of the factors that must be taken into consideration when making measurements. For example, we shall frequently mention the signal input voltage. By this we mean the voltage induced into the aerial circuit by a radio wave. Of course this voltage is very small as previously mentioned—it might be anything from 1 microvolt (.000001 volt) to a few thousand microvolts.

The amount of voltage induced in the aerial is to a large degree dependent on the type and position of the aerial used. For this reason, in measuring the characteristics of receivers, a standard aerial is used. This standard is an aerial having an inductance of 20 microhenries, a capacity of 200 micro-micro-farads and a high frequency resistance of 25 ohms. The aerial system may be a real one or an artificial one. An artificial (phantom) aerial is shown in Fig 1.

The signal intensity for any given locality is measured in microvolts per meter. A standard aerial, one meter off the ground, will have induced in it a definite number of microvolts. The very same antenna, seven meters off the ground, would have induced in it seven times as many microvolts. It is this voltage that feeds the receiver.

Taking a practical example, an aerial ten meters off the ground has, let us say, a voltage of 75 microvolts induced in it.

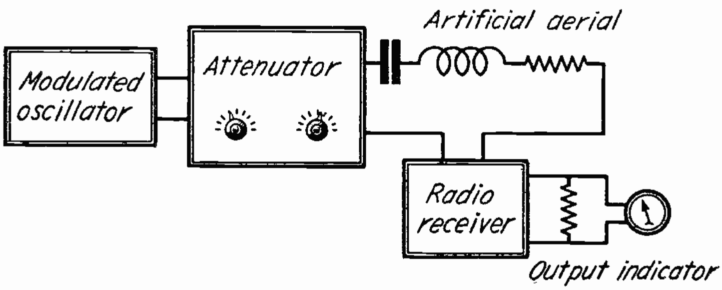


Fig. 2

The field intensity therefore would be 1/10 of 75 or 7½ microvolts per meter. Conversely, if the field strength is 100 millivolts (100,000 microvolts) per meter, an aerial 7 meters high (22 feet above the ground) would have induced in it a signal of 700 millivolts; if the field strength were ½ microvolt per meter, the same aerial would have induced in it 3½ microvolts.

Another standard adopted by radio engineers for use in making fidelity measurements is an input consisting of a carrier frequency, 30% modulated by a 400 cycle audio signal.

The standard output has already been mentioned. This is 50 milliwatts (.05 watt) fed to a non-inductive load (an ohmic resistance whose loss, I^2R, is .05 watt).

Now that we understand the various standards we are just about ready to see how the different measurements are made.

Fig. 2 shows in block fashion the set-up used. There is a modulated oscillator which has a meter in its output to indicate the voltage delivered. Then there is a variable attenuator connected to the oscillator to reduce the comparatively large voltage from the oscillator (one or more volts), to one or more microvolts. The attenuator is calibrated so that by changing the adjustment the voltage delivered by the oscillator can be reduced 1/100th, 1/1000th, 1/10,000th or 1/1,000,000th and variations between these made in definite known steps.

The attenuator may be connected to the regular aerial, but it is more usually connected to the receiver through an artificial aerial. The power output in watts is measured by an all-frequency A.C. voltmeter or ammeter, usually a thermo-couple or vacuum tube device.

THE SENSITIVITY TEST

The receiver we are going to use for purposes of illustration is A.C. operated. This does not, however, affect the method of testing as the same sensitivity test can be made on all receivers regardless of the type of power supply used. The rated line voltage or the power supply is checked before starting. The volume control is adjusted for maximum output and the oscillator adjusted for 30 per cent modulation with an audio frequency of 400 cycles. The attenuator is adjusted at several test carrier frequencies in the receiver range. At each adjustment the output meter must indicate an output of .05 watt. The e.m.f. input required to produce this standard output at various frequencies is calculated from the attenuator setting. When this information is plotted as a graph we have a sensitivity curve. Input voltages (in microvolts) are always plotted as ordinates (along the vertical reference line) and the carrier frequencies as abscissas (along the horizontal reference line).

Fig. 3 shows a typical sensitivity curve. Note that the voltage divisions are not like the frequency divisions. The voltage divisions are logarithmic so that the size of the graph can be kept small. By the use of logarithmic divisions we obtain a hundred divisions in the same space as twenty equally divided divisions. When sensitivity curves do not show wide variations they may be plotted on regular graph paper.

The curve in Fig. 3 indicates that the receiver under test is most sensitive at 1,200 kilocycles and that it requires only 1.5

microvolts input to obtain the standard .05 watt output at 1,200 kc.

Tests for the lowest and highest frequency the receiver will respond to are usually made along with the sensitivity test, for no broadcast receiver can be accepted as satisfactory that does not tune from 1,500 to 500 kc.

THE SELECTIVITY TEST

Selectivity tests are usually made at the representative carrier frequencies, 600, 1,000 and 1,400 kc. In each case the testing procedure is the same.

Suppose we are testing for selectivity at 1,000 kc. The oscillator will be set at exactly 1,000 kc., and the receiver tuned to exact resonance. The input voltage is adjusted so that the

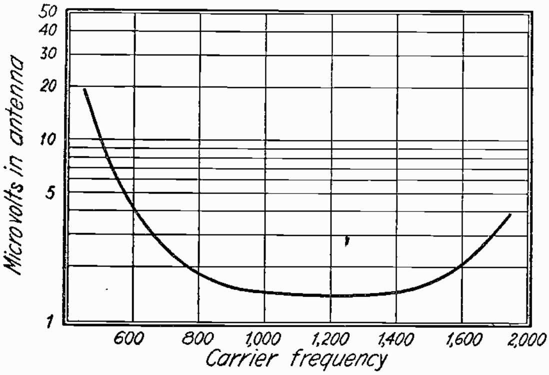


Fig. 3

output power is .05 watt. The input voltage is recorded in microvolts.

What we want to find out now is how much input voltage will be required for signals off the resonant frequency to produce the same signal output. Without touching the receiver the modulated oscillator is set at frequencies of 10, 20, 30, 40, 50, etc., kc. off the frequency to which the receiver is tuned. In the case of the 1,000 kc. resonance we would adjust the oscillator to 990, 980, 970, etc., and 1010, 1020, 1030 kc. In each case the input voltage is increased so that a normal output of 50 milliwatts is obtained and the values of the voltages required are recorded.

So that the three curves can be compared directly, we plot frequency against the *ratios* of the input voltages required at off-resonance frequencies to the resonant input voltage. To obtain the ratio, the input voltage required is divided by the resonant voltage. The ratio for off-frequencies will always be greater than one for naturally it will take a greater signal strength at 970 kc. to feed a receiver tuned to 1,000 kc. than if the signal were of the resonant frequency.

A typical family of selectivity curves is shown in Fig. 4. There is one for each of the standard test frequencies. They show us that selectivity at 600 kc. is much better than at 1,000 kc., and that selectivity at 1,400 kc. is lower than at 1,000 kc. We would expect the receiver to be most selective at low carrier frequencies between 1,000 and 550 kc., and above 1,000 kc. we would expect broad tuning.

A good receiver should have almost identical selectivity characteristics at all frequencies. While receivers of this sort are now being built, still the characteristics shown in Fig. 4 are considered very good.

Note that the ordinates are laid off logarithmically so that a range of 1 to 1,000 may be easily plotted in a small space.

THE FIDELITY TEST

If we are to have audio amplification which does not distort any of the sound characteristics, the receiver must respond equally to an audio range extending from 30 to 5,000 cycles per second. To show the fidelity characteristics of a receiver, we also use a set of curves—one curve for each of the three standard test frequencies.

The modulated oscillator used in making these tests must have a variable audio frequency input—it should be variable from 30 to 10,000 cycles. The frequency should be continuously variable and accurate adjustment must be possible.

Let us say that we are making a fidelity curve at 1,000 kc. We have our standard reference point (we must always set a certain standard before we can make comparisons) of 400 cycles modulated 30% with its 1,000 kc. carrier. The input is varied until 50 milliwatts output is obtained.

The audio frequency is then varied from 30 cycles to as high a frequency above 5,000 as the output signal voltages can be read, keeping the input voltage and the percentage of modulation constant throughout the entire test. As the audio frequency is varied the output voltage will vary, and records are made of both variations with the percentage of modulation kept always at 30.

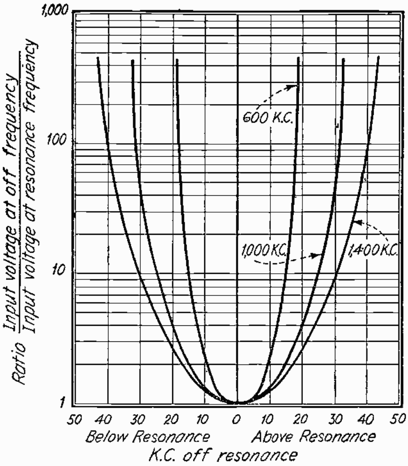


Fig. 4

In a perfect machine there would be no variation in output over the entire audio range.

Fig. 5 shows a family of typical fidelity curves. Notice that at all audio frequencies between 80 and 2,000 cycles, the output

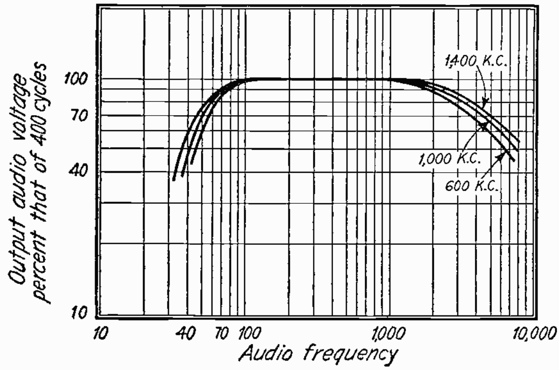


Fig. 5

voltage remains practically the same. But beyond these extremes it drops rapidly. It drops off faster at the high audio end for a 600 kc. carrier than for the others. This may be attributed to greater selectivity and consequently greater side-band cutting.

This family of curves indicates good audio characteristics and when the receiver whose characteristics are shown by these curves is connected to a good loudspeaker, we can be sure of good tone quality.

You will note that both ordinates and abscissas are laid off logarithmically. Sometimes in testing for fidelity characteristics, the output is measured in milliwatts in which case the power at 400 cycles is considered the standard. Then the audio variations are given in decibel units. Methods of decibel calculations by the use of logarithms will be studied later.

The ability to read curves of this kind and to understand what they mean is most important for a Radio-Trician. In your Radio work you will be frequently asked to pass an opinion on various receivers. Don't guess. Get the characteristic curves of the receiver.

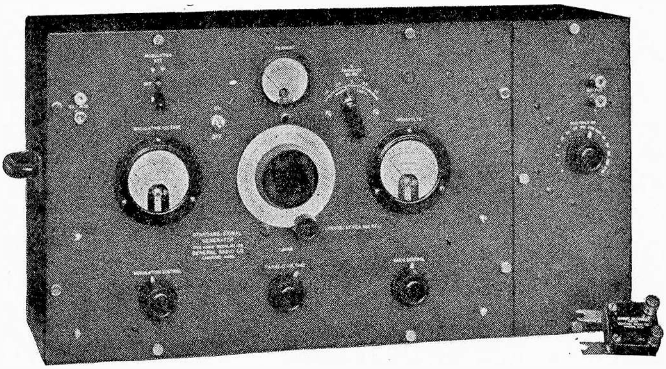


Fig. 6—Typical commercial size generator used in making selectivity, sensitivity and over-all fidelity receiver curves.

Some day you may even represent a large distributor or a purchasing organization—then you will most likely have to make tests of this kind to determine the characteristics of a receiver. If you ever get into this kind of work you will find it most fascinating.

The three tests that have been outlined are only the basic tests. Manufacturers, however, are not satisfied with just these tests—identical tests are made at large outputs, 1 to 4 watts. Then there are tests to determine the presence of harmonics at large output powers, and manufacturers make tests to determine the effect of volume controls on selectivity and fidelity.

Another test is for hum output in A.C. receivers. A rough check can easily be made by placing a voltmeter across the power output with no signal voltage fed to the receiver. A 120 cycle A.C. hum (with full wave rectification supplies) is considered practically inaudible if its output value is no larger than .15 volt. This, however, does not take into consideration the hum harmonics. Manufacturers who make thorough tests use low frequency band pass filters tuned to each of the harmonics. While this is rather an expensive procedure, it is the only way individual tests can be made on the various hum harmonics.

Again it will be well to stress the importance of a thorough understanding of the use of characteristic curves. Study over those given in this lesson carefully and study any others you may have available with the same care.

TYPICAL BROADCAST RECEIVERS

Assuming that you understand the use of the curves explained so far, we are ready to go on and consider the circuits of several standard commercial receivers. For our purposes, we could have chosen any of the receivers made—those that are going to be considered here were chosen more or less at random. They are not the latest or necessarily the best, but they serve our purpose very well.

As the super-heterodyne set is extremely popular at the present time, we shall consider a typical super-heterodyne receiver first.

THE RADIOLA 66

The Radiola 66 is a very well known receiver and it has been well distributed. In your service work you will meet it time and time again. Details of the circuit are shown in the diagram in Fig. 7.

This receiver has a preselector consisting of two tuned circuits, an antenna tuner and one stage of R.F. amplification. You will notice that the R.F. tube is neutralized by the Rice method so that any tendency to feed back is counteracted. There is an R.F. compensating condenser for adjustment of neutralization. The aerial system is tuned to prevent cross modulation of local broadcasting stations. This is just as much a problem in superheterodynes as in tuned R.F. circuits.

The antenna tuner is of a design which was previously studied and provides flat R.F. amplification. A regular secondary

is used, tuned by a variable .00035 mfd. condenser. The primary is weakly coupled to it, but instead of having 5 to 15 turns as in ordinary transformers there are many primary turns. The distributed capacity of the individual turns of wire in the primary winding, together with that of the antenna is sufficient to introduce into the secondary circuit a second resonant peak at a frequency slightly above 550 kc. The result of this is maximum
3 amplification at low radio frequencies. The amplification (with this arrangement) tapers off to a low value at high frequencies. However, at high frequencies regeneration takes place without oscillation in spite of the stabilization provided, and the signal is boosted. In this way a uniform sensitivity characteristic is obtained in the input circuit.

A schematic diagram of the coil used and its circuit is shown in Fig. 8. Due to the large number of primary turns, coupling must be loose in order to prevent broad tuning.

A tuned grid oscillator is employed having a plate tickler feed-back. Notice that the .0008 mfd. condenser and the 3,000 ohm resistor are in series with the oscillator tuned grid. A 40,000 ohm resistor shunts the grid and the cathode. The resistor along with the condenser provides a self-adjusting grid bias. The series grid resistance limits oscillation, as any grid suppressor does, and keeps harmonics from becoming excessive.

The first detector cathode is connected to the oscillator and to C– through a coil inductively linked to the oscillator. The
4 result of this arrangement is that the local signal from the oscillator adds to the C bias of the first detector and so mixes with the incoming signal in the grid of the detector tube.

The tuned circuit of the oscillator consists of a fixed R.F. coil shunted by two condensers in parallel, in series with two other condensers in parallel, one of which is variable. The variable condenser can be made to track with the preselector condensers by adjusting the trimmers and may be ganged for single dial control.

The "mixer" or first detector is followed by two stages of intermediate frequency amplification, exactly pre-tuned (adjusted while in process of construction) to 175 kc.

Regarding the choice of the intermediate frequency, you learned in a previous lesson that the lower the intermediate frequency the better will be amplification and selectivity, yet for freedom from repeat points as high an intermediate as possible should be used (480 kc. being ideal). An in-between value is often chosen as a compromise which is satisfactory from the viewpoint of repeats if the single control arrangement is used to control the preselector and the oscillator.

Another reason for a compromise in the matter of the intermediate frequency is the fact that an absolutely perfect detector

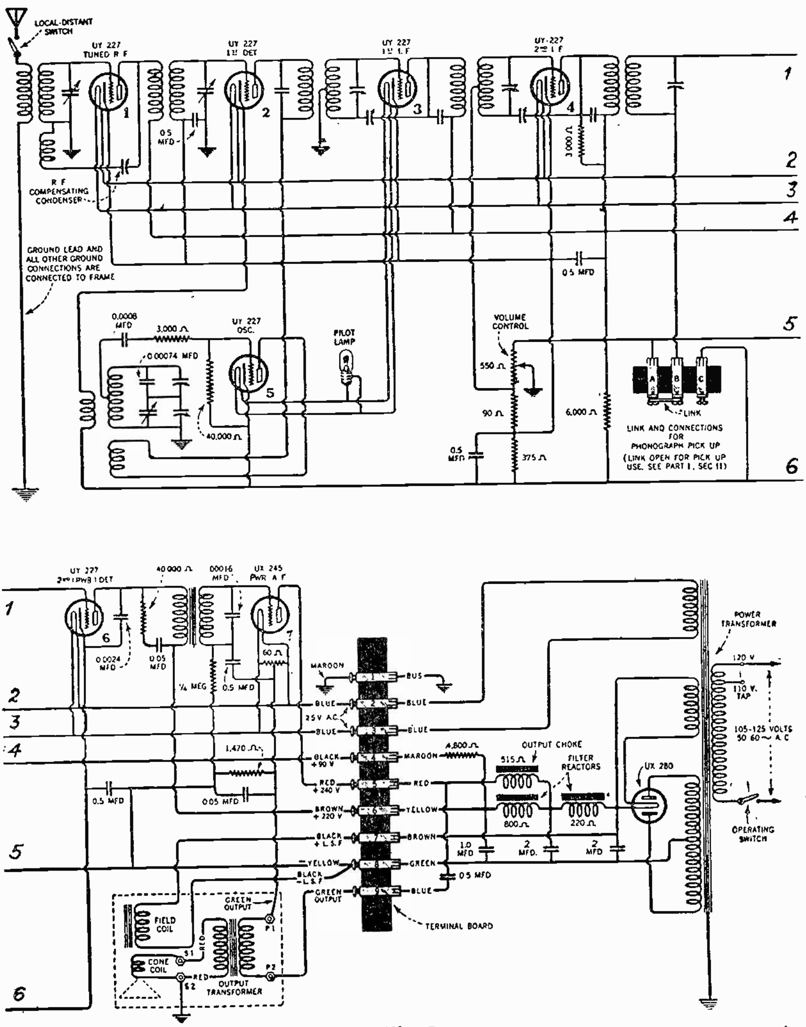


Fig. 7

NOTE.—The symbol Ω used in this drawing represents ohms.

tube has never been made and apparently cannot be made. As a result the first detector distorts the beat frequency in the plate and we have in the plate circuit, not only the beat frequency, but its harmonics, the second, third, fourth, etc. Undesirable regeneration takes place as the '27 tube has grid-to-plate capacity so that the I.F. frequency and its harmonic frequencies are fed back to the grid circuit.

If these feed back frequencies form an A.F. beat with an incoming signal, they modulate on the I.F. and the result is a heterodyne whistle. Assuming that the I.F. is 330, all carrier frequencies received must be reduced to this frequency. But due to detector distortion, harmonics appear, that is, harmonic frequencies of 660, 990, 1320, etc., in the plate circuit, and because of the tube capacity these frequencies appear in the grid circuit. Consequently incoming signals of 660, 990, 1320 kc. will be interfered with if the signal is the least bit off frequency and a whistle will be heard as these will modulate on the I.F. frequency as a carrier. Any I. F. frequency which will produce a harmonic

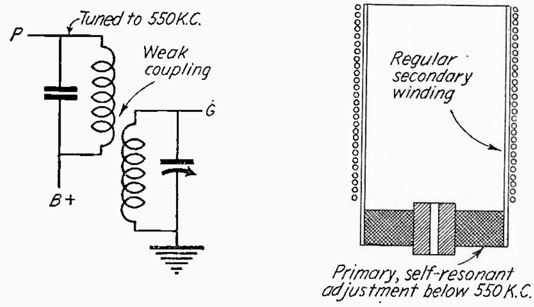


Fig. 8

whose frequency is within the broadcast band may result in an interfering audible beat or whistle.

It is safe to assume that the fourth harmonic is usually so weak that it can be neglected as far as regeneration is concerned. Hence the choice of 175 kc. as the intermediate frequency. Its second harmonic 350 kc. and its third harmonic 525 kc. are outside the broadcast band. Its fourth harmonic, 700 kc., is within the broadcast band but it is usually too weak to make trouble.

Now you might ask why was 175 kc. chosen, why not 180, as its third harmonic, 540 kc., would not be within the broadcast band? Any two picked up signals having a frequency difference equal to that of the intermediate frequency appearing in the preselector will create an interference in the intermediate frequency amplifier after passing directly through the first detector. Suppose the I.F. were 180 kc., and the receiver was tuned to 1,000 kc. Of course, if two signal carriers, one 1090 kc. and the other 910 were picked up they would be weakly amplified by the pretuner and the 180 kc. beat would be rectified by the first detector. This signal would appear in the intermediate amplifier interfering with the desired signal.

The Federal Communications Commission assigns frequencies 10 kilocycles apart to various stations. All assigned frequencies in the broadcast band are in multiples of 10, that is, 910, 920, 930, 1050, 1060, etc. Therefore, any beat frequencies resulting from the combination of two stations' frequencies will also be in multiples of 10, that is, 170, 180, 190, etc. By choosing an intermediate frequency that is a multiple of 5, that is, 165, 175, 185, and by using a sharply tuned intermediate frequency amplifier,

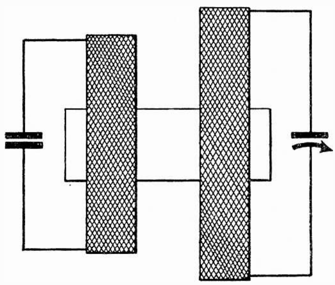


Fig. 9

the interfering signal which might possibly be amplified by the I.F. amplifier will be 5 kilocycles off the I.F. resonance point and the chance for amplifying the interference will be greatly reduced. It is for this reason that a resonant frequency of 175 kc. was chosen for the intermediate frequency of the Radiola 66, and the reason why I.F. values ending in 5 (viz. 125, 135, 175) are chosen by most engineers.

The intermediate frequency stages in the Radiola 66 are accurately tuned to the chosen 175 kc. frequency and its resonance characteristic is made flat topped to a fair degree to prevent side-band cutting. Primaries and secondaries of intermediate frequency transformers are wound in criss-cross fashion and are loosely coupled—see Fig. 9. The primaries are tuned to approximately 175 kc. by means of fixed condensers and the secondaries tuned (by means of the adjustable trimmer condensers) slightly off resonance to effect a flat topped resonance characteristic. A step-up voltage is obtained by the use of more secondary turns than primary turns. Regeneration in the I.F. stages is also prevented by the Rice method of oscillation control.

In this particular super, volume is controlled by adjusting the C bias of all the tubes before the first audio. The control acts on all tubes simultaneously.

The detector of the Radiola 66 is of the grid bias type for minimum distortion and a large A.F. detector output on strong signals is made possible by a very efficient R.F. amplifying system. The audio signal in the detector plate circuit, in fact, is sufficient to swing the grid of a '45 tube without the aid of an intermediate audio amplifier. The omission of this stage tends to reduce distortion and hum. "Flat" audio amplification is obtained by shunting the audio transformer secondary with a condenser and by the use of a shunt condenser across the primary, the latter, however, in series with a resistor. Hum signals are prevented from getting to the last audio tube grid by a series ¼ megohm resistor.

The power for the receiver is obtained entirely from the A.C. current main. All filament currents are obtained from a combination A and B power transformer—from the low voltage secondaries. The split high tension secondaries feed A.C. voltage to an '80 rectifier tube for full-wave rectification. Two filter chokes, marked 800 and 220 ohms and three filter condensers supply B and C voltages for all tubes except the output tube. A special output choke (515^{ω}) feeds a high voltage to the plate of the '45 tube and a 0.5 mfd. condenser prevents the D.C. current from flowing through the primary of the output transformer. The output transformer matches the voice coil impedance to the plate resistance of the '45 tube. Arrangements are made to shunt the field coil of a dynamic speaker of high resistance, across the highest voltage produced by the power pack without materially lowering the supply voltage. In this system the field winding is not used as a filter choke.

SILVER-MARSHALL, SM-724 A. C.

Another commercial Superheterodyne built by a pioneer in the Superheterodyne field is worthy of detailed study. Fig. 10 shows a diagram of one of the Silver-Marshall circuits.

Five screen grid tubes are used in the preselector, intermediate frequency and detector stages. The oscillator employs

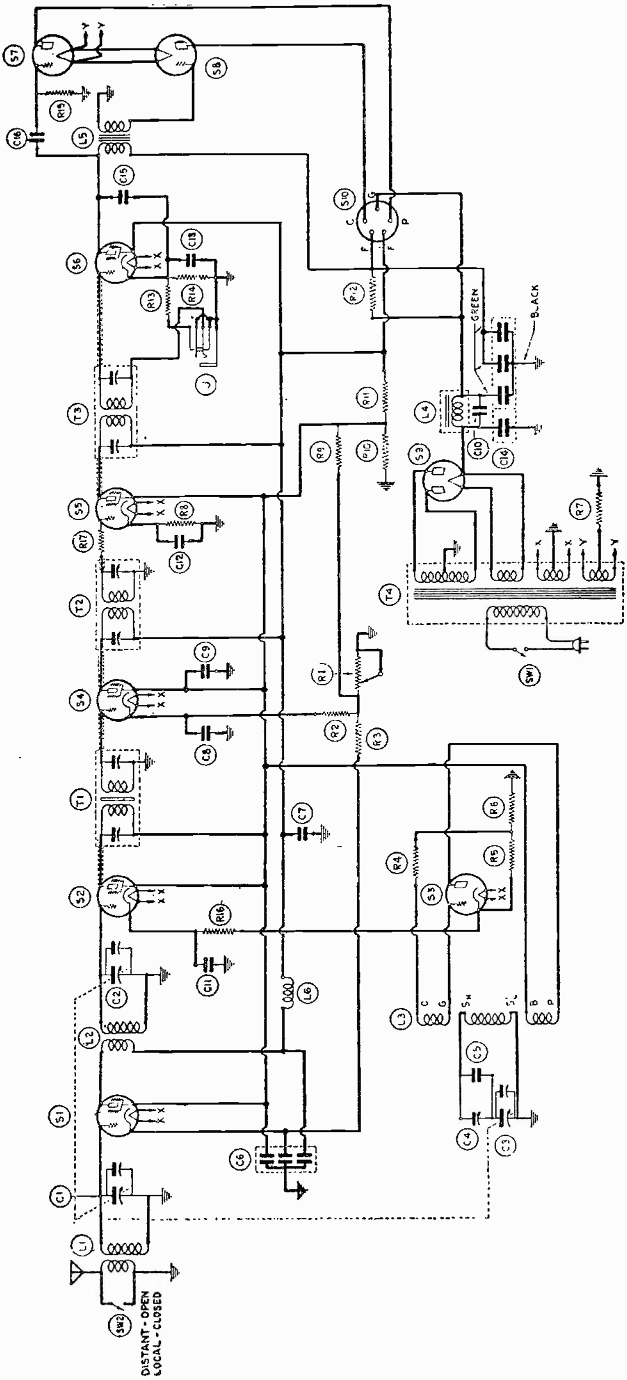


Fig. 10

a three element '27 A.C. tube. Observe that the preselector consists of a tuned aerial coupling system. The secondary is tuned by a .0004 mfd. variable condenser to cover the entire broadcast band. The antenna system includes a primary which resonates at approximately 150 to 200 kc. It is coupled to the first '24, which operates as the preselector tube, followed by a resonance transformer tuned only on the secondary side. The preselector tube feeds into the first detector through this ordinary type of R.F. transformer.

Then follows the first detector using a screen grid '24 tube which is coupled to the first I.F. stage by a tuned I.F. transformer. The transformer *T1* has a copper shielding between primary and secondary to provide extremely weak coupling. This, together with a tuned primary and secondary, gives an exact sharp resonance characteristic and exceptional selectivity. The first detector is grid tuned, and its condenser tracks with the antenna resonant system of the first R.F. stage and with the oscillator condenser. This accounts for the use of a three-section variable condenser.

Directly below the detector on the diagram is a '27 tube used in the oscillatory circuit. The circuit has a tickler feed-back. The coil *SH-SL* is smaller than the secondaries of the R.F. coils and the coil in the detector circuit, but the tuning condenser *C3* is still 400 micro-microfarads. The oscillator must operate at all times at a frequency of 175 kc. above that of the first detector and radio frequency circuits if its condenser is to track with the other two variable condenser sections. The oscillator coil and the shunting condenser systems are so proportioned that the oscillatory condenser tracks with those of the detector and preselector over the middle of the signal frequency range by a universally used scheme, the addition of *C4, C5* and a trimmer across *C3*, the variable.

Condenser *C3* is a section of the main gang of three condensers shunted by a trimmer. Directly above this, two condensers will be seen; *C5* shunted by its trimmer *C4*. *C5* is a relatively large fixed condenser having approximately the value of the tuning condenser and its trimmer combined, It is used to raise the oscillator frequency approximately 175 kc. above the incoming signal. At the center position of *C3* the presence of *C5* should make the local signal exactly 175 kc. above the received signal. The trimmer *C4* is used to align the oscillator at the low frequency end. Shunted across *C3* at the right is the trimmer condenser employed to bring the oscillatory circuit into line at the high frequency end. By the adjustment of both trimmer condensers, *C3* is made to track with the others in the gang.

The resistors *R5* and *R6* keep the oscillator grid at the desired D.C. grid bias potential. The grid feeds through the tickler *L3* and resistor *R4* to a point between *R5* and *R6*. This arrangement limits the amount of feed back. Actual oscillation is maintained by a tickler coil placed as shown below the tuned coil.

The diagram does not show how the oscillator and the first detector are coupled for mixing purposes, and it must be assumed that coils *L2* and *L3* are mounted in line in the chassis for this purpose.

The first detector feeds into the first intermediate transformer which differs from the two following transformers as explained. The purpose of the local-distance switch is to allow reception of local programs, by shorting the antenna system, in which case pick-up is obtained only by capacitive coupling. When the switch is set for distance reception the short is removed, thus providing maximum pick-up.

Three tuned primary-tuned secondary I.F. resonance transformers are used, adding either six tuned sections all resonating to the I.F. frequency, or three tuned sections each with a double humped resonance characteristic for use as band-pass selectors. The latter system is quite universal.

After passing through the second intermediate frequency transformer, the signal passes into the type '24 second I.F. tube. The grid suppressor *R17* prevents oscillation. The two I.F. '24 tubes are operated at 165 volts plate and approximately 90 volts screen. Resistors *R3* and *R1* bias the preselector tube; *R2* and *R1* bias the first I.F. tube; *R8* the second I.F. tube. The variable resistor *R1* which carries the plate currents of the first R.F. and the first I.F. tubes, acts as the volume control. Its controlling effect is increased by the bleeder resistor *R9* connecting to a 90 volt tap which introduces into *R1* a bleeder current. Thus extremely satisfactory control of volume and sensitivity is obtained.

The intermediate frequency transformer consists of a small criss-cross wound coil, mounted on a wooden dowel, with primary and secondary individually tuned by a small compression type mica condenser, having a range of 100 to 220 micro-microfarads. This particular transformer is similar to the one shown in Fig.

9 except that both primary and secondary have the same inductance and consequently both are tuned by the same sized condensers.

In the first intermediate frequency stage the coupling between the primary and secondary is weak, resulting in a very high factor of selectivity, whereas in the second and third stages, the coupling is just below a critical value which makes for a broad topped response or resonance characteristic with extremely sharp, steep sides. This is an important point, for selectivity in a receiver of this type depends almost entirely on the intermediate frequency amplifier. A flat topped response characteristic is essential in order to maintain fidelity which would be seriously affected by an amplifier whose characteristic curve was sharp. With the combination employed, tone fidelity up to 4000 cycles is extremely good. Above 4000 cycles, side-band cutting
6 appears but this is compensated for by using an audio system which has a peaked response characteristic above 4000 cycles.

The screen grid of the second detector operates at a potential of 160 volts. The plate voltage is 208. A semi-automatic C bias is obtained from resistor *R14*. The second detector plate circuit is by-passed by means of a .001 condenser, *C15*. A jack *J* permits a microphone or a phono-pickup to be connected in series with the grid and ground of the detector tube, and the resistor *R13* shunts the regular detector bias resistor *R14* so the tube *S6* has a lower C bias, permitting the tube to function as an amplifier instead of a detector.

The detector is coupled directly to the push-pull amplifier tubes through the transformer *L5,* in a unique arrangement that is characteristic of S.M. Receivers. The grids of the output tubes are fed in 180 degree opposition by phase shifting means and not by a center tapped push-pull input secondary transformer. A regular push-pull output transformer is integral with the speaker and is not shown. It, however, has the conventional center-tapped primary.

A standard full-wave rectifier is used in the power system. The filament supply is of conventional design. That is all filaments of the vacuum tubes are fed through step-down transformer windings. *L4* is the first filter choke, and the speaker field winding acts as the second choke when plugged into the receptacle *S10,* connecting to points *FF*. *R10* and *R11* are voltage divider resistors to supply screen grid and screen grid tube plate voltages. The voltage to the '45 tubes is tapped from *G* at *S10*. *R7* provides the bias for the '45 and *R15* is the grid leak for the output tube *S7*, which, together with condenser *C16* shifts the phase of the grid signal fed to *S7*. *R12* adds to the resistance of the dynamic speaker for voltage supply reduction.

RADIOLA 80

The Radiola 80 is a 9-tube A.C. operated screen grid superheterodyne receiver. A complete circuit diagram is shown in Fig. 11.

The receiver uses four '24 tubes, two '27's, two '45's and a single UX-280. The output audio power is approximately 3 watts.

Starting from the antenna circuit, we find that the aerial is coupled to the first band-pass stage through a transformer having a very large primary which causes the aerial system to resonate at a frequency below 550. This is followed by two resonant circuits, linked to each other by a very weak inductive coupling, providing a "band-pass tuner" ahead of the first radio frequency tube. To the right is the oscillator, employing practically the same system of tracking of the radio frequency and first detector circuits as is employed in the Radiola 66 and the SM-724. Note the bridge connection of the oscillator condensers.

The self-biasing grid arrangement and the high value of the grid suppressor reduce, as far as possible, the development of harmonics. The plate feeds back through a fixed tickler into the grid. The output of the first radio frequency tube is capacitively coupled to the tuned grid circuit in the first detector stage by means of an extremely small coupling condenser (4.5 mmfd.). Notice, too, that the oscillator coil, the plate feed-back tickler and the grid coil of the first detector are inductively coupled together so as to permit mixing of the local signal and the pre-amplified, pre-selected received signal. The entire arrangement is designed so that the four variable condensers will track over the complete broadcast band.

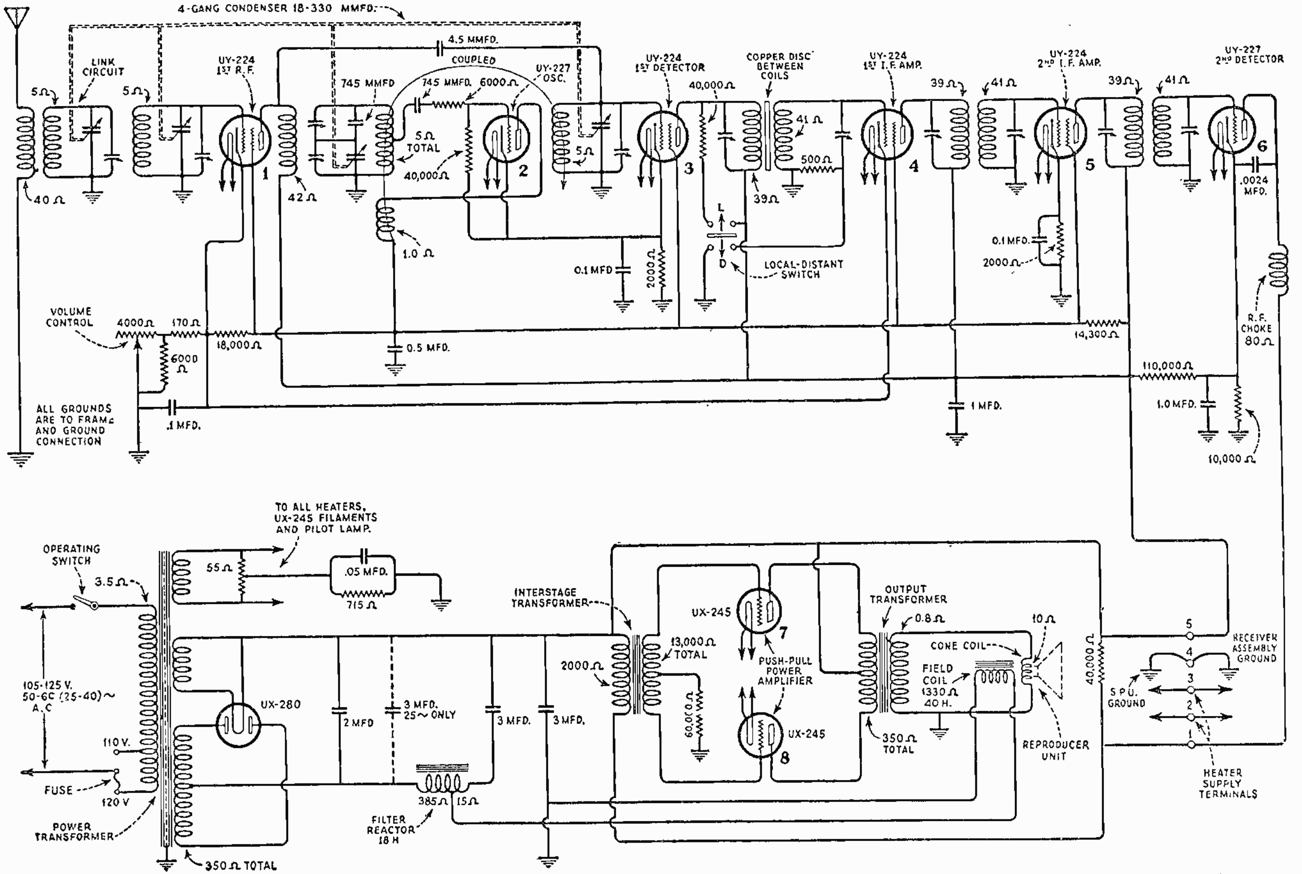
The next circuit is the first detector. The circuit is tuned as we have explained and its condenser is ganged to the preceding variable condensers. In the grid circuit there is present the incoming signal and the oscillator signal, the latter being at a frequency 175 kc. above the former. The first detector is biased so that it operates as a plate-rectification detector and isolates the beat frequency produced by the combination of the signal and the oscillator frequencies. The beat frequency, 175 kc., appears in the plate circuit of the first detector which is tuned to exactly 175 kc. The tubes are, so far, '24's with the exception of the oscillator tube which is a '27. The plate of the detector feeds into the tuned primary, tuned secondary, intermediate frequency transformer. The primary and secondary are shielded from each other by means of a copper disc, so that coupling between the two resonant circuits will be loose and its resonance characteristic will be very sharp. Both primary and secondary are tuned to exactly 175 kc.

Two resistances are connected to the first intermediate frequency transformer through a "local-distance" switch which throws them into or out of the circuit. At the "local" position, the 40,000 ohm resistor is connected across the primary of the intermediate frequency transformer and the 500 ohm resistor
7 is connected in series with the secondary and one side of the tuning condenser. The effect of these resistances is to decrease sensitivity, broaden selectivity and thus improve the fidelity of the set. At the "distance" position, the resistances are out of both circuits and the original selectivity is obtained. (Note that the 500 ohm resistor is shorted to the ground.)

The following two intermediate frequency transformers are tuned on the grid and plate sides by means of adjustable mica condensers. The grid or secondary trimmer is adjusted slightly off resonance to produce a flat-topped, steep-sided response characteristic. In this superheterodyne the primary is smaller than the secondary resulting in a voltage step-up.

The second detector is a high plate voltage, grid-biased type of detector, with sufficient output to drive two '45 power tubes in push-pull arrangement with only an audio coupling. Note that there is not, in this particular audio circuit, any intermediate audio stage and in this sense the second detector acts almost as a power detector.

The power supply is an '80 full-wave rectifier. The filaments are supplied in the conventional manner. The first choke is tapped near the end away from the rectifier tube. The turns up to the tap constitute 96.5 per cent of the total number of turns. The tap leads to the second choke which is the field coil of the dynamic speaker. The remainder of the first choke is led to a 3 mfd. condenser and supplies a hum bucking component, in an arrangement developed by Meissner. Instead of using the conventional voltage divider to supply the B and C voltages.



NOTE.—The symbol Ω used in this drawing represents ohms.

Fig. 11

Numbers 1, 2, 3, 4, 5 and S.P.U. represent binding posts of Socket Power Unit.

resistors are used to feed from one point to the other. Bias resistors are connected between the cathode and the common ground return providing automatic C bias. Volume is controlled by means of a variable C bias resistor connected in series with the cathode of the first R.F. preselector tube. The minimum C bias is limited by a 170 ohm resistor. An $18,000^{\omega}$ bleeder resistor increases the effectiveness of the volume control by introducing an extra bleeder current. A $110,000^{\omega}$ bleeder resistor helps reduce the bias resistance for the second detector.

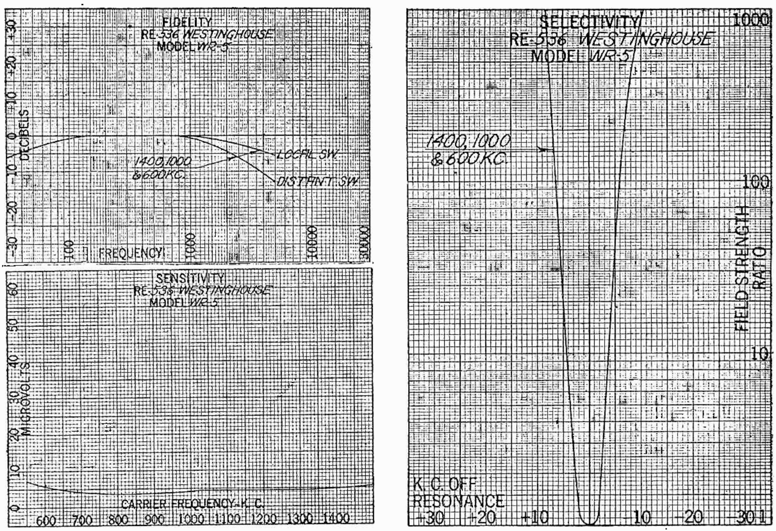


Fig. 12.—Performance Curves of the Radiola 80, Graybar 700, General Electric 31 and Westinghouse WR-5 Superheterodyne Receivers.

This circuit represents one of the finest engineering achievements in radio receiver design. This statement is well borne out by the three performance curves shown in Fig. 12. Notice the absolute 10 kc. separation, the good fidelity over the complete audio range and the remarkable sensitivity. Notice also that the selectivity is the same for all frequencies. More complete tests indicate that this selectivity is maintained for extremely strong signal input.

FADA KF43

This machine is characteristic of recent well-designed tuned radio frequency receivers employing screen grid tubes in the tuned R.F. circuits. In the light of recent developments in superheterodyne receivers, the T.R.F. set is to some extent, giving way to "supers." In spite of this, however, many engineers consider it the ideal form of broadcast receiver and continue to design models with T.R.F. as the basic circuit.

The antenna preselector circuit as shown in Fig. 13 is a conventional band-pass system combined with an R.F. equalization system to increase the R.F. response at low radio frequencies. Note that the antenna circuit inductance has a dead end section that couples also with the secondary resonant circuit. This is quite similar to the equalization system explained in an earlier text, the added capacity tuning the primary to resonance at a low radio frequency. In addition it is shunted by a 10,000$^{\omega}$ potentiometer to permit control of the R.F. energy fed to the entire receiver. This potentiometer is only half the volume control system. The first resonant circuit is inductively linked with the second tuned section by several turns in the latter.

The first and second R.F. screen grid tubes are followed by double coupled transformers, the two primaries designed to give equal R.F. amplification over the tuning range. All four tuned condensers are alike in size and shape so they can track over the complete tuning range. All R.F. circuit return leads are by-passed through a condenser unit consisting of three sections.

A screen grid, C bias detector is used, the bias obtained automatically from a 50,000 ohm resistor shunted by a 1 mfd. condenser connected between the cathode and the ground (the common return for all circuits). A resistance coupled audio follows the detector, and the R.F. unrectified component is filtered out by a π (pi) section R.F. choke-condenser filter.

The resistance coupling used may seem a bit unusual. The plate 250,000 ohm resistor, the .01 mfd. coupling condenser, and the grid leak resistor of 500,000 ohms are conventional. A 125,000 ohm resistor shunted by a 1 mfd. condenser is connected in series with the plate resistor. This capacity-shunted high resistor acts as an anti-motorboat-
8 ing device and prevents the interference that is very common when amplifiers, especially resistance coupled, are connected to high resistance voltage supplies. It acts as a filter, choking back any A.C. that might tend to get into the audio circuit. A similar combination is included in the grid input to the first audio tube.

From the first audio, the audio signal is fed to a push-pull input transformer, shunted on the secondary by a .0005 mfd. condenser to bypass the high frequencies, thus increasing the bass response of the receiver. The output push-pull transformer is integral with the dynamic speaker, the primary connected by lead wires to the plates of the '45 output tubes.

The power supply section of the receiver is unique in its simplicity. All filaments are supplied from the low voltage secondaries of the com-

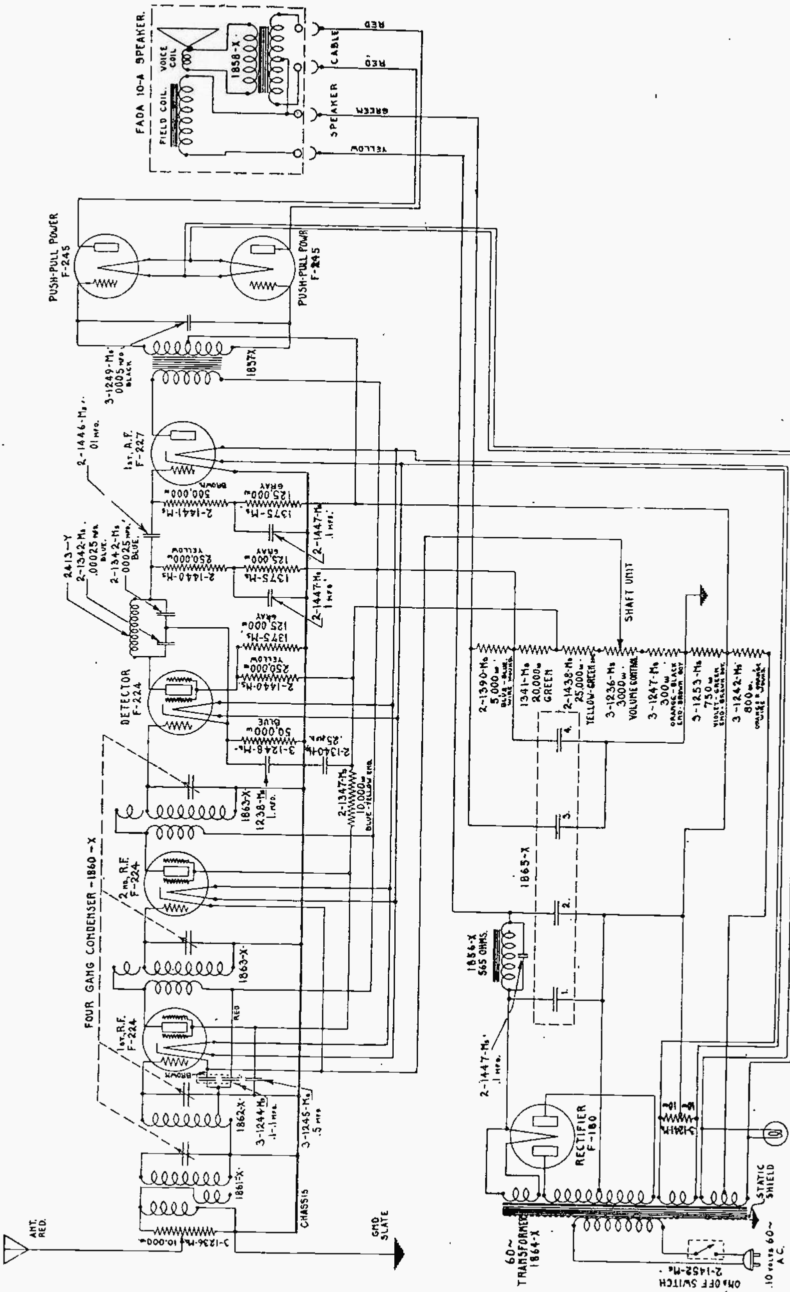

FADA 10-A SPEAKER
FIELD COIL
VOICE COIL
SPEAKER CABLE
RED
GREEN
YELLOW
PUSH-PULL POWER F-245
1st. A.F. F-227
DETECTOR F-224
2nd. R.F. F-224
1st. R.F. F-224
FOUR GANG CONDENSER -1860-X
SHAFT UNIT
VOLUME CONTROL
RECTIFIER F-180
60~ TRANSFORMER 1864-X
ON-OFF SWITCH 2-1452-Ms
STATIC SHIELD
CHASSIS
GND SLATE
ANT. RED.

Fig. 13

bined A-B-C power transformer. The rectifier is a full-wave '80 tube. Two choke coils are used, the second being the field coil of the dynamic speaker. Filter condensers *1, 2,* and *3* having capacities of 2, 2 and 1 mfd. are used. The first filter choke is shunted by a .1 mfd. condenser, thus forming a parallel resonant circuit tuned to the 120 cycle hum ripple, which offers infinite impedance to the hum frequency. Obviously from the formula $f = \frac{1}{6.28\sqrt{LC}}$, if the condenser is .1 mfd., the choke will have an inductance of 17.5 henries when passing maximum D.C. current.

Voltage for the plates of the '45 tubes is obtained by tapping the power supply at a point directly after the second choke (the speaker field coil). The voltage divider comes after the second choke and supplies the remaining voltages. A voltage to feed the C biased screen grid detector is taken off the voltage divider at a point 5,000 ohms below the high voltage end. The next tap feeds the screen grids of the 1st and 2nd R.F. and detector tubes through resistors which reduce the voltage as required. A 3000 ohm potentiometer is connected in series with the voltage divider to permit a variable grid voltage to be fed to the two R.F. tubes. This potentiometer and the potentiometer across the primary of the first preselector coil act in unison, so that when large volumes are desired, a lower bias voltage is fed to the grid of the two R.F. tubes and the coupling between the aerial and the preselector is increased.

The two lower resistors of the voltage divider provide bias voltages for the first audio and the push-pull power tubes. The resistor directly below the ground connection connects to the grid of the first audio and also to the grid returns of the push-pull audio tubes. The lower 800 ohm resistor connects to the center of the filament supply of the '45 tubes, supplying an automatic bias for the power tubes.

MAJESTIC 20

Midget or mantel radio receivers are becoming almost more popular than receivers placed in large cabinets. To the owner of a full-sized set, a midget serves as a second Radio of a portable Radio which can readily be carried from one place to the other and installed wherever an aerial and ground are handy. For those who do not feel that they can afford a large Radio, the midget appears an attractive buy. In spite of the insistence of radio experts, the public fails to appreciate that a small speaker and a small baffle (the speaker housing) will injure the bass response. They do, however, fill a definite need in radio broadcast reception.

The Majestic 20 shown in Fig. 14 is a midget receiver—one that in construction and design rivals the larger machines. In fact, installed in a large cabinet with a larger speaker, it would compare favorably with full-sized sets. It is a machine which typifies the modern portable superheterodyne design and so is included here for circuit study. Of outstanding importance is the use of the type '51 variable mu tubes, which reduces the tendency for cross-talk and R.F. modulation distortion.

The R.F. signal is amplified in a regular superheterodyne arrangement—a preselector consisting of a tuned aerial input and a stage of R.F. amplification. The aerial and ground feed directly to a parallel resonance coil-condenser arrangement, but with a series, separately adjusted condenser, referred to in the diagram as the antenna compensating condenser. Thus the degree of coupling to the aerial and ground may be varied, and a control on sensitivity and selectivity thereby maintained. A .001 mfd. condenser may be connected across the aerial and ground to provide the antenna capacity needed when the set is operated with a small aerial.

An equalized resonance transformer follows the R.F. '51 tube, conventional except that a series inductance is inserted in the primary for equalization of amplification over the entire tuning range. The secondary is tuned by the second section of the three gang variable condenser, each section of which is shunted by a trimmer condenser. Signals are fed into the grid of the first detector (mixer) tube, in this case a '51.

Directly above the preselector and mixer detector is shown the local oscillator, a '27 tube. The oscillator is a simple tuned grid circuit with a plate tickler feed-back. The oscillator condenser, which is ganged with the tuning condensers, is made to track in the usual manner—by the use of one fixed and two adjustable condensers. The oscillator must always produce a local frequency 175 kc. above the frequency of the incoming carrier. Self-adjusting biasing is obtained by the use of the .00005 mfd. condenser and the 100,000 ohm grid leak. A 2000 ohm resistor acting as the bias resistor of the mixer tube, shown below the first two '51 tubes is connected to the mixer cathode in series with a link coil coupled to the oscillator tuned grid coil. The mixer bias resistor is by-passed before connecting to the link coil, hence the local and received signal are present in the mixer grid circuit, where the I.F. frequency results from the beating process.

Then follows the I.F. amplifier tube, also a variable mu type '51, preceded by a double resonance transformer, and followed by a similar transformer. This adds four tuned circuits to the R.F. system, permitting sharp band-pass tuning. Notice that the plate of the I.F. amplifier tube connects to a tap in the following primary, resulting in reduced coupling and so, increased selectivity.

A "C" bias detector separates the audio signals from the I.F. carrier, passing the audio signals directly into a push-pull '45 arrangement of standard design. The C bias of the second detector is auto-
9 matically obtained from a $35{,}000^{\omega}$ resistor in series with the cathode and ground. Two .4 mfd. condensers serve as the by-passes. Radio frequency signals are prevented from entering the input push-pull transformer by the 50 millihenry R.F. choke and the .001 mfd. by-pass condenser between the plate and cathode of the second detector.

The input of the audio transformer may be shorted through a .022 mfd. fixed condenser by means of a switch which connects one side of

SCHEMATIC DIAGRAM OF MAJESTIC SCREEN GRID SUPERHETERODYNE RECEIVER
MODEL 20 CHASSIS 110 AND 220 VOLTS – 50-60 AND 25-40 CYCLE

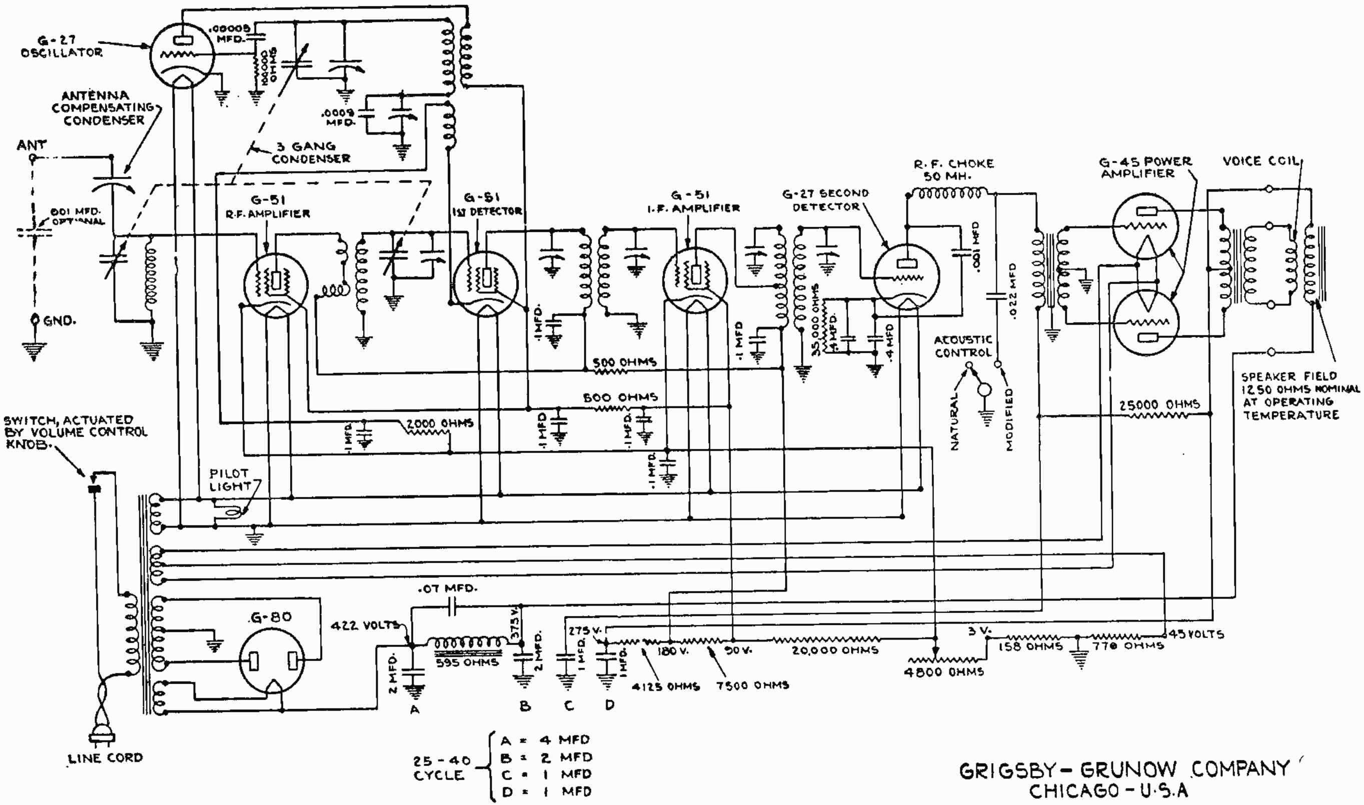


Fig. 14

the condenser to ground. In the alternate position of the switch, the condenser is removed from the circuit. When present in the circuit, high audio frequencies are by-passed, masking the audio signal and contributing a false bass to the reproduced sound. The taps of the switch are labeled natural and modified. In the latter position, noise and normal static may be reduced in intensity.

An output push-pull transformer matches the dynamic speaker voice coil impedance to the push-pull '45 tubes. As a result of modern R.F. design the R.F. amplification of the set is sufficient to produce a detector audio output that can swing the grids of two '45 tubes in push-pull.

A combination A and B supply transformer connects to the line cord; and the filaments are fed from the low voltage secondaries. Rectified B voltage from the full wave '80 tube is first filtered by a parallel resonant choke and then passes through the field of the dynamic speaker which serves as the second choke. Filter condensers are *A, B, C,* and *D,* the capacities of which are made higher if the supply voltage is 110^{V} 25 cycles instead of the customary 110^{V} 60 cycles.

Observe that one lead of the field choke connects directly to the
mid-tap of the output audio transformer feeding 275 volts to the '45
plates. A 770 ohm resistor between the ground and the center tap of
10 the secondary furnishing raw A.C. to the '45 filaments in parallel pro-
vides an automatic 45^{V} C bias for the power tubes. The filter condenser
D is connected between the ground and the power tubes' plate supply.

A 25,000 ohm resistor reduces the 275^{V} of the power tube supply to the voltage required for the power detector, about 200 volts. The resistor of 4125 ohms (near point *D*) reduces this voltage to 180 volts for the plate of the I.F. tube. The 180^{V} is further reduced by a 500 ohm resistor, to the correct value for the plates of the preselector tube and the mixer tube. Following the 4125 ohm resistor, a 7500 ohm resistor serves to further reduce the voltage to 90 volts which is led directly to the I.F. screen grid and to the screen grids of the first two '51 tubes after passing through another 500^{ω} resistor.

Between the 90 volt tap and the ground is a $20{,}000^{\omega}$ resistor, a variable 4800^{ω} and a 158^{ω} resistor. The variable resistor furnishes a varying C bias for the '51 tubes, the proper method of controlling volume when this type of tube is used. All bias and plate voltages are adequately by-passed to keep the signals in their proper route as they proceed from the aerial to speaker.

TEST QUESTIONS

Be sure to number your Answer Sheet 24 FR.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and the best possible lesson service.

1. How and in what terms is the sensitivity of a receiver measured?

2. Describe the construction and purpose of a phantom aerial.

3. How is the Radiola 66 designed so the set will give maximum amplification at low frequencies?

4. How is the local oscillator signal in the Radiola 66 transferred to the first detector?

5. How is exceptional selectivity obtained in the I.F. stages of the S.M. superheterodyne receiver?

6. How are the effects of side-band cutting at the higher audio frequencies compensated for in the S.M. receiver?

7. What is the purpose of the 500 ohm resistance in the grid circuit of the first I.F. amplifier of the Radiola 80?

8. How may motor-boating be prevented in resistance coupled amplifiers?

9. What is the purpose of the 35,000 ohm resistor in the cathode circuit of the second detector in the Majestic 20 receiver?

10. How is the C bias for the two '45 power tubes in the Majestic 20 obtained?

PHOTOELECTRIC CONTROL CIRCUITS WITH RELAYS

25X

REFERENCE BOOK

PIONEER HOME STUDY RADIO SCHOOL

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WASHINGTON, D.C.

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This reference book will prove very valuable should you ever have occasion to deal with photoelectric apparatus, for it contains logical and understandable explanations of the operating principles and characteristics of basic electronic circuits. Give especial attention to the relay section of the text, for you will encounter relays many times in work with radio transmitters and in remote control radio installations such as are used in two-way police car systems, in aircraft radio, and in a host of other commercial radio systems.

Read through the material on the photoelectric and electronic control circuits at least once; each circuit has been carefully selected to show certain fundamental principles which, once understood, can be utilized in designing many other useful circuits of the same general type.

Electronic tubes such as the well-known General Electric Thyratron and the Westinghouse Grid-Glow tubes are being used more and more in industry today; you will find in this text more than ample reference material on this particular subject.

J. E. Smith.

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Photoelectric Control Circuits with Relays

A REVIEW

YOUR study of light-sensitive cells has shown that these "electric" eyes" interpret a change in light as a change in their electrical characteristics. Thus, light causes a photoconductive cell to change its resistance, this change being converted into either a current or voltage change by the cell circuit; a photovoltaic cell actually produces an e.m.f. directly, this generally being used to give a current change in an electrical circuit; a photoemissive cell controls the electron flow in its circuit, thereby producing changes in voltage and current. Although these actions are quite definite, it must be clearly borne in mind that the current changes are quite small, usually of the order of microamperes, but occasionally as large as several milliamperes, depending upon the kind and type of cell used. In order to control electrical apparatus with light-sensitive cells, it is sometimes necessary to build up these comparatively small current changes. Obviously relay devices are necessary; before typical photoelectric circuits are considered, the basic principles of the different types of relays should be understood.

In any practical control circuit, the impulse or electrical power change originating at the photoelectric cell must actuate an electromagnetic relay whose contacts either open or close the circuit to the device which is to be controlled by changes in light. The greater the current required by the device, the greater must be the pressure of one contact against the other, the larger must be the contacts, and the greater must be the power required to operate the relay; a single sensitive relay in the photoelectric cell circuit can therefore control only small loads. Where large currents are to be controlled, the sensitive relay is made to actuate a power relay which has large contacts, capable of handling heavy currents.

Many different schemes for linking the light-sensitive cell with the power relay have been introduced. Electromagnetic relays connected in succession, so the contacts of one control the input to the next, are widely used where conservation of power is desired. For example, a photovoltaic cell may actuate a supersensitive relay which controls a semi-sensitive relay, and this secondary relay in turn operates the final heavy-duty relay.

Because super-sensitive relays are expensive and require considerable attention, many methods have been developed to eliminate their use. A voltage change in the cell circuit can be amplified sufficiently by one or more vacuum tube amplifiers to operate sensitive or heavy-duty relays. The voltage change originating at the cell can also be applied between the grid and cathode of a gas triode (such as a "grid-glow" or a Thyratron tube), and a heavy-duty power relay can be inserted in the plate circuit of the gas triode; in many cases the device being controlled can be connected directly into the plate circuit of the gaseous tube, in place of the power relay.

Thus, you may find between the light-sensitive cell and the controlled device either an electronic relay (consisting of one or more gaseous or vacuum type amplifier tubes), an electromagnetic relay, or a combination of the two. The intervening relay circuits may impart special characteristics to the complete photoelectric control unit, but in general, the final action is to open or close the circuit at the desired time interval after the light on the cell has changed by a certain definite amount.

In considering the characteristics of relays and the selection of a relay for a particular application, certain fundamental facts must be

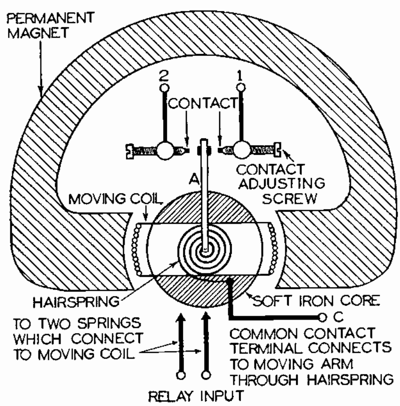


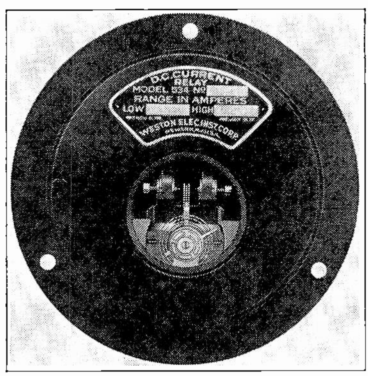
FIG. 1A. The basic construction of a supersensitive or meter type relay, shown above, is very similar to that of a high quality moving coil type meter.

considered. How much current is required to make the relay contacts close? This current is called the *pull-up* current of the relay. At what value of current will the relay contacts open? This is called the *drop-out* current. Other important factors are: How long does it take after the current or voltage reaches the pull-up value before the contacts close completely? How much time elapses, after the relay current is reduced to the drop-out value, before the contacts are opened? Where rapid counting or fast action is required, fast relays are used; for certain jobs, such as illumination control applications, extremely slow relays are needed; where light changes on the cell are small, the difference between pull-up and drop-out currents must be small. The nature of the power supplied to the relay circuit must be considered, for relays designed for D.C. use are as a rule more sensitive than A.C. relays. The ohmic value of the relay coil is another important factor, for the voltage drop across the coil must be considered in the design of the control circuit.

Other factors affecting the selection of a relay are the current, the voltage and the nature of the load in the circuit being controlled. The contacts must be able to carry and break the current through the circuit without serious arcing or sparking. The voltage must not be so high that current will jump across the contacts when they are open. With these basic facts in mind, I will now consider the various types of relays used for photoelectric and electronic control systems.

SUPER-SENSITIVE RELAYS

From a practical viewpoint, super-sensitive electromagnetic relays are really modified moving coil type microammeters, with platinum-iridium contacts mounted on the moving pointer and adjustable contacts, one on each side of the pointer, mounted on the meter scale. Platinum-iridium contacts are used because this alloy does not oxidize or tarnish in air, and resists the pitting (eroding) action of the current.



Courtesy Weston Electrical Instr. Co.

FIG. 1B. Weston Model 534 meter type relay, capable of operating on coil currents as low as 15 microamperes.

The basic arrangement of a typical super-sensitive relay is shown in Fig. *1A;* the two moving coil terminals are connected into the controlling circuit (light-sensitive cell circuit), and the remaining three terminals, going to contacts *1* and *2* and to pointer *A*, are for the controlled circuit. An increase in current through the relay coil will send arm *A* to contacts *1* or *2*, depending on the direction of current flow in the coil circuit. The sensitivity of this relay depends on the strength of the permanent magnet, the number of turns on the coil, and the spring restoring torque (twist), just as with ordinary meter movements; units which will make contact on currents as low as 5 microamperes are obtainable. One commercial form of this relay, the Weston meter-type relay, is shown in Fig. *1B;* the minimum current required to close the contacts is 15 microamperes and the contacts are rated to handle up to 200 milliamperes (non-inductive load) at 6 volts.

A simple super-sensitive relay of this type can be used in the following three ways:

I. With *no current* flowing through the relay coil, arm *A* (Fig. *1A*) is set midway between contacts *1* and *2*, so a positive current (a current flowing in such a direction that it causes the pointer to swing clockwise) will move arm *A* to contact *1* and a negative current (making pointer swing counter-clockwise) will move the arm to contact *2*. The closer together the contacts are placed, the smaller is the current required to move the arm over to one of the fixed contacts.

II. Arm *A* is made to center itself halfway between contacts *1* and *2* for a *definite value* of coil current, making contact with *1* when the current exceeds this value and making contact with *2* when the current falls below this mid-value. Moving contacts *1* and *2* closer together gives relay action for smaller changes in current.

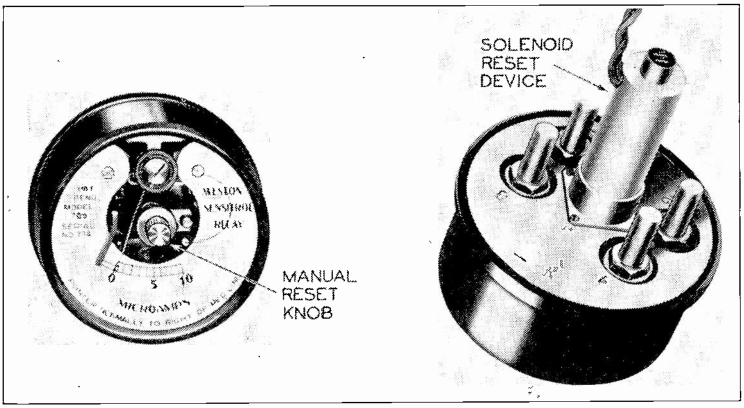
III. Arm *A* is set to make contact with *2* for all coil currents from zero up to a certain definite value in the relay range; currents above this value then move the arm over to contact *1*. The reverse of this action is also possible.

The speed of operation of meter type relays can be increased by moving the fixed contacts closer together; small currents and voltages, usually not over 200 milliamperes at 6 volts, can be controlled where fast operation is desired. There must be no appreciable inductance in the contact circuit which would cause serious arcing.

Any current or voltage range for the moving coil of the relay can be obtained by the proper use of shunts and multipliers. Super-sensitive relays having ranges below 200 microamperes can be connected directly across dry or wet type photovoltaic cells, or placed in series with a battery across photoconductive cells. The contacts of the relay as usually connected through a 4.5 to 6-volt battery to the coil of a semi-sensitive relay, which may in turn actuate a power relay.

The extremely high sensitivity of the meter type (super-sensitive) relay is offset by a number of disadvantages. There is a tendency for the contacts to "chatter," or open and close repeatedly when the actuating coil current is just about enough to make or break a contact; this results in arcing, faulty operation of the relay and eventual destruction of the contacts. To overcome this chattering without depriving the relay of its low current pull-up value, the Weston Instrument Corporation has introduced their so-called *Sensitrol* relay, shown in Fig. *2A*. The basic construction of this relay is like that shown in Fig. *1A*, except that a small soft iron piece or "rider" replaces the contact points on moving arm *A*, and a small but powerful permanent magnet replaces the contact at 1. When the arm swings over to the right it is snapped up against the face of the magnet, making a solid contact. External force must be applied to the pointer to free the rider from the magnet and break the contact. This can be done in either of two ways, by turning the reset knob in the center of the relay, which pushes the pointer back to its no-current position, or by using a solenoid to reset the pointer electrically. The solenoid type Sensitrol is pictured in Fig. *2B*.

Sensitrol relays can be obtained in many different types, to open or close a circuit on either an increase or a decrease in current. These relays are most often used for installations where repeated or continuous control is unnecessary, such as in locations where an attendant can reset the relay after each closing. Time relays can be used in conjunction with the solenoid type Sensitrol to reset the relay automatically; although the apparatus required is quite expensive, it gives the only practical solution to certain types of control problems.



Courtesy Weston Electrical Instrument Co.

FIG. 2A. Weston Model 705 Sensitrol relay with single fixed contact. The manual reset knob must be turned after each operation of this relay.

FIG. 2B. Rear view of solenoid reset type of Weston Model 705 Sensitrol relay. The twisted wires go to a source which provides relay reset current; the four terminal posts are for relay coil and contact connections.

SENSITIVE RELAYS

Relays of the sensitive type require currents of from .5 to 3.0 milliamperes for their operation. This type of relay is used in the plate circuit of a vacuum tube amplifier whose grid is connected to the control element (light-sensitive cell, thermostat, beat frequency oscillator, etc.), and in circuits where it is controlled by the contacts of a super-sensitive relay.

In general a sensitive relay consists of a soft iron armature, pivoted at one end and having contacts on each face at the other end, this armature being attracted to the iron core of an electromagnet when the required current is passed through the electromagnet coil.

Figure *3A* gives the construction of a typical sensitive relay. A large number of turns of No. 30 to No. 40 B. & S. gauge enamelled or insulated copper wire is wound on a bobbin which slips over one leg of a U-shaped core. These coils are designed to have the greatest number of ampere turns for a given operating voltage and current. The weaker the rated pull-up current of the relay, the greater must be the number of turns on the coil; increasing the turns means increasing the resistance of the coil. Relay coils have resistances varying from 1 to 10,000 ohms, depending upon the operating current; sensitive relays for photoelectric work ordinarily have resistances of from 1,000 to 8,000 ohms.

Relay coils are generally rated according to the power in watts required to pull up the armature and close the contacts. This wattage rating allows relays of different voltage and current ratings to be compared as to sensitivity.

Pivoted at one end of the U-shaped core (Fig. *3A*) is the soft iron armature which is attracted to the U-shaped core when the solenoid is excited with sufficient current. The armature is normally held against contact C_2 by the action of the spring; when pull-up current passes through the coil the armature is pulled up against C_1. Thus, by making

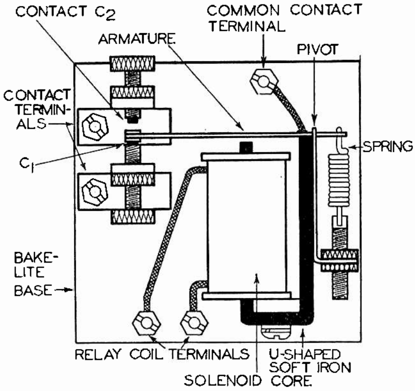
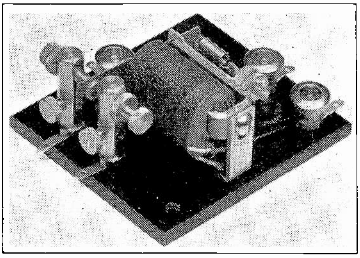


FIG. 3A. Sketch showing construction of a typical sensitive relay. The common contact terminal connects to the armature.



Courtesy Samuel Wein

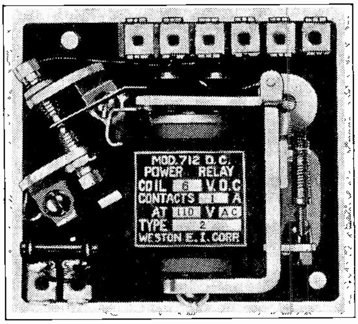
FIG. 3B. This commercial sensitive relay is very similar in construction to that shown in Fig. 3A.

the proper connections to contacts C_1 and C_2 the control circuit can either be opened or closed by the relay, or two separate circuits can be controlled.

It is important that the armature and the core of the relay coil be made of material which will not retain its magnetism when the current falls below the pull-up value. Special alloys of iron with silicon, which change their magnetism as the magnetizing current changes and lose practically all magnetism when the current drops to zero, are therefore used. These alloys have a high permeability, which means that they produce a large magnetic attraction for low values of ampere turns; the lower the electrical power required to pull up the armature, the more sensitive is the relay. Note that one end of the armature (the lower end in Fig. *3A*) rests against one of the poles of the U-shaped core; this reduces the reluctance of the magnetic circuit, giving greater sensitivity.

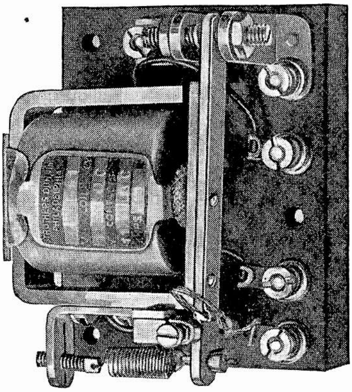
The armature must be properly balanced so it will move freely without wasting any of the attractive force, if maximum sensitivity is to be obtained. The connection to the armature is ordinarily made at some point on the U-shaped core, current passing through the pivot and out along the armature to the double contacts. Pigtails (flexible leads) are sometimes used to bridge the pivot and give a more dependable electrical connection. Sensitive relays of this type will handle about 2 amperes at 110 volts A.C. or ¼ ampere at 110 volts D.C., provided the loads are non-inductive (have no coils which offer an inductive reactance to current flow). Typical sensitive relays are shown in Figs. *3B*, *4A* and *4B*.

Another type of sensitive relay, shown in Fig. *5*, is commonly known as a *telephone type relay*, because it is widely used in telephone circuits. The coil of this relay is about 3 inches long and 1 inch in diameter, and



Courtesy Weston Electrical Instr. Co.

FIG. 4A. Weston Model 712 D.C. sensitive relay, capable of handling up to 1 ampere at 110 volts A.C. The coil is wound for 6 volts D.C. The common contacts are here mounted on a thin springy blade attached to the armature; this gives a wiping motion at the contacts, which tends to keep them clean.



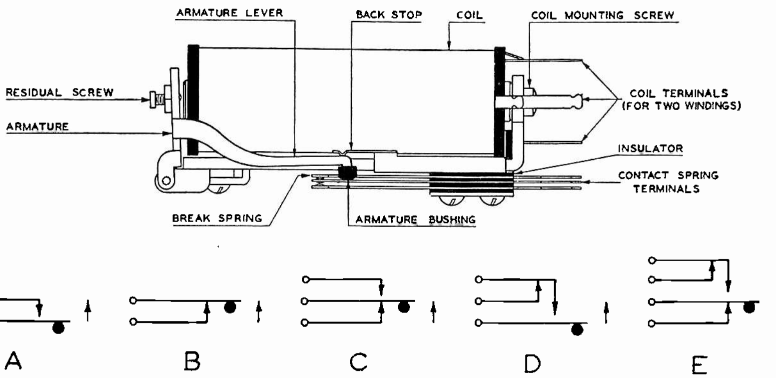
Courtesy Struthers Dunn, Inc.

FIG. 4B. Dunco Type CXB51 sensitive relay, which can be obtained with coils of various voltage and current ratings for either A.C. or D.C. This relay will operate on as little as .01 watt D.C. or .2 watt A.C. U-shaped core has central leg on which coil is mounted. Note pigtail connection to armature.

has a cylindrical soft iron core. At one end of the core a rectangular soft iron armature is so pivoted that it is attracted to the core when current flows through the coil. There are no contacts on the armature; instead there is an armature lever having at its tip an insulated bushing. When the armature pulls up, this lever pushes against springy steel blades on which the contacts are mounted; these contact blades can be arranged either to open or close circuits when the relay operates. The blades are very similar to those used on plug-in telephone jacks. Any number of combinations of make-and-break circuits is possible. A few of the fundamental contact possibilities are shown in Fig. *5*. When the armature button moves in the direction of the arrow, the indicated "make-and-break" or open-and-close action takes place.

The telephone relay is an extremely flexible device; with certain modifications it can be adapted to any practical speed or function. It will pull up in .02 to .05 seconds, and drop out in the same time. A residual magnetism screw, set into the armature to prevent it from sticking to the core when coil current is zero, can be adjusted to reduce the movement of the armature, thus speeding up its action.

The drop-out time of the telephone relay can be increased by using an electrical means for preventing a rapid decrease in magnetic flux.



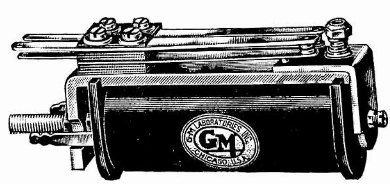
Courtesy Automatic Electric Co.

FIG. 5A. Diagram of a typical telephone type relay, widely used in electronic control apparatus as well as in telephone work. The relay contacts are, according to the manufacturer, capable of handling up to 450 watts; as a general rule, however, it is necessary to use a power relay when the load to be controlled exceeds 200 watts. Below the relay are five basic contact assemblies for telephone type relays (shown in their normal position when no current flows through the relay coil): Form A—Make; B—Break; C—Break before Make; D—Make before Break; E—Break and Make before Break.

For instance, a medium speed relay is obtained by placing a copper sleeve over the iron core (between the coil and the core). A slow speed relay is obtained when a heavy copper washer is slipped over the end of the core. The thickness of the washer determines the speed of operation of the relay. The principle of mutual induction explains why relays can be slowed up in this way; the copper washer or sleeve is really a single turn coil of low resistance, mutually coupled magnetically (by

Courtesy G-M Laboratories

FIG. 5B. A type of telephone relay designed especially for photoelectric work; note that there are two pairs of contacts.



the core) to the relay coil. The thicker the washer, the lower its resistance and the longer it can prevent a change in the flux through the core.

Super-sensitive relays are generally of the fast type; however, sensitive relays are made with fast, medium and slow operating speeds. Fast, sensitive relays are recommended for use in the plate circuit of a vacuum tube. The most dependable relays have a drop-out current which is about one-half the pull-up current; this gives a relay differential (ratio of drop-out current to pull-up current) of 50 per cent. Relays with differentials of 15 per cent to 25 per cent are available, but these in general require more frequent attention; they operate on small differences in exciting current, but this low differential makes for a less sturdy relay and one which has a tendency to chatter.

The sensitive relay can be used in A.C. or pulsating D.C. current control circuits if certain precautions are observed. A.C. voltages are almost always easier to obtain in the various required values, whereas batteries change in voltage and require constant replacement. Where a super-sensitive relay controls a sensitive relay, the exciting voltage, say 6 volts A.C., could be obtained by a step-down transformer; where the sensitive relay is placed in a self-rectifying plate circuit whose supply voltage is raw A.C., pulsating D.C. current would pass through the relay coils; these are practical instances where control equipment is operated directly from an A.C. power line, with no auxiliary batteries.

A telephone relay (designed specifically for D.C. use) may be used in a self-rectified plate circuit if a condenser is shunted across the relay coil. The lower the coil resistance the larger must the condenser capacity be to prevent contact chatter. Always use the smallest capacity

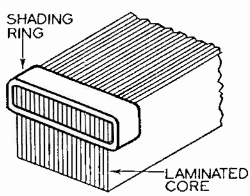


FIG. 6. In order to prevent chatter when relays are operated on A.C., a heavy copper shading ring like that shown here is forced into a slot cut into that end of the laminated iron core which faces the armature.

which will prevent chatter, for too large a condenser would take too much current away from the relay coil. A 2 mfd. condenser is about correct for a 5,000-ohm relay coil.

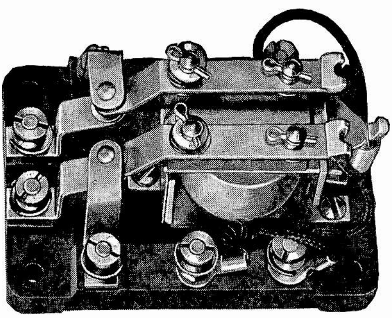
Special types of relays are available for use in A.C. circuits; these are generally less sensitive than the D.C. type, for power is lost because of *eddy currents* and *hysteresis*. A.C. and D.C. relays have much the same construction; the cores and armatures of some A.C. relays are made up of very thin sheets of silicon iron, like audio transformers, while other types use solid cores having one or more slots along one side to reduce eddy currents. Then, too, the mass (weight and shape) of the moving armature, and the spring tension must be such that the moving system has a vibration period which is less than the frequency of the exciting current. As an additional check on chattering, that pole of the core which faces the armature has a split end, in which is embedded a heavy copper ring, called a "shading" ring or coil; this is shown in Fig. *6*. This ring acts like a short-circuited secondary winding, its induced current producing a flux which holds the armature down during that part of the cycle when the current (and the main flux) drops to zero. This shading coil is commonly referred to as a *split phase* device. All these factors tend to make A.C. relays less sensitive and more expensive than D.C. types.

HEAVY-DUTY OR POWER RELAYS

When the power that is to be turned on or off by a relay exceeds 200 watts for A.C. and 25 watts for D.C., the maximum values which can be handled by the *average* sensitive relay, this type of relay is generally connected to actuate a power relay.

The coil of a power relay requires a D.C. input power of about 2 watts, in general, for satisfactory control of up to 1,000 watts A.C.; if a 100 volt D.C. source is used to excite the power relay coil the operating or pull-up current ($I = P/E$) will be $2 \div 100$ or .02 ampere (20 milliamperes). The resistance of the relay coil ($R = E/I$) should therefore be $100 \div .02$ or 5,000 ohms in this case. The required resistance for any relay coil can be figured in this manner. In general, A.C. relays require a higher power input than D.C. relays.

The principle of operation of the power relay is essentially like that



Courtesy Struthers Dunn, Inc.

FIG. 7. Dunco midget heavy-duty relay (Type CDBX1), having two contact blades mounted on the clapper type armature to give double-pole double-throw operation.

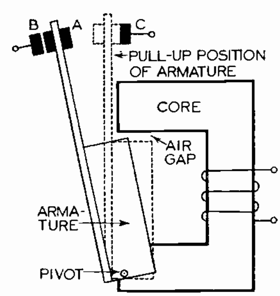
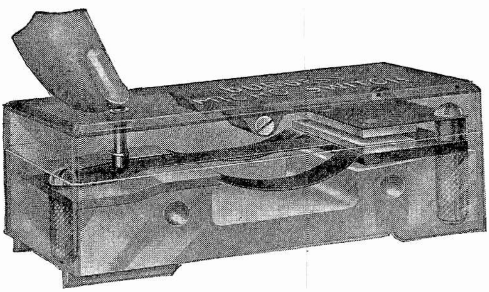


FIG. 8. Diagram illustrating the principle of operation of the minimum reluctance type of power relay. Dotted lines show pull-up position of armature.

of the sensitive relay. The same precautions are taken to prevent chatter on power relays designed for A.C. excitation. A typical power relay (also called an auxiliary relay) is shown in Fig. 7. A rectangular clapper type armature is pivoted in front of an electromagnet, the clapper carrying one or more contact arms which move between fixed contacts. The one shown is a double-pole, double-throw switching relay, one circuit being closed when the relay pulls up, the other being closed when the relay drops out. A large number of make-and-break combinations are possible. Where a super-sensitive relay controls a sensitive relay and this in turn actuates the power relay, the first two relays are essentially simple make-and-break types, while the power relay furnishes the desired type of switching, often quite complex.

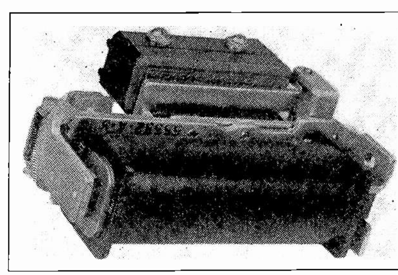
Another form of power relay, one which can apply heavy contact pressures, makes use of the suction or minimum reluctance action of a magnetic circuit. The principle is explained in Fig. *8;* when A.C. or D.C. is fed to the relay coil the armature has a tendency to take a position which will make the reluctance of the magnetic circuit a minimum (by making the air gap between the armature and the poles as small as possible). The armature then takes the position shown by the dotted lines, the contact arm moving from *B* to *C*. (Figure *11B* shows one example of a minimum reluctance type of power relay.)

Both sensitive and power type relays can be made with a small latch or mechanical lock which will hold the armature in position once it has been attracted to the core. Relays with this device are known as *latch-in relays;* they must be released either mechanically (by pushing on the latch) or by an auxiliary electromagnet whose armature is attached to the latch. Latch-in type relays are useful where the relay-



Courtesy C. F. Burgess Laboratories, Inc.

FIG. 9A. Phantom view of the Burgess micro-switch. A slight pressure on the plunger at the left either opens or closes the silver contacts at the other ends of the spring steel blades, depending upon how the contacts are arranged.



Courtesy Automatic Electric Co.

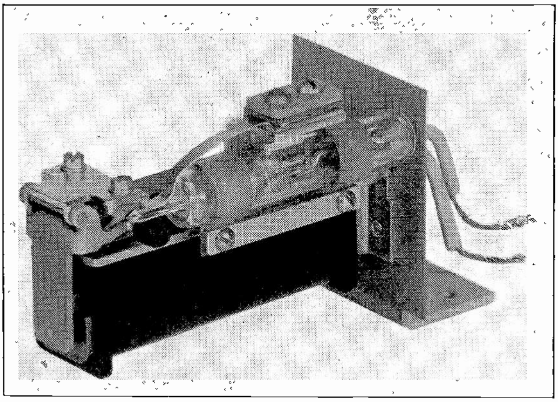
FIG. 9B. A Series FMS Automatic Electric Relay with a micro-switch mounted on one side, its plunger being actuated by the relay armature. This unit can handle loads as large as a ½ h.p. A.C. motor.

actuating current is an impulse (produced by pushing a button or interrupting a light beam) which must keep mechanisms in operation until the desired condition has been reached; the latch can then be released by some type of limit switch, opening the relay in readiness for another control operation. For example, when an intruder passes through a light beam, the photocell, through its relays, can be made to ring a bell continuously until the owner of the establishment releases the latch-in relay.

SPECIAL RELAYS

Although unique control arrangements can be obtained by using sensitive and auxiliary relays together, the use of combinations of relays in this way, where each relay is a potential cause of failure of the entire system, is by no means entirely satisfactory in many cases. The ideal relay is one sensitive enough to operate on extremely low power inputs, yet capable of controlling large amounts of power; the micro-switch and the mercury type contacts, when used on ordinary sensitive relays, closely approximate the ideal relay.

A *micro-switch* of the Burgess type is shown in Fig. *9A*. The operation of this unit depends on the production of sufficient change in the relative forces of two opposing spring systems to cause the contacting silver plates to separate or come together with a positive snap action. This switch operates when a pressure of about 14 ounces is applied to the operating plunger, and releases with the same snap action when the pressure is reduced to about 10 ounces. The actual travel of the plunger is approximately .001 inch. The moving contact is attached to one flat spring and two curved springs. When the flat spring is depressed by the plunger the lower springs bring the contact up to the



Courtesy Automatic Electric Co.

FIG. 10. Vacuum contact switch mounted on telephone type sensitive relay. Insulated knob on armature at left presses against glass lever which extends into the glass vacuum tube and operates the contacts which are inside.

fixed contact with a snap. Switches of this type are available in a number of simple make-and-break combinations.

The micro-switch will continuously control 500 watts of A.C. power, provided the load has no inductive reactance. A typical combination sensitive A.C. relay and micro-switch is shown in Fig. *9B;* the micro-switch is so mounted that its plunger rests against the relay armature. About 100 contacts per second can be obtained, for the relay will pull up in .005 seconds and release in about the same time.

Vacuum contacts are extensively used on relay installations where sparking at contacts may cause an explosion and fire. Reasonably large circuits can be controlled with a sensitive relay and the special vacuum contact shown in Fig. *10*. The contact points, mounted in a highly evacuated glass tube, are operated by means of a glass lever which acts through a flexible glass, lifting the movable contact. As the contacts are in a vacuum only a small gap is required between them, there being no gas to cause ionization or arcing. The contacts therefore have a long life. As much as 6 amperes at 220 volts A.C. or D.C. can be controlled by the unit shown, regardless of whether the load is inductive or resistive, and as many as 40 make-and-break operations per second can be made.

Mercury Contact Switches.—If you place a quantity of mercury on a flat sheet of glass you will observe that the mercury remains in a globule and that the slightest tilt to the glass will cause the mercury to move. This characteristic, together with the fact that mercury is a metal and therefore a good electrical conductor, has resulted in the *mercury contact switch.* A quantity of mercury is placed in a small capsule-shaped glass tube having two (or more) contact wires sealed

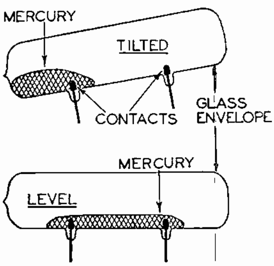
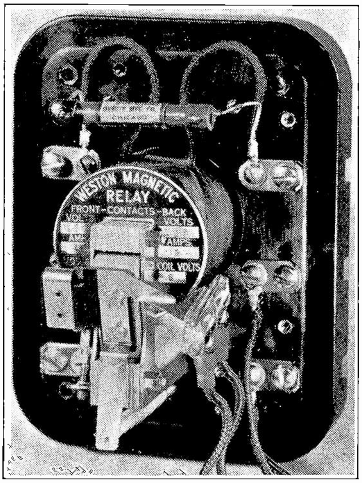


FIG. 11A (above). Tilted and level positions of a simple mercury switch, where a globule of mercury makes electrical connection between the two contacts.



Courtesy Weston Electrical Instr. Co.

FIG. 11B (at right). Model 630 Weston power relay using mercury tube switches in place of contacts. As many as four separate mercury switches can be mounted on one relay. This relay is of the minimum reluctance type, the armature being pivoted at its center. The coil power required is ¾ watt; with a 6-volt source, the coil current would then be 125 ma.

into the glass. The tube is sealed after air is pumped out; an inert gas is sometimes placed in the tube after evacuation, to prolong its life. When the switch is tilted as shown in Fig. *11A*, the mercury makes contact with only one wire or electrode, but in a level position the globule of mercury spreads out over both electrodes, closing the circuit between them. If both electrodes are placed at one end of the tube, tilting the switch in that direction will close the circuit. Many other arrangements of two and more contacts are possible. Mercury tube switches are available in many different types, some with mercury to metal contacts and others where the mercury pools themselves form the contacts; some require large, others small angles of tilt. Switches which must carry large amounts of power in general require more mercury, heavier contacts, and a larger angle of tilt and larger forces to cause the tilt.

Mercury tube switches can be mounted on sensitive or low powered relays, in combinations capable of controlling up to several kilowatts of A.C. power. As many mercury tube switches can be attached to a relay as are required for the control operations, when the desired contacts cannot be made by a single switch. Figure *11B* shows a low power, minimum reluctance type of relay actuating a mercury tube switch capable of controlling 1,000 watts of non-inductive A.C. power. A 6-volt D.C. source will operate the electromagnet. Even greater powers can be handled if larger mercury switches are used. Note that flexible wire leads are used to make connections to the mercury switches.

Time Delay Relays.—Quite often a relay is needed which will not close its contacts for a definite interval of time (5 seconds to 3 minutes) after the coil is energized. An illumination control system for a schoolroom, office or store is a typical system where a time delay type of relay

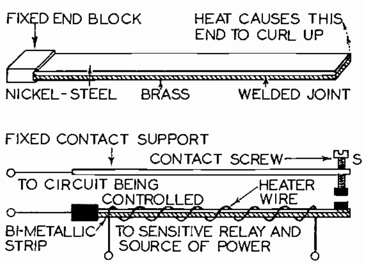
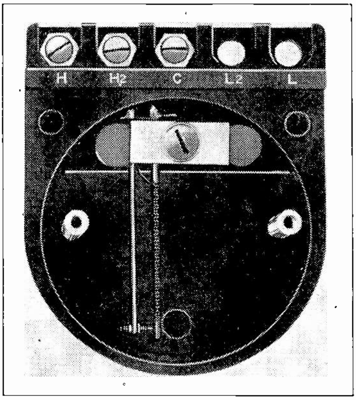


FIG. 12A. Basic principles of the bi-metallic strip type time delay relay are illustrated here. The four connections shown to the relay are often reduced to three by attaching one heater wire to the bi-metallic strip.



Courtesy Weston Electrical Instr. Co.

FIG. 12B. Weston Model 613 time delay relay with cover removed. Heater coil requires 6 volts D.C., while contacts will control 25 watts.

is required. Here a single photocell is made to operate two sensitive relays, one of which turns on lights when room illumination drops below the desired value, and the other turns off the room lights when the photocell "sees" too much light. Clearly, steps must be taken to prevent passing clouds or passing objects from flashing the lights on and off. A time delay relay solves the problem, for it requires current for a definite period of time before the contacts close.

Any mechanism which will produce a mechanical motion when heated can be used to provide a time delay relay; the control current applied by a sensitive relay is sent through a resistance wire which heats the mechanism. For example, the stretching of a wire which is heated by passing a current through it will produce a motion which can close a movable contact. A simpler and more positive type of heat-affected mechanism is the so-called *bi-metallic strip.* If a nickel-steel strip and a hard brass strip are welded together, as in Fig. *12A*, and one end is firmly anchored, a very positive motion will be obtained when heat is applied to the device. For a given temperature increase, the brass increases in length 18 times more than the nickel-steel; the strip must therefore curl upward to allow the brass to stretch. By sending current through a coil of resistance wire wound around this bi-metallic strip, it can be heated. If contacts are placed on the free end of the strip and fixed contacts mounted on either side, this bi-metallic strip can be used to open or close a circuit. By adjusting the positions of the fixed contacts, the time required to make contact can be changed. The contact is usually mounted on an adjusting screw, as at *S*.

Figure *12B* shows a simple but effective time delay relay requiring about 6 volts of D.C. or A.C. for its operation and intended for use with a sensitive relay. The time delay contacts will handle about 25 watts (¼ ampere at 110 volts) A.C.; if more power is to be handled, a heavy-duty relay must follow the time delay relay. This relay always requires 60 seconds for a complete make-and-break operation, but it can be adjusted to make contact in an interval varying from 15 to 45 seconds.

CARE AND OPERATION OF MAGNETIC RELAYS

Prevention of Sparking at Contacts.—To obtain long contact life from relays, sparking must be reduced to a minimum. The most effective protection for a super-sensitive relay, where sparking is especially

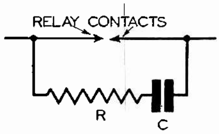


FIG. 13A. A condenser and resistor in series across relay contacts tend to prevent sparking at these contacts.

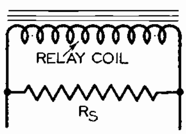


FIG. 13B. A resistor across a relay coil tends to prevent sparking at contacts which control current to the relay coil.

serious, involves connecting a condenser *C* and a resistor *R* in series across the relay contacts, as shown in Fig. *13A*. The time constant (R in ohms times C in mfd. gives time in microseconds; divide by 1,000,000 to get time in seconds) of the combination of *R* and *C* should be much lower than the speed of the relay. In general, a 1 mfd. condenser in series with a 100-ohm resistor will be satisfactory. In A.C. circuits the reactance of the condenser must be sufficiently high (the capacity low) so current passing through the condenser will not operate the power relay or other device being controlled by the contacts. The condenser should have a working voltage of at least 400 volts for circuits using 110 volts or less.

When the relay contacts are connected into the coil circuit of another relay, it is wise to shunt the coil of the second relay with a resistor like R_S in Fig. *13B* whose resistance is at least five times the coil resistance, so that it will not appreciably raise the pull-up current. For a 6-volt coil a resistor value of 500 ohms should suffice. This resistor tends to neutralize the inductance of the relay coil and lessen the tendency towards sparking at the contacts which are in series with that relay coil.

Cleaning Contacts.—To begin with, relays exposed to the air should be kept in dust-proof housings or at least partially protected from dust, chemical fumes and foreign particles. Relays should be cleaned regularly with an air bellows or air pressure line; all contacts and moving parts should be cleaned with carbon tetrachloride (Carbona). When flat type contacts become pitted or corroded, they should be filed flat and bright by placing a thin file (such as that used in cleaning automobile distributor contacts, or a jeweler's file) between the contacts, squeezing the contacts together and slowly drawing out the file, repeating the process as often as necessary. When the contacts are shaped (rounded or cylindrical) they should be polished with fine "crocus" cloth. Never oil or grease the moving parts of relays, for they are designed to give free action without a lubricant. These instructions apply only to sensitive and power relays; super-sensitive relays must be handled just as carefully as meters.

Adjusting Relay Contacts.—All relays come from the manufacturer properly adjusted for pull-up and drop-out current. Tampering with the adjustments should be avoided, but if adjustments are necessary, the following general rules, dealing specifically with sensitive relays, will be helpful:

1. Connect the relay in the test circuit shown in Fig. *14*, which is capable of supplying enough direct current to operate the relay. With current flowing through the coil, loosen the spring tension screw, then adjust the pull-up stop (this is also the pull-up contact in most cases) so the armature gap is about .002″. If there is a copper cap or copper stud in the pole piece (to prevent the armature from sticking), adjust for zero air gap, making certain that good contact is being made between the armature and pull-up contact.

2. Reduce the coil current to the desired drop-out value and gradually increase the spring tension until the armature drops out.

3. Turn out the drop-out stop, adjust the current to the desired pull-up value, then slowly turn in the drop-out stop, bringing the armature nearer to the coil core, until the armature pulls up. The relay is now properly adjusted for the desired pull-up and drop-out currents.

Always adjust the relay in the position in which it is to be used. A relay may just as easily be adjusted in its final operating circuit, following the procedure given above while using operating conditions for pull-up and drop-out currents. If armature drops out sluggishly, increase the armature gap and repeat adjustments *2* and *3*. If the armature pulls in sluggishly, turn in the drop-out stop a little more. It is always wise to check adjustments a few times.

Ordering Relays.—In ordering relays or getting a quotation as to cost, you must first decide upon the type (meter, sensitive, power, mercury contact, etc.) and the manufacturer, after studying the catalogs of different relay manufacturers. You will find that each type of relay can be secured in a number of different voltage and current ratings; in most

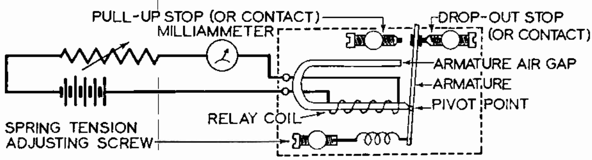


FIG. 14. **Test circuit for sending required current through the coil of a sensitive relay when making adjustments.**

cases it is best to let the manufacturer use his own judgment in making the final choice. When writing to a manufacturer, always supply at least the following information:

1. Catalog number and name of the type of relay you desire.
2. Pull-up and drop-out current (or voltage) values required.
3. State whether exciting current will be A.C. or D.C.
4. Contact arrangements desired.
5. Power to be handled by contacts (voltage and current); state whether A.C. or D.C. power is used and whether or not load is inductive.
6. Speed of pull-up and drop-out, or time for one complete operation (if important in your case).
7. Special information as to how relay will be used.

PHOTOELECTRIC CONTROLS WITH RELAYS ONLY

Inasmuch as a super-sensitive relay will operate on currents below ¼ milliampere—currents which photovoltaic and photoconductive cells will produce with normal changes of light, these cells may be connected directly to super-sensitive relays. Photoemissive cells, however, are not suitable for direct connection to a relay, as the safe current which they can pass is generally insufficient for relay actuation.

Photoconductive cells in general require high D.C. voltages for direct relay operation, but some types operate on low voltages and control enough current to actuate a *sensitive* relay directly. The photovoltaic cell, on the other hand, will supply ample current for a *super-sensitive* relay; it is the only type of cell which is *commercially* used to operate a relay directly. The current outputs of the photoemissive and photoconductive cells are first amplified by vacuum or gaseous tubes in practical commercial equipment.

The simplicity of the connections between a photovoltaic cell and a relay is best demonstrated by a practical circuit like that shown by the heavy lines in Fig. *15*. P is a Model 594 Weston Photronic Cell and R_1 is any of the 0-200 microampere super-sensitive (or meter type) relays. The contacts of relay R_1 control the exciting current to relay R_2, which can be either an ordinary sensitive relay or one with micro-contacts, vacuum or mercury contacts. When the control circuit is to be on intermittently and only for short intervals, the battery B may be used. If the sensitive relay is of the D.C. type, a voltage step-down transformer and a full-wave rectifier can be used to permit operation on A.C.; if relay R_2 is of the A.C. type, a step-down transformer is generally needed. Simply remove battery B and connect the rectifier unit or the step-down transformer to points x and y. In the circuit shown in Fig. *15* the super-sensitive relay operates when light falls on P; this relay closes the circuit to relay R_2, and its contacts close the circuit to the load. If illumination on P is to disconnect the load from the power source, connect lead f to contact e instead of to d; if interruption of a light beam directed on P is to actuate relay R_2 connect lead a to contact c instead of b. Should a time delay be desired in the control, the super-sensitive relay can be connected to a time delay relay, which in turn can actuate a power relay.

When a Sensitrol relay is used and it is desired to keep the load on but to disconnect the original actuating circuit, use a latch-in type power relay and a solenoid reset type Sensitrol relay. Connect the solenoid of the Sensitrol relay in parallel with the load, placing a resistor in series with the solenoid to limit the current to a safe value. Only your imagination plus a knowledge of the relays available is needed to develop any desired type of photoelectric control. For example, by placing P (Fig. *15*) near the window of an office and connecting R_1 to actuate R_2, which turns on room lights when the general illumination in the office is just insufficient for good work, an illumination control is obtained. A time delay relay takes care of passing clouds which normally would throw the lights off and on. If R_2 is replaced with an electromagnetic counter, objects would be counted by passing through a light beam, which would interrupt the light on P.

Recommendations.—A photovoltaic cell delivers the largest current when its terminals are shorted. In selecting a relay which is to have a given pull-up current rating, that which has the lowest coil resistance will give best results. When the illumination on the photovoltaic cell is too low to give relay operation, use two or more cells in parallel to get the current output required by the super-sensitive relay. In figuring the speed of a relay system, *add* the speeds of the individual relays; the more relays used, then, the slower will be the system.

VACUUM TUBE AMPLIFIERS FOR SENSITIVE RELAY OPERATION

The necessity of continually cleaning the contacts of a meter-type relay and the high initial cost of the device are two factors influencing the choice between photovoltaic cells and the other two types of cells for a particular photoelectric control job. In a good many cases control engineers have a decided preference for a vacuum tube amplifier connected between the light-sensitive cell and a sensitive relay. To be sure, the amplifier tube must be replaced periodically (the estimated life of the average tube is the equivalent of 1,000 hours of continuous use), and power must be supplied constantly. When these features are not objectionable, rugged, positive and reliable controls are possible. Photoemissive cells of the gas type and photoconductive cells are generally employed.

The basic circuits are of three types: *1,* the *rise* and *fall* type, where the photoelectric cell causes the vacuum tube plate current to rise or fall in value; *2,* the *impulse* type, where a rapid change in light is converted into an electrical impulse causing quick positive relay action; *3,* the *light*

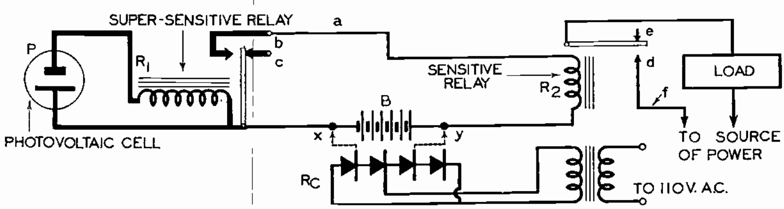


FIG. 15. Typical photovoltaic cell circuit using two relays.

differential circuit, where the vacuum tube amplifier operates the relay when light falling on one photoelectric cell differs from that falling on another cell. The amplifier tubes generally used (tubes like the 30, 31, 01A, 12A and 6C5) have maximum operating values of 2 to 12 milliamperes; in many cases these values can be reduced more than 50 per cent, giving longer tube life if sufficiently sensitive relays can be used. When the light change is too small to actuate a relay through a single vacuum tube stage, two or more direct coupled amplifiers acting in cascade may be employed.

Rise and Fall Circuits, Forward Type.—If the current in the plate circuit of the vacuum tube *rises* when the illumination on the cell is *increased,* we have what is commonly called a *forward* circuit. Figure *16A* shows a simple practical forward circuit which can be used with a selenium cell. Figure *16B* is a forward circuit for a photoemissive cell.

In either case the potentiometer K_1 is adjusted, with illumination removed from the cell, until the relay armature drops out and makes contact with L (this is the armature position for low or drop-out current). Now when the cell is normally illuminated, the resistance of the cell reduces in value, bringing the potential of the grid nearer that of the cathode. The grid, originally highly negative, thus becomes more positive with respect to the cathode, plate current increases and the relay pulls up. Potentiometer K_2 should be adjusted for a pull-up contact pressure just strong enough to prevent chattering. The gas type photoemissive cell (used in Fig. *16B*) should never be operated at a peak voltage greater than recommended for the cell used, and a resistance of at least one megohm should be in series with the cell to limit the current in case the voltage is accidentally exceeded. (Note that a 3 megohm resistor is used for this purpose in Fig. *16B*.) The photoconductive cell should be operated at the minimum voltage which will give satisfactory control if long cell life is to be secured.

In general, in a forward circuit, the C bias voltage (controlled by K_1) is varied to give the desired minimum value of illumination, and the cell excitation voltage (controlled by K_2) is adjusted to give relay pull-up with the desired maximum value of illumination, if the control circuit is to work between definite limits of light values. Only the grid bias control (K_1) is needed in circuits where light is completely cut off to secure the control operation; here either the light beam intensity or the relay contacts can be adjusted to vary the value of illumination which actuates the relay.

Reverse Circuit.—By connecting the load to terminals C and H in Fig. *16B,* a reduction or interruption of the light will open the load circuit; by connecting to terminals C and L, light reduction or cut-off will connect the load to its supply. In both cases the relay armature is pulled up as illumination on the cell increases. When the control unit is to be in operation for long periods of time, and the cell is illuminated the greater part of the time, the amplifier tube is passing maximum current most of the time and its life is consequently shortened. A control circuit can be designed in which illumination on the light-sensitive cell produces a low plate current, so that a reduction in light causes the plate current to increase and actuate the relay. This *reverse circuit,* as it is called (where the relay closes when light is *decreased*), gives longer amplifier tube life and consequently less attention need be given the unit. Such a circuit, using a photoemissive cell, is shown in Fig. *16C;* a photoconductive cell can also be used in this circuit.

The variable arm of potentiometer K_1 in Fig. *16C* is adjusted so the relay drops out when maximum light is on the cell. The photocell current passing through the 3 megohm grid leak places a high negative bias on the amplifier tube, this bias being varied by the potentiometer to get the desired minimum value of plate current. When the light is reduced or cut off little or no cell current flows through the grid leak; the grid bias becomes practically zero, raising the plate current and pulling up the relay armature. If the load circuit is now connected to H and C, light cut-off connects the load to its supply; if the L and C terminals are used, light cut-off disconnects the load from its supply.

You can easily tell whether a vacuum tube amplifier control circuit is of the forward or reverse type. In a *forward* circuit the photoelectric cell connects between the *grid* and a point more *positive* than the cathode; in a *reverse* circuit the cell connects between the grid and a point more *negative* than the cathode. In Fig. *16*, *A* and *B* are forward circuits and *C* is a reverse circuit.

Impulse Control Circuits.—The principal objection to circuits of the forward and reverse type using *photoconductive* cells is that there is some cell current even when no light is on the cell, this current serving to reduce the differential needed for positive control with small changes in illumination. Where simple, rapid off-on light conditions exist, this

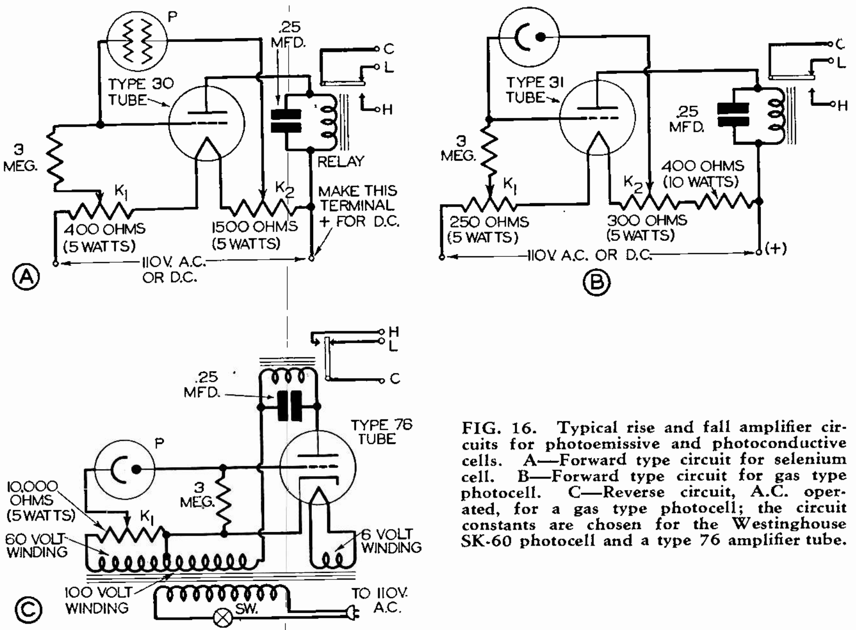


FIG. 16. Typical rise and fall amplifier circuits for photoemissive and photoconductive cells. A—Forward type circuit for selenium cell. B—Forward type circuit for gas type photocell. C—Reverse circuit, A.C. operated, for a gas type photocell; the circuit constants are chosen for the Westinghouse SK-60 photocell and a type 76 amplifier tube.

objection may be eliminated by employing a circuit which utilizes the charge and discharge ability of a condenser.

A simple *impulse* or so-called *trigger* circuit, using a selenium (photoconductive) cell, is shown in Fig. *17A*. A photoemissive cell can be used as well, provided its anode is connected to the potentiometer arm. The unique feature of this circuit is that when the cell is illuminated with *any* steady light value, the plate current is always a definite value which is fixed by the potential of the floating grid of the type 30 tube. The impulse circuit operates in this manner. Assume that the cell is illuminated. Point *A* (Fig. *17A*) is positive with respect to the cathode *K*. As the leakage resistance of the mica condenser is many times greater than the grid-to-cathode resistance, the potential of the grid with respect to cathode is zero or slightly negative, the condenser being charged with the polarity shown. When the light is suddenly cut off, the condenser immediately discharges through the amplifier tube and grid leak circuit. The grid is instantly placed at a high negative potential with respect to the cathode, the plate current goes down and the relay drops out. Gradually the condenser discharges through the grid-to-cathode path, placing the grid at the potential of a floating grid (practically at zero potential with respect to the cathode). When light comes on again the condenser charges as before, and the circuit is ready for another interruption of light.

When the light on the cell is initially low, the grid is near zero potential and the relay is in the pull-up position. An increase in light causes the condenser to become charged with the polarity shown in Fig. *17A*, but since the grid is already near zero potential and the relay arma-

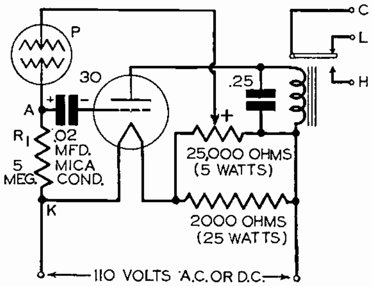


FIG. 17A. **One form of the impulse circuit, using a selenium cell and a type 30 amplifier tube. The relay, normally closed, drops out when illumination on the cell is suddenly cut off. The relay remains pulled up for all constant values of illumination, and pulls up by itself at a definite time after each interruption of light.**

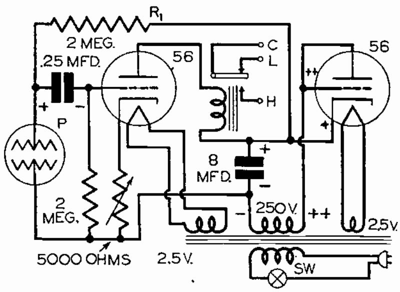


FIG. 17B. **Another form of impulse circuit, which uses an extra tube to secure D.C. Here the relay pulls up only when light on the cell is suddenly interrupted, and drops out automatically in a definite time interval. Current flows through the tube circuits only during the half of each cycle for which polarity is as indicated.**

ture is pulled up, no relay change takes place. Increasing the cell voltage by moving the arm of the 25,000-ohm potentiometer to the plus end produces stronger impulses. This impulse circuit responds well only to sudden light changes; the relay remains closed or in its pull-up position for all constant values of illumination as well as for gradual changes in illumination, and drops out only when the light is suddenly interrupted.

A more practical impulse circuit which insures long cell and tube life and strong, positive trigger action is shown in the circuit of Fig. *17B*. As D.C. is supplied by the 56 tube used as a rectifier, the grid condenser may have a large capacity. With normal light on the cell the 5,000-ohm cathode variable resistor is adjusted to give a negative bias to the grid, so the relay drops out. Now, when the light on the cell is suddenly cut off, the relay coil current "shoots up," pulling up the relay long enough to operate a counting mechanism or other quick-acting electromagnetic device.

Here is how the circuit of Fig. *17B* works. With normal light the cell resistance is low, the voltage drop across the cell is consequently low, and the .25 mfd. condenser receives only a low charge. When the light is cut off the cell resistance rises, there is a larger voltage drop across the cell, the + terminal of the condenser becomes more positive, and electrons flow up through the 2-megohm grid leak to make the — terminal of the condenser correspondingly more negative. These electrons flowing through the grid leak produce in it a voltage drop which reduces the negative bias to zero or even swings the grid positive, and plate current rises, actuating the relay.

When the condenser becomes fully charged (the time required depends on the time constant of the charging circuit) the grid leak current reduces to zero, restoring the normal high negative bias, and the relay

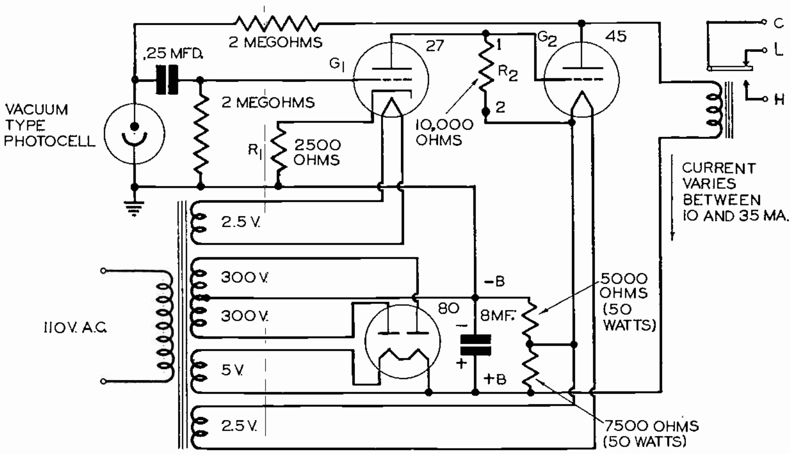


FIG. 18. Typical two-stage amplifier circuit for a vacuum type photocell connected into an impulse circuit; the type 80 tube supplies full-wave rectified D.C.

drops out. When the cell light comes on again the cell resistance drops, and the fully charged condenser partly discharges through the C bias circuit, driving the grid more negative, but as the relay is already in a drop-out condition no further relay action takes place.

In any of these impulse circuits, increases in resistance of the cell (in the case of selenium cells) with age and use can be offset by increasing the ohmic value of the grid leak resistor.

Two or More Amplifier Stages.—Where the change in light is small, sufficient change in current for relay operation can be obtained by adding a second vacuum tube amplifier. With normal light change the use of a second amplifying stage permits the direct use of a heavy duty relay. As the variation in light is generally not a repeated (or cyclic) change, direct coupled amplifiers are needed. Impulses or slow current changes thus are relayed through the amplifying circuits.

A typical two-stage direct coupled photocell control circuit is given in Fig. *18*. A photoemissive cell is shown, but a photoconductive cell may just as well be used. The circuit is shown operating a heavy-duty relay; if small light changes are used for control, the power tube is replaced with a high mu triode voltage amplifier tube which feeds into a sensitive relay, the operating voltages being adjusted. Although an impulse or trigger type input circuit is shown, a forward or reverse photocell connection can be used with good results. A gas cell can be used by lowering the excitation voltage; a tap on the voltage supply divider resistance will give the required low voltage.

This circuit works in the following manner. Grid G_1 is biased negatively by resistor R_1; grid G_2 is biased negatively by the plate voltage drop in resistor R_2 (note that terminal *1* is nearer ground or $B-$ potential than terminal *2*). With normal light on the photocell, all currents in the circuits are at adjusted values. When the light to the photocell is cut off, grid G_1 becomes more positive, increasing the plate current of

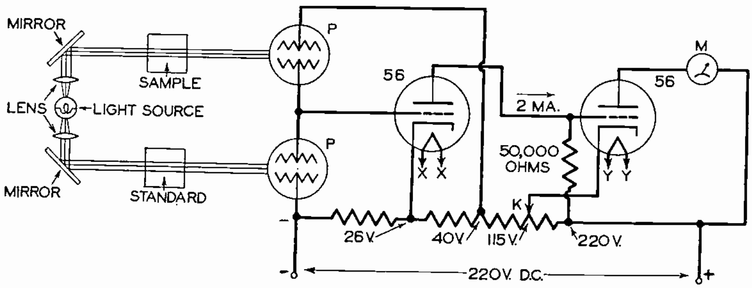


FIG. 19. Typical light differential circuit. The power supply is not shown, but should produce 400 volts D.C.; two separate 2.5 volt secondary windings are needed for XX and YY to prevent leakage reaction between the two amplifier tubes.

the 27 tube (this impulse circuit is practically the same as that in Fig. *17B*); the voltage drop across resistor R_2 increases, driving the grid of the second tube more negative. The plate current of the second tube drops, releasing the armature of the relay. As the power tube plate current will drop from about 35 ma. to 10 ma., a heavy-duty relay may be used. A more sensitive circuit can be designed by using a screen grid tube in place of the 27 in the first stage.

Light Differential Circuits.—Quite often a circuit is desired which will respond to a difference in light from two light sources. Color matching of liquids (such as dyes) is a typical case. The same kind (color content) and intensity of light passes through the standard solution and the solution under test. By using two cells so connected into a control circuit that the difference in the currents which they pass causes a voltage change, the change can be amplified to actuate a meter.

A typical light differential circuit is shown in Fig. *19*, where the light of a single lamp is split into two light beams by two lenses. Each beam is reflected from a mirror, one beam being directed through a glass container holding the standard liquid, the other beam passing through the glass container in which is the liquid whose color or density is being compared. The beam emerging from each container is viewed by a photoelectric cell, which can be either of the emissive or conductive type.

With both containers removed, the arm of potentiometer K is adjusted until meter M reads mid-scale. When the standard and sample products are introduced into the light paths, any difference in the light transmitted to the cells shows up as a deviation of the meter from mid-scale. A relay is sometimes used in place of the meter to give a desired control operation when the two solutions differ in characteristics by a specific amount.

GAS TUBES FOR DIRECT POWER RELAY ACTUATION

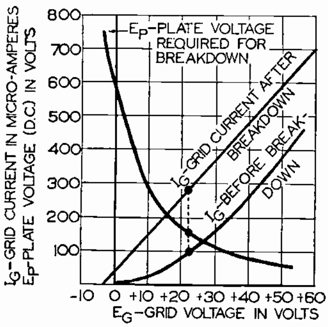
A heavy-duty or power relay can be operated directly from a single amplifier tube circuit without using any sensitive relays, provided that the amplifier tube is of the gas or vapor type.

When triode amplifier tubes have gas in their envelopes, as in the case of Thyratron tubes, they are no longer suitable for linear amplification, but have properties which are valuable for electronic control circuits. The action of such a tube is briefly this: When the tube is given a definite grid bias, and the plate voltage is gradually varied from zero upward to a certain positive anode-cathode voltage, a very large space current suddenly starts to flow through the tube. Now, no matter how the grid voltage is varied, the grid has no control over the plate current. Only the plate *voltage* determines the amount of plate current, and this voltage must be reduced to about 20 volts before the space current stops flowing. The anode voltage must then be raised to the "striking" or "firing" potential, determined by the value of grid voltage, before space current will again flow through the tube. The higher the negative grid bias, the higher the striking voltage required before current flows; likewise if the C bias is reduced or made positive, the required striking voltage will be reduced.

On alternating current the grid has a continuous control over a gaseous tube, for current flow stops once per cycle (when the anode voltage drops to zero); on direct current, however, the grid loses its control once breakdown occurs, and can regain control only if the anode voltage is interrupted by some means. Gas-filled tubes are therefore almost always used in A.C. circuits.

Hot Cathode Gas-Filled Tubes.—Gas triodes and pentodes (gas pentodes work exactly like triodes except that the screen grid protects the cathode and reduces the grid current) are designed to have an oxide cathode of large surface so large quantities of electrons can be emitted. The anode voltage is limited to a value which gives a safe space current; if this current is exceeded, the cathode emitting surface is bombarded by positive ions and destroyed. Although mercury vapor is used in certain tubes which operate on high voltages and deliver high plate currents, argon, helium and neon gases are preferred for low voltage and low current tubes; these gases result in tubes which are fairly independent of temperature. Gas tubes are called *Thyratrons* by the General Electric Company (G.E.), and *grid-glow tubes* by the Westinghouse Electric and Manufacturing Company (W.E.&M.). Mercury vapor tubes are made in sizes capable of passing up to hundreds of amperes, but for control purposes ½ ampere tubes are sufficient to control the heaviest power relays needed.

In hot cathode gas tube control circuits it is highly important that the grid current shall not flow directly through the light-sensitive cell; the cell current should supplement the normal grid current which is made to flow through a *grid resistor*.



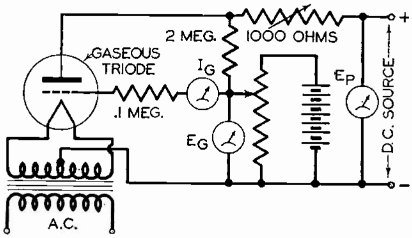


FIG. 20. Characteristic curves of a typical hot-cathode gas filled tube, the Westinghouse type KU-610 grid-glow tube. D.C. starting characteristics for rated anode current are given at the left; the test circuit used appears above.

Figure *20* shows the characteristics of a typical low power grid-glow triode tube, in this case the W.E.&M. type KU-610, which has a maximum rated plate current of ¾ ampere. The circuit used to obtain these characteristics is also shown; the 1,000-ohm resistor prevents the tube from acting as a short circuit across the load when break-down occurs and the tube passes current, this resistor being adjusted to give rated plate current. This tube uses neon gas and has a constant anode-cathode drop of about 22 volts when passing current, which means that the 1,000-ohm resistor must waste the remainder of the source voltage in the test circuit shown in Fig. *20*. The .1 and 2 megohm resistors serve to stabilize the circuits. Although the tube characteristics shown are for D.C. voltages and currents, they also represent instantaneous values in the case of A.C. power.

The curves are used as follows: Assume that the tube is to operate at a plate voltage of 110 volts A.C.; the peak voltage is then 110×1.41, which equals about 155 volts. Referring to the E_p curve, we find that about + 23 volts on the grid will just allow breakdown of the tube; the grid current before breakdown is about 100 μa and after breakdown it is about 300 μa.

With these facts in mind, we may now consider the practical gas tube relay circuit shown in Fig. *21A*. Although a photoconductive cell of a type which has a low minimum resistance and a large dark-to-light resistance ratio is used here, photoemissive cells can also be used. The connections to the secondary of the transformer are such that when the plate of the KU-610 tube is positive with respect to the cathode (here the filament), the grid is also positive with respect to the cathode. The potentiometer across the 60-volt secondary winding furnishes the grid bias for the tube by varying the potential of the cathode with respect to the grid. With light on the cell, this potentiometer is adjusted so the voltage between P and A (on the positive half of the A.C. cycle) minus the voltage drop in R_G due to the cell and gas tube grid currents is just below the value which allows the tube to break down. Now when the cell is darkened, the cell current drops, the voltage drop in R_G becomes less, the grid becomes more positive and the grid of the tube loses control. The plate current rises, actuating the relay.

This action is best understood by studying Fig. *21B,* which shows

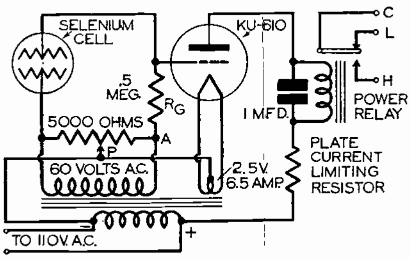


FIG. 21A. A practical photoconductive cell circuit, using a Westinghouse type KU-610 grid-glow tube to operate a power relay directly. Circuit operates entirely from A.C.

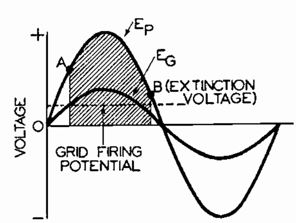


FIG. 21B. When plate and grid voltages of the KU-610 grid-glow tube are in phase, plate current passes for that part of a cycle shown shaded.

the phase relations between the grid and plate voltages. As the circuit is essentially non-reactive, the grid and plate voltages can be made to be entirely in phase or 180° out of phase, simply by reversing connections to the 60-volt winding. The out-of-phase condition is undesirable because as the plate swings positive the grid swings negative and too-high plate voltages are required for breakdown or *firing*. With both grid and plate swinging positive simultaneously (in phase), firing occurs at the plate voltage indicated at point A, this being the first point in the cycle at which the plate and grid voltages together allow breakdown. At point B the plate voltage is no longer enough to sustain plate to cathode ionization (below 22 volts), and the plate current stops. Of course, when the plate and grid swing negative on the next half of the cycle, no plate current can flow. Although there is no control over the plate voltage in this circuit, the grid bias can be adjusted by varying P, which determines the position of A, the point of firing; this potentiometer can be set so the grid bias is sufficient to fire the tube only when the cell resistance goes up (light on the cell is interrupted).

Cold Cathode Gas-Filled Tube.—A hot cathode is not needed to cause ionization in a tube, as you already know from your study of gaseous rectifier tubes. When a gas like neon is used, an appreciable tube current can be obtained with a cathode having no electron emitting surface. Ionization of the gas takes place at a voltage depending on the amount and nature of the gas and upon the distance between the anode and cathode; this ionization results in liberation of the electrons required for the tube space current. A grid can be used to control the breakdown or firing voltage; the more negative (less positive) is the grid, the higher is the voltage required to start ionization and a flow of current.

The arrangement of the internal elements of a cold cathode grid-glow tube is shown in Fig. *22*. The shield, when connected to the cathode through a 2 to 10 megohm resistor, insures greater uniformity and

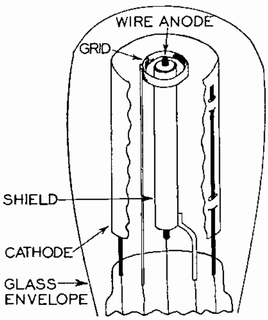


FIG. 22. Cut-away view of a cold-cathode grid-glow tube, showing arrangement of electrodes. The anode is inside a porcelain tube which in turn is surrounded by a metal cylinder, the shield. The grid is simply a thin band or ring of metal surrounding the exposed tip of the anode.

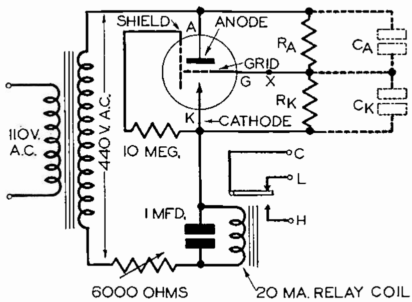


FIG. 23. Basic operating circuit for the Westinghouse KU-618 grid-glow tube. A photoemissive cell or a photoconductive cell of high resistance can be substituted for either of the resistors or condensers connected to the grid. The arrow in the tube symbol represents the cold cathode.

stability of operation, and insures definite tube failure when the maximum useful life of the glow tube is reached.

The Westinghouse KU-618 is a typical high sensitivity, cold cathode grid-glow tube, which has an anode to cathode drop of 180 volts when plate current is flowing. In the basic operating circuit for this tube, shown in Fig. *23*, the tube is connected in series with a relay coil and a 6,000-ohm resistor across the 440-volt secondary winding of the transformer; this current limiting resistor prevents the space current from exceeding 100 ma., for excessive currents would destroy the tube.

In actual practice the *A* and *G* terminals of the gas tube are shunted with either a resistor of 10 to 100 megohm value or a 0 to 50 mmfd. variable condenser, while the *G* and *K* terminals are shunted with either a resistor or condenser of the same value. When resistors are used it is customary for purposes of stability to insert a high ohmic value leak at point *X;* the highest value which will give satisfactory operation is employed, values up to 250 megohms being commonly used. The supply is usually the 440-volt terminal of a small step-up transformer. The values of R_A and R_K determine the potential of the grid; increasing R_A or lowering R_K makes the grid less positive and prevents the tube from firing. If condensers are used instead of resistors, increasing the impedance of C_A (by lowering its capacity) or decreasing the impedance of C_K makes the grid less positive. A voltage divider made up of a resistor and a condenser can be used if desired; in any case either a resistor or a condenser is made variable to allow adjustment of the grid potential. As it is inconvenient to secure variable resistors of such high values, one element is usually a variable condenser.

In actual practice a light-sensitive cell or other device having either a high ohmic resistance or a low capacity which will change in resistance or capacity as a result of the action which is to be controlled is connected in place of one of the resistors (or condensers), and is used as the primary control. The other resistor (or condenser) is made variable to permit adjustment of the point at which control action occurs. This cold cathode glow tube has many electronic control applications.

For a light-sensitive control, vacuum type emissive cells are best, as they have large dark resistances (as much as 5,000 megohms), and will operate safely on high excitation voltages (500 volts is a common value for small cells). In one practical circuit an emissive cell is connected between the anode and grid, and a 0-50 mmfd. variable condenser is connected between the grid and cathode terminals. The condenser is adjusted when the cell is dark so the grid glow tube does not ignite. Illuminating the cell swings the grid more positive and causes the relay to pull up; when the cell light is cut off the relay drops out.

Photoemissive type cells can also be connected between the grid and cathode, the variable condenser being placed between the anode and grid. The condenser is adjusted so the grid glow tube does not ignite when the cell is illuminated; now the tube will break down and pass current, causing the relay to pull up, only when the cell is darkened.

The anode of the photocell should be connected to the anode of the gas tube when the cell is placed between A and G. The cell anode should be connected to the grid of the gas tube when the cell is wired to G and K.

A light-sensitive control using a cold cathode gas tube has the advantage that no power is used in the control circuit when the control circuit is idle, yet heavy-duty relays can be actuated directly. Note that the power used to feed the filament of a hot cathode gas tube is eliminated. Furthermore, the cold cathode tube is extremely sensitive.

LIGHT-SENSITIVE CELLS FOR CONTROL CIRCUITS

25FR-2

PIONEER HOME STUDY RADIO SCHOOL

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NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

ACTION SPEAKS FOR ITSELF

"Be sure you are right, then go ahead"—this has been the motto of many of the world's great men.

In most cases you know instinctively what is right, your decision being based upon your past training, your experience, your common sense and your conscience. In these cases, *act!* Waste no valuable time arguing with others who know less than you; waste no time trying to "pound" your ideas into a cynical world—take the initiative yourself.

It is a thousand times better to *do things* and let your deeds speak for themselves than to spend your time explaining why your proposed course of action is right. Too many friends can hinder your success if you take time to justify your actions to each one of them.

If you need advice—if you are not exactly certain you are right, then go to men who are capable of giving authoritative answers to your questions. You'll find that leaders of men, authorities in a particular field, are glad to answer serious, well-planned questions. Analyze their advice in connection with your own experiences, make your decision, then act!

Give this plan a tryout; you will accomplish a great deal more work, and I am sure you will be a lot happier.

J. E. SMITH.

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Light-Sensitive Cells for Control Circuits

THE ELECTRIC EYE

UNDOUBTEDLY you have read about the magic *electric eye,* a seemingly mysterious device which causes doors to open as you walk toward them, turns on roadside signs in the country as an automobile approaches, sounds alarms when anyone walks over a forbidden area, prevents workers from placing their hands in dangerous machines such as punch presses, and does thousands of other equally amazing and practical feats. In this lesson you will learn about the many different types of electric eyes, which are called either photoelectric or *light-sensitive cells* by technical men. You will learn how each type of cell is constructed, how it functions, and how it can be made to replace man's eyes.

Thousands of light-sensitive cells are in use today in every corner of the world, responding to beams of light which may be perfectly invisible to the human eye, detecting every change in illumination from the sun or from other sources of light; these cells change their *electrical characteristics* with variations in the light which they "see." These light-sensitive cells start and stop heavy machinery, count objects moving past at a mile-a-minute speed, guard against fire, smoke, water, and burglars, and even "read" books for blind persons. Cigars, beans, eggs, fruit and other products are being graded as to color or shade by light-sensitive cells, faster and more accurately than by the human eye.

Although the field of photoelectricity is not new, its development into commercial practicality has taken place within the last few years. Scientists have known for more than one hundred years that certain electrical effects could be obtained by exposing chemical elements and compounds to light, but the lack of suitable apparatus to make use of this electrical effect, and the poor sensitivity of the light-sensitive cells then available, prevented the commercial utilization of this photoelectric action.

Recent developments in the field of television and electronics resulted in a great demand for photoelectric devices, and today the electric eye is looked upon as a dependable and invaluable device for industrial and commercial applications. As men in industry and business realize the value of electronic control, more applications will find their way into everyday use. Only the imagination of man stands in the way of accomplishing deeds which are best called *magic*.

As a sideline for the radio man, the field of photoelectric control offers great opportunities, for in this branch of electronics are many simple, basic applications requiring only standard equipment now available at reasonable prices, a knowledge of the fundamentals of photoelectricity and a goodly amount of mechanical ingenuity and common sense.

A COMPLETE PHOTOELECTRIC INSTALLATION

Before taking up the different types of light-sensitive cells I want to describe briefly a complete photoelectric installation, in order that you can better understand the important part which is played by the light-sensitive devices which you will study. The six important basic parts of a complete photoelectric control installation are as follows:

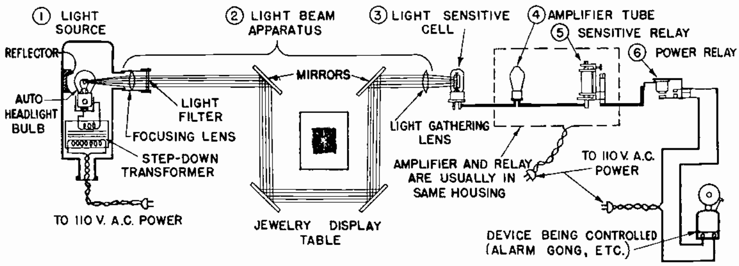
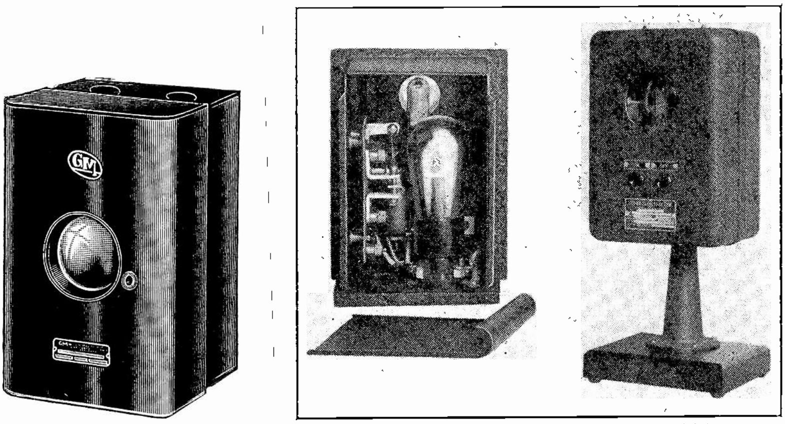


FIG. 1. Simplified diagram of a complete photoelectric installation such as might be used to protect valuable jewelry on a display table. The infra-red light filter on the light source makes the light beam practically invisible.

1. *The source of light.* The light which is directed upon the electric eye may be the natural light from the sun or artificial light from an incandescent lamp, gas flame, arc light, etc.
2. *Light beam apparatus.* On some photoelectric installations it is necessary to concentrate the light into a narrow beam in order to make it travel over a definite path before reaching the light-sensitive cell; lenses and curved mirrors are used at the light source to accomplish this. Again, it may be necessary to change the direction of the beam of light by means of a mirror, or to make the light beam invisible to the human eye by using filters which absorb the visible light rays. Where insufficient light reaches the light-sensitive cell it may be necessary to use a collecting lens which gathers light and concentrates it upon the relatively small area of the light-sensitive cell.

3. *The light-sensitive cell.* The electric eye or light-sensitive cell changes its electrical characteristics in response to changes in illumination.
4. *The photoelectric amplifier.* With certain types of light-sensitive cells it is necessary to build up the strength of the variations in current or voltage from the light-sensitive cell by means of a vacuum tube amplifier, which may contain one or more ordinary radio amplifier tubes or gaseous tubes.
5. *The super-sensitive and sensitive relay.* When the relay is connected directly to the output of the light-sensitive cell, a super-



Courtesy G-M-Labs. Inc. *Courtesy J. T. Rhamstine* *Courtesy General Electric Co.*

FIG. 2. Typical commercial photoelectric apparatus. Each unit contains a gas type photoelectric cell, an amplifier tube, and a sensitive relay. The G-M Phototube Relay (left) has a 3″ diameter light-collecting lens mounted in front of the photocell. Center: Rear view of the Rhamstine Photoelectric Relay, with cover removed to show tubes and relay. Right: G-E Photoelectric Relay for indoor illumination control.

sensitive relay is needed; when connected into the plate circuit of the amplifier tube, an ordinary sensitive relay is satisfactory. The contacts of the sensitive relay start and stop the electrical equipment which is to be controlled, or control the current to the operating coil of a heavy duty relay. Relays which operate on currents of less than 250 microamperes are classed as *super-sensitive;* those which require from ¼ to 10 milliamperes are classed as *sensitive* relays.

6. *The heavy duty or load-controlling relay.* This additional relay, used after the sensitive relay, is necessary in installations where the preceding relay is not capable of handling the cur-

rent required by the device being controlled. In some very large installations two or even more power relays, one operating the other, are required. Relays which require more than 10 milliamperes are considered the *heavy duty* type.

The simplified diagram in Fig. *1* gives you the relations between the various parts in a typical photoelectric installation (the alarm gong sounds when light beam is intercepted at any point along its path). Fig. *2* shows a few typical commercial photoelectric units having several of the basic parts mounted in one housing.

By properly choosing circuits and relays, you can make a change in cell illumination produce any desired control operation, choose the degree of light intensity at which the relays will operate, and speed up or slow down the action of your controls as much as you desire. The only actual limitations to a photoelectric control system are the sensitivity of the light-sensitive cell with its associated apparatus and the ingenuity of the control engineer.

As an example of how this photoelectric equipment operates, I will describe a typical installation, that where a photoelectric eye is used to open the doors of a garage when a car enters the driveway. The light source can be mounted on a post on one side of the driveway; this source throws a beam of light across the driveway at such a height that the beam will be intercepted by a car coming in or going out. The beam of light is directed on a light-sensitive cell mounted on the opposite side of the driveway. The apparatus is so connected that nothing happens while the beam of light illuminates the light-sensitive cell. When an automobile approaches, the light beam is interrupted; the light-sensitive cell detects this immediately and causes the value of the current in the plate circuit of the amplifier tube to change. This operates the sensitive relay; its contacts close and send current through the heavy duty or power relay. The contacts of the power relay close, sending current through the electric motor which operates the door opening mechanism. All this happens so quickly that the garage doors are completely open by the time the car reaches them.

WHAT IS LIGHT?

The importance of light in any photoelectric installation should be quite obvious from what I have said up to this time. I think you will find this Lesson more interesting if you first learn a little about light itself; that is why I am including a brief discussion of light and how it is measured.

The greatest source of light is the sun; it sends out waves which are very similar to those which we use in radio communication except that they are a great deal shorter in wave length. Light waves which can be seen by the human eye vary in length from 40 to 70 millionths of a centimeter. The wave length of light can for convenience be expressed in millimicrons, units of length equal to one-thousandth of one-millionth of a meter or one ten-millionth of a centimeter; the human eye therefore responds to a light between 400 and 700 millimicrons, as shown in Fig. *3*. Radio waves, which range from .01 to 25,000 meters in length are therefore more than one million times as long as light waves. Study Fig. *3* carefully, noting how the human eye responds to the different colors in the visible spectrum.

The electric eye, in addition to "seeing" those frequencies of light which can be detected by the human eye, will also respond to ultra-vio-

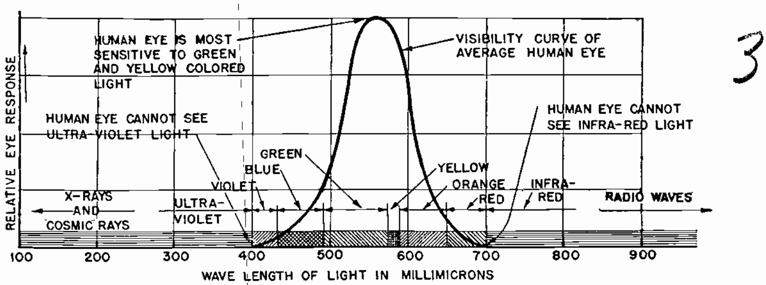


FIG. 3. The relative sensitivity of the average human eye to light of various colors (various wavelengths) is given by this curve.

let light and infra-red light, both of which are invisible to the human eye. It is this characteristic of the electric eye which makes it possible to use invisible light beams to control machinery or to operate burglar alarms.

Light-sensitive cells respond to various types of artificial light as well as to natural light. The ordinary incandescent electric lamp is the most common of artificial sources of light for photoelectric equipment. Here the filament, a very fine wire of high resistance, is heated by a current of electricity until it becomes incandescent and gives off light. Electric lamps designed for automobile headlights are ideal for photoelectric work because the source of light is concentrated into a very small space, approximating a point source of light. The smaller the source of light, the easier it is to focus that light into a beam.

Other artificial sources of light include natural gas lights, coal gas lights, the carbon arc lamp, the mercury vapor lamp, and gaseous conduction tubes (better known as neon tubes).

How Light Is Measured. As you know, the wax or tallow candle was one of the first artificial sources of light. When new light sources began to take the place of the candle, it was natural that their power should be expressed in terms of the old and familiar candle. Eventually a candle made according to certain specifications and burned under certain conditions was selected as the unit of light intensity, and the light given off by this candle was said to have an intensity of *one candlepower.* If an electric bulb was found to be 40 times as strong as this candle, it was said to have a candlepower rating of 40. The average electric lamp used in the home has an intensity of about one candlepower per watt of power used.

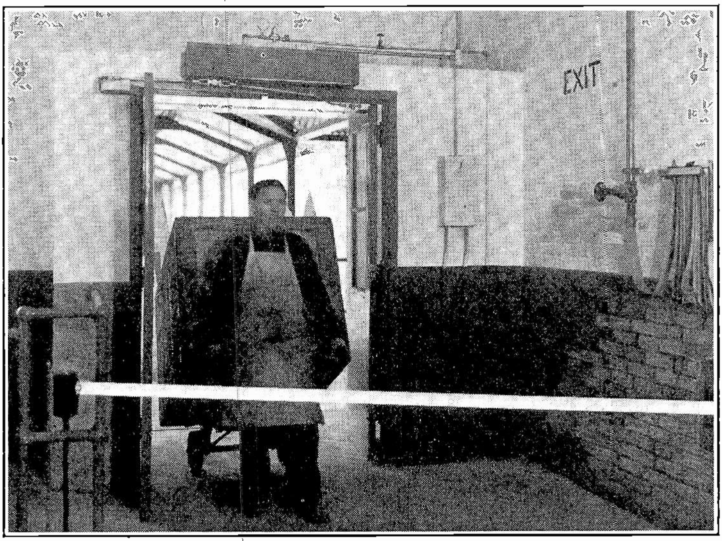
Undoubtedly you have noticed that the strength of the light on a certain object, such as a book, decreases very rapidly as the book is moved away from the source of light. Actually the intensity of the illumination produced by a source of light varies *inversely as the square of the distance* from the source of light. In other words, if the
4 illumination at a point two feet from the source is a certain value, the illumination at a point four feet from the source (twice as far away) will be one-fourth of that at the first point.

The practical unit of illumination is the *foot-candle.* This is the amount of light received on a surface which is directly facing and one foot away from a light source which has an intensity of one candlepower. For example, the correct illumination for general reading purposes is about 15 foot-candles; this means that the illumination on the printed page should be equivalent to that which would be produced by 15 standard candles located one foot above the page.

Another unit of illumination, the *lumen,* represents the *amount* of light (or light flux) falling on a surface one square foot in area, every point of which is one foot from a point source of light having a strength of one candlepower. Practically, however, to determine the amount of light (number of lumens) falling on a uniformly-illuminated surface of limited area, you multiply the area of the surface (in square feet) by the intensity of the illumination at the surface (in foot-candles); the answer will be in lumens. To determine the number of lumens of light emitted by a lamp, multiply the candlepower rating of the lamp by the number 12.6.

The foot-candle is a measure of the *intensity* of light at a *certain point,* such as at the face of a light-sensitive cell; the lumen is a measure of the *amount* of light falling on a *given area,* such as the sensitive surface of a light-sensitive cell. *Light intensity at the cell (in foot-candles) multiplied by effective area of the cell (in square feet) gives the number of lumens of light on the cell.*

Brightness is another factor which must be considered by the photoelectric engineer, for he will often direct a light on a certain surface and use an electric eye to pick up the light reflected from that surface. Brightness can be expressed in *candles per unit area;* this means that brightness is a measure of the ability of an illuminated surface to act as a source of light. For example, a surface has a brightness of 10



Courtesy The Stanley Works

Installation of photoelectrically controlled door opener in a factory. Light source is at left, and photocell cabinet at right. One light beam is directed across each side of doorway; interrupting first beam causes pneumatic door operator to open doors, and interruption of second beam, after person has passed through doorway, causes doors to close again. Interlocking relays prevent improper operation.

candles per square foot when each square foot of this surface reflects as much light in a given direction as would 10 candles.

Light Sources. In photoelectric work it is generally very desirable to have a definite beam of light directed on the electric eye. Naturally, it is desirable to use as small a light source as possible, in order to economize on power and make a compact unit. Most commercial light sources for photoelectric work use the small but powerful 32-candlepower automobile headlight bulb, getting the required low voltage from a step-down transformer which is connected to a 110-volt A.C. line, and concentrating the light into a beam with a lens. Since only that light which falls on the lens is useful in producing the beam, reflectors are generally used back of the bulb to reflect light back to the lens. Some light is absorbed at each reflection and each passage through a lens, so it is usually necessary to make adjustments of the light source and the relay apparatus until satisfactory operation is secured.

TYPES OF LIGHT-SENSITIVE CELLS

Although photoelectric or light-sensitive cells of various types are being manufactured today by many different firms, all of these can be divided into three basic classes. These three classes of light-sensitive cells are:

5

1. *Photoemissive cells.* Electrons, emitted from the cathode of the cell by the action of light, are collected by an anode which is at a positive potential. Photoemissive cells are better known as *photocells;* some technicians prefer to call them phototubes, since they are always built into glass envelopes like glass type radio tubes. In many technical books and articles you will find all types of light-sensitive cells referred to as photocells, but you can generally determine which type of cell is meant from the nature of the article. Remember that when we speak of photocells in this book we are referring specifically to *photoemissive cells.*
2. *Photoconductive cells.* In these cells the resistance (or conductivity) of a material changes under the action of light. Selenium is the most common resistance material used in these cells; you will find that photoconductive cells which use selenium are often referred to as *selenium cells.*
3. *Photovoltaic cells.* These cells develop their own voltage under the action of light. They are likewise often referred to as photoelectric cells, but photovoltaic cells or self-generating cells are the terms which will be used in this Course. The term photoelectric cell, as used in this Course, will refer to light-sensitive cells in general, regardless of their type.

Each light-sensitive cell has its own characteristics, and naturally transfers these characteristics to the associated photoelectric apparatus. The successful photoelectric technician must be familiar with each type of cell, in order that he can choose the best cell, the best circuit, and the best apparatus for each particular job. Knowing how the different cells behave, he can compare the advantages and disadvantages of the various types of photoelectric units on the market and can understand the specifications and ratings for each unit. Some cells are more dependable than others; some require external sources of voltage which may fail; some cells have a comparatively short life; all these factors must be taken into consideration where failure of the photoelectric control would in any way endanger human life or damage valuable equipment. For these reasons I am giving you, in the following pages, detailed descriptions of each type of cell, telling how they are constructed, how they operate, and basically how they are used.

PHOTOEMISSIVE CELLS

The photoemissive cell can be compared to a diode or two element tube, for both contain two electrodes mounted in a glass envelope. In the radio tube, the electrons which make up the current through the tube are secured by heating the cathode (filament), but in the photoemissive cell the rays or "bullets" of light activate the sensitized surface of the cathode and cause electrons to be emitted. The other electrode, called the anode, attracts the emitted electrons, as it is positively charged with respect to the cathode. The photoemissive cell acts like a variable resistance whose ohmic value changes with light; the more light there is shining on the cell, the greater is the current passed and the less is the resistance of the cell.

The construction of a typical photocell is shown at *A* in Fig. *4*. Here the cathode is a semicircular cylinder of metal (usually oxidized silver) supported inside the glass envelope by stiff wire leads made of nickel. The anode is simply a nickel rod or wire mounted in the axis of this cathode cylinder. The anode is untreated, but on that surface of the cathode which faces the anode is a thin film made up of caesium oxide, sodium, potassium, or lithium. I suggest that you consider the cathode film as simply a layer of light-sensitive chemical compound.

Soda-lime glass is used as the envelope for most of the photocells made today, it being easy to form into the desired shape. Higher priced cells use either pyrex glass or fused quartz, for these have lower light losses and allow more ultra-violet rays to pass. Lead glass is never used for photocells, because it combines chemically with the materials used on the cathode, discoloring the envelope, and because lead glass is a poor transmitter of light (it absorbs a high percentage of the rays).

The modern photocell is made by automatic machinery in much the same way as radio tubes are made. The proper chemical is sprayed on the cathode, the two electrodes are mounted in the glass stem, and this stem is then sealed to the glass envelope. The bulb is evacuated by vacuum pumps, then given a special treatment in a high frequency electrical furnace to complete the processing of the coating on the cathode.

Note that the anode in a photocell is the *smallest* electrode; this is necessary so the anode will not cast too large a shadow on the cathode and reduce the efficiency of the cell. In regular radio tubes the opposite holds true, for the plate or anode of a radio tube is the *largest* electrode.

Two types of photocells are in common use, these differing only in that one contains a gas while the other has a "hard" or high vacuum. Gas is introduced to give an increased current output for a given amount of light. The inherent sensitivity of a photoemissive cell is controlled by the cathode materials; the introduction of a gas reduces the effect of the space charge and permits greater sensitivity to be attained.

Photoemissive cells are always used in conjunction with one or more amplifier tubes, for the current passed by the cells is too small to operate even a supersensitive relay. A typical circuit which can be used with either gas or vacuum type photocells is given in Fig. *4B*. An ordinary radio tube such as the 30 or the 12A serves as amplifier tube; the relay is of the sensitive type, with its contacts connected into the power supply leads of the device being controlled. In this basic circuit the grid of the amplifier tube has a negative bias, and therefore draws no current. The relay resistance (usually somewhere between 1,000 and 10,000 ohms), is comparatively low with respect to the circuit resistance, so consider the photocell and resistor *R* to be in series across points *A* and *B* of the batteries. When the photocell is dark (no light on it), its resistance is very high and no current flows through it and *R;* the resistance drop (IR drop) in *R* is very low, then, and the grid of the tube can be considered as having almost the same negative potential as point *A*. With a highly negative grid, little or no electron current passes from cathode to plate in the amplifier tube and the relay armature is not attracted to the relay core.

When light falls on the photocell, reducing its resistance, a larger current flows through *R* and the photocell (resistors in series add; reducing the resistance of the cell reduces the resistance of the combination and allows more current to flow) and the IR drop in *R* becomes greater. Electron flow is from *A* through *R,* through the photocell and through the relay to *B;* point *C* is more positive than point *A*. The grid thus becomes more positive than point *A* when light falls on the photocell; with a lowered negative bias on the grid, plate current flows through the relay, causing the armature to be attracted to the relay core. In a practical circuit the grid bias would be controlled by a potentiometer connected across the grid bias battery, in order to adjust the circuit for maximum response to changes in light.

It is only necessary to reverse the positions of R and the photocell in this circuit in order to make the relay operate when the cell, originally illuminated, is darkened (as when some object interrupts a light beam directed on the cell).

VACUUM TYPE PHOTOCELLS

In the vacuum type of photocell the total tube current is made up of electrons which are emitted by the cathode (see Fig. 4C). This cell

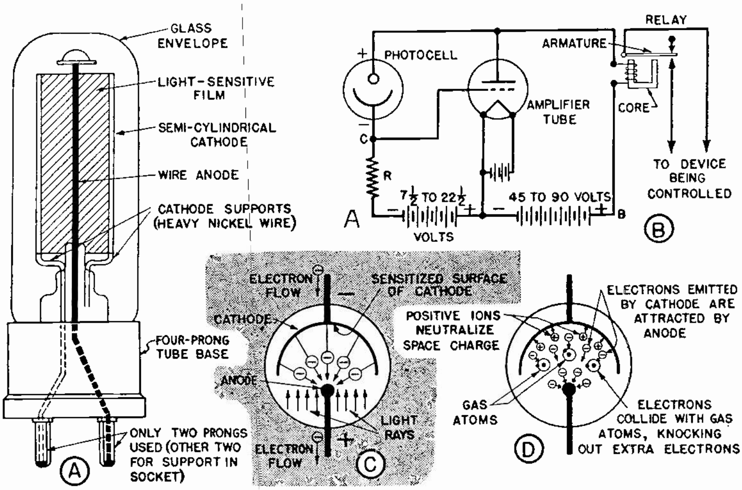


FIG. 4. The construction, the schematic symbol, the theory of electron flow in both gas and vacuum type tubes, and the diagram of an amplifier circuit for a typical photoemissive cell are given here.

will respond to light variations of almost any frequency, which means that it is ideal for use with television apparatus and for the fastest of counting jobs. The capacity between the anode and cathode is the only important limitation to the highest light variation frequency to which this cell will respond.

Just as curves are used to illustrate the characteristics of the vacuum tubes which you have studied, so too can curves be used to illustrate photocell characteristics. The stronger the light the greater will be the current flow, but does this relation hold at all times? Is the current affected by the voltage applied to the cell? These are important questions which can be answered easily by making some simple tests.

Current-Illumination Curve. This important photocell characteristic curve is obtained by applying a fixed voltage (say 40 volts) to a cell and measuring (with a micro-ammeter) the current passed by the cell at different intensities of illumination. With a vacuum type photocell the results obtained will give a curve like that in Fig. *5A*, showing that the current output is directly proportional to the amount of light falling on the cell. Here the cell current doubles when the light flux is doubled.

With a vacuum type photocell, light varying in intensity at frequencies as high as 1,000,000 cycles (encountered in television systems) can be accurately converted into electrical variations, for the straight line characteristic shown in Fig. *5A* holds true at all frequencies encountered in practical television service.

Current-Voltage Curve. If a vacuum type photocell, illuminated by a constant light intensity of about .5 lumen, were connected to a variable source of D.C. voltage, and measurements were made of the current passed by the cell for each value of voltage, the curve obtained would be like that shown in Fig. *5B*. Notice that once the voltage reaches a certain value (above the knee of the curve) the cell current increases very little as the voltage is further increased. At this point, called the *saturation value* of current, practically all of the electrons emitted by the cathode under the action of the fixed light are drawn to the anode. Clearly, then, there is little to be gained by increasing the voltage above this value. A small size vacuum cell can safely withstand up to 500 volts; oftentimes such a high value must be applied to the cell because of circuit conditions.

A standard incandescent electric lamp, whose voltage is adjusted to operate the filament at a constant and fixed temperature, is used in securing characteristic curves for all types of light-emissive cells; the illumination on the cell is varied by changing the distance between lamp and cell rather than by varying the light source.

The curve in Fig. *5B* can be made to show the relation between the sensitivity of the cell and the cell voltage simply by dividing the current values by the number of lumens of light on the cell. The vertical scale at the right in Fig. *5B* was obtained in this way, by dividing each value of current in the scale at the left by .5, the number of lumens of light on the cell. Now it is easy to see that a vacuum type cell should be operated at a voltage corresponding to a point *above the knee* of the curve if greatest sensitivity is to be obtained.

Color Response Curve. Another very important photocell characteristic is its response to light of different colors (wave-lengths). The curve in Fig. *5C* gives this information for a typical vacuum type photocell; in general the color response of a photocell differs considerably from that of the human eye (shown by dash-dash curve). Since this particular cell has a maximum response very near the infra-red light region, it is ideal for use with invisible light beams. Various light-sensitive materials are used on the cathode to get a certain desired color characteristic. Quartz must be used for the envelope where a tube is to be highly sensitive to ultra-violet light, since ordinary glass does not transmit ultra-violet rays.

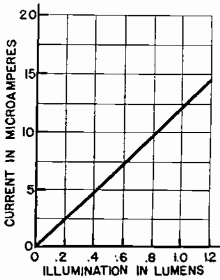


FIG. 5A. Current-Illumination Curve for a typical vacuum type photocell (Westinghouse SR-50 phototube).

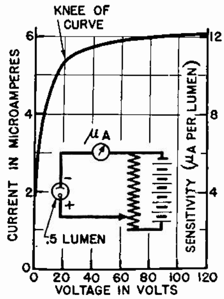


FIG. 5B. Current-Voltage Curve for Westinghouse SR-50 phototube, obtained with constant illumination of .5 lumen.

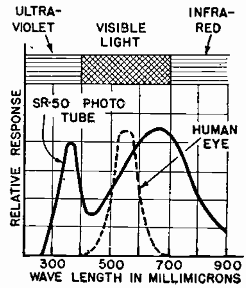


FIG. 5C. Color Response Curve for Westinghouse SR-50 phototube, with response of human eye shown for comparison.

GAS TYPE PHOTOCELLS

The gas type photocell differs from the vacuum type only in that after evacuating a small quantity of an inert (inactive) gas such as argon, helium or neon is admitted before sealing off the tube. In this gas type cell the electrons emitted by the cathode, traveling at high speed towards the anode, have sufficient force to knock out electrons from gas atoms into which they collide, thus splitting up the atoms into positive ions and free electrons; this process is known as *ionization.* The electrons resulting from these collisions are attracted to the anode along with the emitted electrons, and serve to build up the photocell current. The positive ions (atoms from which electrons have been knocked out) move to the space cloud near the cathode, neutralizing the electrons there and allowing more of the electrons from the cathode to find a free path to the anode. If the ionization is made too strong by excessive anode voltage, causing a glow discharge, the gas ions bombard the cathode, destroying the tube.

This "ionization by collision" process is shown in Fig. *4D*. The original tube current can be increased as much as ten times by the ionization of the gas; the amount of ionization increases rapidly as the voltage is increased, but the voltage must be kept below a critical value in order to prevent a glow discharge (similar to that in neon sign tubing) from destroying the tube. With too-high voltages the gas type tube will pass current even when no light is falling on the cathode. Resistors are often placed in series with a gas type tube in order to limit this discharge current to a safe value in case the voltage becomes too high. The operating voltages vary between 25 and 100 volts for the average gas photoemissive tubes, depending upon their construction; under no conditions should this voltage be exceeded.

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Characteristic curves for a typical gas type photocell, the General Electric PJ-23 phototube, are given in Figs. *6A*, *6B* and *6C*. The current passed by the gas type cell increases practically in direct proportion to the *illumination,* just as in the vacuum type cell (Fig. *5A*).

The curves in Fig. *6B* give you a very good idea of the characteristics of a gas type photocell; at voltages below 20 volts this cell behaves almost exactly like a vacuum type cell (Fig. *5B*), for at these low voltages the emitted electrons do not reach a sufficiently high speed to knock electrons out of the atoms of gas inside the photocell. At some voltage above about 20 volts (above the knee of the curve) ionization starts, and further increases in voltage give much greater increases in current than would be obtained with a vacuum type cell. The dotted lines (Fig. *6B*) show how the current would vary at higher voltages if there were no gas in the tube.

The voltage and current rating specified by manufacturers for gas type tubes must be carefully followed if the tube is to be in operation for long periods of time. Voltages slightly higher than rated values shorten tube life considerably, and very high voltages cause a glow discharge which destroys the tube. In general, the maximum safe operating voltage of the average gas type photoemissive cell is about 100 volts. The operating voltage can sometimes be increased for low values of illumination (see the curve for .1 lumen illumination in Fig. *6B;* here the current is far below the maximum rated value of 20 ma. at maximum rated voltage) provided that the maximum rated value of current is not exceeded; it is a good idea to place a resistor in series with the tube to limit current to a safe value in case the illumination is accidentally increased.

Gas Ratio. The ratio of the current passed by a gas photocell at its maximum safe operating voltage to the current passed just before ionization and gas amplification begins is known as the *gas ratio* of the tube. For example, the gas ratio of the General Electric PJ-23 tube (Fig. *6B*) is about 7; this value was obtained by dividing the current at 90 volts by the current at 25 volts, the illumination being held constant at a value which limits the current at 90 volts to a safe value. Maximum values are generally specified for gas ratios, since the ratio becomes less as illumination on the cell is decreased.

Color Sensitivity. The color response of a gas type photocell depends upon the kind of glass used for the envelope and upon the nature of the light-sensitive material used on the cathode. The curve in Fig.

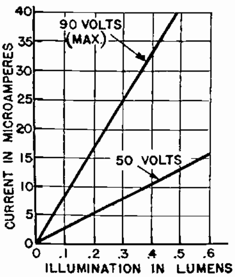


FIG. 6A. Current-Illumination Curves for a typical gas type photocell (General Electric PJ-23 Phototube).

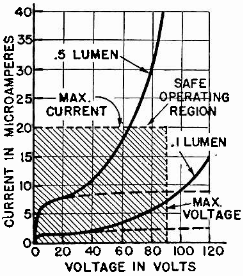


FIG. 6B. Current-Voltage Curve for General Electric PJ-23 phototube, for two different values of illumination.

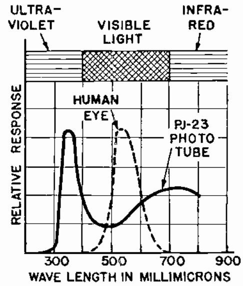


FIG. 6C. Color Response Curve for General Electric PJ-23 phototube. Note peak in ultra-violet region.

6C is therefore just one of many color characteristics associated with gas photocells. This particular tube has high sensitivity to ultra-violet and infra-red, but comparatively low sensitivity to visible light.

Gas and Vacuum Photocell Ratings. Just as radio tubes have certain definite ratings which must not be exceeded, so do photocells have maximum voltage and current values which cannot be exceeded in ordinary practice.

The *maximum anode current* is the maximum value of current which can be safely passed by the tube. For A.C. this is the peak value of current.

The *maximum anode voltage* is the maximum value of voltage which can safely be applied to the tube. For A.C. this is the peak value of voltage.

The *maximum illumination* is more important in connection with gas type cells than with vacuum type cells. At high values of illumination, the voltage applied to a gas type photocell must be considerably lower than the rated value in order to keep the current down to a safe value (in the safe operating range shown in Fig. *6B*). Vacuum type cells are ordinarily not designed to withstand direct exposure to sunlight for long periods of time; at high values of illumination the voltage should be kept at the minimum value which gives satisfactory operation.

The *sensitivity* of a photocell is generally expressed as the current passed in microamperes per lumen of light flux; this is usually measured at a light intensity of either .1 or .5 lumen, in order that sensitivity ratings of various tubes can be compared. The sensitivity of vacuum type cells varies from about 5 to 35 microamperes per lumen (the sensitivity of the vacuum type cell in Fig. *5A* is about 15 μa per lumen), while for gas cells, rated sensitivity values may be as high as 300 microamperes per lumen (the average sensitivity rating of the gas type cell in Fig. *6A* at an anode voltage of 90 volts is 50 microamperes per lumen).

Figure 7 shows a number of typical photoemissive cells. Gas and vacuum type photocells look the same, since the gas used is invisible.

PHOTOCONDUCTIVE CELLS

The operating principle of this cell is the change in electrical resistance (change in ohmic value) of a material when exposed to varying intensities of illumination. The photoconductive cell is essentially a high resistance whose ohmic value varies with the light falling upon the cell. The stronger the light falling on the cell, the lower becomes the resistance. Since this type of cell does not generate its own voltage, it requires an external potential and will pass some current even when in the dark.

The photoconductive effect was first noticed by an engineer named Willoughby Smith, who, while stationed in the Azores Islands in 1871, noticed that the selenium resistors he was using changed their resistance when exposed to sunlight. Reporting the discovery to a group of
7 scientists, he announced: "By the aid of the telephone I heard a ray of light fall on a bar of metal!"

Photoconductive cells are being made almost exclusively from selenium, although certain other compounds, one of which is thallium oxysulphide, show appreciable photoconductive effects. Many different forms of selenium cells are on the market today.

The term "cell" is somewhat misleading when used in connection with photoconductive cells and photoemissive cells, for these do not generate their own voltage and are therefore not to be compared to a battery. The word *cell,* is, nevertheless, commonly used among technical men for all three classes of light-sensitive devices, and is therefore used in this lesson. You will always be able to tell what is meant

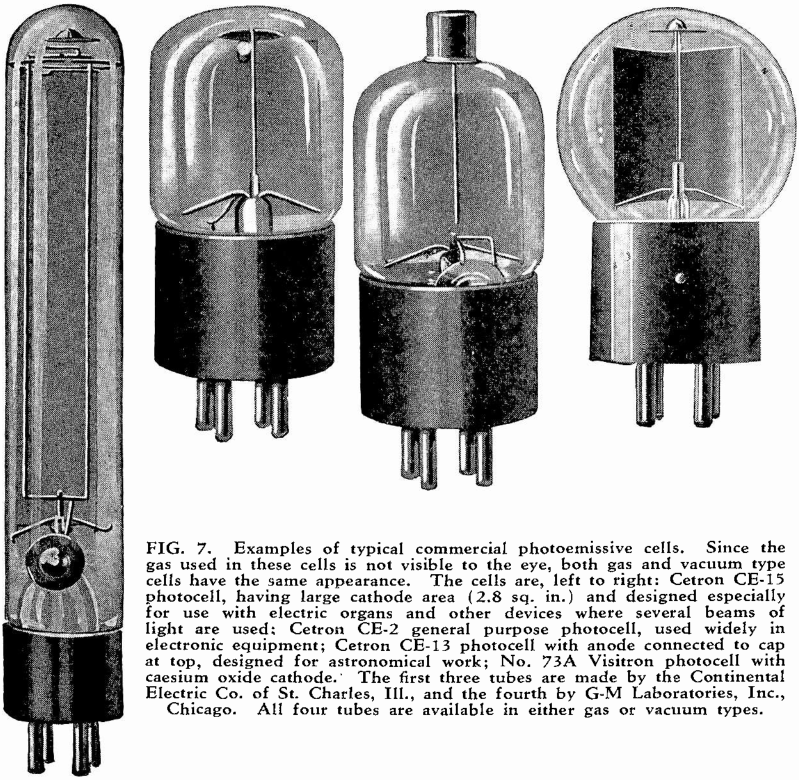


FIG. 7. Examples of typical commercial photoemissive cells. Since the gas used in these cells is not visible to the eye, both gas and vacuum type cells have the same appearance. The cells are, left to right: Cetron CE-15 photocell, having large cathode area (2.8 sq. in.) and designed especially for use with electric organs and other devices where several beams of light are used; Cetron CE-2 general purpose photocell, used widely in electronic equipment; Cetron CE-13 photocell with anode connected to cap at top, designed for astronomical work; No. 73A Visitron photocell with caesium oxide cathode. The first three tubes are made by the Continental Electric Co. of St. Charles, Ill., and the fourth by G-M Laboratories, Inc., Chicago. All four tubes are available in either gas or vacuum types.

by referring to the circuit diagram, for the symbols for light-sensitive cells are quite different from the symbols for batteries.

A selenium cell consists essentially of two electrodes between which is deposited a thin film of selenium. The electrodes, which can be either of copper, iron, nickel, aluminum, silver, gold, platinum, metal alloys, lead, graphite or carbon, are mounted on some insulating block such as quartz, glass, clay compounds, porcelain, slate, mica or bakelite.

The construction of a simple selenium cell is pictured in Fig. *8A*. Two pieces of metal foil are cut out as shown and cemented to the flat base, after which a thin layer of molten selenium is spread evenly over the foil plates and all gaps between the foil. Sometimes the selenium in powder form is sprinkled over the plates, then heated and spread out, or selenium is heated to its boiling point and the vapors allowed to condense on the plates. In any event, the cell must be annealed by heating carefully until the selenium changes from its pitch black form to the gray crystalline form which is highly sensitive to light, then cooled slowly.

Commercial selenium cells are made in a number of different ways. One type of cell has two wires wound over an insulating slab, with a thin layer of selenium deposited between the wires. Each wire

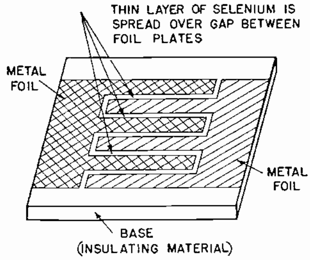


FIG. 8A. The basic construction of a simple selenium cell is illustrated in this sketch.

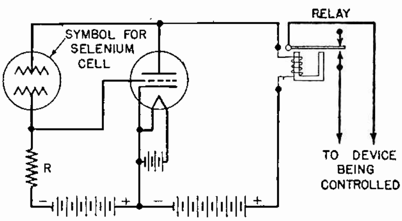


FIG. 8B. Basic circuit for a selenium (photoconductive) cell. Note symbol used to represent this cell.

serves as a terminal of the finished cell, the resistance between the two wires being determined by the resistance of the selenium layer. A flat piece of slate is sometimes coated with a film of graphite which is polished with a chamois skin, then divided into two interlacing sections with a sharp tool and selenium deposited over the entire surface.

In other types of selenium cells a thin film of platinum, gold or silver is fused into the surface of a block of glass or quartz. This thin metal film is then divided into two sections by a zigzag or comb-like line made with a precision instrument known as a "dividing engine." There may be as many as one hundred lines or scratches per inch on the cell. When the metal film has been divided into two separate electrodes in this manner, a thin layer of selenium is placed over the entire unit, this selenium serving to bridge the gaps between the two electrodes. This method gives a very small separation between the two plates and a long gap covered with selenium.

The Acousto-Lite Type 50A2 cell, characteristics of which are given in Fig. *9,* belongs in this last class; it is highly sensitive to changes in illumination but is not recommended for operating voltages higher than 80 volts or light intensities of more than 20 foot-candles. As a precaution against breakdown due to excess voltage or excess current, a one-megohm resistor is usually connected in series with the cell.

Looking first at the Current-Illumination curve (Fig. *9A*), you can see that the current passed increases with illumination, but the effect of the light (the increase in current) is less at the higher values of illumination. Notice that the current does not drop to zero when the cell is dark (the applied voltage being held constant); selenium cells have a definite "dark" resistance, so current can drop only to the dark level when light is cut off from the cell. The resistance of this particular cell is about 10 megohms in the dark and about 2 megohms

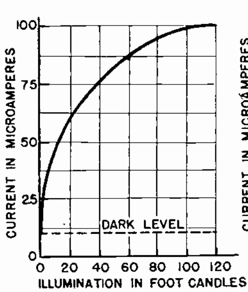


FIG. 9A. Current-Illumination Curve for Acousto-Lite Laboratories Type 50A2 selenium cell.

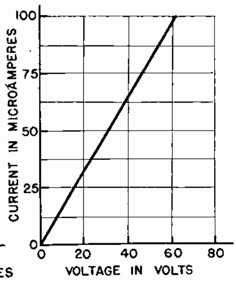


FIG. 9B. Current-Voltage Curve for Type 50A2 selenium cell (with constant illumination).

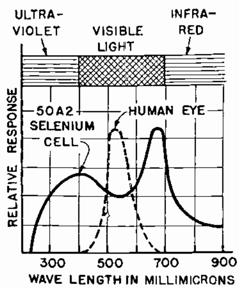


FIG. 9C. Color Response Curve of Acousto-Lite Laboratories Type 50A2 selenium cell.

at an illumination of 10 foot-candles, hence this cell has what is called a dark-to-light resistance ratio of 5.

When illumination is held constant on a selenium cell and the voltage varied, the current varies exactly as it would for an ordinary fixed resistance. You know that the current passed by a resistor varies directly with the voltage applied; that is why the curve in Fig. *9B* is a straight line.

You will find that most selenium cells have a maximum sensitivity to red or infra-red light, with a lower peak (in some instances) in the ultra-violet region (Fig. *9C*).

Photoconductive cells are generally used with vacuum tube amplifiers, just as are photoemissive cells, but it is possible to make them with a resistance sufficiently low to permit direct operation of a sensitive relay. A battery delivering somewhere between 15 and 45 volts must then be connected in series with the cell and relay, for photoconductive cells do not generate a voltage. The current passed by the cell under constant illumination depends only on the voltage applied to the cell; the maximum current is determined by the maximum voltage which can be applied without causing breakdown of the selenium in the gap between the plates.

The amplifying circuits required for selenium cells are very similar to those used with photoemissive cells. A fundamental selenium cell circuit is given in Fig. *8B*. Light falling on the selenium cell changes its resistance, thereby changing the bias voltage on the grid of the tube. In the circuit shown, increases in light make the grid of the tube less negative (more positive), thereby causing the plate current to increase and operate the relay. With this circuit, therefore, the device being controlled by the relay operates whenever a strong light falls on the cell. If the positions of the selenium cell and the resistor *R* are reversed, the relay will be closed when the cell is dark but will open just as soon as sufficient light falls on the cell.

Selenium cells are generally sealed in moisture-proof cases, for they are quite sensitive to changes in humidity. The stability of the cells is in general quite poor; those cells which have a very high sensitivity to changes in light usually have a short life, and their sensitivity changes with use. Mounting in moisture-proof cases also improves cell stability, but with many cells the current passed varies slightly even with constant illumination. Their power output is limited by the maximum voltage which can be impressed without causing breakdown across the electrodes and by the amount of heat developed in the cell (excess heat changes the selenium to an insensitive form).

Selenium cells ordinarily have a time lag and are rather slow to respond to changes in light, but with certain types of construction they can be made to respond satisfactorily to light frequencies of up to 6,000 cycles, as in sound picture work. The use of selenium cells for audio frequency work is, however, the exception rather than the rule. It takes several minutes after an increase in light before an ordinary selenium cell will allow maximum current to flow, but fortunately for control use, the current reaches 95 per cent of its final value in about .03 second. Selenium cells, however, are unsuited for use in television systems and in any other circuits where very rapid response is required.

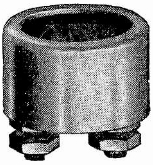
Advantages of Selenium Cells. Some selenium cells are very sensitive to infra-red light, and these are especially valuable where control is to be secured with an invisible light beam. Selenium cells can be made to have a low sensitivity to changes in light and a high current output, or a high sensitivity with low current output, just as is desired. Their output is in general considerably greater than that of photoemissive cells. Typical selenium cells are shown in Fig. *10*.

Precautions in Using Selenium Cells:

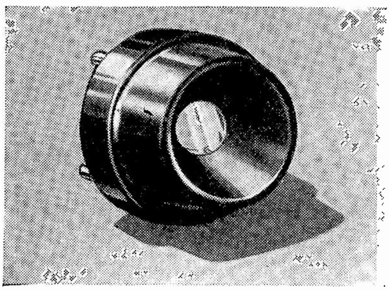
1. Keep cells cool. The heating effect resulting from too large currents through the cell, from exposure to an intense light source or by using the cell in locations where temperature is excessive, will cause the selenium in the cell to become soft and possibly melt, thus rendering it unfit for photoelectric use.

2. Keep cell dry. When not in use, place in a dark box containing a few pieces of calcium chloride in order to absorb moisture near the cell.

3. High potentials should be avoided. Use the lowest possible voltage which will give the desired results. Choose high resistance relays



Courtesy Acousto-Lite Labs.



Courtesy Hugh H. Eby, Inc.

FIG. 10. Examples of typical selenium cells. At the left is the Acousto-Lite Type 50A2 cell, curves for which are given in Fig. 9. The Eby Electric Eye (right) has its light-sensitive element sealed in moulded bakelite; it will operate on voltages up to 250 volts and at frequencies up to 9,000 cycles. The response of the Eby cell is not sufficiently linear, however, to make it suitable for use with sound-on-film movie projectors.

or place a limiting resistance in series with the cell for protective purposes. In general, 4 milliamperes is more than ample for relay work.

4. Exposure to intense lights for long periods of time should be avoided, for this causes "fatigue" which makes the cell temporarily, and in many cases permanently, insensitive to light.

5. When not in use, cells should be kept in the dark, but they may be exposed to light regularly, for short periods of time, to aid in retaining their sensitivity.

6. If the resistance of a cell drops greatly, it can be raised, at least temporarily, by applying pulsating or alternating currents.

PHOTOVOLTAIC CELLS

8 Photovoltaic cells are really small batteries or sources of direct current, since they generate a current which varies with the intensity of the light falling on the cell; more correctly, they transform the radi-

ant energy of light directly into electrical energy. Although the voltage output of these cells is quite low, the current delivered is sufficient to operate an indicating meter or a *super-sensitive* relay without using any batteries or auxiliary apparatus.

Types of Photovoltaic Cells. There are two general types of photovoltaic cells: the *dry* or electronic type, which is today the most common, and the *wet* or electrolytic type. These differ only in the methods of construction and in general characteristics, for each generates its own voltage.

Dry Type Photovoltaic Cells. This type of cell consists essentially of a metal disc, perhaps one-sixteenth inch thick, on one side of which is a film of light-sensitive material; this basic construction is illustrated at *A* in Fig. *11*. The metal disc forms the positive terminal of the cell, and a thin metal film deposited on part or all of the sensitized surface forms the negative terminal. The action of light forces electrons to the surface of the sensitized layer, where they are collected by the thin metal film which serves as the negative terminal of the cell. The metal disc is the positive terminal, for it must make up for the electrons drawn out of the sensitized layer by the action of light. A voltage therefore exists across these terminals when the cell is illuminated, and electron flow will be in the direction indicated at *B* in Fig. *11*.

Photovoltaic cell circuits are quite simple, the cell being connected directly to the coil terminals of some type of super-sensitive relay, as in Fig. *11C*. Since the contacts of this relay ordinarily cannot handle the current required by the device to be controlled, a sensitive relay is generally used. The contacts of the super-sensitive (meter type) relay then control the current to the coil of the sensitive relay, which in some cases may operate a heavy duty relay.

Although the dry type of photovoltaic cell can be made in a number of different ways, the following is a typical manufacturing procedure. An iron disc about 2 inches in diameter and one-sixteenth inch thick is first thoroughly cleaned, then covered on one side with ordinary solder. A thin layer of selenium is deposited over this layer of solder, and this layer is annealed or heated under pressure. When the cell has cooled, a thin film of either gold, silver or platinum is deposited on the selenium surface, this film being thin enough to allow light to pass through. This film can be applied as a very thin sheet of the metal (called "gold beater's metal") or can be sprayed on the selenium in molten form from a special spray gun. In some cases the translucent metal film is deposited on the selenium by a process called "cathode sputtering," which is carried out in a vacuum chamber. The cell is completed by making contact to the iron disc and to the translucent metal film with thin metal washers of the same diameter as the iron disc. Naturally the cells must be handled very carefully, for the translucent metal film will rub off very readily. A glass window is customarily set into the cell housing to protect the light-sensitive layer.

Photronic Cell. The Weston Photronic cell, one of the first commercial selenium iron type cells to be developed in the United States, is constructed in much the same manner as was described above; this is today one of the best known of all photovoltaic cells in this country.

The component parts of a Photronic cell are shown in Fig. *12;* at *A* is the thin disc made of iron, on one side of which is the layer of light-sensitive selenium. The cell is assembled as follows: The glass

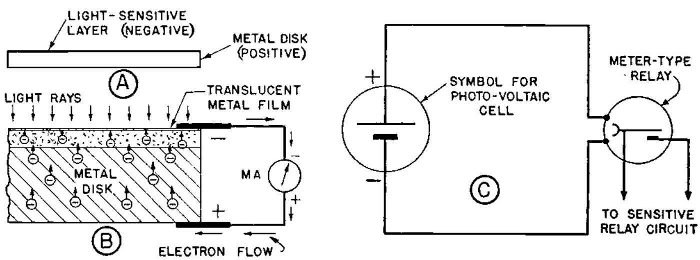
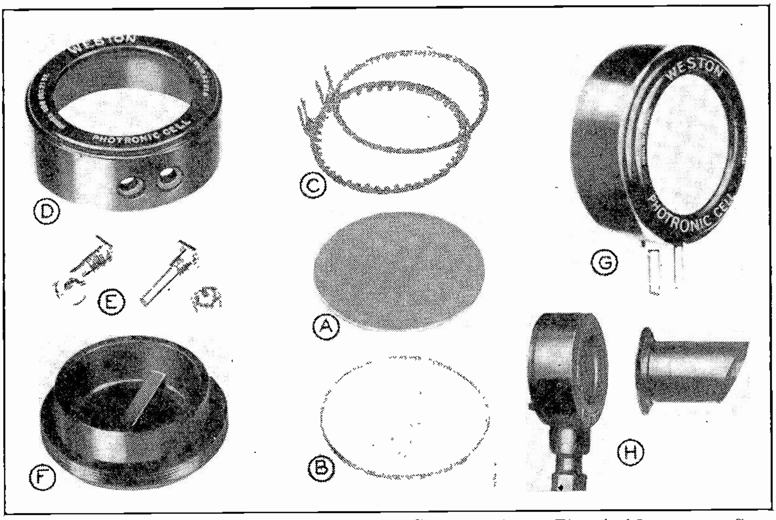


FIG. 11. Basic construction of and basic circuit for the dry photovoltaic (self-generating) cell.

window is placed in the bakelite housing; the iron disc, with one of the metal contact rings on each side, is placed in the housing next, with the sensitive side against the glass; the contact rings are turned so each terminal lug is over one of the holes in the side of the housing, and the terminal bolts are set into place, heads inside the housing; finally the bakelite cap is screwed into the housing. The projecting ends of the bolts are of the same diameter as radio tube prongs, and fit into an ordinary four-prong tube socket.

Characteristic curves for the Weston Photronic cell are given in Fig. *13*. The current output varies with the external resistance connected to the cell as well as with the illumination, the output being linear (proportional to illumination) for low values of external resistance. This linear relation for low resistances holds true even when the cell is in direct sunlight (about 175 lumens of illumination) ; the maximum current in direct sunlight, for a 3-ohm external resistance, will be about 20,000 microamperes or 20 ma. In using meters or relays with Photronic cells, therefore, it is necessary to consider their resistance. Low resistance meters are used where it is necessary that the current produced be directly proportional to the light intensity; for low values of illumination (below .1 lumen or below 10 foot-candles), sufficiently linear response can be obtained with instruments having 1000-ohm or higher resistances, for the curves are practically straight in this region (see Fig. *13A*).

The voltage output of the Photronic cell for varying intensities of illumination, measured by a method which involved no flow of current



Courtesy Weston Electrical Instrument Co.

FIG. 12. View of component parts of the Weston Photronic cell, a dry type photovoltaic cell. A—sensitized iron disc; B—glass window; C—metal contact rings; D—bakelite housing; E—terminal bolts; F—bakelite cap; G—assembled cell; H—Photronic cell in weatherproof housing, with visor to keep out unwanted light.

through the cell, is shown in Fig. *13B*. The curve is not linear, and the values of voltage are quite low; this cell, together with all other photovoltaic cells, is in general not used with vacuum tube amplifiers, which require large changes in grid voltage to get useful changes in plate current in a single amplifier tube.

The relative color response curve for the Photronic cell, given in Fig. *13C*, shows that the cell and the human eye have a maximum response to about the same color, yellow-green. The manner in which a glass window absorbs ultra-violet light can be seen; a much higher response to ultra-violet light is obtained with a quartz window in the

9 cell. Filters (panes of colored glass) which give the Photronic cell almost exactly the same color response as the human eye can be obtained from the manufacturer; these filters are necessary whenever the cell is to replace the human eye in making measurements of light. The Weston illumination meter, where the cell is connected directly to an indicating current instrument reading in foot-candles, is an example of this use.

Photronic cells should be used as current sources rather than voltage sources, for the current output of the cell varies directly with the light falling on the cell. In order to obtain a constant voltage from this type of cell, it is necessary to connect a resistance across the cell and take off the voltage across the resistor. This voltage will then be proportional to the light falling on the cell.

10 It is possible to connect two or more Photronic cells *in parallel* to

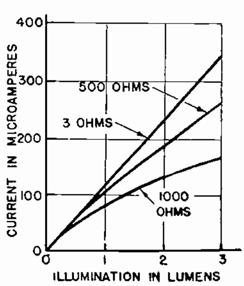


FIG. 13A. Current-Illumination Curve for Weston Photronic cell.

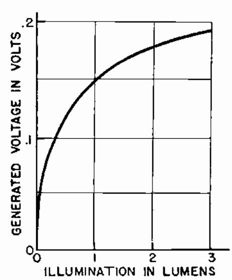


FIG. 13B. Voltage-Illumination Curve for Weston Photronic cell.

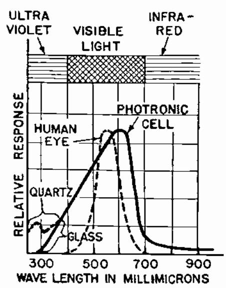


FIG. 13C. Color Response Curve for Weston Photronic Cell.

obtain a greater current output for a given intensity of illumination; connections are exactly the same as for dry cells, minus to minus and plus to plus. The dark resistance of these units is quite high, which means that a number of cells at different points can be connected together in parallel without the possibility of one cell feeding current into the others. The total current delivered by a system made up of a number of dry photovoltaic cells will be proportional to the total light falling on all of the cells; for instance, if three cells in parallel furnish 100 microamperes when illuminated by light sources of equal intensity, the combination of cells would give exactly 67 microamperes if one cell were completely darkened. Individual cells have this same characteristic; practically the same current response is obtained when light is concentrated on one part of the cell as when the *same amount* of light is spread uniformly over the entire active surface.

The Electrocell, a dry disc type of self-generating cell imported from Germany, consists of a light-sensitive layer of selenium deposited on the surface of an iron disc, contact being made to the layer with a transparent conducting film of silver. Transparent lacquer sprayed over the greater part of the cell protects it from rough handling. The sensitivity of this cell is 480 microamperes per lumen; in direct sunlight the 1¾-inch diameter cell will deliver as much as 20 ma. It is claimed that the Electrocell, in the larger sizes, delivers enough current to operate a sensitive relay directly, thus eliminating the need for an expensive super-sensitive relay. The smallest Electrocells, ⅜-inch in diameter, have a sufficiently low capacity to be used at frequencies up to 8000 cycles.

Another type of dry photovoltaic cell which is now on the market, the Westinghouse Photox cell, consists of a disc of copper on which has been formed a thin film of cuprous oxide. Contact is made to the copper and to the oxide layer in much the same way as was done with the selenium iron type cell. Gold is the material used as the translucent film on this cell.

The Lange cell, of German manufacture, is quite similar in construction to the above-mentioned photovoltaic cells; according to data furnished by the manufacturer, it has a very good current output.

The General Electric Company's selenium-on-iron type photovoltaic cell is mounted in a bakelite case and provided with prongs which permit mounting it in an ordinary four-prong radio socket. This cell and two types of multiple Photronic cell units appear in Fig. *14*.

General Characteristics of Dry Photovoltaic Cells. Dry photovoltaic cells are generally connected directly to super-sensitive relays, these being built much like a milliammeter or microammeter, but with contacts on the moving pointer and fixed contacts on the meter scale. These relays respond to currents of the order of microamperes, and are therefore quite costly.

For all practical purposes, the response of a dry photovoltaic cell to changes in light can be considered to be practically instantaneous. Actually these cells are fast enough to detect the passage of a rifle bullet through a beam of light. Because of the high parallel capacity of the cell, however, (about .5 mfd.) dry photovoltaic cells are not suitable for use in audio frequency apparatus, such as for responding to a light beam which has been modulated at audio frequencies. Photoemissive cells are more generally used for this purpose.

The output of a photovoltaic cell can be increased considerably by connecting a small potential, not over 6 volts, in series with the cell. Too high voltages may permanently change the characteristics of the cell; in fact, the manufacturers of the Photronic cell recommend that no external voltages be used if maximum cell life is to be obtained. A photovoltaic cell behaves much like a photoconductive cell when an external potential is used in series with the cell.

Dry photovoltaic cells are believed to have an unlimited life; that is, they will retain their characteristics for long periods of time if kept at temperatures below about 120° Fahrenheit. The cells must be

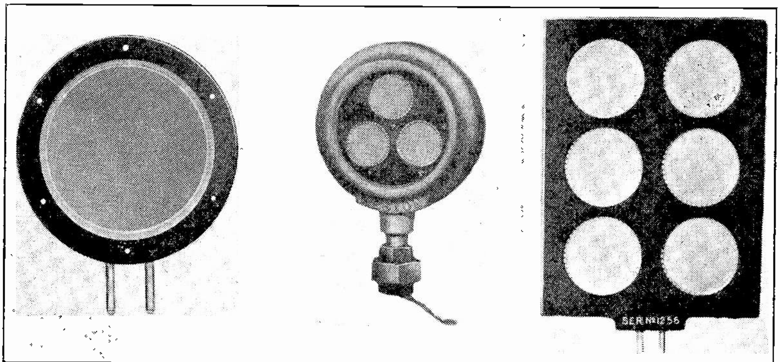
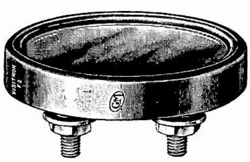


FIG. 14. Typical photovoltaic cells. Above, left to right: Blocking layer cell, a type of photovoltaic cell made by General Electric Co.; a Weston unit consisting of three Photronic cells in a weatherproof housing; Weston unit consisting of six Photronic cells in parallel, made by the Weston Electric Instrument Co. for use in measuring very low intensities of illumination. At right: Visitron F-2 cell, made by G-M Laboratories, Inc. All photovoltaic cells shown here are capable of generating sufficient current to operate super-sensitive relays directly.



tightly sealed in their cases, for they are critically affected by chemical vapors and by dampness.

Wet Photovoltaic Cells. The photovoltaic cell in wet form is now almost 100 years old, for its principle, known as the Becquerel effect, was discovered by Edmund Becquerel in 1839. While experimenting with the ordinary type of voltaic cell known in that day, he noticed that his cell gave out a much greater output in direct sunlight than in the subdued light of his laboratory.

In its simplest form, the wet photovoltaic cell consists essentially of two metals which are immersed in an electrolyte, one of these metals or electrodes being exposed to a source of light. Research workers have developed two types of these wet photovoltaic cells, one in which the electrodes themselves are light-sensitive, and another in which the electrolyte is light-sensitive, but neither type is believed to be of great commercial importance at the present time.

Wet photovoltaic cells can be constructed with a number of different electrode materials and electrolytes. One form of this cell has two copper electrodes, on one of which is a film of cuprous oxide. Another type uses one copper electrode on which is the film of cuprous oxide, and one lead plate; the electrolyte in this case is a dilute solution of lead nitrate.

The wet type of photovoltaic cell has a number of drawbacks. In some types destructive gases were formed in the cell while it was standing idle. Industry in general hesitates to adopt equipment like this, in which there is a possibility of leakage of liquid.

Naturally polarity must be considered when connecting photovoltaic cells of all types into a circuit, for the cells are really small voltaic cells. In the wet type of cell, the electrode having the oxide layer is always *positive*.

Choosing Light-Sensitive Cells. The electronic control engineer seldom finds it necessary to make a choice between the different types of light-sensitive cells for a particular application, as manufactured equipment which already includes the light-sensitive cell is now available in many different forms. The information on light-sensitive cells which has been given in this lesson will, however, help you to understand the operation of photoelectric apparatus, for only by a thorough knowledge of the fundamental principles of photoelectricity can you use available equipment to the best advantage. Leave experimenting and research with light-sensitive cells up to the factory engineers who have the necessary equipment and training to do this type of work.

TEST QUESTIONS

Be sure to number your Answer Sheet 25FR-2.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and you will receive the best possible lesson service.

1. What is the general effect of variations in light on a light-sensitive cell?

2. Name the six basic parts of a complete photoelectric control installation.

3. What kinds of light are invisible to the human eye, yet can be "seen" by the electric eye?

4. Name the practical unit of illumination.

5. Name the three classes of light-sensitive cells.

6. What is the maximum safe operating voltage of the average gas type photoemissive cell?

7. Do selenium cells respond instantly to changes in light?

8. What type of light-sensitive cell will operate a super-sensitive relay without auxiliary apparatus?

9. What device is used with the Photronic cell to make it have exactly the same color response as the human eye?

10. How would you connect two or more Photronic cells to secure a greater current output for a given intensity of illumination?

LOUDSPEAKERS AND HOW THEY OPERATE

26 FR

PIONEER HOME STUDY RADIO SCHOOL

NRI

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

THE SUBJECT OF LOUDSPEAKERS

To me, the subject of loudspeakers has always been a most interesting one. After all, a Radio receiver can be no better than the speaker you use with it. The speaker is the final link between the transmitter and the ear. And no matter how good a receiver you have, no matter how well it amplifies the signal carrying current, no matter how little distortion is introduced into the signal by the receiver, if the speaker is no good, the receiver might just as well be no good too.

Then in connection with speakers, there are so many important details, so many small things that vitally affect music and voice reproduction that in servicing speakers, the Radio-Trician has a real opportunity to demonstrate his knowledge of the fine points of Radio reception. Even such small things as the location of the speaker in the home may mean all the difference between the satisfaction and dissatisfaction of the set owner. Service men who do not realize this might waste many hours trying to find a defect in the receiver—and yet if they really knew their business, they could give the set owner real service in fifteen minutes.

In the past few years, engineers have devoted much time to the perfecting of loudspeakers. New types of speakers have been developed. Problems have come up which may lead to the development of still more kinds of speakers. In the books on speakers which we have found necessary to include in our course, you learn about all the various types of speakers developed thus far. You learn of the mechanical features of each type—along with its advantages and disadvantages. The main purpose of these books is to give you a thorough grasp of the problems involved in speaker maintenance and design—study them carefully and with the knowledge you gain from them, who knows but that you may some day make a valuable contribution to loudspeaker development.

J. E. SMITH.

NATIONAL RADIO INSTITUTE

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Loudspeakers and How They Operate

LOUDSPEAKERS

In previous books, we have often said, "The output of the Radio receiver is connected to a suitable loudspeaker." A very simple statement—but to determine what is a suitable speaker for a certain receiver is not such a simple matter.

The loudspeaker is used to translate the electrical energy obtained from the output of the last audio tube into sound energy which emanates from the moving system of the loudspeaker. The loudspeaker unit can well be considered a motor because electrical energy is fed into it and it delivers mechanical energy which in turn creates the sound waves we are interested in.

Like a motor, this sound translating device should be as efficient as possible. By this we mean that the sound output energy must be as large as possible in comparison with the input energy. Loudspeakers are ridiculously inefficient when compared with other energy transforming devices—electric motors, water wheels, gasoline engines—which may have an efficiency between 40 and 85 per cent. Compare this with the efficiency of a speaker which is seldom more than 7 per cent and which is more likely nearer 3 per cent.

Then, a speaker must have good operating characteristics by which we mean that all frequencies supplied to the speaker, from 30 to 8,000 cycles of audio current, must be translated into sound in exact proportion to the electrical input. Not only should this be true at low sound levels, but just as much so at high levels.

The output must not sound like anything except the original transmitted sounds, whether they be voice, music or noise. Being the final link from the source of sound to the ear, it is important that a speaker be as nearly perfect as it can be made. It would be futile to attempt to operate an imperfect device on a perfect electrical output and expect faithful reproduction.

Not only should the loudspeaker be a perfect instrument, but it should also be intelligently used and installed. Conscientious manufacturers will not sell their chassis separately and allow an untrained installation man to pick an appropriate loudspeaker; the two depend on each other too much. Some manufacturers even insist that perfect reproduction can be obtained only if the speaker is scientifically installed in the cabinet. How true this is can be realized to the fullest extent only after many years of experience.

The science which deals with the proper construction and the proper placing of a sound source is called *acoustics* and as a Radio-Trician you should be familiar with the fundamental principles of this science which is so closely related to Radio.

Loudspeakers are divided into two main groups—magnetic and electrostatic speakers. The former works on the principle of magnetic attraction and repulsion; the latter on the attraction and repulsion of two charged metallic surfaces. Both principles are as old as the science of electricity but their efficient application to sound converting devices has been a comparatively recent accomplishment.

The function of the speaker, however, is not only to convert electrical power into motion—sound must be created. Sound is the result of the rarefaction and condensation of air in space, in the form of wave motion. The more air that is put into motion the greater the sound that is created. No one would think of fanning himself on a hot day with a lead pencil. A large piece of cardboard would be more efficient. And the larger it is the greater breeze can be produced with the same amount of motion.

Loudspeakers of the magnetic type employ a magnetic unit or motor which operates the load, a diaphragm or a cone. In electrostatic speakers the load is part of the electrostatic unit. We will first study in detail the motor unit, and then consider the load.

Speaker units employing the magnetic principle are classified as follows: the iron diaphragm, the balanced armature, and the moving coil types. We may go even farther and subdivide these according to the type of magnet used, whether a permanent magnet or an electromagnet. From the latter classification we derive the common, everyday names for speakers and speaker units. A unit using a permanent magnet is referred to as a *magnetic speaker*. Units using electromagnets are referred to as *dynamic speakers*. These names have been rather injudiciously chosen but common usage has forced their acceptance. Magnetic units usually employ the iron diaphragm and balanced armature systems, whereas dynamic speakers employ moving coil systems. Each of these systems will be considered alone—a detailed study of each is well worthwhile.

IRON DIAPHRAGM UNITS

The iron diaphragm units used in speakers are like those used in headphones which were universally employed in the

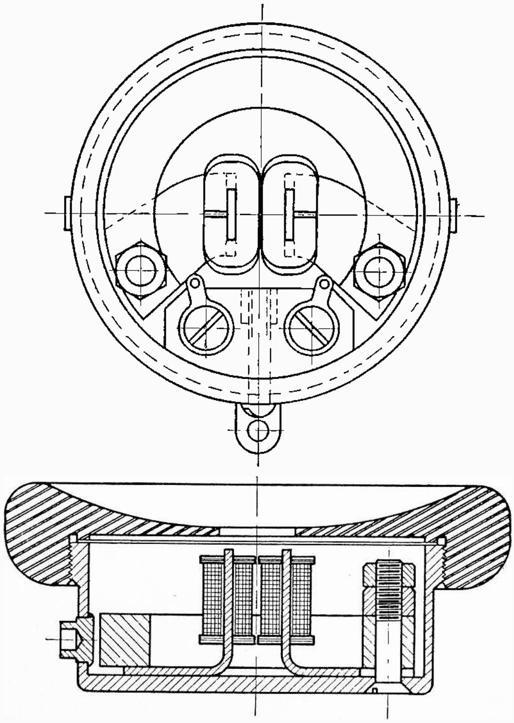

Fig. 1—Illustration Showing Details of the Bi-Polar Type Headphone Unit

early days of Radio but which today are used chiefly in commercial telegraphic and ship Radio reception. A description of the one will do for the other. They differ merely in size, in electrical impedance and in the mechanical construction of the diaphragm.

Bi-polar types of units are shown in Figs. 1 and 2. Refer to Fig. 2; A and A′ represent the pole pieces which consist of bobbins wound with many thousands of turns of wire; P and P′ are the iron pole tips; D the diaphragm; G and G′ the air gaps between the pole pieces and the diaphragm; M is a permanent magnet. As the current (I) passes through the winding as indicated, pole tips P and P′ which are naturally of opposite polarity, are further strengthened, and a magnetic circuit is completed through the pole pieces and through the iron diaphragm.

The amount of diaphragm attraction to the pole pieces depends on two factors; the strength of the permanent magnetic field and the strength of the created magnetic field. The current which passes through the bobbins, being a pulsating current, that is, always in the same direction but varying in strength, attracts the diaphragm toward the pole pieces when the A. C. component of the pulsating current is positive, that is, when it adds to the D. C. component. When the A. C. component of the audio current is zero, the diaphragm returns to its neutral position. Of course the diaphragm must be so designed that the magnetization of the pole pieces by the direct current component will not be sufficient to overcome the inertia of the diaphragm and move it out of the neutral position.

The strength of the magnetic field around the pole pieces is directly proportional to the amount of current passing through the bobbins, the number of turns in the bobbins, and the quality of the steel of which the pole pieces are made. The product of the number of turns and the current in a bobbin is the ampere-turns of the bobbin. This product should be as large as it can be made. In telephone headsets, three to five thousand turns of very small enameled wire, usually No. 40 to 42 B. & S. Gauge, are used on the bobbins. Since the quality of iron in the pole pieces has a great deal to do with the efficiency of the unit only the best grades of iron are used such as high grade Swedish iron, very carefully treated pure soft iron, or the better grades of silicon steels having 3 to 5 per cent silicon content.

The magnetic field about the pole pieces passes through the diaphragm, therefore, the metal of which this diaphragm is made must also be of the best quality, either of soft iron or silicon steel. In headsets, where the ear piece comes in contact with the air and the ear, the diaphragm is lacquered or japanned to prevent rusting.

The length of the air gaps G and G′ is dependent only on the amount of maximum vibration of the diaphragm, the gaps being so adjusted that the diaphragm will not touch the pole pieces.

The permanent magnet itself is of sufficient size and strength to provide the initial magnetization of the pole pieces P and P′. This magnet is so designed that it will not lose its magnetism under ordinary usage. Chrome and Tungsten magnets are usually employed. In the high grade units Tungsten magnets are preferred because they hold their magnetism for a much longer time than Chrome magnets.

The attraction of the diaphragm to the pole pieces is approximately proportional to the square of the magnetic field passing from pole to pole through the metal diaphragm. From this it can be seen that the greater the permanent magnetic field, the greater will be the efficiency of the unit.

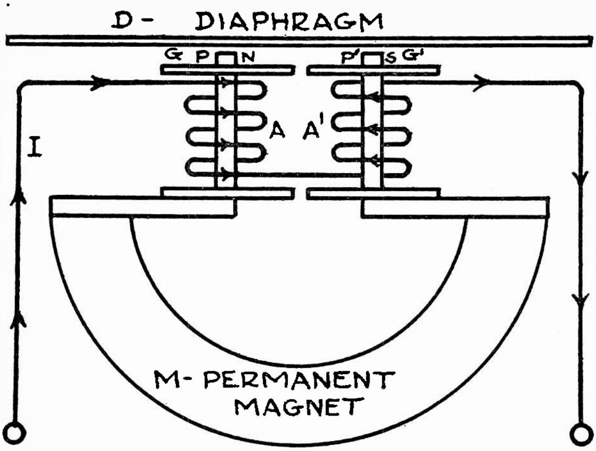

Fig. 2—Schematic of Bi-Polar Units

The magnetic field can be increased by strengthening the magnet or by using a thicker diaphragm, or by reducing the size of the air gaps between the diaphragm and the pole pieces. But there is a limit to the useful increase in the strength of the permanent magnet set by the point of magnetic saturation of the diaphragm. If, with a diaphragm of a certain thickness, we increase the strength of the magnet beyond the point of magnetic saturation, the superfluous magnetic field will cause a magnetic leakage which will be entirely wasted as it cannot be crowded through the diaphragm.

Of diaphragms of a given diameter, a thicker one has a larger path for magnetic lines of force and being thicker it can be brought nearer the pole pieces. This would indicate that a thick diaphragm will be better than a thin one. We must not overlook the fact, however, that a diaphragm is like a ball suspended from a coiled spring which tends to vibrate by itself when set into motion. When set into motion, it will tend to oscillate in a periodic manner like a pendulum but up and down instead of from side to side. The heavier the mass, the longer will be the period (the time it takes to move up and down). The stiffer the spring, the shorter will be the period. Both factors, therefore, have opposite effects and both must be taken into consideration in determining what is called the "natural frequency of oscillation" of the system. An iron diaphragm has weight, stiffness (inertia) and spring action and its natural frequency of oscillation will depend on these factors. When a vibrating force is applied to such a mechanical system consistently, that is, when it is pulled and pushed at a frequency of motion equal to its natural frequency, the actual distance traveled will be maximum. In other words, the force is applied at the mechanical resonance of the system.

If an iron diaphragm is so designed that its natural mechanical period of vibration is near that of the current through the bobbins, the motion of the diaphragm will be the greatest and consequently, its output will be maximum. However, there is this disadvantage, that the response for other frequencies is not uniform—and uniformity of response is essential for good fidelity. A compromise is attempted by designing the natural period of a diaphragm just outside the frequency response. But even when this is done response is not uniform for the entire band.

When we were considering Fig. 2, it was brought out that there were two kinds of magnetic fields in the magnetic circuit, the permanent magnetic field produced by the permanent magnet and the varying magnetic field produced by the pulsating current passing through the bobbin coils. Following both of these fields through the magnetic circuit, you will see that both have the same path, that is, from one pole piece through the air gap G, through diaphragm D, across air gap G′ to the other pole piece and through the permanent magnet back to the first pole piece.

Due to the high reluctance or magnetic resistivity of the permanent magnet to this varying magnetic flux, if some other path could be provided besides that through the permanent magnet, the varying magnetic flux would be stronger at the pole piece tips P and P′. In the improved iron diaphragm for loudspeaker use, a path for this flux has been provided.

Figure 3 shows a redesign of the pole pieces of a telephone unit for a horn type loudspeaker. R is a very small reluctance gap between five and ten-thousandths of an inch wide. This prevents short circuiting the flux from the permanent magnet but allows a very good path for the varying magnetic flux as shown by the arrows. This not only increases the magnetic force acting upon the diaphragm, but increases the efficiency of the loudspeaker unit at the lower frequencies.

In ordinary telephone headsets, the energy passing through the unit is so small that laminating the pole pieces doesn't appreciably increase their efficiency. But in loudspeaker

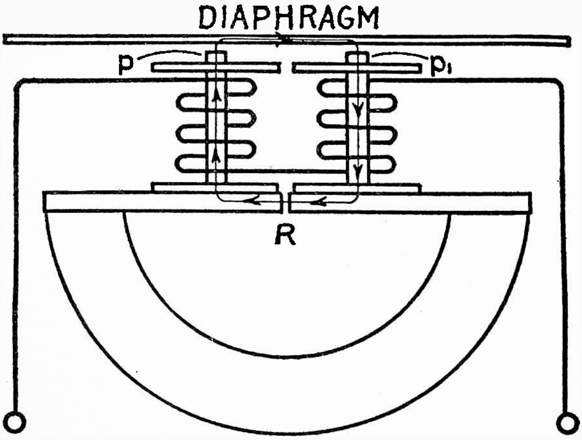

Fig. 3—Addition of Reluctance Gap to Bi-Polar Unit

units, as the energy coming from audio amplifiers is comparatively great, it has been found that laminating the pole pieces increases their efficiency tremendously. As you know, laminating iron decreases the iron losses, caused by eddy currents (stray currents set up in the cores of electromagnets) and hysteresis (the tendency of a magnetized core to resist any change in magnetization) and, in laminating the pole pieces in loudspeaker units, the principal iron losses due to the eddy currents induced in the solid pole pieces are eliminated.

Larger and thicker diaphragms of silicon steel, bigger and better magnets, redesign and the introduction of the reluctance gap in the pole pieces resulted in a much improved horn type loudspeaker.

BALANCED ARMATURE UNITS

A radical improvement over the old diaphragm unit was made with the introduction of the balanced armature unit, details of which are given in Fig. 4. A soft iron armature is placed in the center of an electromagnetic coil which is mechanically placed so as not to touch the armature. The diaphragm is connected to one end of the armature by a connecting link. The armature is pivoted in the center and held in position by a small spring at the end opposite to the end which is fastened to a driving pin. This spring counterbalances the spring effect of the diaphragm.

Tips of two sets of pole pieces are located at both ends of the armature and these are magnetized by the permanent magnet M. As the current passes through the coil winding, the ends of the armature become north and south alternately.

4

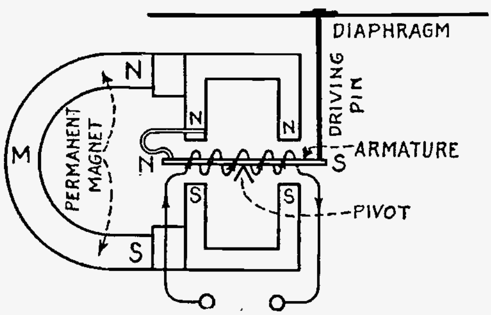

Fig. 4—Balanced Armature Type Unit

When the current is in such a direction that the poles are north and south as shown in the figure, the north side will, of course, be attracted to the south pole of the permanent magnet and the south pole at the other end will be attracted to the north pole of the magnet. The armature pivots on a fulcrum and moves the diaphragm. The greater the movement of the armature, the greater the movement of the diaphragm.

The attraction or repulsion of the armature to the pole pieces is governed by the same law as in the bi-polar unit, the movement of the armature depending on the amount of current passing through the coil, the number of turns on the coil, the quality of the iron of which the armature and pole pieces are made and the strength of the magnetic field at the pole pieces.

The coil has several thousand turns of fine wire, or there may be two coils in series. Clearance between the armature and the permanent magnetic poles is essential—the proper movement of the armature must not be restricted. The coils are not supported by the armature but the armature pivots within the fixed coils as shown in Fig. 5. Many variations of this balanced armature unit exist, but basically they are one and the same. Although the magnetic units have been very successful and are extensively used in modern speakers, they have one serious limitation. In order that the unit may have sufficient sensitivity, that is, a large movement for a weak current, the air gap between the armature and field poles must be small so that the magnetic reluctance can be reduced to a minimum and allow the existence of the large variable flux. Low notes require large displacements of air
5 therefore a large diaphragm and armature movement is

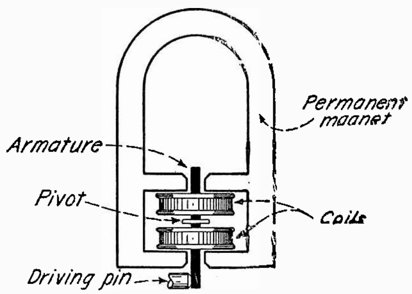

Fig. 5

necessary at low audio frequencies. This may cause the armature to strike and possibly stick to the pole pieces resulting in a loud rattle. If the air gap is made large enough to take care of this required motion and the turns on the electromagnetic coils are increased, the high frequencies will be lost. Then too, the distributed capacity which is always associated with a large number of turns of wire will bypass the high frequencies. Therefore, these units are satisfactory only for a narrow range of audio frequencies.

DYNAMIC UNITS

For high sound levels, the dynamic units were developed. These employ moving coils, and the general construction is shown in Fig. 6.

Around the center core of the cast iron shell "A" is a large magnetizing coil "B" called the *energizing field*. This winding magnetizes A which is often called the "pot" so that the center core B is "north" and the outer ring is "south." Centrally located in the gap between the center core and the outer ring is a small coil VC known as the voice coil. This voice coil is in a very strong magnetic field, set up by the energizing field B. The current which is passed through this voice coil is alternating voice current from the last tube of the audio amplifier (the output of power audio tubes must be filtered so that the D. C. component doesn't enter the windings of the loudspeaker). The coil is shown in cross section. Now let us assume that the current in the left winding is coming toward us as represented by the arrow and the current in the right winding is going away from us as represented by the other arrow. It is a law of electric motors that when a current is passed through a coil of wire in a magnetic field, the wire will be forced to move, and by the left-hand rule for motors, the movement of the voice coil is "down." When the current in the voice coil is reversed, the movement of the coil is "up." It is this movement of the voice coil that causes the diaphragm to vibrate.

The operation of this type of unit is based on one of the most important electrical principles—when a wire carrying current lies at right angles to magnetic lines of force, the wire experiences a force, at right angles to the direction of flux and this force is proportional to the length of wire, to the strength of the flux and to the current in the wire. This force can be calculated from the formula:

$$F = K \times B \times N_v \times I_v$$

where B = flux density in lines per sq. cm.
N_v = number of turns
I_v = current through the voice coil
K = proportionality constant

The dynamic unit is so universally used at the present time that a more than casual study of this equation should be made. The force of the moving coil is used for the purpose of setting into vibration the diaphragm to which it is connected and to put into motion the air in front of it, to give us the sound we want. Of course, the larger this force the greater will be the motion, and we assume that the motion in a dynamic unit may be as much as ½ inch as required for the reproduction of low bass notes.

This force may be affected by three factors; the flux density, the number of turns in the voice coil, and the current through the coil. Designers of dynamic units are responsible, in a great measure, for proper selection of all three factors, although the improper adaptation of a loudspeaker may affect the current. Any increase in one of these factors, which will not effect a decrease in the others, will increase the dynamic force.

The amount of flux, that is, the flux density, is definitely dependent on the design of the magnetic circuit. See Fig. 7. From our study of magnetic circuits, we know that the amount of flux in a cylindrical shell of this sort will be dependent on the iron and the air paths. Due to the clearance needed for the voice coil, the greatest reluctance will be in the air gap. Nevertheless, great care is exercised in the design of the iron circuit to keep the reluctance of that section as small as possible. The metal should be of the best possible grade of soft steel, properly annealed. All joints should be perfect in every respect.

It is safe to assume that the flux density is essentially controlled by the air gap, whose area is the product of the average circumference between the center core and the pole which forms

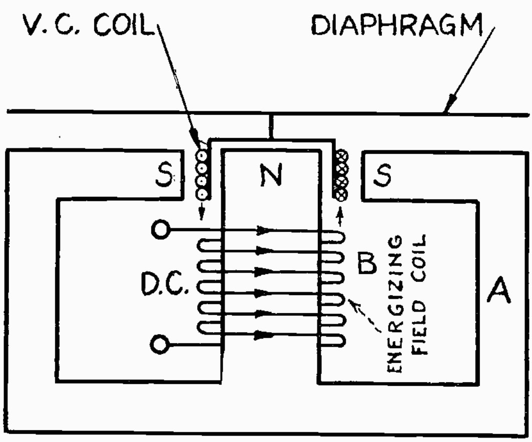

Fig. 6—Moving Coil Unit

the case, multiplied by the gap width itself. Leakage around the pole faces is by no means negligible and often the upright core is undercut at C to restrict all air gap flux at the pole faces. Under these conditions the flux is:

$$\Phi = \frac{.4\pi\ N\ I}{\frac{l}{A}}$$

where N = turns in electromagnet
I = current in electromagnet
l = air gap length
A = area of the gap

As the flux density (B) is $\frac{\Phi}{A}$, we can see from this formula that:

$$B = \frac{.4\pi\ N\ I}{l}$$

From this we can see that the flux density, an important factor in obtaining a large moving force, is inversely proportional to the air gap length. That is, as "l" is made larger and larger, B becomes less, or more NI, ampere-turns, are required to keep the flux densities the same.

The maximum flux in the air gap is limited by the saturation point of the iron and is rarely over 12,000 lines per square centimeter. Any attempt to increase the flux above this point would not be effective, as above the magnetic saturation point the reluctance in iron goes up tremendously.

NI is the ampere-turns in the electromagnet. The required NI may be obtained by using a few turns and a large field current, or many turns of fine wire and a small current. As you will learn later in this text, when we study means of exciting the electromagnet, the customary practice is to use from 20,000 to 40,000 turns fed with 60 milliamperes. This electromagnet has no connection whatsoever with the audio system and in many cases it is separately excited, that is, from a source independent of the Radio receiver.

The number of turns on the voice coil (N_v) should be as great as possible, with, of course, minimum resistance. In the attempt to make the current in the voice coil I_v as large as possible, the I^2R loss in the coil will naturally become large. Then, too, the coil is wound on a non-magnetic tube, usually bakelite, threaded so that the winding is evenly spaced. In the ordinary dynamic unit, the coil is a single layer of small wire so that the air gap can be made as small as possible. Every possible scheme is used to make this small and still have a low ohmic resistance and a large number of turns.

The determination of the amount of current that passes through a voice coil is a most difficult problem in the study of dynamic units. The current will depend on the audio signal voltage delivered from the output tube or tubes, either directly or indirectly, and the impedance in the circuit.

The total impedance is made up of the internal tube impedance and the dynamic speaker impedance. For maximum current in the voice coil, the two impedances should be equal, but for the tube to deliver the maximum amount of undistorted power, the load (speaker) impedance should be twice that of the tube impedance. An exact match is not possible and it is best to have the speaker impedance slightly more than twice the tube impedance.

In a simple electrical circuit, the impedance (Z) is governed by the ohmic resistance R and the reactance X. In a loudspeaker unit, the resistance R is the D. C. resistance of the voice coil which is usually measured by means of a Wheatstone bridge and with direct current. The reactance X includes both the capacitive and inductive effects which the winding will have on the flow of alternating or fluctuating current. For very small frequencies, X is small and the value of Z, the impedance (which corresponds to R in D. C. circuits) for low frequency alternating current, becomes very nearly equal to R. However, for very high frequencies, the value of X is several times greater than R and the losses in the unit are greatly increased. The reactance of the unit is similar to the reactance of a choke coil, its value depending upon the number of turns of the winding, the quality of the iron parts in the magnetic circuit and the length of the air gap.

Note that the voice coil has practically the same magnetic circuit as the electromagnet. To obtain the reactance of a unit, the inductance value L is measured on an A. C. inductance bridge and X is calculated from the formula:

$$X = 2\pi f L$$

where L = inductance measured in henries
f = frequency in cycles per second
$2\pi = 2 \times 3.1416 = 6.28$.

Again if it is believed that the capacity of the voice coil system is effective in determining the voice coil current, the distributed capacity of the coil may be included as well as the ohmic resistance by measuring the total impedance in an impedance bridge. It is highly important when taking these electrical measurements of the voice coil system, that the latter does not move.

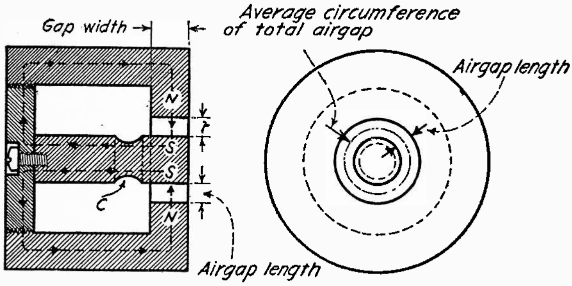

Fig. 7

For a given frequency, the electrical impedance value should be obtained when the voice coil or armature is blocked and cannot move; this is called then the blocked or damped impedance Z′ Then the impedance value is determined again with the diaphragm free, that is, in actual vibration. This is called the free impedance Z which will always be greater than the damped impedance. The difference between this free and damped impedance is called the "motional" impedance Z″, that is, the additional impedance due to the motion of the voice coil system, which includes the coil, the diaphragm or sound producing system, and whatever electrical losses are present due to the motion of the coil in the magnetic field. We have, therefore, the formula:

$$Z'' = Z - Z'$$

It is very important that a Radio-Trician understand the significance of the motional impedance of a loudspeaker unit, whether it be a dynamic or magnetic unit. The greater this value, that is, the larger the difference between the damped and free values, the greater the transfer of mechanical energy into sound. Motional impedance is an extremely important factor in mechanical and acoustic resonance.

The idea of mechanical reactance may seem strange at first sight. We are all familiar with an electrical circuit containing resistance, inductive reactance and capacitive reactance, and we know that such a circuit may oscillate. A mechanical system such as the diaphragm or vibrating cone, has what may be called mechanical resistance (mostly air friction), mechanical inductance (mass) and mechanical capacity (elasticity) and will, therefore, have mechanical reactance and resonance as well. When such a device is closely associated with an electrical circuit from which it derives driving power, these properties affect the electrical proper-

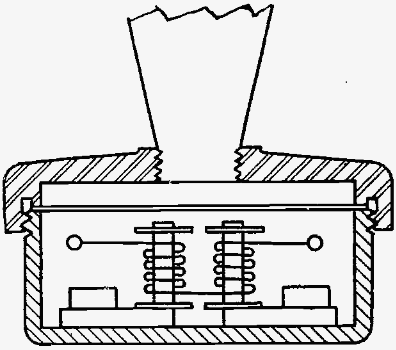

Fig. 8—Early Loudspeaker

ties of the circuit, the result being a mechanical motional impedance. The mechanical system will also oscillate as can be easily recognized by a trained ear. At this point, the effect of mass and elasticity balance and only mechanical resistance is left in the mechanical circuit with the result that a large motion takes place and, of course, a surprising increase in sound.

It is very difficult to measure these mechanical properties in terms of mechanical units. Consequently, they are expressed in equivalent electrical values. Motional impedance must be considered as part of the plate load impedance if we wish to have maximum current flow.

Before dropping the subject of mechanical impedance, it is worth noting that the mechanical resistance is the real determining factor with regard to the amount of mechanical power used for sound purposes. Its electrical value, multiplied by the square of the current, is the sound power in watts.

HORN LOUDSPEAKERS

The first loudspeakers were nothing more than horns placed on telephone units as shown in Fig. 8.

Any of the units described may be used with horns. However, in public address systems and sound picture installations, where exponential horns are used, dynamic units are invariably preferred because of their ability to handle large powers.

The diaphragms used in horn units vary in diameter from 1½ to 4 and 5 inches and in thickness from .006 in. to .03 in. Larger diaphragms are used in loudspeakers than in headsets in order to obtain greater frequency response.

Diaphragms employed in bi-polar types of units are perfectly flat and made of a good grade of magnetic material, generally silicon steel.

In the balanced armature type of unit, great varieties of diaphragms are used, several of which are illustrated in Figs. 9 and 10.

Fig. 9—Different Types of Diaphragms

Fig. 10—A Type of Diaphragm Made of a Non-Magnetic Material, the Thickness at the Center Being Greater Than at Its Edges

Figure 9 shows at the left a flat corrugated type of diaphragm commonly used, the material of which is generally light pressed aluminum, the corrugations running concentrically. The corrugations not only add stiffness and rigidity to the diaphragm, but break up its local vibrations. This figure also shows two types of conical diaphragms, one being plain and the other corrugated. Light pressed aluminum is also often used in these type of diaphragms. By making the diaphragm in the form of a cone, greater rigidity is obtained, and slightly better performance results. Figure 10 illustrates one type of diaphragm made of a non-magnetic material, a moulded composition, its thickness at the center being greater than at its edges. A magnetic metal button is fastened at the center. Most of the diaphragms are clamped at the edges, but not rigidly. Two methods of clamping are shown in Figs. 11 and 12.

Figure 11 shows two rubber tubes used on each side of the diaphragm. The pressure of the clamping depends upon the compression of the tubing against the diaphragm. Figure 12 shows a similar method but in this case, rubber gaskets are used in place of the rubber tubing. By clamping the diaphragm between rubber tubes or gaskets, the diaphragm is not rigidly held at its edges and it has greater freedom of vibration, particularly helpful for response to lower frequencies.

Two types of horns were used on loudspeaker units—conical and exponential. In the conical horn, the area varies directly per unit length as shown in Fig. 13 while in the exponential horn, the area varies exponentially (logarithmically) per unit length as shown in Fig. 14. The purpose of the horn is to let the comparatively small diaphragm get a grip on the air and force a large volume of air ahead of it into motion. This is, in effect, putting a load on the unit, which has already been compared to a motor.

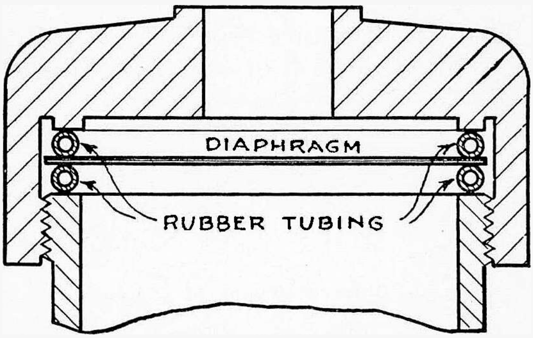

Fig. 11—Illustration Showing How Two Rubber Tubings Are Placed on Each Side of the Diaphragm

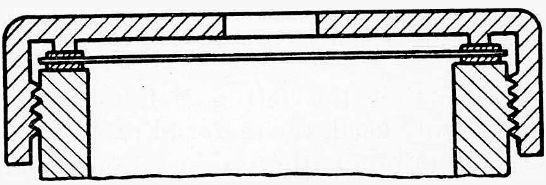

Fig. 12—Illustration Showing How Rubber Gaskets Are Used in Place of the Rubber Tubing

The correct type of horn for a loudspeaker is one which places a sufficient air pressure upon the diaphragm, and which allows the pressure to be released through the horn gradually. The taper of the horn controls the air pressure in the horn, and it is important that this air pressure be not released rapidly until towards the free end of the horn. It is for this reason that the exponential horn is far superior to the conical horn, for as an examination of the illustrations, Figs. 13 and 14, will show, the rate of change of area at the beginning in the respective horns is very much greater in the conical horn than in the exponential. The exponential horn is used now entirely.

An exponential horn is one whose cross section doubles in value at equal intervals of length. For example, the throat which fits snugly into the unit may have an area of one-quarter square inch. If at a distance of one foot from the unit the area is one-half square inch, at two feet, one square inch, at three feet the area will be two square inches, at four feet, four square inches and so on.

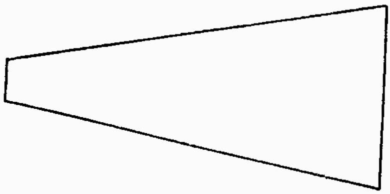

Fig. 13—The Conical Horn

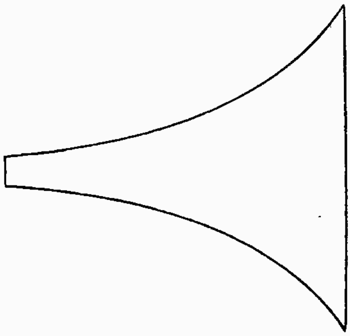

Fig. 14—The Exponential Horn

Another exponential horn might double its area every two feet of length. This rate of growth has considerable to do with the lowest frequency which the horn will properly radiate as sound. Doubling the area each foot of length will reproduce sound of as low a frequency as 64 cycles; doubling the area of horn every two feet of length lowers the response to 32 cycles per second. This low sound frequency is called the cut-off frequency.

It was pointed out that the advantage of the exponential horn was that it does not release the air suddenly and back pressure is prevented. The larger the mouth of this type of horn, the better will the horn reproduce the low notes. This area at the mouth as well as the rate of area growth determines the cut-off frequency, that is, the lowest frequency at which back pressure will not be created. Those frequencies transmitted will be determined by the diameter of the mouth, considering it to be circular, equal to one-fourth the cut-off frequency wavelength.

The velocity of sound in air being 1,089 feet per second, the wavelength will be equal to the velocity divided by the frequency. Therefore:

$$\text{Diameter} = \frac{1089}{4 \times \text{cut-off frequency}} = \frac{272}{\text{cut-off frequency}}$$

For a 64 cycle cut-off, a mouth whose diameter is 272/64 or 4.3 feet is necessary. If a square horn is used, an equivalent area should be employed.

Present practice is to employ a circular air throat, ⅝ in. in diameter. From experience, this has been found best for high and low note reproduction.

It should be evident that if the cut-off frequency depends first on the rate of area increase in an exponential horn, second on the area of the mouth and third if it is good practice to have a throat of ⅝ of an inch in diameter, considerable length will be necessary to reach 64 and 32 cycles. Therefore, we would expect small, short horns to sound thin and high pitched, and long, large mouthed horns to be rich and full in response due to the faithful reproduction of low notes. Horns will vary in length from a foot and a half to 16 feet long, depending on the purpose for which they were designed.

A consideration of the material used in the construction of horns cannot be neglected. The material of which a horn is made is as important as the size of the mouth, the size of the throat, the rate of area expansion and the total length. If the material has any resonance effects—any tendency to vibrate—these should be extremely low. Some manufacturers use sawdust molded into form with a binder. Others employ various cloths, molded and bound. Wood in many cases has been successfully used. The shape of the final horn makes little difference, although in coiling, sharp angles must be avoided. Due to their rather unattractive appearance, horns are to be heard and not seen. In theatres, where they are constantly used, they are behind the screen. In the home, if they ever come to be used with dynamic speakers, they must be placed in attractive cabinets.

LIMITATIONS OF HORN TYPE SPEAKERS

It has been brought out that the horn type speaker was greatly improved by advances in the design of units, by the use of larger and thicker diaphragms and longer and better horns. However, even after all these improvements it was still noticed that speech and music were not distinct and clear, that articulation was not all it could be and that reproduction of music at times was unnatural with an over-exaggeration of the low notes.

Design factors that make for good reproduction of the lower frequencies in horn type speakers are as follows:

1—Low reluctance magnetic circuits.

2—Large diaphragms.

3—Long air column horns.

4—Strong magnetic fields.

The factors which make for good high frequency response are:

1—Laminated magnetic pole pieces, to reduce the magnetic losses.

2—Small or thick diaphragms.

3—Short horns.

For good reproduction of speech and music, the loudspeaker should reproduce frequencies from 100 cycles to 5,000 cycles per second, that is, the diaphragm should be able to respond faithfully to vibrations between 100 and 5,000 per second.

Because in horn type speakers the diaphragm is clamped at its edges, it is very difficult for it to vibrate at a high frequency. The best horn type speaker does not show very good response above 2,500 or 3,000 cycles. Then, at the low frequencies, to reproduce fundamental notes of 100 to 200 cycles, diaphragms have to be very large. Yet if they are large enough to reproduce the lower frequencies, the higher frequencies suffer. The use of very long horns to obtain these low notes offers difficulties both in development and manufacture. At its best, the choice of parts in the design of a horn type speaker is a compromise. Satisfactory high frequency response could not be obtained and lower frequency response is obtained only with difficulty. This was the problem in horn type speakers that led to the development of the cone type of speaker.

CONE TYPE SPEAKERS

The introduction of a cone diaphragm was a great improvement over the flat diaphragms used in horn type speakers. It had been realized for some time that large diaphragms were desirable. Before the time of cones, these were flat diaphragms made of a variety of materials. But these proved unsatisfactory because local vibrations would be set up in portions of the flat surface, introducing harmonics into the original vibrations given to the diaphragm, resulting in distortion. By designing the diaphragm in the form of a cone, the diaphragm was made stiff and rigid and vibrated entirely in accordance with the vibrations given to it at its apex.

In Fig. 15 we see an application of the balanced armature type unit. The balanced armature has always been desirable because the mechanical system of the unit itself, consisting of

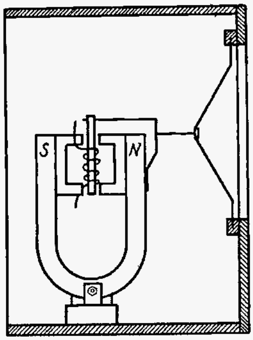

Fig. 15

a small armature free to pivot inside an exciting coil, is flexible and responds to slow vibrations and at the same time is capable of extremely rapid vibration. These rapid vibrations were limited to the diaphragm in the horn type speaker, not to the mechanical system of the unit, and so when cones were employed for diaphragms, improvement in results was immediately noticed.

The cone used as a diaphragm was so designed that it is free to vibrate without distortion, in accordance with the mechanical vibration at its apex. The vibration of the cone sets up an air displacement about it and sound results.

The conical portion (C in Fig. 16) is generally made out of a good grade of paper, ranging in thickness from .005 in. to .025 in., and from 6 in. to 36 in. in diameter. "Waterfall's ledger" (a trade name), Alhambra low frequency and high grade manilla are some of the best papers used. The plain peripheral portion D may be paper, rubber, leather, or even string, supported at the ponderous rings AA.

As the apex B is actuated from a mechanical source, the cone is set into vibration as shown in Fig. 17. An actual wave vibration is set up from the apex to the edge of the cone and nodes "N" appear, depending upon the frequency and the distance from the apex to the edge of the cone. The greater this distance the better will be its response to the lower frequencies, as the cone will have a lower natural period.

Cones are generally circular, but some cones are made elliptical. There is very little advantage to be gained in using cones of peculiar design as the cost and difficulty of manufacture do not warrant the little acoustic gain obtained. As the cone is made to vibrate, on the first swing

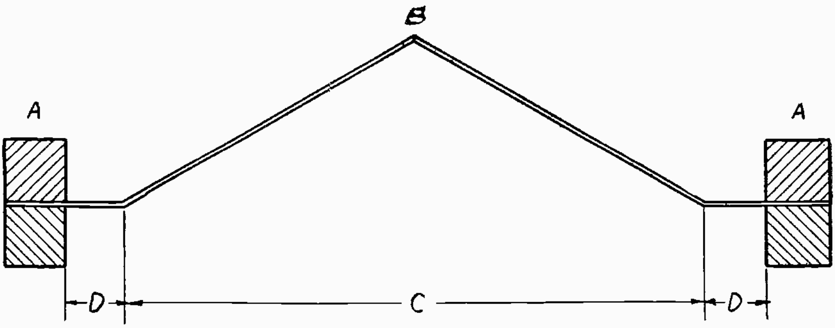

Fig. 16—Details of the Original Hopkins Cone

back the air in front of the cone is rarefied, and the air in back of the cone is condensed. On the next swing forward, the rarefaction and condensation are reversed. Thus, sound waves are set up in front and in back of the cone opposite in phase relation therefore it is necessary to use a baffle, because, if the sound waves emitted from the back of the cone are allowed to come around to the front of the cone, these waves, being 180 degrees out of phase with the sound waves emitted from the front will neutralize them. This is particularly noticeable at the lower frequencies or longer waves, since the length of the sound wave at these lower frequencies is sufficient to extend around to the front of the cone.

It is for this reason that the "baffle board" plays an important part in the reproduction of the lower frequencies of a cone speaker.

9

Figure 18 shows how a baffle board is used with a cone. It can be seen that the baffle is of such proportion that it prevents the sound waves from the back of the cone from interfering with the waves emitted from the front of the cone.

A good baffle board should be made of wood or wall-board from ¾ in. to 1½ in. thick. This baffle board should be of non-resonant material so that it will not vibrate or rattle and radiate sound when the unit is being operated. The opening in the baffle must be of the proper diameter, determined by the size of the cone being used. The unit should be mounted behind the baffle board with a felt ring on the front of the cone housing, pressed evenly and tightly against the board.

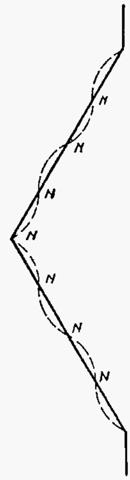

Fig. 17—Illustration Showing How the Actual Wave Vibration is Set up From the Apex to the Fixed Edge of the Cone

The unit is fastened in this position by screwing down the base to a shelf provided for that purpose. It is not necessary or desirable to screw the cone housing itself to the baffle board.

Baffles may be either flat surfaces or in box form. A flat square baffle is the ideal type to use and it should be as large as is possible and convenient. The shortest distance from the front of the cone around the baffle to the nearest rear surface, determines the low frequency cut-off.

The maximum distance a sound wave can travel before its intensity is at maximum, is one-quarter of a wavelength. If the sound wave, in traveling this distance, reaches the rear of the cone, that wave will be cancelled out. Therefore, as sound waves travel at the rate of 1,089 feet per second, the formula for cut-off frequency is:

$$\text{Cut-off frequency} = \frac{\frac{1}{4} \times 1{,}089}{\text{distance}} \text{ or } \frac{272}{\text{distance}}$$

A flat baffle, 2 feet square (having a 2 foot travel) would cut off at 136 cycles; if it were 9 feet square, it would cut off at 30 cycles. Ordinarily, a 4 foot square baffle is sufficient. Where a speaker can be mounted in a wall between two rooms, a very large baffle is obtained. It is important that air space exist at the front and rear cone surfaces.

A cabinet or box type baffle will give good results. Its cut-off frequency can be determined by the above formula. The value for the distance (D) can be found as shown in Fig. 19. The sides, the top and the bottom, should be as narrow as possible with respect to the width of the front. If this width is more than ¾ the front space, precautions must be exercised

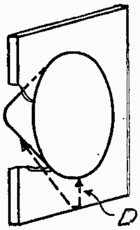

Fig. 18

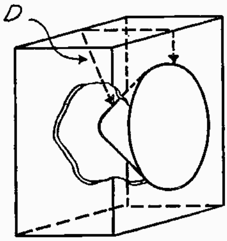

Fig. 19

to prevent "barrel" effects, that is, low frequency resonance. Holes may be drilled in the sides, the top and the bottom, or the inside may be lined with felt or some sound absorbing material like celotex. In any case, the back must be entirely open. However, a screen or grilled cloth may be used.

You probably have noticed that when a cone speaker is placed in a cabinet, a difference in response is noted, particularly at the lower frequencies. This is due to the baffle effect of the cabinet, the partitions around and behind the cone serving as a good baffle. Very small cones with large baffles can produce practically the same results as large cones with small or no baffles. A cone of large diameter not only reproduces lower frequencies on account of its lower natural frequency, but on account of its large size it acts in itself as a baffle.

THE DYNAMIC SPEAKER—THE POWER CONE

The types of cone speakers described so far, excel by far the horn type speakers because they are able to reproduce the higher frequencies much better, reproducing frequencies as high as 4,000 cycles per second. At the same time, reproduction of the lower frequencies is more pleasing and natural.

For a loudspeaker to reproduce very low frequencies satisfactorily, the cone and armature must vibrate at large amplitudes. And in cases where large volume is desired, the amplitudes may become so great as to cause rattles as the armature may hit against the pole pieces. Distortion may also result from the whipping movement of the paper cone.

Power from audio amplifying tube circuits is necessary for the proper reproduction of low notes at high sound levels. The speakers so far described cannot use this power to full advantage. It was to obtain better reproduction at large volume that the dynamic or moving coil type of cone speaker was developed.

What has already been said about the design of the moving coil unit used with horns applies to moving coil units with cones attached. The design of the cone, its attachment to the moving coil and the mounting of the periphery is the result of careful study on the part of dynamic speaker engineers. Figure 20 shows the basic design of modern dynamic speakers.

The voice coil is wound on a circular molded bakelite tubing which is cemented to the cutaway apex of the cone. A specially treated paper is used for the cone. Maximum diameters at the present time are 7, 9, 10, 12, and 14 in. The apex angle of the cone is usually about 120 degrees. A soft leather (chamois) is cemented to the periphery of the cone and the leather fastened to a metallic supporting ring.

Dynamic speakers differ principally in the method of centralizing the voice coil in the magnetic air gap. Most dynamics use a 3 point suspension method of positioning the voice coil, as shown in Fig. 21. The large center hole is affixed to the voice coil tubing whereas the other three supporting members are fastened to the "pot" shelf. A suspension method like this allows a large free movement of the coil system.

Some voice coils are centralized by a central suspension, rigidly affixed to the center of the core. See Fig. 22. Due to the limited movement possible in this method, the cone is usually much larger and quite shallow. Some of the suspensions are non-metallic, such as bakelite; others are made of aluminum, or phosphor-bronze.

A conical, spider framework, bolted to the magnetic housing, supports the entire moving system.

As the impedance of the voice coil is very small, an output transformer is required to match the speaker load to the internal impedance of the power tube. Ordinarily this unit is mounted on a steel frame which serves also to support the entire dynamic speaker. The center line of the cone when installed should be perpendicular to a vertical panel.

The paper cone, the moving coil, and the suspension constitute a vibratory mechanical system which has a natural

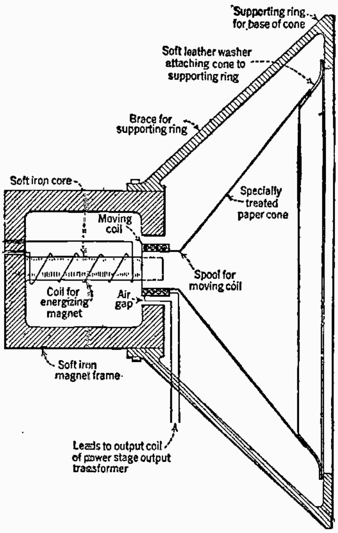

Fig. 20—Construction of the Moving Coil Type of Dynamic Speaker

period of vibration like any diaphragm. This is used to advantage when the resonant frequency is made between 20 to 70 cycles per second. Then bass amplification in the audio system is favored and better bass response obtained. Ordinarily, this resonant motion is not effective over 100 cycles and does not affect the natural response of the speaker.

At low audio frequencies, the entire cone moves in and out like a piston. Up to 3,000 cycles per second, fidelity is good because of this piston action. But the high audio frequencies are reproduced by the vibration of the cone surface. At the point of change, that is, the point where we might say it changes from the piston action to the cone surface vibration, irregularity in fidelity appears. When the latter action occurs, large response is usual as the cone acts as a horn for the sound wave.

The shape of the cone and the pitch of the angle are important. Angles between 75 and 150 degrees have been used. A small angle tends to maintain the piston-like action of the cone and it is said that with a small angle cone efficiency is greater.

However, in a cone of this type there is a large number of mechanical resonance points and fidelity may be irregular. A cone having a large angle tends to have a much lower resonant frequency, which is desirable, and to be more faithful in its response to higher frequencies. Much also depends on the size of the cone and the material used.

After a speaker has been designed, the one important factor for its successful adaptation is the baffle. The size of

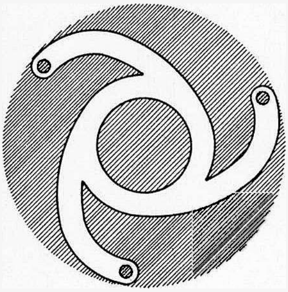

Fig. 21

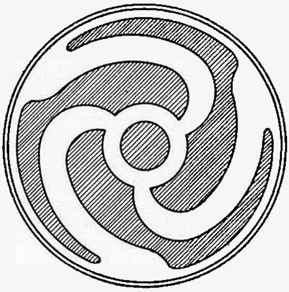

Fig. 22

the baffle is of the utmost importance in the proper reproduction of the base notes. Never operate a dynamic speaker without a baffle as this acts as a partition, separating the sound waves produced at the front surface of the cone from those produced at the rear surface. It often happens that more than one speaker is operated on a single baffle, particularly if the audio output is supplied by one or more '50 type output tubes. This is especially true in theatres, auditoriums and in open air installations. Each speaker should be fed with the maximum amount of power. There is usually one for each '50 tube (3 to 4 watts output). The speakers themselves are grouped in the center of a flat baffle.

7 For example, five dynamics may be mounted on a 6 foot square baffle, one in the center and one along each diagonal away from the central speaker. The diagonal speakers are

well placed when they are one-third the distance from the center of the baffle to the corner. The placement of the group is a matter that requires experience with acoustics in buildings. If the building has a high ceiling, the speakers may face down toward the center of the hall. In a long hall, as for example, a long narrow theatre, the speakers should be placed at one end—that is on the stage platform, facing straight out. The baffle should be perpendicular to the floor of the platform.

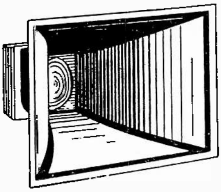

Fig. 23

In every case where two or more speakers are operated on the same or adjacent baffles, the cone movements must be in phase, all cones must move in and out together. To reverse the phase of a single cone, reverse the input lead to the field. Using one cone as a reference, compare the other to it with the ear, one at a time. The response from two must be greater than from one speaker. A more positive test is to apply a 25 volt D. C. current to the inputs of all the speakers.

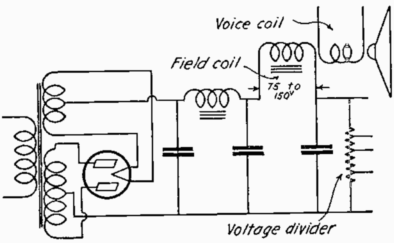

Fig. 24

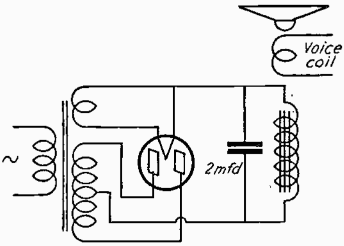

Fig. 25

Each speaker will move in and out quickly and come back to normal position slowly. Compare visually. Reverse the field coils if necessary, until all are in phase.

Figure 23 shows a horn type baffle, attached to a dynamic speaker. Some engineers claim that a horn baffle is equivalent to a flat baffle having a return distance twice the length of the horn baffle. That is, a horn one foot long will have the same baffle effect as a straight baffle that extends two feet from the edge of the speaker. Then, too, a horn places an air column load on the speaker unit and so reduces blasting. Decided directional effects are obtained when designed for this effect. They may best be found for a certain installation by experimenting.

It should be borne in mind that in any event it is useless to design or use a baffle to carry a frequency lower than the lowest frequency the audio system is capable of amplifying.

FIELD EXCITATION FOR DYNAMIC CONES

Many schemes are used to provide D. C. current for field excitation for dynamic speakers. Of course, the ampere turns for a field are fixed for a given design. For low, 6-14 volt supplies, the turns are few and the current high. For high voltage supplies (75 to 400 volts), the turns are many and the current low.

Where socket power is not available, a 6 or 12^{v} storage battery can be used to excite a low resistance field.

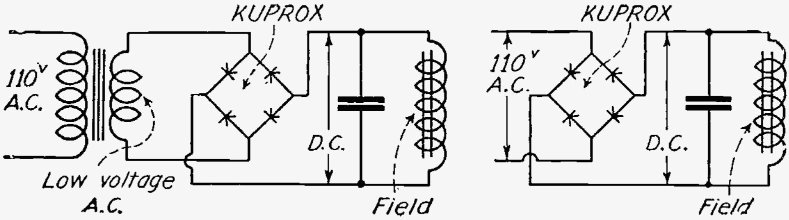

Fig. 26—Step Down and Direct Voltage Supply for A. C. Dynamic Speakers

Most A. C. receivers use the field or "pot" of the speaker as one of the chokes in the filter of the B supply system. The permissible voltage drop of such an arrangement—see Fig. 24—is 75 to 150 volts and the current 40 to 80 milliamperes. Thus the resistance of the field must be about 2,300 ohms.

Often a 10,000 ohm field winding, a coil of many turns of fine wire, is placed across a 350 volt output of a 280 rectifier tube. The current drain in this case will be 35 milliamperes. See Fig. 25.

A step-down A. C. transformer is often used to cut down the A. C. voltage for dry metallic plate rectifiers such as the Westinghouse, Kuprox or Elkon dry rectifiers. Some designed for 12 volts A. C., will deliver 6 to 7½ volts D. C. at the rate of 1 ampere. Connections are shown in Fig. 26. Some dry rectifiers feed directly from 110 volts A. C. and will deliver 50 to 100 milliamperes D. C. at 60 to 100 volts.

Considerable hum may appear in dry rectifier systems and for this reason a hum neutralizing coil is often included in the rectifier system. This coil is wound on the central core of the speaker, connected in series with the voice coil, but acting in the opposite directon.

10 The correct number of turns will induce in the voice coil a current sufficient to balance out the hum current. Naturally it will also balance out the voice frequencies of 60 or 120 cycles, depending on whether the field current is half-wave or full-wave rectified. A second method, however, of eliminating hum due to improper field current rectification is to connect a 1,500 mfd.—12 volt dry electrolytic condenser across the field coil if the field voltage is low. If a high voltage is used across the field a 2 to 4 mfd. condenser should be used.

TEST QUESTIONS

Be sure to number your Answer Sheet 26FR.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and the best possible lesson service.

1. Why can a loudspeaker unit be considered a "motor?"
2. What is the difference between the magnets used in magnetic speakers and dynamic speakers?
3. Upon what does "the natural frequency of an iron diaphragm" depend?
4. Show by a neat drawing the essential parts of a balanced armature unit.
5. In the balanced armature unit is diaphragm and armature movement large at high or low audio frequencies?
6. What <u>two</u> things determine the low cut-off frequency of an exponential horn?
7. What precautions must be observed when several cones speakers are operated on the same or adjacent baffles?
8. In what <u>two</u> ways does the action of the power cone diaphragm reproduce the low and high audio frequencies?
9. Explain the purpose of a baffle.
10. What would you do to eliminate hum in a speaker which was due to improper field current rectification?

RECENT DEVELOPMENTS IN LOUDSPEAKERS AND TONE CONTROLS

27 FR-1

PIONEER HOME STUDY RADIO SCHOOL

NRI

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

DELIVER THE GOODS

"There are 57 rules for success. The first is to deliver the goods. Never mind the rest."

Like very many striking assertions, the quotation above is not altogether true, because there are some other rules you can't ignore. But there is a big truth in it.

If you want to be a success in life, deliver the goods. No matter what your opportunities in life, no matter how good your training, regardless of your good intentions, you will be a failure unless you deliver the goods.

Employers want men who can be depended upon to deliver the goods every time. If you have your own business, you will find that your customers come back to you only if they find that you have delivered the goods.

You can always excuse yourself if you fail—but nobody else will ever excuse you. People may be polite to you, they may feel sorry for you—but they will hire somebody else, they will trade somewhere else, they will have someone else do their service work.

You must choose between failure—or delivering the goods.

Make it your business in life to be where you are needed, when you are needed, with the service or the help that is needed. Have the knowledge that is needed on tap in your brain. Be the man on the job, the man who delivers the goods and gets the money.

J. E. SMITH.

NATIONAL RADIO INSTITUTE

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Recent Developments in Loudspeakers and Tone Control

INDUCTOR DYNAMIC SPEAKERS

Three new types of speakers have been commercially introduced in recent times. They are the inductor dynamic speaker, the electrostatic speaker and the airplane cloth speaker. Although these are not widely used, for the dynamic speaker at the present time reigns supreme, they have special
5 uses under certain conditions and you may meet them quite often in your work.

The Farrand inductor dynamic speaker, is really a special type of magnetic speaker. However, it does not have the

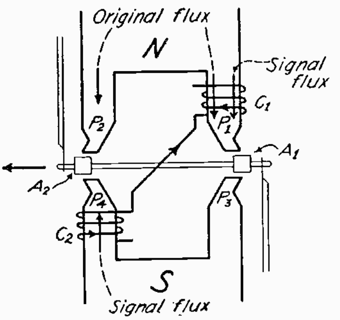


Fig. 1a

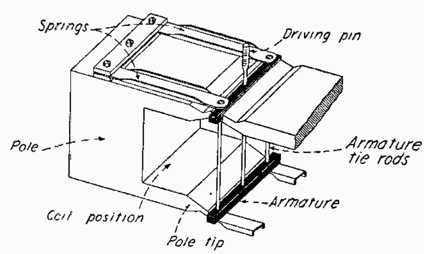


Fig. 1b

apparent shortcoming of ordinary magnetic speakers, that is, limited armature motion. Instead of the armature being pivoted on a fulcrum, it swings to and fro much like a swing seat pushed from side to side. Figure 1a shows a schematic cross section of the unit. N and S are the pole faces of a permanent magnet. In the actual unit, the magnetic flux is provided by two large permanent magnets. Notice the peculiar pole tips, P_2 and P_1, P_3 and P_4, the upper tips north and the lower tips south.

The armature coils of many thousands of turns carrying the signal current, are wound in equal sections on opposite pole tips. They are marked C_1 and C_2 in the diagram. Bear in mind that only a cross section is shown and that the tips have thickness. The armature consists of two rectangular soft iron bars, fitted with the least permissible clearance between the pole tips. Rods at the ends connect these into a single system. A driving pin control through the center connects them to the vibrating cone. Four springs in line with the tie rod centralize the armature between the pole tips, allowing a movement in the direction from A_2 to A_1, or from A_1 to A_2 but not up and down. See Fig. 1b for armature details.

When no current flows through the armature coils C_1 and C_2, the armature remains in the exact center. The original flux due to the permanent magnet flows from P_2 to P_4 and from P_1 to P_3 downward from N to S. Now suppose a current flows through the coils C_1 and C_2 as shown, thereby increasing the flux on the pole tip P_1 downward and reducing the downward flux in the path P_2-P_4. One gains the flux that the other loses. As armature A_1 is in the field of greater flux, it is drawn to the left to reduce the reluctance across the gap. (A hollow electromagnet will draw an iron core into its center when a current flows in its windings.)

Armature A_2 being in a weaker field will not oppose a movement to the left. If the current is reversed, armature A_2 is sucked in and the armature system moves to the right. Under the influence of an audio signal current, the armature system A_2 and A_1 will swing to and fro, following the variations in the audio current exactly.

Notice the special cutaway design of the pole tips, to keep leakage at a minimum and to concentrate the flux between the pole faces. The force developed is proportional to the flux density.

It should be clear from this explanation that a large movement of the armature is possible and so it is capable of handling large signal current variations. Furthermore, the air gap can be made very small and the unit's sensitivity made very high. The armature will not pivot toward the pole tips to an appreciable degree if the spring is suspended some distance away from the armature plane of motion.

If any D. C. current is allowed to flow through the coils, the neutral position of the armature system will be shifted from the exact center. For this reason, the coils are protected by an output transformer or by a choke coil coupling condenser system. When a push-pull arrangement of tubes is used, the necessary third lead is taken from the connection between C_1 and C_2. This lead is connected to B+ and the leads at the end of C_1 and C_2 are connected to the plates of the tube. In this case the D. C. current flowing will contribute flux to the poles and strengthen the flux density at the tips, resulting in improved performance.

When this type of speaker is used, it is very important that a coupling device be used having an impedance which closely matches the tube impedance.

Cones having diameters of 8, 10, and 12 inches are employed and the stiffness of the spring is made such that mechanical resonance can be obtained at any frequency where inefficiency may exist. Thus it is possible to produce a speaker with good low response. Baffling is important and what has

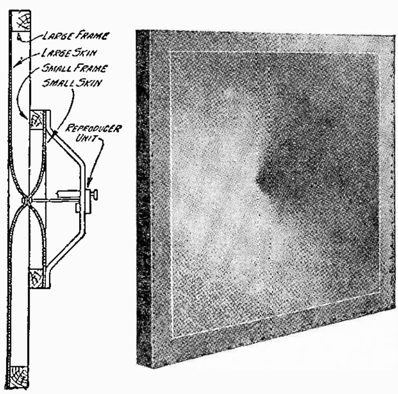


Fig. 2

been said about baffles for other speakers applies to the inductor dynamic speaker.

THE AIRPLANE CLOTH SPEAKER

When the airplane cloth speaker was first introduced to the Radio world, it took it by storm and there are still many who favor it.

Essentially it consists of two vibrating surfaces—rectangular or square pieces of airplane cloth stretched over wooden frames, placed back to back. The area of one surface is much larger than that of the other. They are rigidly fastened at a distance of three or four inches from each other. The centers of the surfaces are drawn together and fastened by a hollow clamp. The material is treated with "dope"—a liquid which stiffens it. See Fig 2.

A balanced armature magnet is fastened to the frame behind the small diaphragm surface and the driving pin locked into position with a hollow diaphragm clamp. The large diaphragm handles the low and intermediate sound frequencies, and the small diaphragm the high notes. The large surface is made as small as 12×10 in. for table models, and as large as 48×18 in. for wall or floor model speakers. Not being attractive in appearance, cabinets and coverings are essential.

Airplane cloth speakers are rigid and fairly durable. The tension of one diaphragm is balanced by the other and only a slight motion of the unit will cause the system to respond. It will handle volumes up to the capacity of the unit and the diaphragm will never rattle if the driving system is properly chosen. Due to its extreme sensitivity, it is a good speaker to use on battery and D. C. electrical receivers where power outputs are limited.

CONDENSER SPEAKERS

A few American manufacturers are introducing the electrostatic speaker and recent demonstrations and installations in Radio receivers have been satisfactory. The principle employed in this speaker is by no means new, having been used as a reproducer in a limited way since the year 1881 when it was first discovered.

When two flat conducting surfaces are separated by a non-conductor, we have an electrical condenser. When these two conductors are charged with electricity of like polarity, they tend to repel each other and when charged with electricity of unlike polarity, they tend to attract each other. Suppose, as in Fig. 3, a flat, heavy, metallic surface is held close to but not touching a thin, flexible surface, both being of approximately the same area, and a voltage difference is connected to the terminals of these two surfaces. A force is exerted, tending to draw the flexible surface towards the heavy, unmovable one. This force will depend directly on the area, that is, if the area is doubled, the total force over the movable surface will be doubled. If the voltage is doubled, the force will be increased four times, that is, the force depends on the square of the voltage between the two plates and if the distance between the two plates is doubled, the force will be ¼. In other words, the force will vary inversely as the square of the distance.

Clearly, in order to have a large moving force, an electrostatic speaker requires large sized plates, small separation between them and as great a voltage difference between the plates as is possible.

If an alternating voltage, however, let us say a 60 cycle, 110 volt house current, is applied to the two plates, the movable area will move in and out at twice the frequency, that is, 120 times per second. This result will naturally be obtained since the plates tend to pull together, both on the positive and negative halves of their cycles, all of this being due to the fact that under both conditions the polarity of one plate will always be opposite that of the other. Consequently, when a 60 cycle audio signal is connected to the plates, the sound

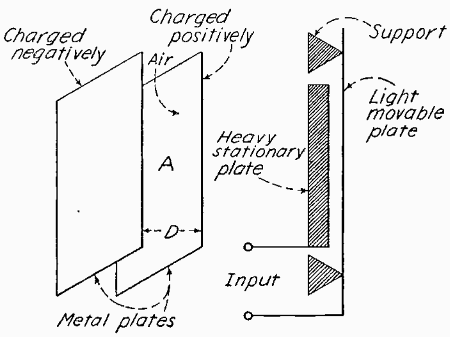


Fig. 3

will be 120 cycle note. If such a condenser speaker were connected to an audio amplifier whose output is connected through a coupling transformer so only the A. C. signal remains, the movable plate would move in the same direction for both the positive and negative alternations of the signal current and reproduction would be entirely distorted.

The adaptation of the condenser-principle for use in loudspeakers is definitely the result of a scheme by which the movable plate, which we call the diaphragm is moved in exact response to the signal current. Suppose now that we connect the condenser-speaker to a 500 D. C. voltage. There will be a strong, constant attraction between the diaphragm and the fixed plate. Now, if we introduce in series with the D. C. voltage a much smaller 60 cycle sine wave voltage, that is, we super-impose A. C. on D. C. and obtain a pulsating voltage, the diaphragm will be alternately attracted more and less, depending upon the value of the voltage change. Or we might say that the force on the diaphragm is alternately greater and less than the original condition when 500 volts alone were applied to the condenser speaker terminals.

This does not mean, however, that there is not a vibration of the 120 cycle movement of the diaphragm, in and out, but if this variation in A. C. voltage is small in comparison to the D. C. voltage which we will call from now on the "polarizing" or "biasing" voltage, the second harmonic distortion will be at a minimum. In this respect, an electrostatic speaker is no different from any other loudspeaker in that it will have, like the others, inherent qualities which tend to distort the final sound signal. This force which rarefies and condenses the air on the surface of the diaphragm can only be analyzed mechanically and we are told by loudspeaker experts that the greatest response is obtained when the plates are as close together as possible, when the constant biasing voltage is high and the A. C. signal is as large as possible.

There are, therefore, definite limitations in the design and adaptation of condenser speakers. First, the signal voltage must be comparatively small in relation to the biasing voltage in order to minimize distortion. Secondly, the biasing voltage which must be as high as possible, cannot exceed 500 or 600 volts because the dielectric used between the plates will break down under higher voltages. Third, the distance between the two plates must be made as large as possible in order to get an appreciable movement of the diaphragm which is limited, of course, by our second problem of break-down and short-circuiting. Condenser speakers, therefore, demand careful engineering and designing in order to effect a balance between all these controversial factors. Present compromises result in a loudspeaker, the sensitivity and efficiency of which is comparatively low. The motion of the diaphragm being limited, low tones naturally are not reproduced with perfect fidelity.

In spite of all this there are features in this speaker which have prompted its rapid development for commercial use and it will be further developed until it reaches a place with that of the dynamic and magnetic speaker. Chief among these features of superiority is its great simplicity of construction. There are no magnets, coils, intricate parts or elaborate magnetic field constructions—merely one fixed and one movable system. There is only one moving diaphragm, the area of which is large. Movement is practically uniform over the complete surface. This results in the elimination of notes which are detrimental to perfect reproduction. The construction is such that a single unit can be built as thin as a quarter of an inch, making for economy in space when it is necessary. The movable system is extremely light and flexible, resulting in a diaphragm which will vibrate faithfully at high audio frequencies, an absolute requirement in the reproduction of speech and music. The sound emitted from a flat surface is more uniform over a wide frequency range than that from a conical or shaped surface.

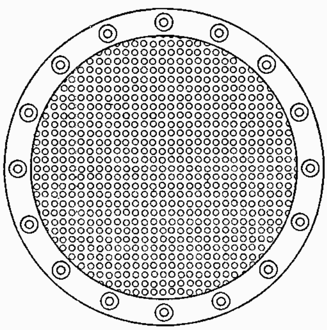


Fig. 4

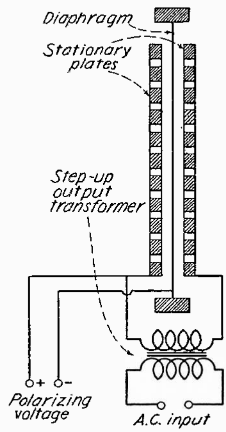


Fig. 5

Condenser speakers although commercially introduced are still in their infancy. Therefore, it is only important now for us to analyze the successful constructions to date. The condenser loudspeaker was given its original impetus in Germany. The back of the stationary part of the condenser loudspeaker is made of rigid metal, either iron or aluminum. The diaphragm is made of exceedingly thin, tough metal, usually some alloy of aluminum, stretched tightly over a frame which is clamped to the metallic back. In stretching the thin, flexible material, the natural mechanical period of the diaphragm is raised to a point beyond audibility and results in a straight response curve over the complete frequency range. In view of the in-and-out movement of the diaphragm, there must be a circulation of the air to the back as well as to the front, requiring, therefore, perforations in the rigid material. Naturally, the number of holes must be kept small in order to maintain an effective area between the movable and fixed plates. A circular condenser speaker is shown in Fig. 4.

A push-pull condenser speaker invented by Hans Vogt makes use of two stationary plates with a moving diaphragm between them. The diaphragm consists of a thin, flexible, insulating material, such as India rubber, gelatin or paper, coated on both sides with gold or aluminum or even painted with a conducting material such as graphite. Such a diaphragm is exceedingly light and has no definite mechanical period of its own. As it is not in a state of tension, it is easily moved by a small force. Then, too, the insulating material of which the diaphragm is made has a dielectric constant which tends to increase the force by its value. In other words, in the case of rubber, the dielectric constant will be 3 and will increase the force by that amount.

Figure 5 shows a schematic drawing of the push-pull condenser type speaker. The diaphragm is balanced by the potentials on both stationary plates and in this way the moving diaphragm is not in a state of tension. The step-up transformer used in this case is connected from the output of the power tube directly to the two stationary plates. The diaphragm and one of the stationary plates are connected to the polarizing voltage. By this method, the second harmonic distortion is eliminated and a more uniform response obtained. The perforations in this type of speaker are important and there must be enough of them to allow a free passage of air while the diaphragm is in motion.

Colin Kyle has made numerous valuable contributions to the development of the American electrostatic speaker. In the speaker developed by Mr. Kyle (see Fig. 6), the back space is perforated and ribbed, and over this is stretched a rubber-like material called "kylite." Over this is cemented a thin, flexible surface which serves as the diaphragm. Note the shape of the diaphragm between the air spaces and the back plate. Under the action of the applied voltage between the diaphragm and the back plate, these wedge-shaped air spaces tend to become narrower, and the entire diaphragm acts as if it were made of a multitude of small fixed plates and diaphragms. The thickness of the dielectric material "kylite" in this speaker, is approximately 0.005 in., and it has a dielectric constant of 3. Due to the presence of air and an insulating medium, the dielectric constant will be between 1 and 3, depending upon the proportion of kylite and air employed.

Speakers of this type are made in units of approximately 8×12 inches and if a greater sound radiating surface is required, as many units as needed are connected in parallel in order to give a larger surface from which sound may radiate. As many as 96 of these units have been used in a multiple arrangement. In connecting such units in multiples, it is preferable to arrange them in a curved surface in order to eliminate direct sound radiation. Baffles are also employed with condenser speakers and are calculated and designed in the same manner as for dynamic or magnetic horn units.

The American condenser speaker has a capacity of approximately .00318 mfds. with the result that at 1,000 cycles,

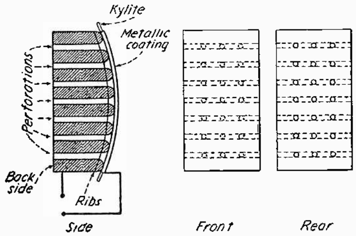


Fig. 6

the impedance is 50,000 ohms. This decreases with higher frequencies and increases a tremendous amount for low bass notes. It is essential that the impedance of all speakers and especially capacity speakers, be at least twice the internal impedance of the power tube. A tube such as the UX-250 has a plate impedance of 1,800 ohms and it is, therefore, essential that an impedance correcting device be placed between the condenser speaker and the terminals of the output tube. This may be accomplished by means of a step-up output transformer* but we are still concerned with the high impedance at low frequencies and low impedance at high frequencies. Usually an absolutely noiseless resistance is placed in series with the condenser speaker which has the effect of lowering the variations in impedance for varied frequencies.

Figure 7 shows four ways of attaching a condenser

*The American practice is to use several condenser speakers in parallel which permits a direct match through a choke coil—condenser coupler as in Fig. 7. This arrangement increases the sound radiating surface.

speaker to the output of a tube. "A" is an output impedance across which is shunted a condenser speaker in series with a ½ mfd. coupling condenser. A ½ megohm resistor is connected between B— and the fixed element of the condenser, thus completing a path for the polarizing voltage to the unit. "B" shows the connection for the push-pull audio output and a polarizing voltage is obtained by means of the external battery or B supply in series with a ½ megohm resistance. The drain on the battery will be extremely small as there is practically no current required for the polarization of the condenser. Figure C shows a separate B supply used as the biasing voltage. It is perfectly feasible in this instance to employ a '01A tube to deliver large voltages as the actual

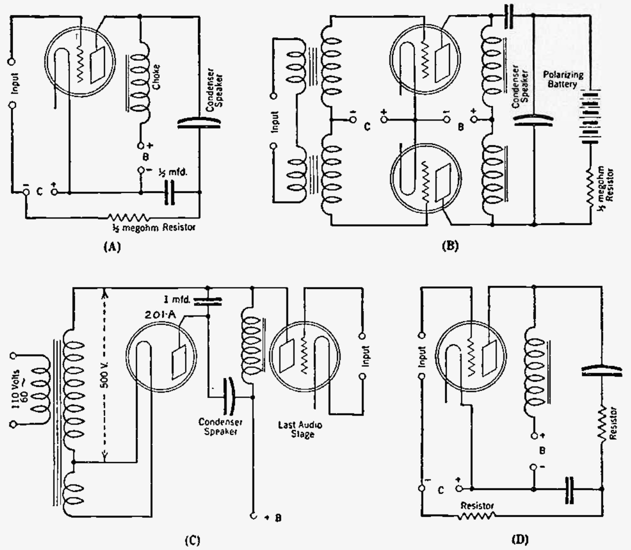


Fig. 7

flow from filament to plate is extremely low. "D" is a duplication of "A" but showing a resistor in series with a condenser speaker in order that a flatter impedance curve over the operating range might be obtained.

TUBE-TO-SPEAKER COUPLING DEVICES

3 Two requirements must be considered in connecting the output of the power tube to the loudspeaker signal input terminals. First, no D. C. current should flow in the speaker, and second,* the impedance of the speaker should be equal to twice the impedance of the output tube or tubes. The first require-

*This is not true for pentodes, in which case the speaker impedance should be made about 1/5 that of the tubes.

ment is to prevent the speaker coils from burning out, and to keep an undesirable force from acting on the diaphragm. The second requirement is to provide maximum *undistorted* signal to the speaker.

However, the maximum power is delivered when the plate impedance and the load impedance are equal. This is shown in Fig. 8 in which the curve of load impedance for 1, 2, 3, etc., times that of the output tube impedance is plotted against power output gain or loss. Note, however, that the output is measured in *db* gain or loss employing the output when speaker impedance is twice that of the tube as a standard of comparison in view of its ideal condition. Although an apparent gain is obtained by a load plate ratio of ½ to 2, it is not wise to operate at less than 1 due to serious distortion in the speaker. And, if the load impedance is 2 to 5 times as great as the tube impedance, the loss is only 2 *db* and not noticeable.

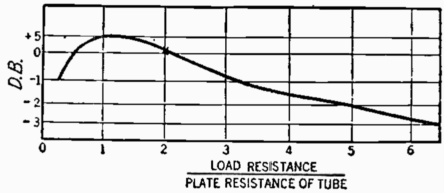


Fig. 8

Precise information on impedance values of various speakers is not usually given, but most reliable reproducer manufacturers will furnish it to customers when essential. A magnetic speaker may have a D. C. resistance of 1,000 to 2,000 ohms. At audio frequencies the impedance of the speaker will vary from the D. C. resistance value to 10,000 or 15,000 ohms, depending on the frequency. This is the result of the inductance of the windings and will be highest at the highest audio frequency.

We must not overlook the capacity effects of the coil and above all the motional impedance of the speaker due to its vibration in emitting sound. The dotted line in Fig. 9 shows the variation in impedance when the speaker is free and the solid line shows the impedance when the speaker is choked.

The blocked impedance is merely an indication of load offered by the electrical constants of the speaker. The difference between free and blocked impedance indicates sound and mechanical load. If the latter load was uniform the free impedance curve would be smooth and above the blocked or choked curve. The sharp rises and drops indicate mechanical resonances and losses.

In the usual types of dynamic speakers, the impedance of the voice coil will vary from 6 to 8 ohms at 100 cycles, to 15 to 30 ohms at 5,000 to 8,000 cycles. A curve of blocked and motional *resistances* of a dynamic speaker voice coil is given in Fig. 10. These curves mean more to speaker engineers than response curves. Note in the last case that the approach of the free to the blocked values at 350 and 2,000 cycles, indicates poor response, and good response is indicated by the peaks at 100, 1,500, and 5,000 cycles.

Some dynamic speakers have a single turn on the voice coil and its impedance is less than .001 ohm. Compare these load impedances with the plate impedance of 1,800 ohms for a UX-250, and 1,700 for a UX-245. Clearly these speakers with the possible exception of magnetic speakers, cannot be connected directly to the tubes as the power delivered would be extremely small, to say nothing of the current distortion.

Let us consider first, one of the commonly accepted methods for coupling a magnetic speaker to a single output tube, that is, the choke and condenser method shown in Fig. 11a. The plate of the output tube is connected to B+ through a 30 to 50 henry iron core choke, with as low a D. C. resistance as possible. This tends to keep the audio signal out of the B supply due to its high impedance, allowing, however, the D. C. to feed the plate. A 2 to 4 mfd. paper condenser is connected in series with the loudspeaker and shunted across the plate and cathode. The higher the impedance of the choke, the greater is the signal voltage applied to the series speaker circuit; and the larger the condenser, the nearer the combined condenser and speaker impedance will approach the value of the speaker impedance alone. A very small condenser should not be used as series resonance may result, nullifying the impedance.

This filter circuit obviously prevents D. C. current from passing through the speaker, at the same time allowing maximum signal current to flow to the speaker. The impedance of this load (the choke which is very large, in parallel with the combination of the speaker in series with the condenser, which is in this case small) will be slightly less than the smallest impedance. Therefore, we can neglect the impedance of the choke and consider the impedance of the condenser in series with the speaker. The impedance of the condenser in the case of magnetic speakers can be overlooked, as its impedance is very low as compared with the speaker impedance and is only appreciable at very low frequencies, far below that frequency where a suitable response is obtained.

Thus in the case of magnetic speakers, the coupling device is used primarily to keep D. C. out of the speaker windings. It has very little to do with the matching of impedance. Let's take the case of a magnetic speaker whose impedance at 100 cycles is 2,500 ohms, at 300 cycles 5,000 ohms, at 750 cycles 10,000 ohms, at 1,750 cycles 20,000 ohms, and 30,000 ohms at 5,000 cycles. When used with a '71A output tube, having a plate impedance of 2,000 ohms, maximum power output would be obtained from 75 to 300 cycles and slow tapering off in power up to 750 cycles, rapidly falling off in

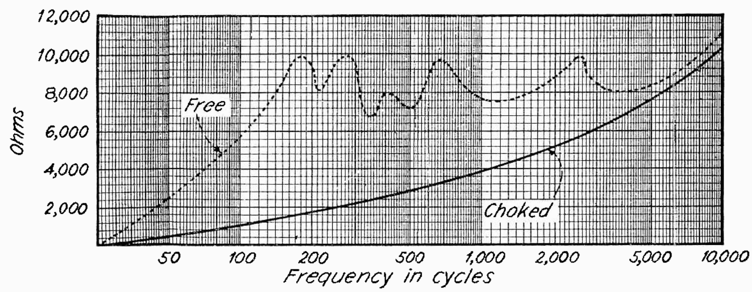


Fig. 9

power beyond this point. We would expect a good bass response and a fair high frequency response as cone magnetics are naturally sensitive at high frequencies. Choke and condenser systems are ideally adapted for use with magnetic speakers, due to the speakers' comparatively high impedance. The use of a '12A tube would be out of the question with this type of filter using this speaker as it has a tube impedance of 5,000 ohms, corresponding to maximum signal at 300 cycles, and response to frequencies below 300 cycles would be very poor. '50 and '45 tubes are out of the question with single magnetic speakers due to their excessive power output, which is far more than the speaker could handle.

Output transformers—see Fig. 11b—are more flexible and can be made to match widely differing impedances. In a coil, the inductance is proportional to the square of the turns. A transformer has a primary and secondary and the number of turns in each may be varied at will, so as to step up or step down the voltage as required. The relation between the number of turns, primary and secondary, and the impedance of each are given in the formula:

$$\frac{N^2_S}{N^2_T} = \frac{Z_S}{Z_T}$$

where N_S = turns on speaker side (secondary)
N_T = turns on tube side (primary)
Z_S = impedance of speaker side (secondary)
Z_T = impedance of tube side (primary)

The primary is usually wound to an impedance of twice the tube impedance. That is, Z_T is twice the tube impedance and Z_S is made equal to the speaker impedance. Thus the step-up or step-down ratio can be determined for ideal conditions by the formula:

$$\frac{N_S}{N_T} = \sqrt{\frac{Z_S}{Z_T}}$$

As an example: A '50 power tube has a tube impedance of 1,800$^{\omega}$ and is to be coupled to a dynamic voice coil whose impedance at 200 cycles is 9 ohms. What is the transformer turn ratio required?

$$* \quad \frac{N_S}{N_T} = \sqrt{\frac{9}{1{,}800 \times 2}} = \frac{3}{60} = \frac{1}{20}$$

That is, a step-down transformer of 20 to 1 ratio is required.

As a further example, suppose the previously considered magnetic speaker is to be connected to a '12A tube whose impedance is 5,000 ohms. Maximum undistorted power is desired at 100 cycles and the speaker impedance will be 2,500 ohms.

$$\frac{N_S}{N_T} = \sqrt{\frac{2{,}500}{5{,}000 \times 2}} = \sqrt{\frac{1}{4}} = \frac{1}{2}$$

Therefore, a step-down transformer of 2 to 1 ratio would be required.

A coupling or output transformer as it is commonly called, prevents the D. C. from reaching the speaker and may at the same time match the two divergent impedances. The same care should be exercised in its design that is given to audio amplifier transformers. The cores should be quite large as the large magnetizing current may cause distortion due to magnetic saturation if small cores are used. Exact matching is not essential, and a coupling transformer designed for a

*Square root of 9 is 3. 1800x2 equals 3600 and the square root of 3600 is 60. We then have 3/60. 3 into 3 goes once and 3 into 60 goes 20 times so we have 1/20.

high tube impedance would work with a tube having as much as twice the impedance. Invariably, when connecting any tube or tubes to a speaker, a step-down transformer must be used, for example, a '45 tube having a recommended load of 34,000 ohms which may have to match a 1 to 10 ohm voice coil. Obviously a step-down transformer must be used.

In systems using more than one tube in the output placed in parallel (only when the tubes are identical in characteristic and operation), the plate impedance will be 1/2, 1/3, 1/4, 1/5, etc., of one tube, depending on whether 2, 3, 4, or 5 tubes are used. In this case, 1, 2, 3, 4, 5, etc., speakers connected in parallel should be used to reduce the load impedance in the same manner. If several speakers are used when one speaker has the proper impedance, as in Public Address Systems, we use a series-parallel arrangement. That is, two speakers in series are connected in parallel with another pair in series. This keeps the total load impedance approximately equal to the impedance of one, thus matching the tube impedance. A coupling transformer turn ratio must take into

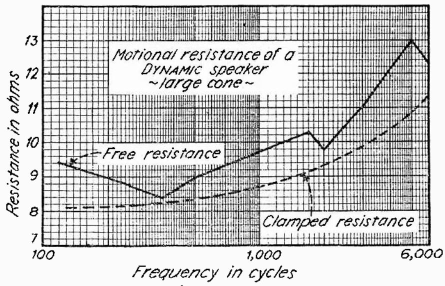


Fig. 10

consideration the arrangement of the load and its final impedance if the precautions for correctly connecting multiple speaker arrangements are not observed.

The push-pull arrangement of output tubes is by far the most commonly used output arrangement. Refer to Fig. 11c. The plate circuits of both tubes are in series with the output transformer primary. A push-pull '45 circuit would have a tube impedance of twice 1,700 or 3,400 ohms. As a result, for maximum undistorted power, the impedance of the primary Z_T should be twice the plate impedance of the two tubes in series or $2 \times 3{,}400$ which is 6,800 ohms. Or we could say that Z_T should be four times the plate impedance of a single tube.

In many theatre and public address amplifiers, two tubes are used in parrallel on each leg of the push-pull arrangement, resulting in a total series plate resistance of 2 R_p divided by 2, or a total of R_p. Consequently, an output transformer having a primary suitable for a single tube will suffice provided it is center tapped and will carry the total plate current.

The D. C. current, in push-pull, however, flows from B+ to the plates through equal sections of the primary, but in opposite directions (current considered by engineers to flow in a direction opposite to electron flow) with the result that the iron core is not magnetized. Therefore, there is no possibility of magnetic saturation and the varying current causes a uniform increase and decrease in flux. Push-pull arrangements are subject to less distortion than other output arrangements, due to the cancellation of even harmonics originating in the tube. Moreover, any A. C. hum in the plate or grid circuits will be balanced out.

LOUDSPEAKER RESPONSE CURVES

How are we to know when a loudspeaker is good? While the ear can be said to be the final judge in a matter of this kind, we realize that the ear is not nearly as accurate an indicator as electrical meters. It may surprise many to know that about 15 per cent of the people in the United States have defective hearing. It might shock us to learn, if we could gather the facts, how many of us have distorted hearing. At the time of writing, the people in London, England, have available at a public institution, a reproducing machine where music and speech are reproduced perfectly in order that individuals might train their ears to perfect sound.

No, the ear is not a good indicator of the characteristics of the loudspeaker. Even engineers differ as to how to measure the performance of sound reproducers. In a previous study, we brought out the interesting fact that a speaker had a blocked impedance and a free impedance. Some loudspeaker experts claim that the difference between the free impedance and the blocked impedance is an indication of response. While the latter curve is rather smooth and has a definite increase, generally towards the high frequencies, the free impedance is a curve usually above the blocked impedance showing many sharp inclines. A sharp rise indicates a large response—a sharp drop indicates a poor response. A curve of this type is illustrated in Fig. 9.

Other experts are more exacting. They prefer to compare the blocked resistance with the free resistance, the difference being, theoretically, a true indication of the amount of power converted into mechanical, and then sound energy. A curve of this type is also shown in Fig. 10.

By far the greatest number of loudspeaker engineers prefer to measure the sound power output exactly as the ear would hear it. The actual measuring is not difficult. A variable audio oscillator or a phonograph record on which have been recorded standard audio frequencies, produces the audio frequencies which are amplified and a definite amount of power is fed by the amplifier to the loudspeaker through an impedance correcting output transformer. Maintaining power input to the speaker constant, the frequency is varied from 30 to 10,000 cycles per second.

In front of the loudspeaker there is a condenser microphone and the sound energy is converted into electrical energy

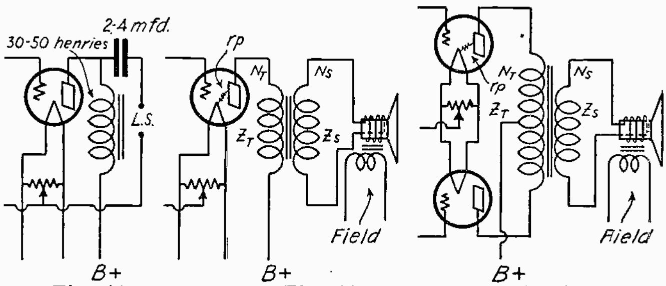


Fig. 11a Fig. 11b Fig. 11c

then boosted by means of an amplifier which has a power indicating meter at its output. After each frequency measurement, the audio oscillator is disconnected from the loudspeaker and through a power reducing arrangement (an attenuator calibrated in db's), the same amount of power is forwarded through the audio amplifier and meter, the source in this case being the power which fed the speaker originally. The attenuator is adjusted until the meter reading is the same as the reading obtained from the loudspeaker through the condenser microphone. As the attenuator is calibrated in db's we can get from it the information needed to record a loudspeaker response curve. A typical response curve is shown in Fig. 12.

The curve shown is for a dynamic unit attached to an exponential horn, designed to have a cut-off frequency at 115 cycles. The test was made out-of-doors and the microphone was placed 2 in. from the mouth of the horn. The calculated cut-off frequency is borne out faithfully. Notice the decline in response at 750 cycles—the rise in response from 2,000 to 3,500 cycles and the sharp cut-off at 5,500 cycles. These curves must be read in the light of the full significance of a decibel. You must not overlook the fact that in music or any complex sound, 3 db's change is just about noticeable. In this curve, the normal level of sound output is 43 db's. Notice that the value drops to 40 db's at one point and on the sharp rise it goes up to 50 db's. In either case, from our knowledge of the decibel, this difference will be quite apparent. Very few of us will have the opportunity of taking response curves, yet our Radio journals are periodically showing them in order to indicate progress in loudspeaker development. This information is, therefore, of great importance in that it will help us to understand the full significance of good loudspeaker performance.

The very same speaker, taken into a room, would have different response characteristics and by taking the microphone to different positions in the room, still more response curves will be obtained. Why not? Convince yourself sometime, by listening to an A. C. machine which has a perceptible hum. Listen for the hum in various parts of the room—notice how much louder it appears when heard from certain angles. If a response curve is taken with the apparatus set up in the direction of a strong wind and then again at right angles to the wind, the results will differ widely. In spite of all this, these curves are the best indications of the many features of the speaker such as the cut-off frequency, both low and high, and points of poor and normal response are readily detected. In general, the response curve taken in a fairly large, thickly carpeted and felt-lined room is a fair indication of the average performance of a loudspeaker.

When definite information is available on the response characteristics of a loudspeaker, it is possible to make certain corrections when designing the audio system. Take, for example, a horn dynamic speaker whose response curve shows 115 cycle cut-off. The curve is peaked at 2,000 cycles and gradually drops off from this point. If this speaker were connected to an amplifier having a sharp cut-off at 100 cycles, a gradual tapering off in amplification from 2,000 to 3,500 and a resonance peaked amplification at 5,000 cycles, the combination effected would be quite "flat." It is not difficult for a capable designer to make this correction. See Fig. 13a.

Loudspeakers and their audio amplifiers work hand-in-hand and knowing the characteristics of both, it is possible to correct the inherent deficiencies of one with the other. If the response characteristics of an audio amplifier is poor at low audio frequencies it is possible to use a speaker with it that has a peaked low frequency response characteristic. Figure 13b shows what one can expect from a perfect amplifier and a poor speaker where the amplifier makes up for poor high frequency loudspeaker response.

In Radio receivers, the actual selectivity curve of the radio frequency detector systems is never flat topped, and side band

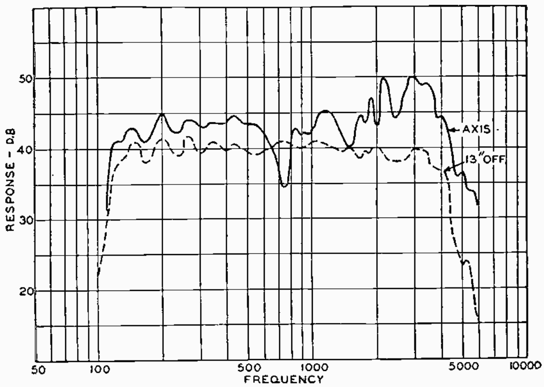


Fig. 12.—Curve marked axis is for sound in front of the cone, 13" indicates the condition 13 inches away from the cone rim.

cutting in a selective receiver is the rule rather than the exception, particularly with distant reception. For Radio receivers, a combination audio amplifier speaker response is designed to rise at 4,000 to 5,000 cycles and often to have a sharp cut-off at 5,000 cycles. This in a way compensates for the side band cutting and at the same time reduces background noises to a minimum.

Compromise and adjustment are the tools that good designers employ. As a service man, don't overlook the pains and care that the engineer has spent on the machine, be it a Radio receiver, a broadcast transmitter, a sound or public address system or even a Television amplifier. Don't destroy what resulted from a compromise unless you are sure the arrangement can be improved upon.

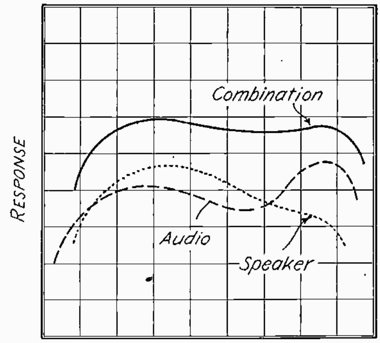
TONE CONTROL

Designers of Radio receivers and audio reproducers are fast recognizing that people differ in music and speech appreciation. It is fatal, from a business point of view, to force a customer to accept the opinions of engineers and experts. In fact, these eminent leaders have finally been convinced that the public's appreciation, in many cases, has sound reason behind it. For example, many sets which are designed to have no A. C. hum have poor bass response. In well designed receivers, this is overcome by the use of a greater amount of power pack filtering, lower gain first audio amplification, less sensitive power detectors and bigger and better push-pull amplifiers, resulting without question in a decided increase in the cost of manufacturing.

Some people prefer low bass with a little hum—others would rather be without proper bass notes than have hum. Can we satisfy the varying demands in a single model? Can we correct old machines to eliminate hum or increase bass response? To a considerable measure, this may be done by the use of devices known as filters which have led to our present method of tone control.

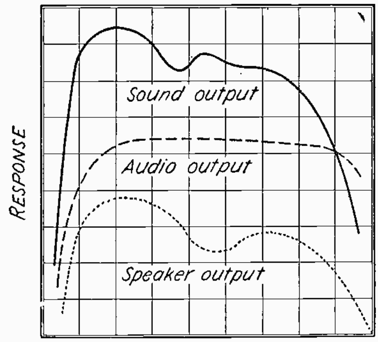
Most likely, you have heard the uninformed Radio public compare various machines. Maybe you have heard one person remark to the other: "My machine would suit me perfectly if I didn't get that infernal background of noise. Did you notice the noise last night?" To which, the other might reply: "Jim, you should have a Radio like mine. I never get noise unless there is a lightning disturbance." Strange as it may seem, both statements are correct and the two individuals may be neighbors; they may even be living in the same house. Our first Radio enthusiast has a machine with an audio system and loudspeaker, capable of reproducing perfectly from 50 to 8,000 cycles per second, whereas the second man has a machine which reproduces merely from 100 to 4,500 cycles per second. The man with the better receiver is the least satisfied. And after a visit to our second friend's home, the dissatisfied individual would be convinced that he, if he is a real lover of music, would rather have a little noise than listen to a Radio without brilliance, due to lack of high frequency response and the presence of a false bass.

Tone controls can be used to cut-off the high frequencies and thus get rid of a particular high noise frequency. They may be adapted to machines with perfect amplification. The cutting off of the high frequencies, however, tends to throw the power into the bass and the result is a false bass.



Frequency in C.P.S.
Fig. 13a

When you go to the theatre or a concert, you may prefer to sit in the front row, perhaps in the center or even in the rear. If you prefer to sit close. you no doubt want to hear (more likely to feel), the drums, the bass string instruments and the big horns. If you sit in the rear, you prefer to listen to the middle register or enjoy a more perfect blending of all



Frequency in C.P.S.
Fig. 13b

the musical instruments. People differ. Some prefer a good bass response—to others it is nerve-racking.

Years of experience have taught Radio designers that a perfect response output from a loudspeaker still does not make the reproduction exactly like the original. Microphones used to pick up a performance are invariably placed close to the performance. Yet would everybody sit in the front row—even if it were physically possible? Some musicians prefer to sit in the gallery with their eyes closed, half asleep. Too close, they claim, makes the performance seem too mechanical. Yet that's what we receive through even a perfect Radio, and it is this that makes the machine sound like a Radio, a sound picture or a phonograph.

For perfect reproduction we should run our reproducing device at the same sound level as the original and be able to hear it as though we were in our favorite seat in the house, in the theatre, or concert park. If every one would be allowed to run the Radio at the level he found most satisfying, the probability is that the Radio would be run low and quietly. But what happens to the bass? It is there, of course, but not at the proper level. We must not forget that the ears are more sensitive to frequencies from 500 to 8,000 than below 500 cycles. The bass, in order that it may sound like the bass in the original, should be loud enough so that we can just about feel it. Clearly, when a Radio receiver is run at a low sound level, we lose the bass, yet with a tone control we might boost the bass even though falsely, and allow the middle and higher registers to be low. But let us emphasize here that tone controls are not cure-alls. They may not even work effectively in all installations, as room conditions may alter the situation. As a Radio service man, who appreciates the shortcomings of a Radio receiver, it is imperative that you do not force your customer to an ideal tone quality—merely suggest what might appeal to him. And installing a tone control in his receiver may really help to satisfy his personal musical tastes.

In the past, many receivers have been designed for exceptional bass response at the sacrifice of high frequencies. This was followed by a cycle of reaction and later receivers were designed for "flat" amplification and output. When these Radio receivers were run at low levels, the absence of bass was common. Now we have a means of controlling tone so that a receiver with a flat amplification may have a control to permit a varying high frequency cut-off, resulting in a large bass response at will.

What are these tone controls? How do they work and where are they installed?

Before correcting for poor bass response, you must not overlook the fact that bass signals will not be of any value if the speaker is not capable of reproducing them. One correction may be made before tone control and that is the correction of baffles. A small baffle has a high cut-off. Increase its size in the manner described in the discussion on baffles. This correction might even indicate that the bass was there but not reproduced.

In correcting an old type receiver, we are confronted with other problems which the service man must keep definitely in mind, otherwise his repair work will be ineffectual. The speaker that will not respond even with a proper baffle to a low bass signal cannot be corrected; install a new speaker. An audio system that uses small transformers or a poor impedance or resistance coupled system, cannot be expected to

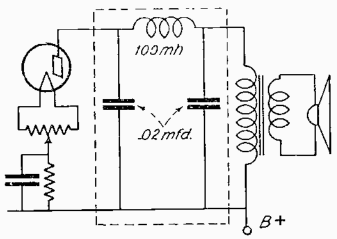


Fig. 14a

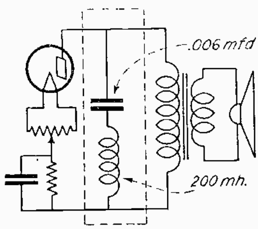


Fig. 14b

pass rich bass signals to the speaker. In correcting old type receivers, well designed transformers must be installed and the whole audio amplifier must be carefully redesigned. This has been considered before. First, the receiver should be redesigned to have as nearly flat amplification as possible. Distributed capacity in the primaries and secondaries of transformers spells death to high notes. Naturally, therefore, bypasses across them will do the same. The only by-pass needed is the one across the detector plate to exclude Radio frequency from the amplifier system. By-passes, however, are essential from the B+ to cathode in each plate circuit and a large one will aid the passage of bass notes. In resistance and impedance coupled audio systems, the coupling condenser should be comparatively large and a value of from .1 to .5 mfd. is usually employed. If too large a value is used, "motorboating" may result.

When a Radio receiver is used for local reception, high frequency notes are prominent (high frequency peaks) as side band cutting in the receiver is not present. However, high frequency peaks result in sounds unpleasing to the ear when the volume level is raised. Any large high frequency signal has a tendency to make the ear ring. Filters are used extensively to rid the system of these peaks. What is called a "pi" filter is shown in Fig. 14a. In this arrangement, the inductance has a value of 100 to 200 millihenries and the capacity is about .01 to .02 mfd. This filter tends to cut off the audio signals above 3,500 cycles. Another form of filter is the series resistance filter shown in Fig. 14b. A very sharp cut-off may be obtained if the resistance, in series with the capacity and inductance is kept low. Such filters are often called "scratch" filters as they were originally used in electric phonograph pick-ups to eliminate the attending scratch. Series-resistance filters may also be used in the output leads to the speaker

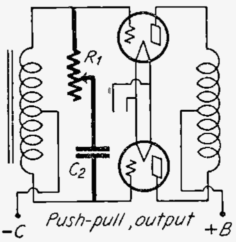


Fig. 15a

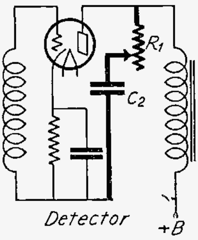


Fig. 15b

in order to rid the system of peaks at any frequency at which they might appear. The installation of these high frequency filters has a double effect on the ear. First, it reduces background noises, and secondly, it tends to make the bass notes more prominent giving a false but more evident bass response. This led to the tone control shown in Fig. 15a and Fig. 15b.

Figure 15a shows the method used when the output of the receiver is of the push-pull variety. To make the desired changes it is necessary only to solder two wires to the grids of the tubes. One wire goes to the variable resistor R_1 (500,000 ohms)—the other to the condenser C_2 (.005 mfd.). C_2 and R_1 are then wired together. A howl may result if the new leads are run near the input of the other stages. This may be eliminated by properly placing the wiring so that no energy is transferred to other circuits. You will have to experiment until the proper position is found.

R_1 may be mounted on the panel and acts as a variable tone control. By increasing or decreasing the amount of resistance at R_1 one is able to vary the depth of tone to any level desired.

There are some receivers which use only one stage of audio. In this case the tone control is placed in the plate circuit of the detector tube as shown in Fig. 15b. Be sure to use a condenser having a voltage rating of at least 200 volts, preferably a mica condenser. (An XL type variable of .005 to .01 mfd. may be advisable.) This will prevent the condenser from breaking down under any load which might be placed upon it.

Where the receiver uses a single power tube in the output, better results will be obtained by using the same control combination—connected from the plate of this tube to the ground.

4

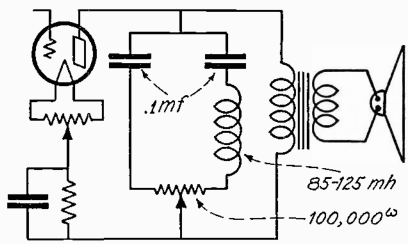


Fig. 16

It will then be necessary to use a larger working voltage condenser. The voltage rating, of course, will depend on the type of tube employed. If the set is equipped with a '45 tube, the condenser should be built to withstand a potential difference of 400 volts; if a '50 tube is used, its voltage rating must be 600 volts.

This rather universal form of tone control, a condenser and variable resistance only, has the tendency to by-pass high audio frequencies, resulting in a prominent bass. Not having a series inductance, the action is strictly one of by-passing, and the larger the condenser, the greater will be the by-passing action, extending to the lower notes. This scheme is quite effective if the Radio receiver is operated at low sound levels, as the low frequencies which are not by-passed will stand out. The variable series resistance naturally controls the effect of the by-passing.

Another quite effective tone control employs a double shunting arrangement as shown in Fig. 16, one shunt being a condenser and the other a condenser in series with an inductance. Note that they are connected together by means of a 100,000 ohm potentiometer having the variable contact connected to the cathode or grid return. Turning the variable slider towards the right in the direction of the inductance in series with the capacity, we include mainly the series resonant circuit which is so proportioned that it will shunt out the low frequencies and accentuate the high notes or treble. When moved to the left, to include the condenser only, the circuit becomes capacitive and acts merely to shunt the high frequency resulting in the predominance of bass frequencies. All the values are given and it is a valuable tone control to add to the well designed amplifier.

In receivers where there is a choke-condenser output filter system, tone control may be added as shown in Figs. 17a and 17b which are self-explanatory. Method 17a employs a selective system of coupling condensers and naturally the greater the value of the condenser the better the bass response. This, however, does not appreciably control the high frequency cut-off. Method 17b, employs an additional fixed coupling condenser, effective enough to pass a low bass note. The loudspeaker is shunted by a selective system which selects one of several condensers. With a large condenser, a greater range of high frequencies is by-passed. Method 17b, therefore, is to be preferred with a flat response amplifier and loudspeaker combination.

Speakers themselves are designed to have a good bass or a good high frequency response characteristic. It is not rare to find one of each in a high grade Radio receiver. Perhaps the receiver under consideration may have one or the other alone but where room permits, it may be wise to add another speaker having the opposite response characteristic, arranged as shown in Fig. 18. Note the variable resistance across the output secondary, permitting more power to be supplied to that speaker whose tone it is desired to bring out. It is essential in cascading speakers, that both devices be in phase and the correction made as explained before.

In conclusion, the value of any tone control is not to make lower tones or higher tones better. Its purpose is to allow the operator to choose a tone suitable to his taste.

LOCATING THE SPEAKER IN THE CUSTOMER'S HOME

Manufacturers and dealers have sold the buying public on the idea of perfect reception and the customer will not accept excuses. It is unfortunate that the public will not realize the shortcomings of Radio and expects the impossible. Not that the manufacturer has said things that cannot be justified, but we must realize that his claims are based on ideal conditions.

The final step in the installation of a receiver is its placement. The inside of the room, that is, its size, its surroundings, are of vital importance. The listener desires to hear the signal as if he were at the broadcast station, in an ideal position, and naturally desires that proportion of high and low frequencies which pleases him. We are not only concerned with this, but with the direction of the sound. We are en-

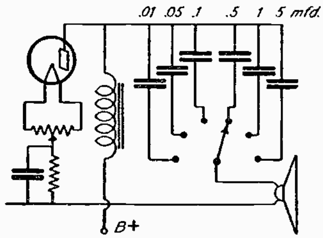


Fig. 17a

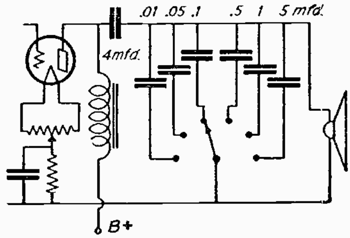


Fig. 17b

dowed with two ears and in a theatre it would not be a matter of great difficulty to point, with our eyes shut, in the direction of the organ, the fiddles, the drums, the bass horn, etc., provided, of course, we knew enough about music to discern these. In other words, each instrument is definitely placed in an orchestra with a view to maximum ear appeal.

In a Radio speaker, the sounds emanate from one source and the sense of position is lost. It is another of those things that makes a Radio sound mechanical. Then, too, the listener is not accustomed to hearing a band or a soloist in a small room and the selection over the Radio does not sound natural. For these reasons, the installation service man might suggest that the receiver be placed in an adjacent room so that the sound may come through the door, resulting in more life-like reproduction.

In installing a speaker in a room where it is to be listened to, it should be pointed to the center of the room from the wall which is the farthest distance from its opposite side, so that the sound waves may travel the longest distance without being reflected back. A loudspeaker pointed toward a carpeted floor will sound booming and, therefore, will be unsatisfying to the purchaser. This is due to the high frequency sound being absorbed by the rug. Likewise, if it is directed to a bare wall or ceiling, the high frequencies will predominate because of repeated reflection and reproduction seems unnatural. A position towards the center is best.

A room that is bare is far from ideal. Some of the sound
10 frequencies which are reflected from the wall will reinforce

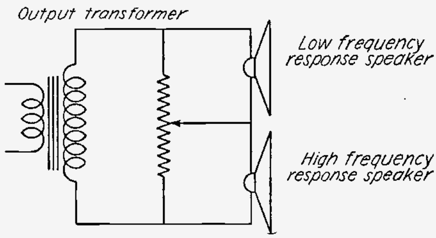


Fig. 18

themselves and others will be cancelled. The result will be one of entire unnaturalness. The music will sound hollow and echoes may be present. A room with a rug practically covering the floor, a few curtains or drapes, and an irregular arrangement of covered furnishings tends to break the reflection which cancels some of the frequencies and reinforces others.

A Radio speaker should not be close to the wall nor should loose pictures, vases or various pieces of furnishings be allowed to vibrate. An observant installation man should consider all these facts and suggestions should be made to a customer. However, never force an opinion. It is better to submit even in the face of your better judgment, if your suggestion is not acceptable to the set owner.

TEST QUESTIONS

Be sure to number your Answer Sheet 27FR-1

Place your Student Number on every Answer Sheet

Never hold up one set of lesson answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and the best possible lesson service.

1. Why should the signal voltages applied to a condenser speaker always be small as compared with the biasing voltage?
2. If the response characteristic of the audio amplifier was poor at low audio frequencies, what kind of a response characteristic should the speaker used with the set have so that the low frequencies would not be lost?
3. For what two reasons must coupling devices be used between the output of a receiver and a loudspeaker?
4. How would you connect a magnetic speaker to a single output tube without the use of a transformer? Illustrate your answer with a neat diagram.
5. What advantage does the inductor dynamic speaker have over the ordinary magnetic speaker?
6. When coupling a '45 tube to a dynamic voice coil would you use a step-up transformer or a step-down transformer?
7. Why is it desirable to have audio amplifier-speaker systems of radio receivers designed to have a rising response characteristic at 4,000-5,000 cycles and to cut off sharply at 5,000 cycles?
8. How would you add a simple tone control to a receiver having a push-pull output stage?
9. Is the impedance of a magnetic speaker at 5,000 cycles, higher or lower than at 1,750 cycles?
10. Why is a bare, unfurnished room unsatisfactory for speaker reproduction?

14 CIRCUIT DIAGRAMS EACH WITH TESTING INFORMATION

27 SS

SERVICE MANUAL

PIONEER HOME STUDY RADIO SCHOOL

NRI

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

FOREWORD

This booklet is one of a series of service manuals which contain service sheets giving typical information on radio receivers. Each service sheet shows the circuit diagram in the usual symbolic form for that radio receiver. Many of the service sheets will contain such special service information as space will permit.

By studying each service sheet, you will gradually develop the ability to read any diagram or manufacturer's service manual and learn the usual methods of set adjustment. Enough typical receivers have been selected to give you quickly a good insight to the entire radio problem.

In reading a circuit diagram, learn to trace independently the power supply and the signal circuits. Then locate the special control circuits, such as the automatic volume controls, tuning indicators, manual volume controls, etc. Detailed information on power, supply, signal and control circuits, as well as set servicing, is given in the course, to which reference should be made.

J. E. SMITH.

WPC3M10536 Printed in U.S.A.

RADIO-TRICIAN Service Sheet

REG. U.S. PAT. OFF.

Compiled Solely for Students and Graduates

NATIONAL RADIO INSTITUTE, WASHINGTON, D.C.

ATWATER KENT MODELS 70, 74, 75 AND 76

(Chassis Type L and Type P)

The type L chassis has three stages of screen grid radio frequency amplification, plate detection, one stage of resistance coupled audio, and a stage of push-pull audio amplification. This chassis is used in models 70, 74 and 76 receivers.

In some models of the L Chassis the Bleeder Resistor No. 1 is connected to the end of the Volume Control Resistor No. 2 instead of directly to the movable arm as shown in the diagram.

Type P chassis is similar to type L but instead of a "local-distance" switch it has a "Radio-Phonograph" switch. This chassis is used in model 75.

Synchronizing Condensers

When the variable condenser unit has been replaced or adjusted in any way, it is necessary to check the alignment as follows:

(1) Loosen the pointer set-screws.

(2) Move the rotor plates of the condenser so that they just barely mesh with the stator plates.

(3) With the rotor in this position, adjust the pointer to the 1500 K.C. position and tighten the pointer set screws.

(4) Note how far down on the 1500 K.C. mark the pointer comes, then turn the condenser knob to the 550 K.C. mark. The pointer should come down on this mark approximately the same as on the 1500 K.C. mark. If it does not, it is an indication that the front panel is not centered.

(5) If the front panel is not centered, loosen the screw at each end of the bottom of the front panel and shift the panel one way or another as necessary. Tighten the panel screws and then reset the pointer accurately.

Important Service Notes

In these receivers it is very important to arrange the three control-grid leads to the screen-grid tubes exactly parallel to each other. If these leads are not parallel, and two of them come close together, the dial readings will not be accurate, especially at the high-frequency end of the scale.

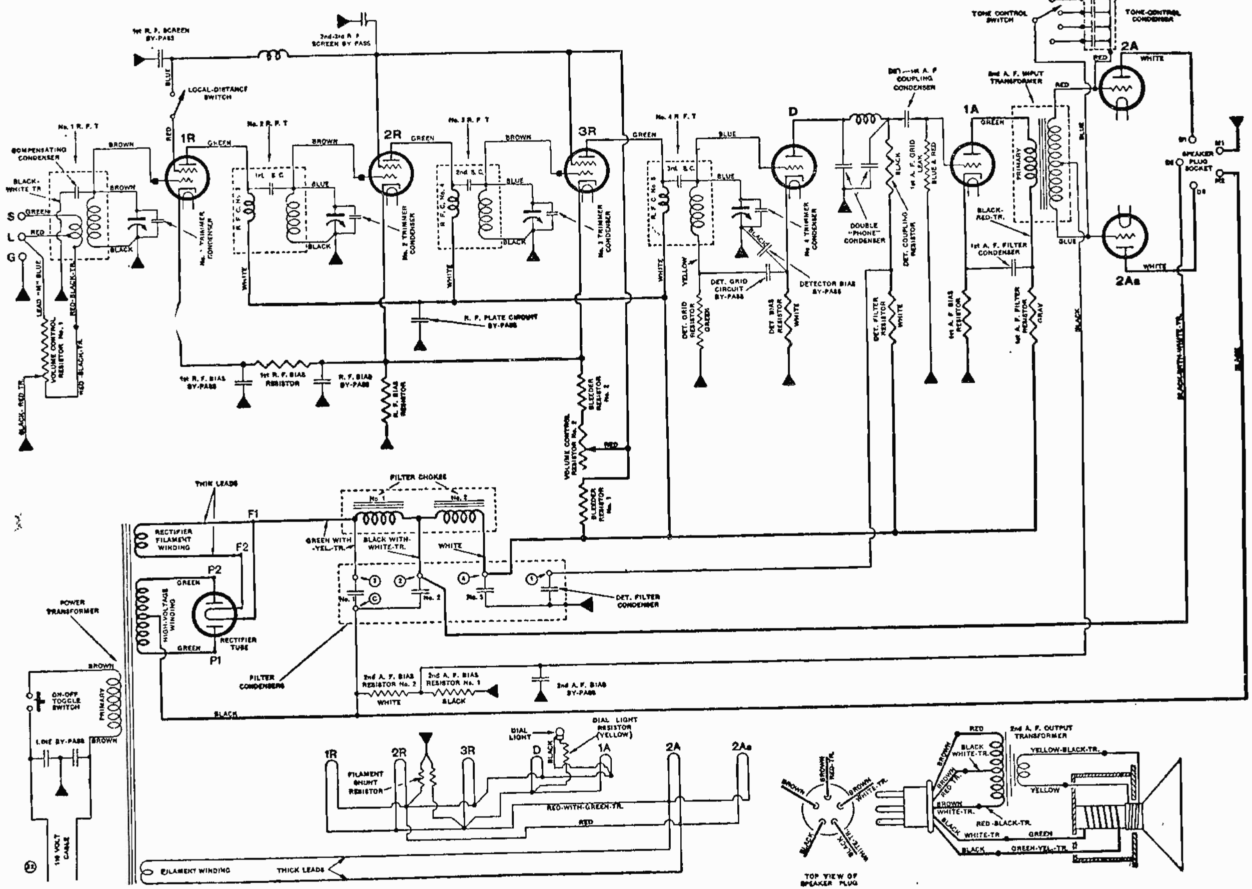
When replacing a flexible resistor, care must be taken to use a resistor having the same value. In the event of any uncertainty, make a continuity meter reading of a good resistor of the same type in a stock set, and then use a replacement resistor that gives the same reading on the continuity meter.

VOLTAGE TABLE FOR TYPE L AND P CHASSIS
Set in operation. Volume control at maximum.
Approx. Voltages, Using 120 V. Line.

Tube	Filament Voltage	Plate Voltage	Control-Grid Voltage	Screen Voltage
1st R.F.	2.4	180	5	85
2nd R.F.	2.35	180	4.5	86
3rd R.F.	2.35	180	4.5	86
Detector	2.35	110	14**	..
1st A.F.	2.35	70	2	..
2A	2.45	250	55*	..
2A a	2.45	250	55*	..
Rectifier	5.	...	...	..

*Use 250-volt scale.

**This is the voltage across the detector bias resistor; when measuring from grid to cathode, the voltage reading is only 2. All readings made from cathode in heater-type tubes, and from —F in plain-filament-type tubes.


1R
2R
3R
D
1A
2A
2As
TONE CONTROL SWITCH
TONE-CONTROL CONDENSER
LOCAL-DISTANCE SWITCH
COMPENSATING CONDENSER
No. 1 R. F. T
No. 2 R. F. T
No. 3 R. F. T
No. 4 R. F. T
R. F. PLATE CIRCUIT BY-PASS
DOUBLE "PHONE" CONDENSER
DETECTOR BIAS BY-PASS
DET. GRID CIRCUIT BY-PASS
2nd A. F. INPUT TRANSFORMER
1st A. F. FILTER CONDENSER
SPEAKER PLUG SOCKET
FILTER CHOKES
THIN LEADS
RECTIFIER FILAMENT WINDING
HIGH-VOLTAGE WINDING
RECTIFIER TUBE
POWER TRANSFORMER
ON-OFF TOGGLE SWITCH
LINE BY-PASS
FILTER CONDENSERS
DET. FILTER CONDENSER
2nd A. F. BIAS BY-PASS
DIAL LIGHT
DIAL LIGHT RESISTOR (YELLOW)
FILAMENT SHUNT RESISTOR
FILAMENT WINDING
THICK LEADS
2nd A. F. OUTPUT TRANSFORMER
TOP VIEW OF SPEAKER PLUG
F1
F2
P1
P2
S
L
G

RADIO-TRICIAN Service Sheet

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NATIONAL RADIO INSTITUTE, WASHINGTON, D.C.

EMERSON MODEL 109, CHASSIS U4A

GENERAL NOTES

1. The filament dropping resistor (R13—see schematic) is a resistance wire built into the special line cord. The cord will, therefore, become warm under normal conditions. To insure good heat radiation stretch out the line cord to its full length. Do not attempt to shorten it by cutting.

2. One side of the power line is directly grounded to the chassis base. Under no circumstances, therefore, should a ground wire be permitted to come in contact with any metal part of this receiver.

3. If replacements are made or the wiring disturbed in the r-f section of the circuit the receiver should be realigned.

4. When replacing the oscillator coil, be sure to mount it in the correct position. The locating hole in the square fibre terminal strip should be nearest the rear of the chassis.

TUBE DATA

1—6A7—Pentagrid oscillator-modulator
1—6F7—Triode amplifier-pentode detector
1—43—Pentode power output
1—25Z5—Dual half-wave rectifier

VOLTAGE ANALYSIS

Voltage readings should be taken with a 1000 ohms-per-volt-meter. Voltages listed below are from point indicated to ground (chassis).

Tube		*Plate*	*Screen*	*Cathode*	*Osc. Plate*	*Fil.*
6A7		105	60	1.35	105	5.5
6F7	Pentode / Triode	55	15	2.25	——	5.5
43		98	105	14.4	——	23.0

Voltage across speaker field—115
Voltage across choke—10.5

ADJUSTMENTS

An oscillator with frequencies of 456 and 1425 kc should be used.

An output meter should be used across the voice coil or output transformer for observing maximum response.

Location of I-F's and Trimmers: The first i-f transformer, is in an oblong coil can, located on top of the chassis directly behind the speaker. The two trimmers for this i-f are accessible through holes in the top of the coil can.

The second i-f transformer, is in a round coil can located on top of the chassis to the left of the speaker. The single trimmer for this i-f is accessible through a hole in the top of the coil can.

The oscillator and antenna trimmers are located on the top of the variable condenser. The oscillator trimmer is on the rear section and the antenna trimmer is on the front section.

Alignment Procedure: 1. Rotate variable condenser to minimum.

2. Feed 456 kc to grid of 6A7 tube.

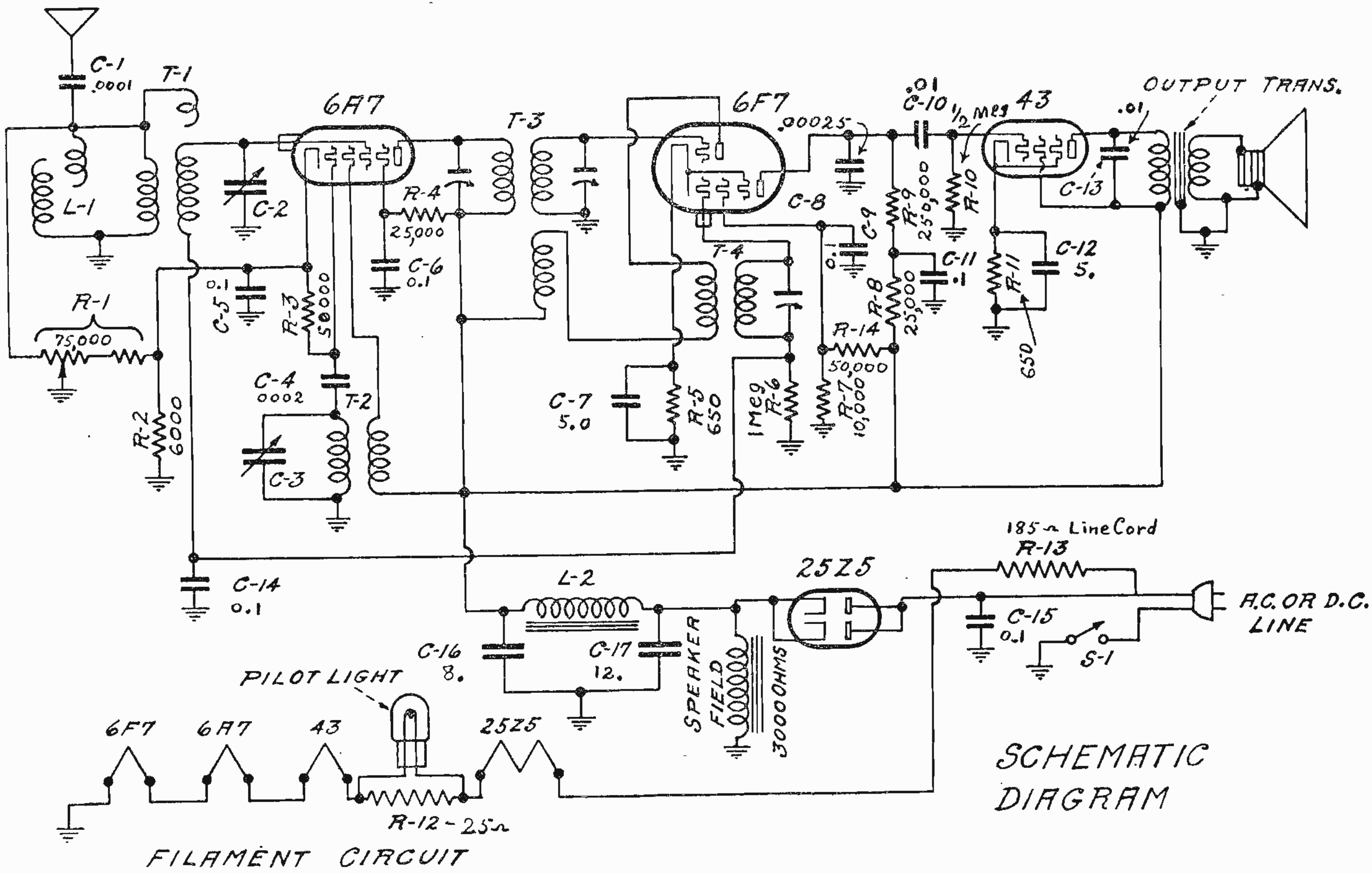
3. Adjust the three i-f trimmers, repeating for maximum response.

4. Set dial pointer to 1425 and feed 1425 kc through the antenna.

5. Adjust the oscillator (rear) trimmer for maximum response.

6. Adjust antenna trimmer for maximum response.

Emerson Model 109, Chassis U4A



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Sparton Model 82 Country Home Superheterodyne
(Battery Operated)

Schematic Diagram, Voltage Analysis and Continuity Chart

VOLTAGE ANALYSIS AND CONTINUITY CHART

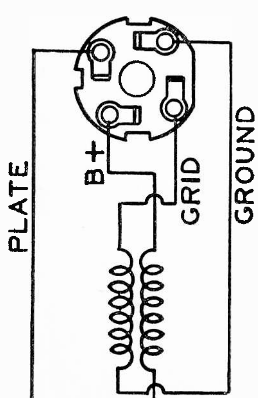
Condition of "A" Battery—Good
Condition of "B" Batteries—Good
Condition of "C" Battery—Good

Position of Volume Control—Full with Antenna Disconnected
Position of Band Selector Switch—Broadcast

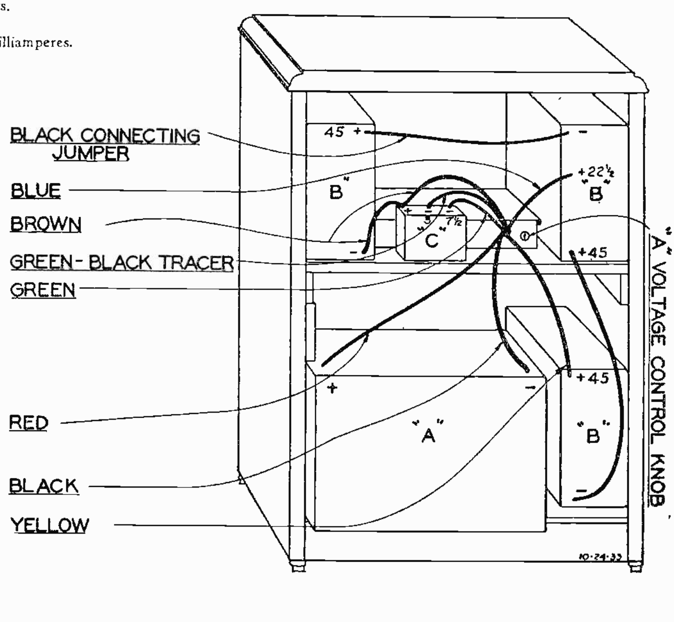
Tube	Location	PLATE Volts	PLATE Ma.	Screen Grid Volts	Control Grid Volts	Grid Res. to Preceed. Plate (Ohms)	RESISTANCE TO GROUND (OHMS) Plate	Screen	C. Grid	Cathode
1A6	1st Det.-Osc.	135	1.3	67.5	—3.	—	12.5	0	750,000	0
32	I-F Stage	135	1.7	67.5	—3.	500,000	12.5	0	500,000	0
32	2nd Det.	135	.6	50.	—3.	500,000	350,000	500,000	500,000	0
30	1st Audio	135	3.0	—	—7.5	85,000	80	—	500,000	0
19	Power Stage	135	4.0	—	—3.	300	75	—	220	0

NOTES· Allow 15% + or — on all resistance measurements (all battery leads connected together).
All filament voltages: 2.0 volts.
"A" battery drain .6 ampere.
"B" battery drain 25 to 35 milliamperes.

HOOK UP OF TERMINALS ON OSCILLATOR COIL A-10330

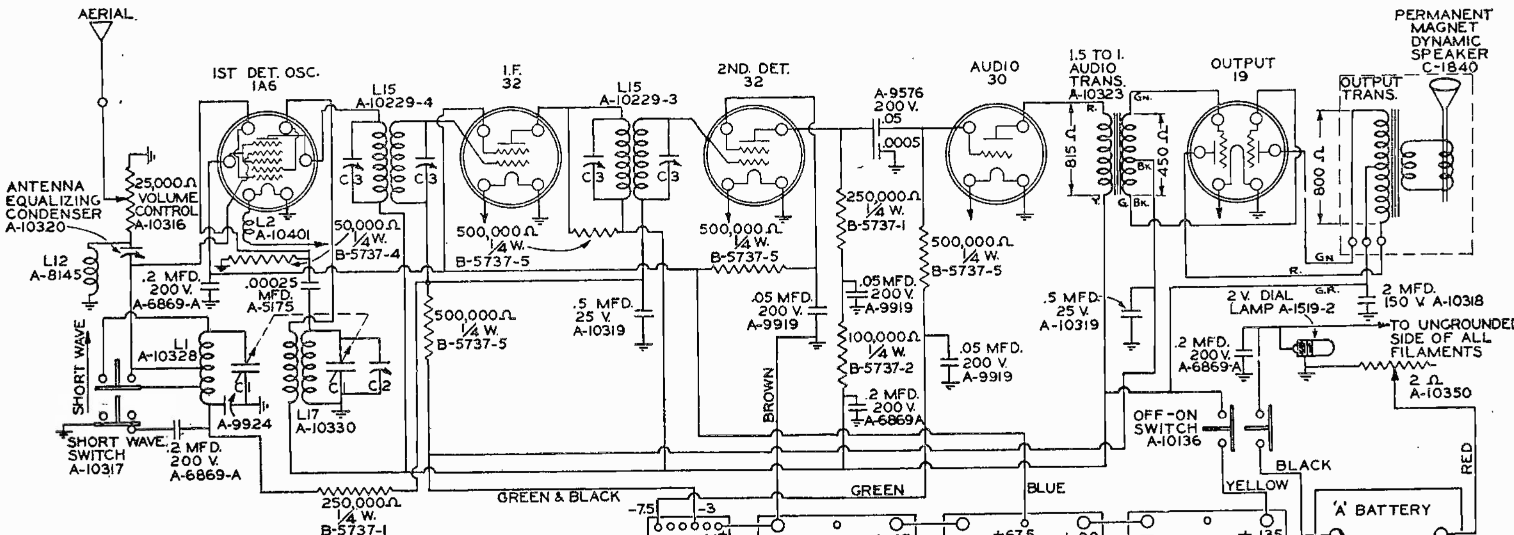


MODEL 82



SPARTON MODEL 82 WIRING DIAGRAM

SPARTON MODEL 82 COUNTRY HOME RECEIVER
SUPERHETERODYNE—BATTERY OPERATED



C1 VARIABLE CONDENSER
C2 EQUALIZING CONDENSER
C3 ADJUSTABLE CONDENSER
L2 CATHODE CHOKE

L1 TUNING COIL
L12 ANTENNA CHOKE COIL
L15 I.F. TRANSFORMER 456 K.C.
L17 OSCILLATOR COIL

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FARMERS AND OTHERS IN RURAL COMMUNITIES

ARE FINE RADIO PROSPECTS

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Service Sheet

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NATIONAL RADIO INSTITUTE, WASHINGTON, D. C.

GENERAL ELECTRIC MODELS L-50 AND L-51 RCA VICTOR R-22 SERVICE DATA

ELECTRICAL SPECIFICATIONS

Voltage Rating....................100–125 A. C. or D. C.
Frequency Rating (A. C.)..................25–133 Cycles
Power Consumption: A. C. 60 Cycles, 115 Volts—60 Watts; D. C. 115 Volts—40 Watts
Number and Types of Radiotrons...............1 RCA-78, 1 RCA-6A7, 1 RCA-77, 1 RCA-43, 1 RCA-25Z5—Total, 5
Undistorted Output (A. C.).....................1.5 Watts
Undistorted Output (D. C.).....................0.5 Watts
Frequency Range......540–1710 K. C. and 2400–2500 K. C.

This receiver is a five tube Super-Heterodyne designed to operate on A. C. or D. C. over a wide voltage and frequency range. Features such as compact construction, dynamic speaker, single Pentode Output tube and the inherent sensitivity, selectivity and tone quality of the Super-Heterodyne are included in this instrument.

The circuit consists of an R. F. stage using Radiotron RCA-78, a combined oscillator and first detector using Radiotron 6A7, an I. F. transformer using two tuned circuits, a second detector using Radiotron RCA-77 and a power stage using Radiotron RCA-43. The rectifier is Radiotron RCA-25Z5 which is used in a voltage doubling circuit. This results in considerable more output when the receiver is used on A. C. than that obtained from D. C. operation.

LINE-UP CAPACITOR ADJUSTMENTS

The line-up capacitor adjustments for the I. F. stage and the gang capacitors are made in the following manner:

(a) Procure a modulated oscillator giving a signal at 175 K. C., 1400 K. C., 1710 K. C. and 2440 K. C. An output meter and non-metallic screw driver are also necessary.

(b) The I. F. line-up capacitors should be first adjusted. This is done by placing the oscillator in operation at 175 K. C. coupling its output between the control grid and ground of the first detector, connecting the output meter across the cone coil of the loudspeaker and adjusting the two I. F. line-up capacitors until maximum output is obtained.

(c) After the I. F. circuits are aligned, the broadcast band R. F. is adjusted at 1710 K. C. This is done with the Range Switch at the broadcast position (counter-clockwise). A similar manner is used as that of the I. F. except that the oscillator is set at 1710 K. C., its output is connected from antenna to ground of the receiver, and the dial is set at 8 (minimum dial position). The adjustment is made with the trimming capacitors located on top of the gang capacitor and each capacitor is adjusted for maximum output.

(d) After making the 1710 K. C. adjustment, set the dial at 18 and the oscillator at 1400. Then adjust the first detector and R. F. line-up capacitors only. This adjustment is made so that the R. F. and 1st detector will be aligned over the broadcast band but the receiver will still tune to 1710 K. C. due to the oscillator line-up capacitor not being readjusted.

(e) Then set the Range Switch at its clockwise position. The oscillator should now be set at 2440 K. C. and the signal tuned in. Two points on the dial will be noted where the signal is heard, one of which may be louder than the other. Set the dial at either point. Note—the 2440 K. C. signal will still be heard at two points since these R. F. stages act as fixed tuned circuits. Adjust the two high frequency trimmers, located on the lower side of the gang capacitor until maximum output is obtained.

RADIOTRON SOCKET VOLTAGES

115 Volts D. C. or 60 Cycle A. C.
Divide all A. C. Values (Except Heater) by 1.3 for 25 Cycles

Radiotron No.	Cathode to Control Grid, Volts D. C.		Cathode to Screen Grid, Volts D. C.		Cathode to Plate, Volts D. C.		Plate Current, M. A.		Heater Volts
	A. C.	D. C.	A. C.	D. C.	A. C.	D. C.	A. C.	D. C.	
RCA-78 R. F	2.6	1.5	90	50	157	88.5	5.5	3.0	6.0
RCA-6A7 Oscillator	—	—	—	—	157	88.5	1.7	1.0	6.0
1st Detector	2.6	1.5	90	50	157	88.5	2.5	1.5	—
RCA-77 2nd Detector	Plate and Bias Supply 160 Volts						—	—	6.0
RCA-43 Power	21.0	12.0	135	80	125	72.0	35.0	20.0	25.0
RCA-2525 Rectifier	115 R. M. S.						89.0 Total	35.0 Total	25.0

Voltage Across Loudspeaker Field (115 Volts, 60 Cycles—185; 115 Volts, 25 Cycles—140; 115 Volts, D. C.—105)

REPLACMENT PARTS

Insist on genuine factory tested parts, which are readily identified and may be purchased from authorized dealers.

Stock No.	DESCRIPTION	List Price
	RECEIVER ASSEMBLIES	
2747	Contact cap—Package of 5	$0.50
2963	Resistor—8,000 ohms—Carbon type—1 watt—Package of 5	1.10
3033	Resistor—1 megohm—Carbon type—¼ watt—Package of 5	1.00
3555	Capacitor—0.1 mfd.—Connected across loudspeaker field	.36
3569	Knob—Station selector and volume control knob—Package of 5	.65
3572	Socket—7 contact Radiotron socket	.38
3584	Ring—Antenna coil shield retaining ring—Package of 5	.40
3594	Resistor—50,000 ohms—Carbon type—½ watt—Package of 5	1.00
3602	Resistor—60,000 ohms—Carbon type—¼ watt—Package of 5	1.00
3623	Shield—Antenna, R. F. or oscillator coil shield	.30
3632	Resistor—500 ohms—Carbon type—1 watt—Package of 5	1.10
3640	Capacitor—0.05 mfd.	.25
3641	Capacitor—0.1 mfd.	.35
3682	Shield—Radiotron shield body	.22
3683	Shield—Radiotron shield cap	.20
3684	Switch—Toggle type—AC-DC operation	.94
3685	Coil—Choke coil—Second detector plate	.54
3697	Escutcheon—Station selector escutcheon—Package of 2	.28
3698	Escutcheon—Volume control escutcheon—Package of 2	.28
3700	Resistor—450,000 ohms—Carbon type—½ watt—Package of 5	1.00
3701	Capacitor—0.01 mfd.	.30
3702	Capacitor—0.25 mfd.	.42
3710	Capacitor—60 mmfd.	.36
3711	Capacitor—80 mmfd.	.40

Stock No.	DESCRIPTION	List Price
3712	Capacitor—400 mmfd.	$0.40
3713	Capacitor—0.05 mfd.	.32
3725	Capacitor—1,130 mmfd.	.50
6114	Resistor—20,000 ohms—Carbon type—1 watt—Package of 5	1.10
6228	Resistor—200,000 ohms—Carbon type—½ watt—Package of 5	1.00
6250	Resistor—4,000 ohms—Carbon type—½ watt—Package of 5	1.00
6303	Resistor—20,000 ohms—Carbon type—½ watt—Package of 5	1.00
6464	Transformer—Intermediate frequency transformer	1.68
6505	Reactor—Filter reactor	1.06
6506	Condenser—Three gang variable condenser assembly	3.24
6507	Resistor—180 ohms—Porcelain type	.60
6508	Volume control—Complete with mounting nut	1.36
6510	Capacitor—8.0 mfd.	1.00
6511	Capacitor—Comprising one 8.0 mfd. one 10 mfd. and 4.0 mfd.	1.49
6518	Capacitor—Comprising two 8.0 mfd. capacitors	1.58
6519	Coil—Antenna coil	.88
6520	Coil—R. F. coil assembly	.94
6521	Coil—Oscillator coil assembly	.60
7485	Socket—5 contact Radiotron socket	.40
	REPRODUCER ASSEMBLIES	
6509	Transformer—Output transformer	1.34
7606	Coil assembly—Comprising field coil, magnet and cone support	2.06
8937	Cone—Reproducer cone complete with voice coil—Package of 5	5.00

GENERAL ELECTRIC MODELS L-50 AND L-51 RCA VICTOR R-22

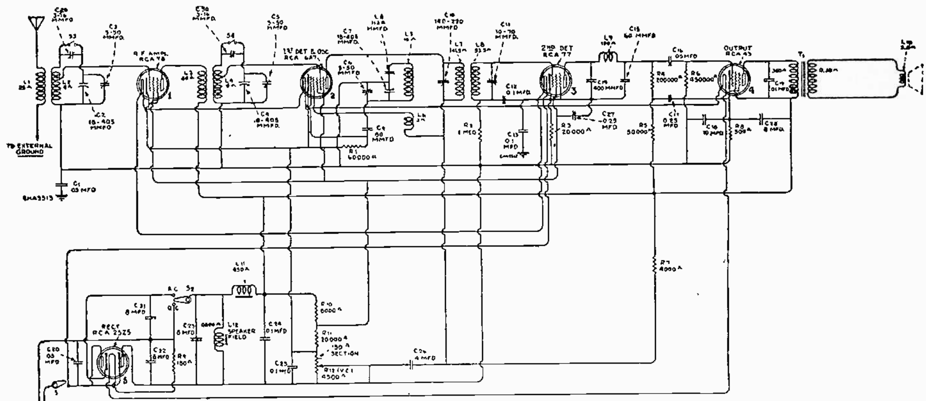

Figure A—Schematic Circuit

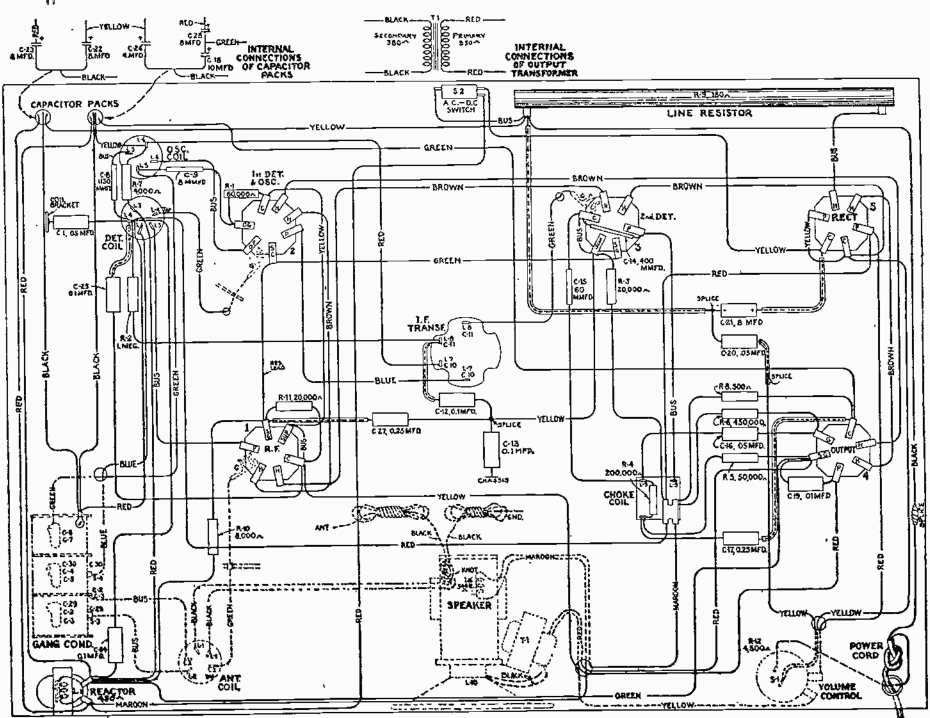

Figure B—Wiring Diagram

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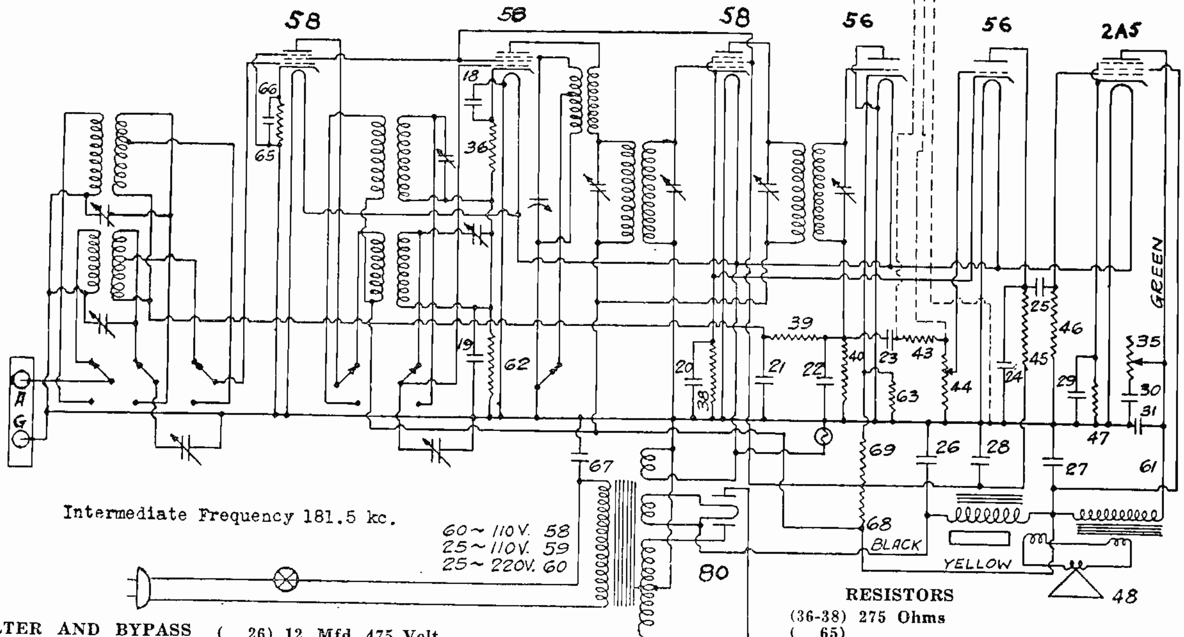
CROSLEY MODEL 179

Tube	Position and Use	Plate	Screen Grid	Cathode	Supp. Grid	Filament
		Voltages				
58	RF Amplifier	260	125	3	3	2.5
58	Oscillator-modulator	260	125	34	0	2.5
58	IF Amplifier	260	125	4	4	2.5
56	Diode detector	0		0		2.5
56	AF Amplifier	50		4		2.5
2A5	Output	250	260	16.5		2.5
80	Rectifier	355				2.5

Voltage limits are plus or minus 10% of values given.

Line Volts 117 A.C.



Intermediate Frequency 181.5 kc.

MODEL 179 WIRING DIAGRAM

FILTER AND BYPASS CONDENSERS

(18-19) .02-.02 Mfd. 200 Volt
(20-21)
(22-23) .00017-.03 Mfd. 400 Volt
(24-25) .001-.03 Mfd. 400 Volt
(26) 12. Mfd. 475 Volt
(27-28) 7.-6.-8 Mfd. 450-400-25 Volt
(29)
(30-31) .05-.008 Mfd. 400 Volt
(66) .02 Mfd. 200 Volt
(67) .01 Mfd. 400 Volt

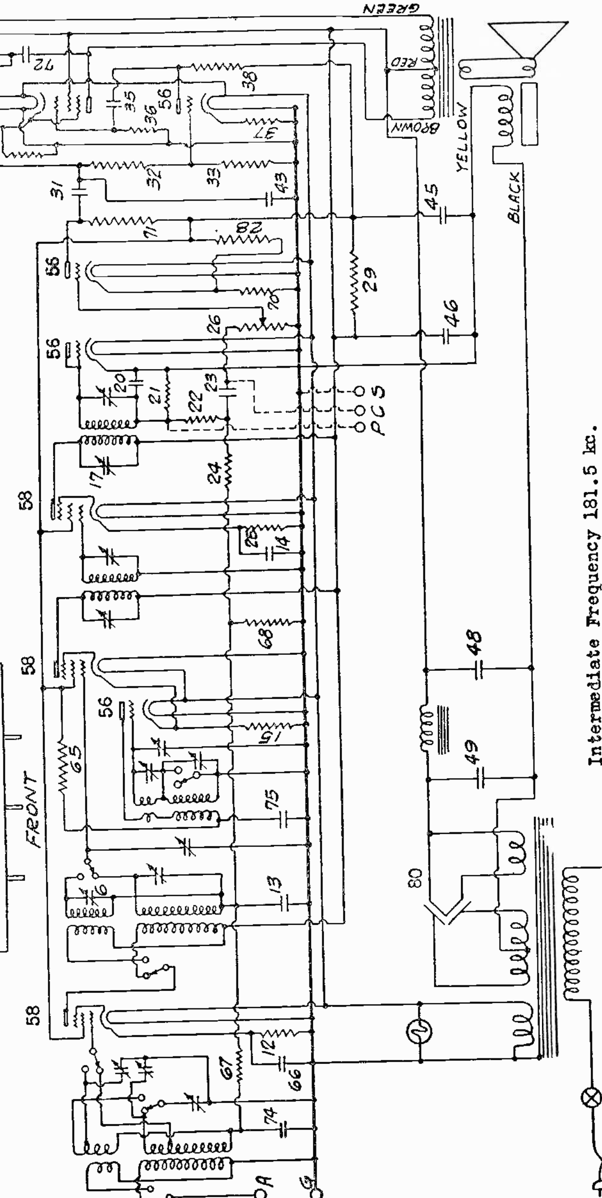
RESISTORS

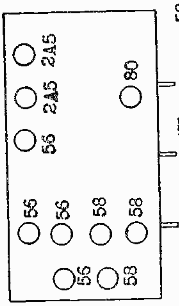
(36-38) 275 Ohms
(65)
(39) 3 Megohm
(40) 1 Megohm
(43-46) 500000 Ohm
(45) 150000 Ohm
(47) 450 Ohm
(62) 4500 Ohm
(63) 450 Ohm
(68-69) 8500-2500 Ohms (Candohm)

CR179

CROSLEY MODEL 180

Intermediate Frequency 181.5 kc.





FILTER AND BYPASS CONDENSERS

(13-14) 0.1-0.1 Mfd. 200 Volt
(20) 0.0001 Mfd. 200 Volt
(23) 0.006 Mfd. 200 Volt
(31-35) 0.05 Mfd. 400 Volt
(43) 0.005 Mfd. 200 Volt
(66) 0.02 Mfd. 200 Volt
(74-75)
(72-73) 0.05-0.004 Mfd. 400 Volt
(45-46) 8.-8.-8. Mfd. 250, 450, 450 V.
(47)
(49) 12. Mfd. 475 Volt

RESISTORS

(71) 150000
(12-70) 275 Ohm
(15) 375 Ohm
(21) 1 Megohm
(22-23) 300000 Ohm
(36-37)
(24) 3 Megohm
(25) 350 Ohm
(28-29) 11000 7000 Ohm
(33) 40000 Ohm
(34) 220 Ohm
(37) 2700 Ohm
(38) 60000 Ohm
(65) 10000 Ohm
(68) 5 Megohm

Voltages

Tube	Position and Use	Plate	Screen Grid	Cathode	Filament
58	Modulator	270	112	5.5	2.5
58	RF Amplifier	270	112	3.5	2.5
56	Oscillator	50		5.5	2.5
58	IF Amplifier	270	112	3.7	2.5
56	Diode	0		0	2.5
56	AF Amplifier	50		3 0	2.5
56	Phase Inverter	50		3 0	2.5
Two 2A5	Output	260	270	17 5	2.5
80	Rectifier	360			4.8

All voltage limits are plus or minus 10% of values given.

Line Voltage 117 A. C.

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EMERSON MODEL 106, CHASSIS U6B

(Serial Numbers Higher Than 636,900)

I. F. and Wave-Trap Alignment. The I. F. coils are located in cans on top of chassis. The second I. F. transformer is directly behind speaker. The four trimmers are located at tops of cans.

Turn wave-band switch to broadcast position, clockwise. Rotate variable condenser to minimum position and feed 456 kc. to grid of 6A7 tube. Adjust four I. F. trimmers for maximum response. Feed 456 kc. through antenna lead and adjust 456 kc. wave-trap trimmer for *minimum response.* Trimmer is on small wave-trap which is mounted on bracket extending from right-hand chassis wall.

Location of Coils. Broadcast and short-wave antenna coils are wound on one form, mounted on vertical bracket at right-hand side of chassis. Trimmers for these coils are on same assembly facing outward, and available through holes in bracket. Lower trimmer is for short-wave antenna coil; upper for broadcast antenna coil.

Broadcast and short-wave oscillator coils are wound on one form mounted below chassis deck. Trimmers are mounted on same assembly, facing outward, and accessible through holes in right-hand chassis wall. Front one is for short-wave oscillator coil and rear one for broadcast oscillator coil.

Dual padding condenser for oscillator coils is mounted inside of front chassis wall. Adjusting screws available through holes in front wall of chassis. Upper screw, broadcast padder; lower, short-wave padder.

Broadcast Alignment. Turn wave-band switch to clockwise position (broadcast), set dial to 600 (use center of speaker as reference point), and feed 600 kc. through antenna. Adjust broadcast oscillator padder for maximum response. Set dial to 1425; feed 1425 kc. through antenna. Adjust broadcast oscillator trimmer for maximum response and adjust broadcast antenna trimmer for maximum response. Reset dial to 600 and rock variable condenser while re-aligning broadcast oscillator padder.

Short-Wave Alignment. Turn wave-band switch to counter-clockwise position (short-wave), set dial to 570; feed 1600 kc. through antenna. Adjust short-wave oscillator padder for maximum response. Set dial to 1280, feed 3600 kc. through antenna. Adjust short-wave oscillator trimmer for maximum response and then adjust short-wave antenna trimmer for maximum response. Reset dial to 570, feed 1600 kc. and rock variable condenser while readjusting short-wave oscillator padder.

GENERAL NOTES

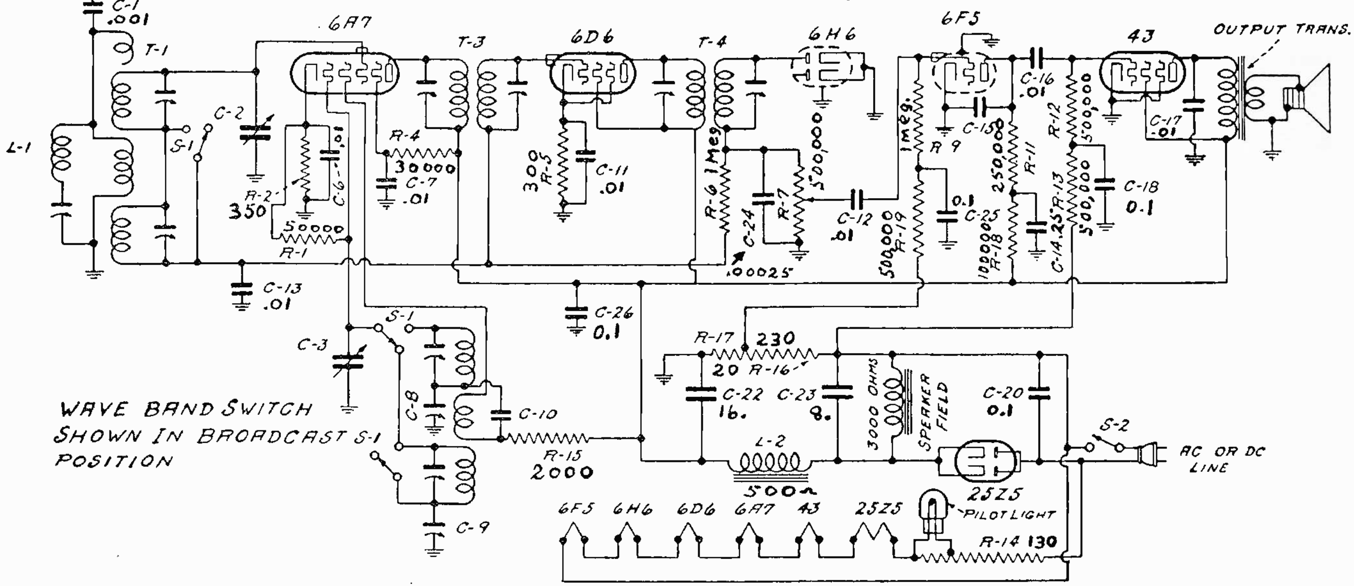
1. On early production runs bias for the grid of the 6F5 is obtained by a small, one-volt battery (bias cell). Cell assembly is mounted on a bakelite strip inside of the left-hand chassis wall. Do not put a voltmeter across this bias cell. If the set distorts, check by temporarily replacing with a new cell, or other one-volt source. To remove bias cell simply pull up on the spring clip and lift the cell from its cap. On replacing, be sure clip makes good contact.

2. If adjustment of sliding scale dial is necessary, loosen two slotted hexagon-head guides at top edge of scale. Adjust guides by moving up or down in slotted holes in chassis. Do not bring them so far down that the pinion gear binds on rack. Scale should move freely —without appreciable vertical movement.

3. After replacing a dial scale take care to align it properly with variable condenser. Rotate variable condenser to maximum capacity, loosen set-screw on hub of pinion gear and slide scale so that extreme right-hand mark (near 55) is in line with center of speaker. Then tighten set-screw.

Emerson Model 106, Chassis U6B

(Serial Numbers Higher Than 636,900)



VOLTAGE ANALYSIS

Readings should be taken with a 1000 ohms-per-volt meter. Voltages listed below are from point indicated to 43 cathode (B minus). Line voltage for these readings was 117.5 volts, 60 cycles, a-c. Voltage across speaker field (25Z5 cathode to line switch—125 volts).

Tube	*Plate*	*Screen*	*Cathode*	*Osc. Plate*	*Fil.*
6A7	105	55	1.7	100	6 a-c
6D6	105	105	2.75	——	6 a-c
6H6	——	——	0	——	6 a-c
6F5	55	——	0	——	6 a-c
43	100	105	0	——	24 a-c

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Stewart-Warner Model R-119 Chassis

CIRCUIT DESCRIPTION

The Stewart-Warner Model R-119 Chassis is a six-tube super-heterodyne. It will cover the broadcast and short wave ranges from 530 to 3750 K. C. The tuning dial is calibrated from 530 to 1740 K. C. and a short wave range is provided through a switch on the back of the chassis, for reception up to 3750 K. C. (80 meters).

The R-119A Chassis is designed for operation on 115 volt, 60 cycle power circuits while the R-119EF is adaptable for use with voltages of 115, 125, 230, 240, or 250 at any frequency from 25 to 60 cycles. To accomplish this, the power transformer has two separate tapped primaries. The method of connecting these primaries is shown on a tag attached to the chassis. The R-119-EF chassis is wired for operation with a high impedance phonograph pick-up.

In the R-119A and EF chassis, the incoming signal is amplified by a stage of tuned radio frequency to improve selectivity and sensitivity, and to prevent image frequency interference. It then goes to the 6-A-7, first detector and oscillator, where its frequency is converted to 177.5 K. C.

The 177.5 K. C. intermediate frequency signal is amplified by the high gain I. F. stage, and is then rectified by the diodes of the 85 tube. Detection is accomplished by the diode connected directly to the I. F. transformer. A modulated D. C. voltage drop is produced across the 500,000 ohm potentiometer by the rectified current. The volume is controlled by selecting any desired portion of the A. F. voltage with the moving arm of the potentiometer which is connected to the grid of the 85 tubes. The triode section of this tube acts as an audio amplifier and is resistance-coupled to the 42 output tube.

Delayed A. V. C. is obtained by using the voltage drop produced by the rectified current of the second diode of the 85 tube, for bias on the 78 and 6A7 tubes. This diode, which is coupled to the I. F. transformer by a .002 mfd. condenser, is 17.5 volts negative with respect to the cathode since it is biased by the cathode bias resistor. Consequently, no rectification and no A. V. C. action can take place in this circuit until the incoming signal is strong enough to exceed this value. This represents the minimum signal capable of giving full audio output. Through the use of the delayed A. V. C. any signal which cannot be amplified to this minimum value is not reduced in volume by the action of the A. V. C. circuit.

Short wave reception is accomplished by shorting a portion of the antenna coil, shorting the secondary of the broadcast r. f. coil so that only the short-wave r. f. coil is active, and by switching in a short wave oscillator coil. These operations are performed by a single two-position switch located on the back of the chassis.

ALIGNING THE R-119 CHASSIS

Before attempting to align a set, the service man should become familiar with the general layout of the chassis and with the function and location of the various trimmer condensers. The following discussion briefly explains the action of each alignment step.

R. F. alignment and calibration are accomplished by the three trimmer condensers located on the top of the variable condenser gang. The oscillator is kept in exact step with the other R. F. circuits by the special shape of the stator plates in the oscillator tuning section.

Both windings of the first I. F. transformer are tuned but only the plate coil (primary) of the second I. F. transformer is tuned. The three I. F. tuning trimmers are mounted on the rear of the chassis and may be reached through holes which are covered with flat metal buttons. The buttons may be pried out with a knife or screw-driver.

EQUIPMENT AND PRELIMINARY STEPS

A good modulated oscillator and an output meter are essential for proper alignment. The attenuator on the oscillator must be capable of reducing the signal to a low value because the A. V. C. will function if the signal is too strong and thus make correct alignment impossible. The output meter must **be sensitive enough to give a satisfactory reading with this low signal.**

The output meter should be connected from the plate of the 42 tube to ground through a .25 mfd. condenser or across the speaker voice coil, depending upon the type used.

All alignment adjustments should be made with the volume control full on but with no broadcast signal being received.

ALIGNING THE I. F. CIRCUITS

An insulated, 1/4 inch socket wrench is needed for I. F. alignment since two of the trimmers are connected to B plus. A Stewart-Warner phasing tool (No. T-79890, net price 75c) should be used although a Spintite wrench insulated with tape so that it will not short to the chassis, can be employed.

The step-by-step routine given below should be carefully followed after reading the preceding instructions:

1. The modulated oscillator must be tuned exactly to 177.5 K. C. This frequency can be acurately determined by checking the oscillator harmonics against broadcast stations. First check the accuracy of the broadcast dial, and then tune in either the fourth or eighth harmonic of the 177.5 K. C. signal. If they come in at exactly 710 or 1420 K. C. the oscillator frequency is correct. To be sure that you have the harmonic of a 177.5 K. C. signal instead of some other frequency, tune in the other 177.5 K. C. harmonics on the broadcast dial. These should come in 177.5 K. C. on either side of the original setting. Do not use the oscillator calibration curve to determine this intermediate frequency.

2. Connect the oscillator output across the 6-A-7 grid cap and ground.

3. Set the oscillator output to give about half scale deflection on the output meter.

4. Adjust all three I. F. trimmer condensers, in each case tuning carefully to get maximum deflection of the output meter. Reduce oscillator output if output meter goes off scale.

It is very important that no inward or sideward pressure be applied to the alignment tool or the condenser may spring back to a different setting as soon as the tool is removed.

5. Repeat all three adjustments since the adjustment of each I. F. trimmer may affect the others to a certain extent. Replace buttons covering trimmer holes to prevent tampering.

ADJUSTING R. F. AND OSCILLATOR CIRCUITS

1. Connect a .0001 mfd. condenser from the blue aerial wire to the output of the oscillator, and ground both set and oscillator. Adjust the oscillator frequency to 1400 K. C. and carefully tune the receiver to give maximum output. Set the oscillator output to produce about half scale deflection of the output meter.

2. Carefully tune the radio frequency, "A" trimmer, which is the back one on the condenser gang, until the output meter reading reaches a maximum.

3. Retune the set and adjust the first detector "B" trimmer, which is the middle one, for maximum output. The oscillator, or "O" trimmer should not be touched unless the set is badly out of calibration at the high frequency end of the dial.

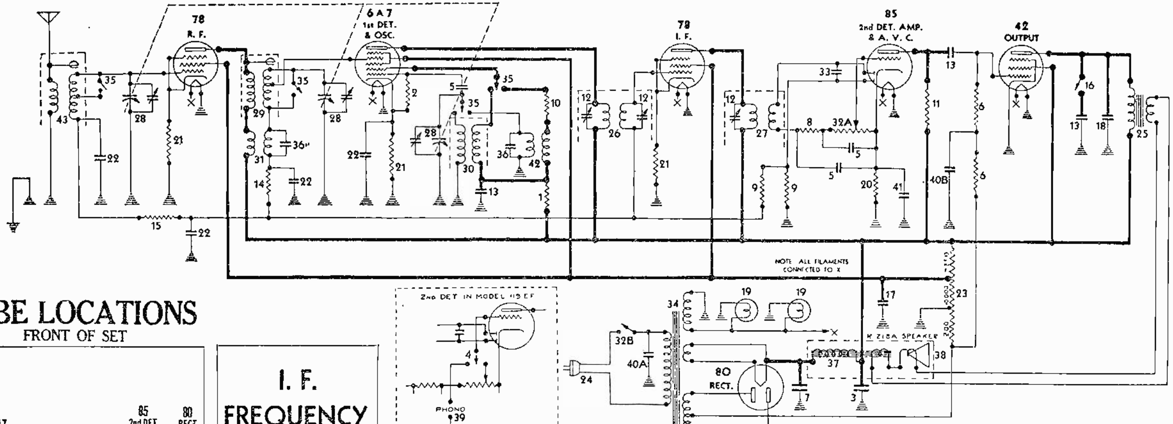
CALIBRATION

Calibration can be checked by arranging a wire pointer above the condenser shaft center and then tuning in several stations of known frequency. With the condenser plates fully meshed, the lowest dial division (530 K. C.) should line up with the pointer.

If the set is out of calibration, it can be re-calibrated as follows: Disconnect the test oscillator, connect an aerial to the blue wire, and set the tuning dial at the frequency reading of some station between 1200 and 1500 kilocycles, whose exact frequency is known and which can be picked up without any difficulty. Adjust the oscillator trimmer "O" until this station is brought in with maximum volume. Then use the modulated oscillator and output meter to re-adjust the "A" and "B" trimmers, since these are always affected by any change the oscillator tuned circuit, taking care to retune the set between adjustments.

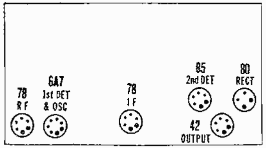
No adjustment is provided for aligning the set for the short wave band.

STEWART-WARNER MODEL R-119



TUBE LOCATIONS

FRONT OF SET



I. F. FREQUENCY 177.5 K. C.

VOLTAGE TABLE

Line Voltage 115 A.C. — Volume Control Full On

Type of Tube	Position in Circuit	Filament Voltage	Plate Voltage	Screen Grid Voltage	Control Grid Voltage	Cathode (Bias) Voltage
78	R. F.	6.1	260	104		3.2
6A7*	1 Det. & Osc.	6.1	260	104		3.0
78	I. F.	6.1	260	104		3.0
85	2nd Det	6.1	50	—		17.5
42	Output	6.1	247	260	-1.8†	0
80	Rectifier	5.1	320 Volts D. C. From Filament to Ground			

* Oscillator plate voltage 175; Oscillator grid voltage -5.

† Actual bias on 42 tube is 17.3 volts measured across 200 ohm section of voltage divider.

Speaker Field Voltage, 60.

All D. C. voltages are to be measured with respect to ground, using a high resistance voltmeter of 1000 ohms per volt. Readings will vary, depending upon voltage range of meter, being higher for higher range instruments. This variation is most marked for the second detector plate voltage. Readings taken with set analyzers will be different because such instruments generally measure voltages with respect to cathode.

R-119 PARTS LIST

Diag. No.	Part No.	Description	List Price
1	67100	20,000 ohm, 1 watt Carbon Resistor	
2	67301	75,000 ohm. 1/4 watt Carbon Resistor	
3	67328	8 Mfd. 440 volt. Wet Electrolytic Condenser	
4	73689	Phonograph Switch (Note: Used in Models R-119 EF only)	
5	81157	.00025 Mfd. Mica Fixed Condenser	
6	81161	250,000 ohm, 1/2 watt Carbon Resistor	
7	81347	8 Mfd. 485 volt Wet Electrolytic Condenser	
8	81681	29,000 ohm, 1/4 watt Carbon Resistor	
9	81682	1.1 Megohm, 1/4 watt Carbon Resistor	
10	81727	1000 ohm, 1/4 watt Carbon Resistor	
11	81810	100,000 ohm, 1 watt Carbon Resistor	
12	81940	I. F. Trimmer Condenser	
13	83007	.02 Mfd. 600 volt Fixed Condenser	
14	83078	2000 ohm, 1/4 watt Carbon Resistor	
15	83081	76,000 ohm, 1/2 watt Carbon Resistor	
16	83179	Tone Control Switch	
17	83214	.25 Mfd. 250 volt Fixed Condenser	
18	83219	.01 Mfd. 600 volt Fixed Condenser	
19	83278	6.3 volt Pilot Light Bulb	
20	83285	10,000 ohm, 1/2 watt Carbon Resistor	
21	83293	300 ohm, 1/4 watt Carbon Resistor	
22	83353	.05 Mfd. 100 volt Fixed Condenser	
23	83398	9250-10,000-200 ohm Voltage Divider	
24	83406	Power Cord and Plug	
25	83408	Output Transformer	
26	83410	1st Intermediate Transformer Coil	
27	83412	2nd Intermediate Transformer Coil	
28	83413	3 gang Variable Condenser	
29	83418	Broadcast 1st Detector Coil	
30	83419	Broadcast Oscillator Coil	
31	83420	Short-Wave 1st Detector Coil	
32-A / 32-B	83424	500,000 ohm Volume Control / Line Switch — In one unit	
33	83436	.002 Mfd. 1000 volt, Fixed Condenser	
34	83442	Power Transformer, 115 volt, 60 cycle (Note: See No. 83469 for 25-60 cycle 115-250 volt Transformer used in Model R-119EF)	
35	83444	Range Switch (4 sections)	
36	83448	25 Mmfd. Fixed Condenser	
37	83454	Speaker Field and Humbucking Coil As'mbly	
38	83455	Diaphragm, Voice Coil, Spider and Shell Assembly	
39	83463	Terminal Strip (Used in Model R-119EF only)	
	83469	Power Transformer, 115-250 volts, 25-60 cycles (Note: Used on Model R-119-EF only)	
40-A / 40-B	83476	.02 Mfd. 1000 volt Fixed Condenser / .5 Mfd. 100 volt Fixed Condenser — In one unit	
41	83537	10 Mfd. 25 volt Electrolytic Condenser	
42	83599	Short Wave Oscillator Coil	
43	83602	Antenna Coil	

MISCELLANEOUS PARTS NOT SHOWN ON DIAGRAM

Part No.	Description
67236	Rubber Drive Roller
81834	6 prong Tube Socket
81837	4 prong Tube Socket
81941	Tube Shield
81949	7 prong Tube Socket
83049	Button for covering trimmer holes
83405	Pilot Light Bracket and Socket
83458	Pilot Light Socket and Volume Control Dial
83460	Dial and Gear
83461	Escutcheon for Models R-1191-2-3
83497	Knob for Model R-1191-2
83505	Knob for Model R-1193
R-218A	Dynamic Speaker (8 inch)

RADIO-TRICIAN

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Service Sheet

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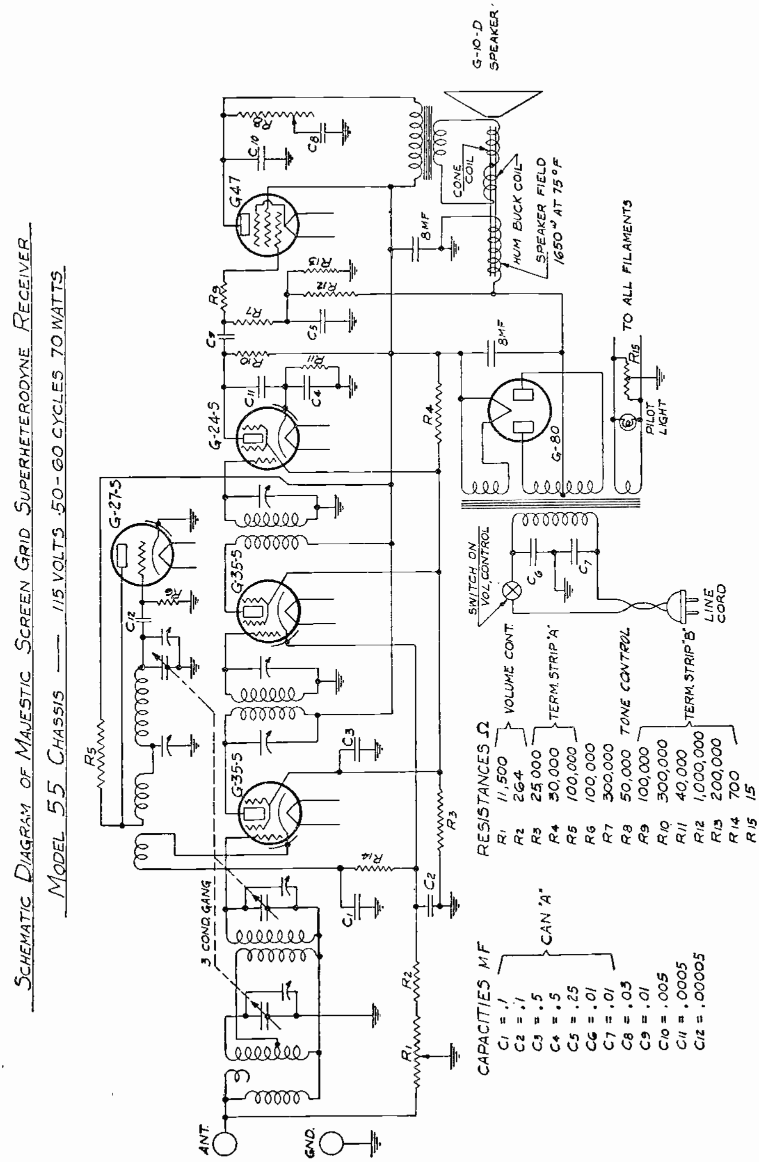
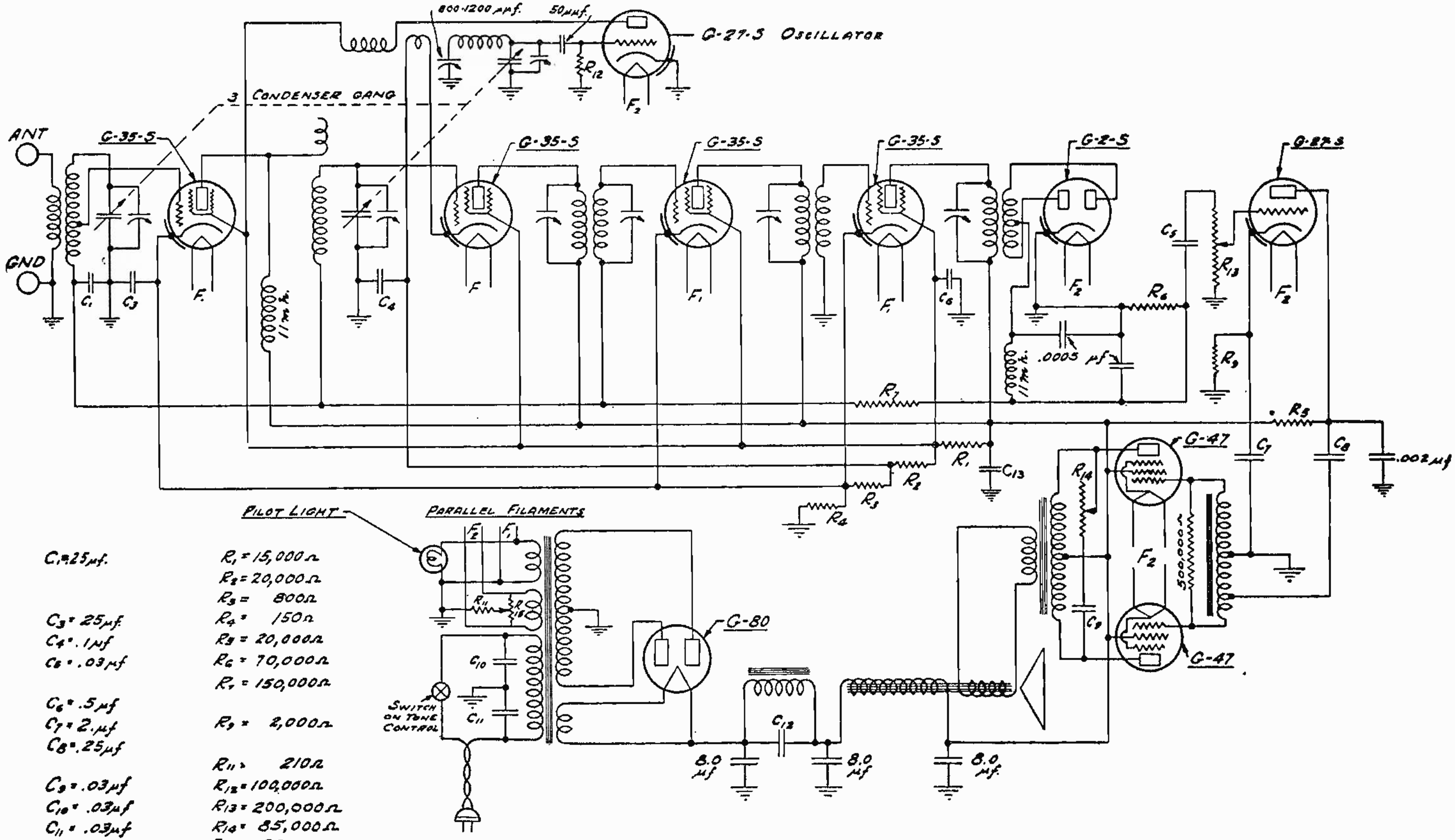
MAJESTIC SCREEN GRID SUPERHETERODYNE
MODELS 55 and 210



SCHEMATIC DIAGRAM OF MAJESTIC SCREEN GRID SUPERHETERODYNE
AUTOMATIC VOLUME CONTROL RECEIVER. MODEL 210 CHASSIS.



C_1 = .25 μf.

C_3 = .25 μf
C_4 = .1 μf
C_5 = .03 μf

C_6 = .5 μf
C_7 = 2. μf
C_8 = .25 μf

C_9 = .03 μf
C_{10} = .03 μf
C_{11} = .03 μf
C_{13} = .1 μf
C_{12} = .2 μf ON 60 CYCLE MODEL

R_1 = 15,000 Ω
R_2 = 20,000 Ω
R_3 = 800 Ω
R_4 = 150 Ω
R_5 = 20,000 Ω
R_6 = 70,000 Ω
R_7 = 150,000 Ω

R_9 = 2,000 Ω

R_{11} = 210 Ω
R_{12} = 100,000 Ω
R_{13} = 200,000 Ω
R_{14} = 85,000 Ω
R_{15} = 20 Ω

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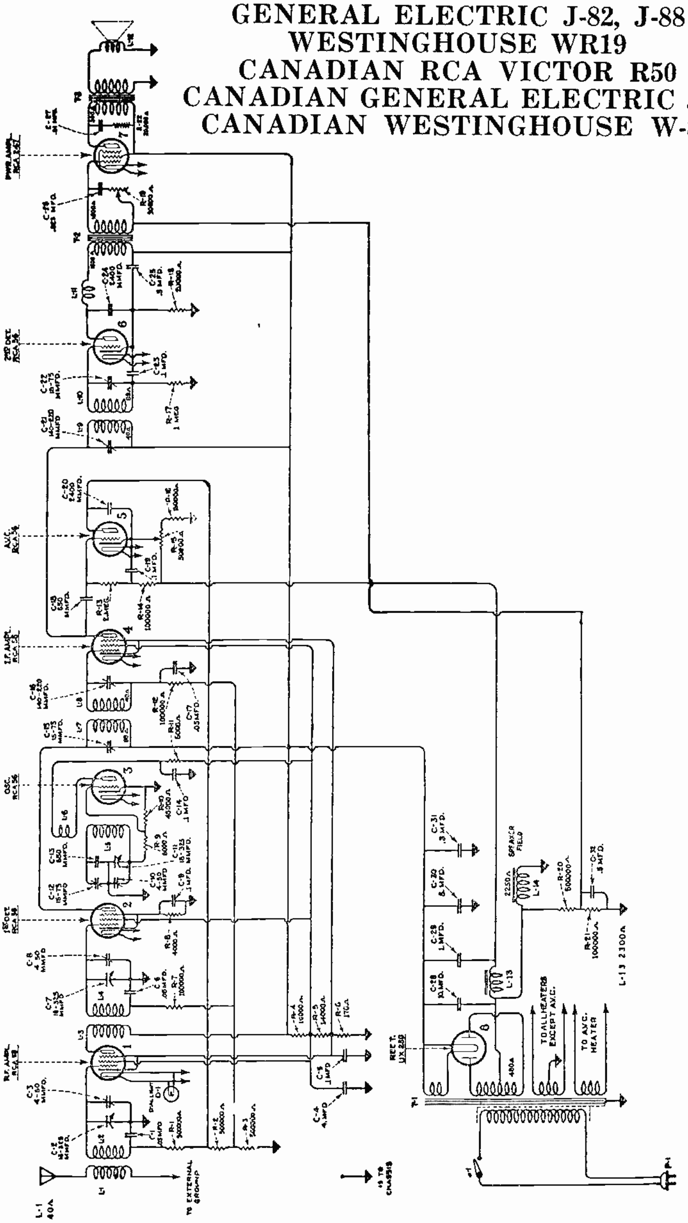
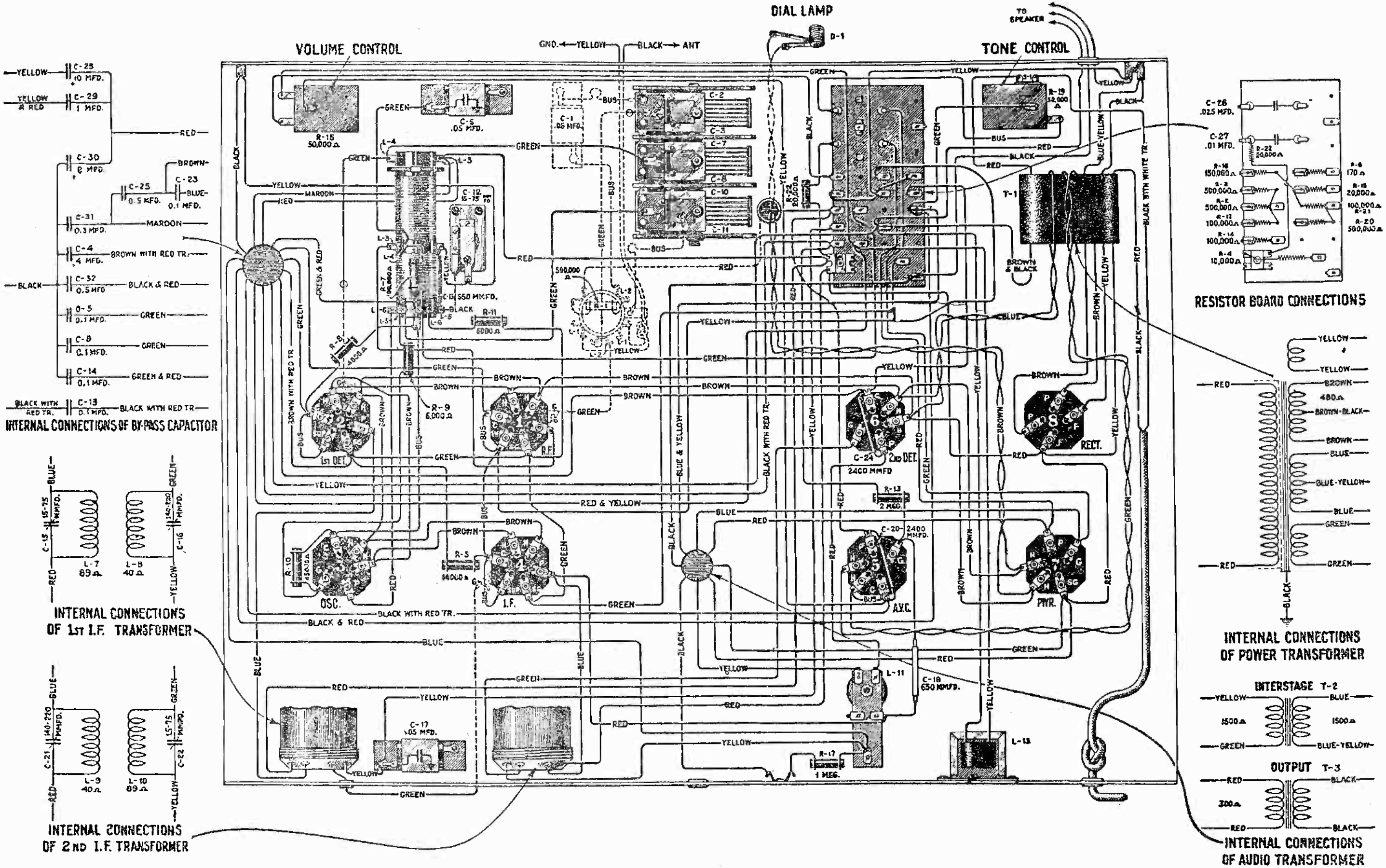
R.C.A. VICTOR MODELS R71—R72
GENERAL ELECTRIC J-82, J-88
WESTINGHOUSE WR19
CANADIAN RCA VICTOR R50
CANADIAN GENERAL ELECTRIC J-82
CANADIAN WESTINGHOUSE W-82




VOLUME CONTROL
DIAL LAMP
TONE CONTROL
TO SPEAKER
GND. YELLOW BLACK ANT
RESISTOR BOARD CONNECTIONS
INTERNAL CONNECTIONS OF BY-PASS CAPACITOR
INTERNAL CONNECTIONS OF 1st I.F. TRANSFORMER
INTERNAL CONNECTIONS OF 2nd I.F. TRANSFORMER
INTERNAL CONNECTIONS OF POWER TRANSFORMER
INTERSTAGE T-2
OUTPUT T-3
INTERNAL CONNECTIONS OF AUDIO TRANSFORMER
OSC.
1st DET.
R.F.
I.F.
2nd DET.
A.V.C.
RECT.
PWR.

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Stromberg-Carlson No. 60 Type Radio Receivers

ELECTRICAL SPECIFICATIONS

Type of Circuit .... Superheterodyne
Tuning Ranges .... 540—1570 k. c. and 5.5 to 15.5 mc.
Type and Number of Tubes .... 1 No. 6D6, 1 No. 6A7, 1 No. 6B7, 1 No. 37, 2 No. 41, 1 No. 80
Voltage Rating .... 105-125 Volts
Frequency Rating .... 50-60 Cycles
Power Consumption Rating .... 80 Watts

CIRCUIT DESCRIPTION

The No. 6D6 tube is used as the R. F. amplifier. The No. 6A7 tube is used for the oscillator-mixer. The No. 6B7 tube serves as the I. F. amplifier, A. V. C., and demodulator. The No. 37 tube is the first audio amplifier and the two No. 41 tubes function as the power output stage. The No. 80 is the rectifier in the power supply circuit.

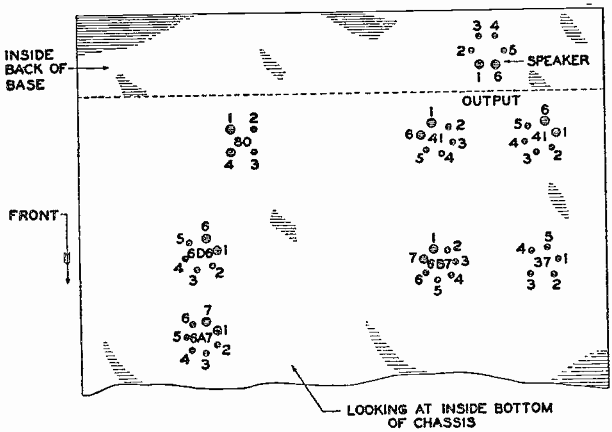

Fig. 2. Terminal Layout for Voltage Measurement Chart.

Tube	*Circuit*	*Cap.*	*Terminals of Sockets* 1	2	3	4	5	6	7	*Heater Voltages Between Terminal Nos.*
6D6	R. F. Amp.	G 0	H 0	P 145	S 85	Sup. 5.5	K 5.5	H 0	—	1-6—*6.5* volts
6A7	Mixer-Osc.	Mix. G 0	H 0	Mix. P 145	S 85	Osc. P. 175	Osc. G —20	K 5.5	H 0	1-7—*6.5* volts
6B7	I. F., Dem.	G 0	H 0	P 145	S 85	D 0	D 0	K 3	H 0	1-7—*6.5* volts
37	1st Audio	—	H 0	P 140	G 0	K 8	H 0	—	—	1-5—*6.5* volts
41's	Output	—	H 0	P 250	S 250	G 0	K 16	H 0	—	1-6—*6.5* volts
80	Rectifier	—	F 270	P *298*	P *298*	F 270	—	—	—	1-4—*4.9* volts
Speaker Socket			245	145	270	270	250	245		

A. C. voltages are indicated by italics

St60

NORMAL VOLTAGE READINGS

These voltage readings are obtained by measuring between the various tube socket contacts and the bases with the tubes and speaker plug in place. The set is therefore in operation when the measurements are made. Fig. 2 shows the terminal layout of the sockets with the proper terminal numbers. The terminals of each socket are numbered, starting with one heater or filament pin and proceeding around the pin circle clockwise to the other heater or filament pin. This is done looking at the bottom of the socket. Tune Receiver to 1500 k. c.

Voltages are given for a line voltage of 120 volts and allowance should be made for differences when the line voltage is higher or lower. A meter with a resistance of 1,000 ohms per volt should be used for measuring the D. C. voltages. The Volume Control should be set all "On" (clockwise) before measuring voltages.

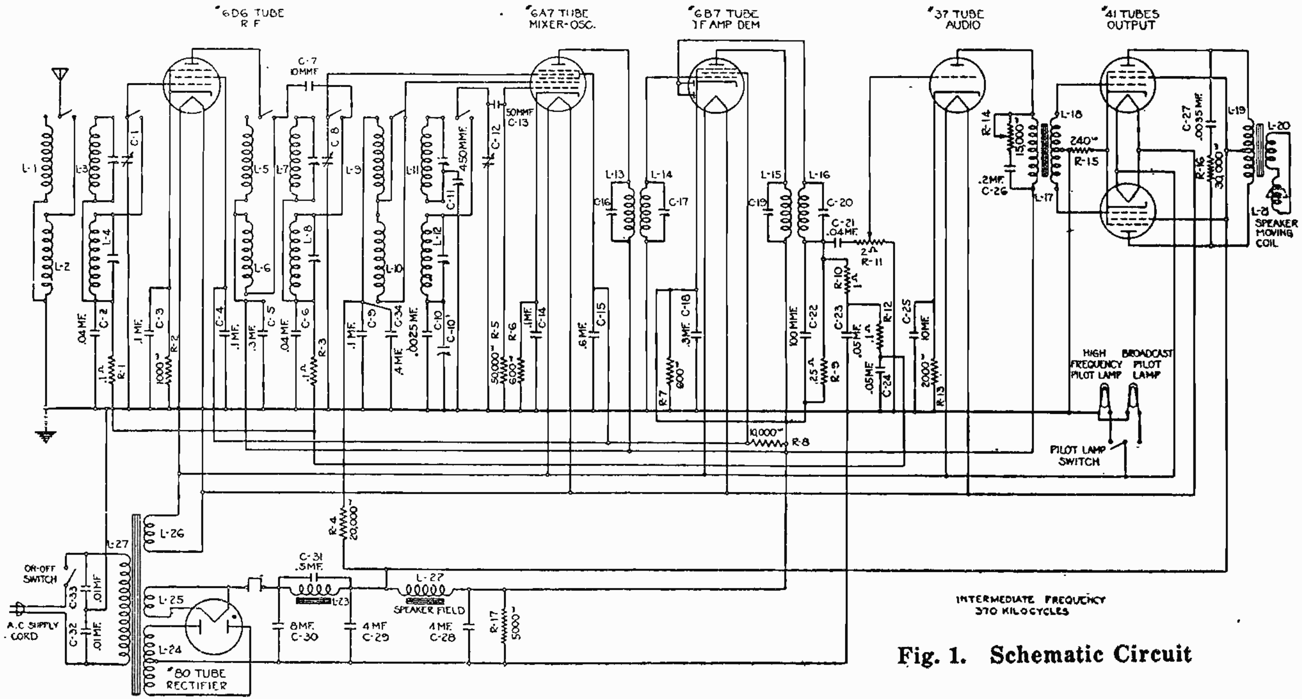

Fig. 1. Schematic Circuit

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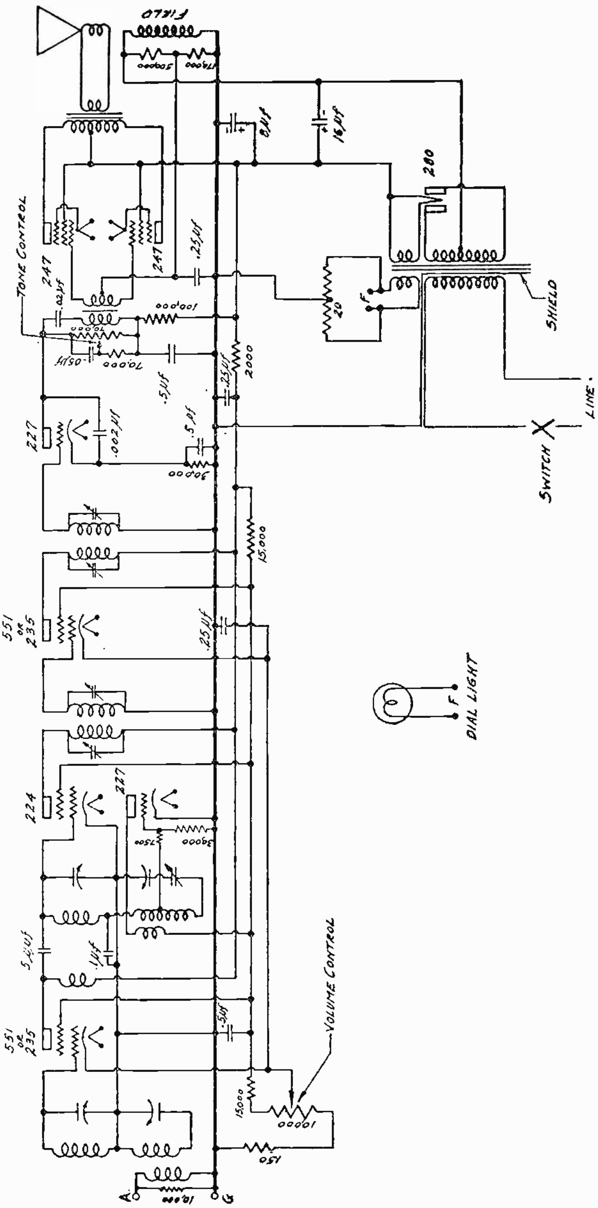
LYRIC SUPERHETERODYNE SERIES "S8"



LYRIC SUPERHETERODYNE RECEIVERS

BALANCING

FOR the sake of clarity balancing operations are described under two headings, "Radio Frequency Circuits" and "Intermediate Frequency Circuits."

Radio Frequency Circuits

Viewing the variable condenser from the front of the chassis the four sections tune the various circuits in the following order:

1st section—Antenna circuit.
2nd section—Link.
3rd section—Oscillator.
4th section—First Detector.

The oscillator being tuned 175 kilocycles above the desired signal at all times its frequency range is from 725 kilocycles to 1675 kilocycles. This is a smaller percentage difference in frequency than the difference between 550 kilocycles and 1500 kilocycles and requires a smaller tuning capacity range. To secure this reduced capacity range an adjustable fixed "padding" condenser is connected in series with the oscillator section of the variable condenser. The adjusting screw for this padding condenser is accessible through a hole in the chassis pan between the shield partitions of the oscillator condenser.

Owing to the complex nature of the superheterodyne receiver, balancing is a critical task and the operations are described in minute detail. The procedure outlined below must be followed without any deviation. Any other routine will take longer and will give less satisfactory results.

Before attempting to balance the variable condenser circuits the service man should be sure that the intermediate frequency amplifier is tuned to EXACTLY 175 Kilocycles.

CAUTION: DO NOT at any time alter the setting of the dial pointer on the condenser shaft.

1. Set R.F. test oscillator to some known frequency between 1400 Kc. and 1500 Kc.
2. Set receiver to this frequency on dial.
3. Adjust trimmer condensers for maximum output on output meter.
4. Set R.F. test oscillator to some known frequency between 550 Kc. and 600 Kc.
5. Set oscillator padding condenser for maximum output on meter.
6. Align circuits at approximately 1000 Kc., 750 Kc. and 550 Kc. by bending segments of condens[illegible]tor end plates.
7. Repeat operations 1, 2, 3, 4, 5 for finer adjus[illegible]ent.

IMPORTANT—Do not attempt ganging with an ordinary screw-driver as capacity effects render accurate settings impossible. Use fibre screw-driver having SMALL metal tip.

The procedure outlined above insures perfect alignment of the antenna link and first detector sections and accurate tracking of the oscillator with these circuits.

Intermediate Frequency Circuits

The sensitivity of the receiver is directly dependent upon the tuning of the four intermediate frequency transformer tuning condensers. These are carefully adjusted at the factory to precision oscillators.

Several very excellent oscillators are available from instrument manufacturers as listed above and we recommend that the best obtainable be purchased.

Do not attempt adjustment of intermediate frequency transformers unless you have an accurately calibrated source of a 175 kilocycle signal for tuning.

Read and understand the following instructions thoroughly before doing any work on the receiver.

1. Remove grid clip from cap of first detector tube.
2. Connect output of 175 kilocycle oscillator between cap of first detector and chassis pan.
3. Tune four I.F. tuning condensers for maximum output on meter.
4. After all four condensers have been adjusted carefully a final check should be made by going over all adjustments a second time to bring them into perfect alignment.

On the production line it has been found that tuning the secondary of the I.F. transformer before tuning the primary results in greater accuracy and speed. Viewing the transformer from the bottom with the adjusting screws toward you, the right hand screw adjust the secondary tuning condenser. We suggest that you follow this routine.

VOLTAGE TABLE

Position of Tube	Type of Tube	Filament Voltage	Cathode Voltage	Plate Voltage	Screen Voltage	Grid Volta[illegible]
R.F. Amp.	—51 or —35	2.5 A.C.	2.1	200	70	[illegible]
1st Det.	—24	2.5 A.C.		205	70	0
Oscillator	—27	2.5 A.C.	0	70		0
I.F. Amp.	—51 or —35	2.5 A.C.	2.1	200	70	0
2nd Det.	—24	2.5 A.C.	10	125		0
Output	—47	2.5 A.C.		235	250(note)	—17.0**

Speaker field current —91 M.A. Volume Control Maximum

Note—Screen of pentode is connected to cathode pin on socket.

** Owing to the high resistance of the circuit these voltages can be measured accurately only with an electrostatic voltmeter.

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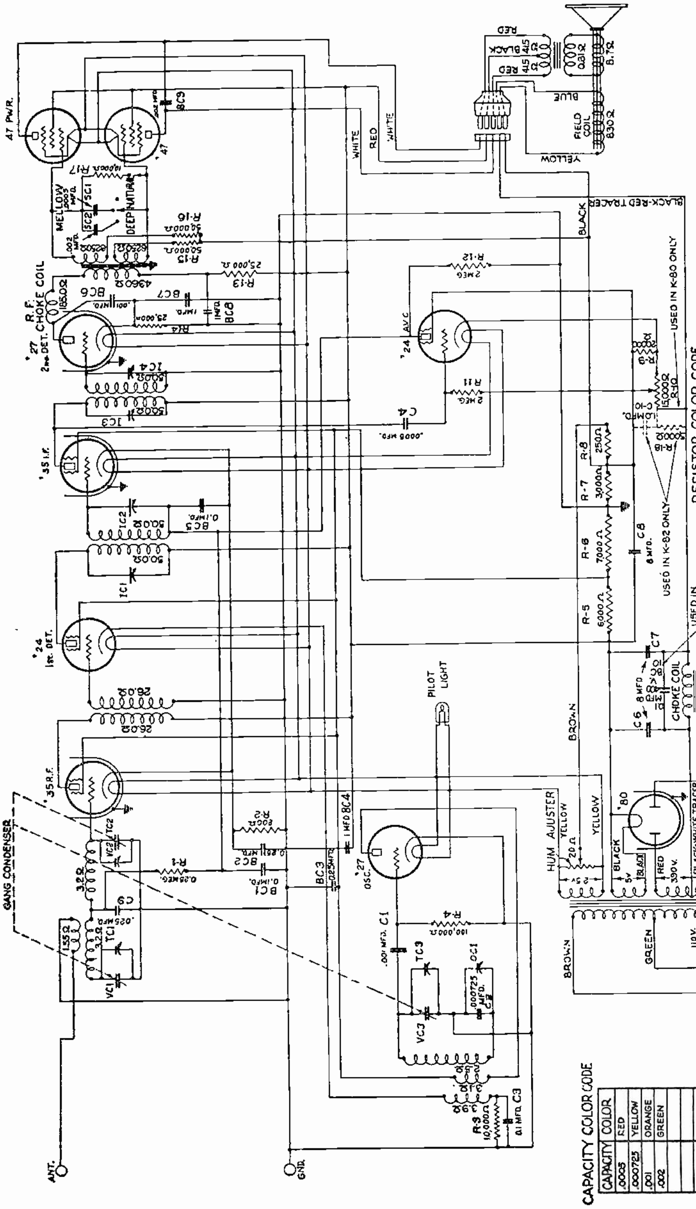
KOLSTER INTERNATIONAL RADIO MODELS K80-K82



RESISTOR COLOR CODE

VALUE	BODY	TIP	DOT
0.25 MEG.	RED	GREEN	YELLOW
2 MEG.	RED	BLACK	GREEN

VALUE	BODY	TIP	DOT
200	RED	BLACK	BROWN
5,000	GREEN	BLACK	RED
10,000	BROWN	BLACK	ORANGE
20,000	RED	BLACK	ORANGE
25,000	RED	GREEN	ORANGE
50,000	GREEN	BLACK	ORANGE
100,000	BROWN	BLACK	YELLOW

CAPACITY COLOR CODE

CAPACITY	COLOR
.0005	RED
.000725	YELLOW
.001	ORANGE
.002	GREEN

Volume Control Maximum
Tone Control Natural Position

KOLSTER K-80-82 VOLTAGE READING CHART

*Indicates incorrect reading due to high resistance in circuit.
All voltages will vary with change in tubes.

	TUBE-80 Rectifier		TUBE-27 Oscillator				TUBE-35 1st R.F.					TUBE-24 1st Det.					TUBE-35 1st I.F.					TUBE-24 A. V. Cont.					TUBE-27 2nd Det.				TUBE-47 Pentode A.F.				TUBE-47 Pentode A.F.				Causes of Incorrect Readings
	M A	M A	Grid V.	K. V.	Pl. V.	Pl. M A	C. G.	SG V.	K. V.	Pl. V.	Pl. M A	CG V.	SG V.	K. V.	Pl. V.	Pl. M A	C. G V.	SG V.	K. V.	Pl. V.	Pl. M A	C. G V.	S.G V.	K. V.	Pl. V.	Pl. M A	Grid V.	K. V.	Pl. V.	Pl. M A	Spa. Chg.	Grid V.	Pl. V.	Pl. M A	Spa. Chg.	Grid V.	Pl. V.	Pl. M A	
NORMAL READINGS	48	48	*0	52	80	6.0	*0.4	80	48	185	2.5	5.5	80	58	185	.6	*0.2	90	44	195	1.0	0.5	44	-60	15	0	15	75	150	0.6	245	*12	225	30	245	*12	225	30	-
No plate v.; high grid v. on 1st R.F. & 1st I.F.							*0 6	0	60	0	0						*0.6	0	60	0	0																		Open 200 ohm res., 1st I.F. & 1st R.F. K to gnd. (R-2)
High M.A. on 1st R.F. & 1st I.F.							*0.2	75	60	165	7.0						*0.2	70	66	160	5.0																		Open 250M ohm res., 1st R.F. & 1st I.F. grid bias (R-1)
No plate v. or M.A. on 2nd det.																											16	75	0	0									Open 25M ohm 2nd det. Cath. res. (R-14)
No plate v. or grid v. on 2nd det.																											0	60	0	0									Open 25M ohm 2nd det. plate v. res. (R-13)
No grid v. on Pent.																															165	0	135	40	165	0	135	40	Open 50M ohm pwr. Pent. bias res. (R-15-16)
High plate and high S.G. v.	25	25	*5.0	0	110	6.0	*2.0	145	-40	300	.5	12	115	0	265	1.	*8.0	145	0	300	1.5	0	20	-80	15	0	20	0	205	0.8	85	*50	80	0	85	*50	80	0	Open 250 ohm sect. of vit. res. (R-8)
No plate and high Cath. v.	46	46	0	250	0	0	*0 5	0	250	0	0	0	0	250	0	0	*0.5	0	250	0	0	0.5	38	-54	50	0	0	250	0	0	260	*12	235	35	260	*12	235	35	Open 3M ohm sect. of vit. res. (R-7)
High plate and no S.G. v.	45	45	0	-15	0	0	*0.5	0	-15	300	0	0	0	15	300	0	*0.5	0	-15	300	0	0.2	35	-54	25	0	20	5	235	1.0	242	*13	260	30	245	*13	260	30	Open 6M ohm sect. of vit. res. (R-5)
High S.G. and low Cath. v.	50	50	*4.0	66	100	6.5	*1.0	150	24	200	2.0	10	100	75	155	1.0	*0.5	165	24	210	2.5	0.1	40	-58	10	0	12	78	130	0.5	240	*10	220	30	240	*10	220	30	Open 7M ohm sect. of vit. res. (R-6)
No plate v. and low Cath. v. on A.V.C.																						0	30	-48	0	0													Open 2 meg. res. grid of A.V.C. to vol. cont. (R-11)
No plate v. or C.G. v. on A.V.C.																						0 5	42	-58	0	0													Open 2 meg. res. plate of A.V.C. to gnd. (R-12)
No plate v. and high S.G. v. on A.V.C.																						0 4	72	-88	0	0													Open 20M ohm A.V C. S.G. to K res. (R-9)
No plate v. or S.G. v. on A.V.C.																						0	0	-12	0	0													Open 15M ohm vol. cont. (R-10)
No M.A. on osc.			0	50	80	0																																	Open 100M ohm osc. grid to gnd. res. (R-4)
High grid v. on osc. & 1st det.			*2.0	50	85	4.0						7.0	0	58	0	0																							Open 10M ohm 1st det. Cath. res. (R-3)
High C.G. v. & high M.A. on 1st R.F.							*1.5	70	50	165	5.0						*5.0	75	58	175	1 0																		Shorted .025 mfd. pre-selec. coup. cond. (C-9)
No plate v. & high grid v. on 2nd det.																											75	135	0	0									Shorted 2nd det. bridg. cond. (BC-6)
No grid v. & high M.A. on 2nd det.																											0	55	50	5 0									Shorted 2nd det. Cath. by-pass cond. (BC-7)
No grid & no plate v. on 2nd det.																											0	60	0	0									Shorted 1.0 mfd. pl. to gnd. by-pass cond. (BC-8)
Slight drop of M.A. on 1st R.F.							*0.4	80	48	185	1.5						*0.4	90	44	195	1.0																		Shorted .25 mfd. 1 R.F. & 1 I.F. K by-pass cond. (BC-2)
No osc. pl. v. or S.G. v. on 1st R.F., 1 det. 1st I.F.			0	68	0	0	*0.5	0	68	165	0	0	0	65	160	0	*0.5	0	68	165	0	0 4	45	-60	20	0													Shorted .25 mfd. S.G. to gnd. by-pass cond. (BC-3)
No plate & high Cath. v.	60	60	0	180	0	0	0	0	180	0	0	0	0	180	0	0	0	0	180	0	0	0 5	54	-65	35	0	0	180	0	0	180	*8	165	20	180	*8	165	20	Shorted 1.0 mfd. by-pass cond. (BC-4)
No C.G. v. & high M.A. on 1st I.F.																	0	68	70	156	6 0																		Shorted 0.1 mfd. by-pass cond. (BC-5)
High plate v. & no M.A. on A.V.C.																						0 4	44	-60	125	0													Shorted 0.1 mfd. pl. of A.V.C. to gnd. by-pass cond. (BC-1)
No C.G. v. & high M A. on 1st det.												0	78	60	175	3.0																							Shorted 0.1 mfd. 1st det. Cath. by-pass cond. (C-3)
No C.G. on 1st R.F.							0	75	54	165	6.5																												Open 2nd pre-selec. coil.
No plate v. or M.A. on 1st R.F.							*0.4	80	50	0	0																												Open pri. of untuned transf.
No C.G. on 1st det.												0	60	72	170	2.0																							Open sec. of untuned transf.
No plate v. or M.A. on 1st det.												5.5	80	58	0	0																							Open pri. of 1st I.F. transf.
No C.G. on 1st I.F.																	0	80	65	180	7 5																		Open sec. of 1st I.F. transf.
No plate v. or M.A. on 1st I.F.																	*0 2	80	50	0	0																		Open pri. of 2nd I.F. transf.
No grid v. on 2nd det.																											0	50	125	1.0									Open sec. of 2nd I.F. transf.
No plate v. or M.A. on 2nd det.																											0	45	0	0									Open R.F. choke or pri. of audio transf.
No grid v. & high M.A. on one Pent.																															150	0	170	56	205	*14	200	8	Open sect. of sec. of audio transf.
No grid v. & high M.A. on one Pent.																															205	*14	200	8	150	0	170	56	Open sect. of sec. of audio transf.
No plate v. or M.A. on one Pent.																															250	*12	0	0	250	*12	225	35	Open sect. of output transf.
No plate v. or M.A. on one Pent.																															250	*12	225	35	250	*12	0	0	Open sect. of output transf.
No plate v. or M.A. on both Pent.																															250	*10	0	0	250	*10	0	0	Open center tap of output transf.

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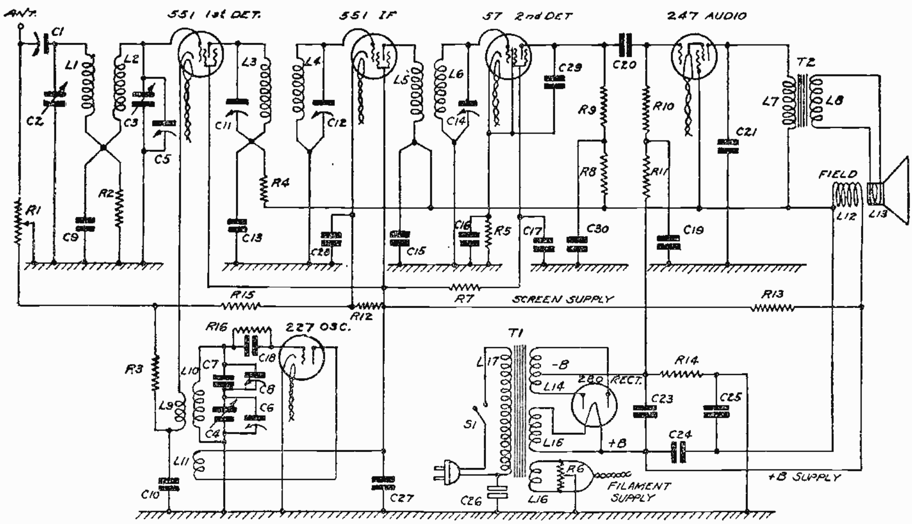
NATIONAL RADIO INSTITUTE, WASHINGTON, D.C.

BOSCH MODELS 200-1-5-6-36-3



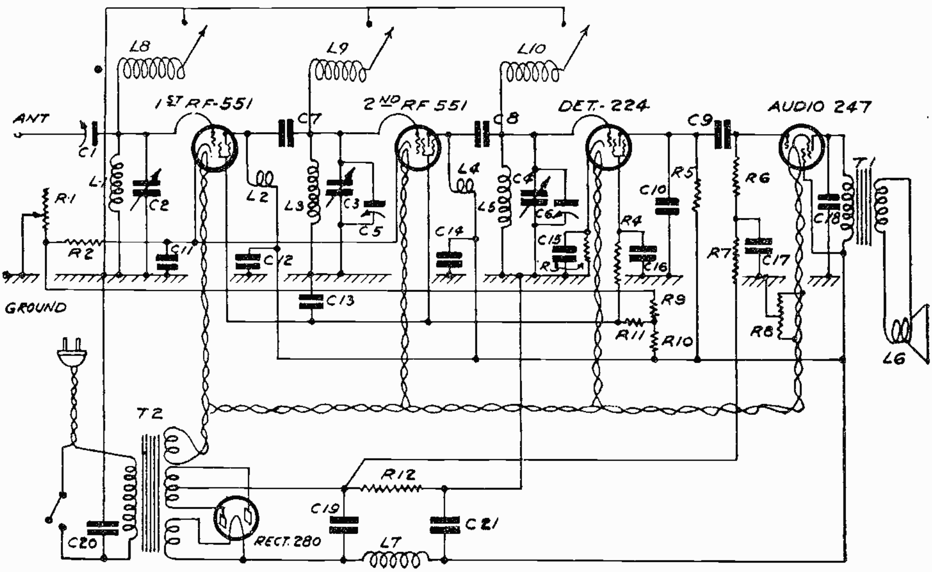
Schematic Diagram of Model 236 Receiver

ELECTRICAL VALUES

R1 - 10000 ohms	C1 - Trimmer	C17 - .25 mfd.
R2 - 1000 ohms	C2 - Tuning	C18 - .0001 mfd.
R3 - 5000 ohms	C3 - Tuning	C19 - .05 mfd.
R4 - 1000 ohms	C4 - Tuning	C20 - .01 mfd.
R5 - 25000 ohms	C5 - Alignment	C21 - .006 mfd.
R6 - Mid Tap	C6 - Alignment	C23 - 8. mfd.
R7 - .5 megohm	C7 - Alignment	C24 - .05 mfd.
R8 - .1 megohm	C8 - Alignment	C25 - 4. mfd.
R9 - .5 megohm	C9 - .05 mfd.	C26 - .01 mfd.
R10- .5 megohm	C10- .05 mfd.	C27 - 8. mfd
R11- .1 megohm	C11- Alignment	C28 - .02 mfd.
R12- 20000 ohms	C12- Alignment	C29 - .0001 mfd.
R13- 30000 ohms	C13- .05 mfd.	C30 - .01 mfd.
R14- 350 ohms	C14- Alignment	
R15- 300 ohms	C15- .05 mfd.	T1 - Power Trans.
R16- .1 megohm	C16- .5 mfd	T2 - Audio Trans.

STAGE	TUBE	PLATE	SCREEN	CATHODE	GRID	FIL.	PLATE MA
1st Det.	551	250	80	35	8	2.2	2
Osc.	227	75	--	* .1	* .1	2.2	8
I.F.	551	250	80	3	3	2.2	4
2nd Det.	224	60	*5	2	2	2.2	*.1
Audio	247	250	250	-	*3	2.2	32
Rect.	280					4.8	29

* These values will vary considerably with the type of test kit employed, due to the high resistance in the circuit.



Schematic Diagram of Model 200 Receiver

Models 205 and 206 use same hookup, without coils L8, L9 and L10.

ELECTRICAL VALUES

R1 - 10,000 ohms	R11 - 10,000 ohms	C9 - .006 mfd.	C19 - 8. mfd.
R2 - 200 ohms	R12 - 400 ohms	C10 - .0001 mfd.	C20 - .01 mfd.
R3 - 50,000 ohms	C1 - Trimmer	C11 - .05 mfd.	C21 - 4 mfd.
R4 - 2 megohms	C2 - Tuning	C12 - .05 mfd.	L1 - Ant. Coil
R5 - 1 megohm	C3 - Tuning	C13 - .25 mfd.	L2 - Primary
R6 - 500,000 ohms	C4 - Tuning	C14 - .01 mfd.	L3 - Secondary
R7 - 100,000 ohms	C5 - Alignment	C15 - 1. mfd.	L4 - Primary
R8 - Center Tap	C6 - Alignment	C16 - .25 mfd.	L5 - Secondary
R9 - 20,000 ohms	C7 - Coupling	C17 - .05 mfd.	L6 - Voice Coil
R10 - 15,000 ohms	C8 - Coupling	C18 - .01 mfd.	L7 - Field Coil

Note: Electrolytic filter condensers C19 and C21 are a single assembly. Condensers C11 to C18 inclusive are also a single assembly contained in the square can underneath the base plate.

STAGE	TUBE	FIL.	PLATE	SCREEN	CATHODE	GRID	PLATE MA
1st RF	551	2.3	250	90	2.5	3.0	4.5
2nd RF	551	2.3	250	90	2.5	3.0	4.5
Det.	224	2.3	*150	*20	3.0	1.5	.5
Audio	247	2.3	250	250	-	*16	32
Rect.	280	4.8		Plate current of each plate			20

The readings were made with the volume control in the full "on" position.

*These voltages are the correct values altho the average test kit will probably give much lower readings (as low as 1/10 of these values) due to the high resistance included in the detector plate and screen circuits, and the audio grid circuit.

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R.C.A.-VICTOR 121, 122, GENERAL ELECTRIC K64, WESTINGHOUSE WR37, CANADIAN GENERAL ELECTRIC K64, CANADIAN WESTINGHOUSE W64.

LINE UP CAPACITOR ADJUSTMENTS

In order to properly align this receiver it is essential that an oscillator be used. This oscillation should cover the frequencies of 370 K. C. to 15,000 K. C. continuously. In addition to the oscillator, a non-metallic screwdriver and an output meter are required. The output meter should be preferably a thermocouple galvanometer connected across or in place of the cone coil of the loudspeaker.

I. F. Tuning Adjustments—Two transformers, comprising three tuned circuits (the secondary of the second transformer is untuned), are used in the intermediate amplifier. These are tuned to 370 K. C. and the adjustment screws are accessible, as shown in Figure 1. Proceed as follows:

(a) Short circuit the antenna and ground leads and tune the receiver so that no signal is heard. Set the volume control at maximum and connect a ground to the chassis.

(b) Connect the test oscillator output between the first detector control grid and chassis ground. Connect the output meter across the voice coil of the loudspeaker and adjust the oscillator output so that, with the receiver volume control at maximum, a slight deflection is obtained in the output meter.

(c) Adjust the primary of the second, and the secondary and primary of the first I. F. transformers until a maximum deflection is obtained. Keep the oscillator output at a low value, so that only a slight deflection is obtained on the output meter at all times. Go over these adjustments a second time as there is a slight interlocking of adjustments. This completes the I. F. adjustments.

R. F. and Oscillator Adjustments—The R. F. line-up capacitators are located at the bottom of the coil assemblies instead of their usual position on the gang capacitor. They are all accessible from the bottom of the chassis, except the 600 K. C. series capacitor, which is accessible from the rear of the chassis. Proceed as follows:

(a) Connect the output of the oscillator to the antenna and ground leads of the receiver. Check the position of the indicator pointer when the tuning capacitor plates are fully meshed. It should be coincident with the radical line adjacent to the dial reading of 54. Then set the test oscillator at 1,400 K. C., the dial indicator at 140 and the oscillator output so that a slight deflection will be obtained in the output meter when the volume control is at its maximum position.

(b) With the range switch at the "in" position, adjust the three trimmers under the three R. F. coils, designated as L. W. in Figure D, until a maximum deflection is obtained in the output meter. Then shift the test oscillator frequency to 600 K. C. The trimmer capacitor, accessible from the rear of the chassis, should now be adjusted for maximum output while rocking the main tuning capacitor back and forth through the signal. Then repeat the 1,400 K. C. adjustment.

(c) Now place the range switch at the "out" position, shift the test oscillator to 15.000 K. C. and set the dial at 150. Adjust the three trimmer capacitors designated as SW in Figure 1 for maximum output, beginning with the oscillator trimmer. It will be noted that the trimmer on the oscillator will have two positions at which the signal will give maximum output. The position which uses the minimum trimmer capacity, obtained by turning the screw counter-clockwise, is the proper adjustment. The other point is known as the "image." This completes the line-up adjustment.

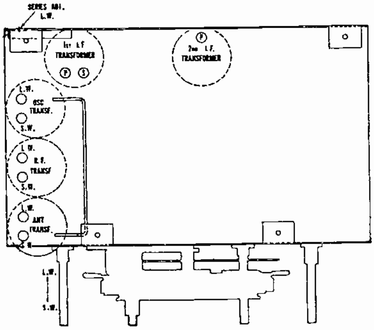
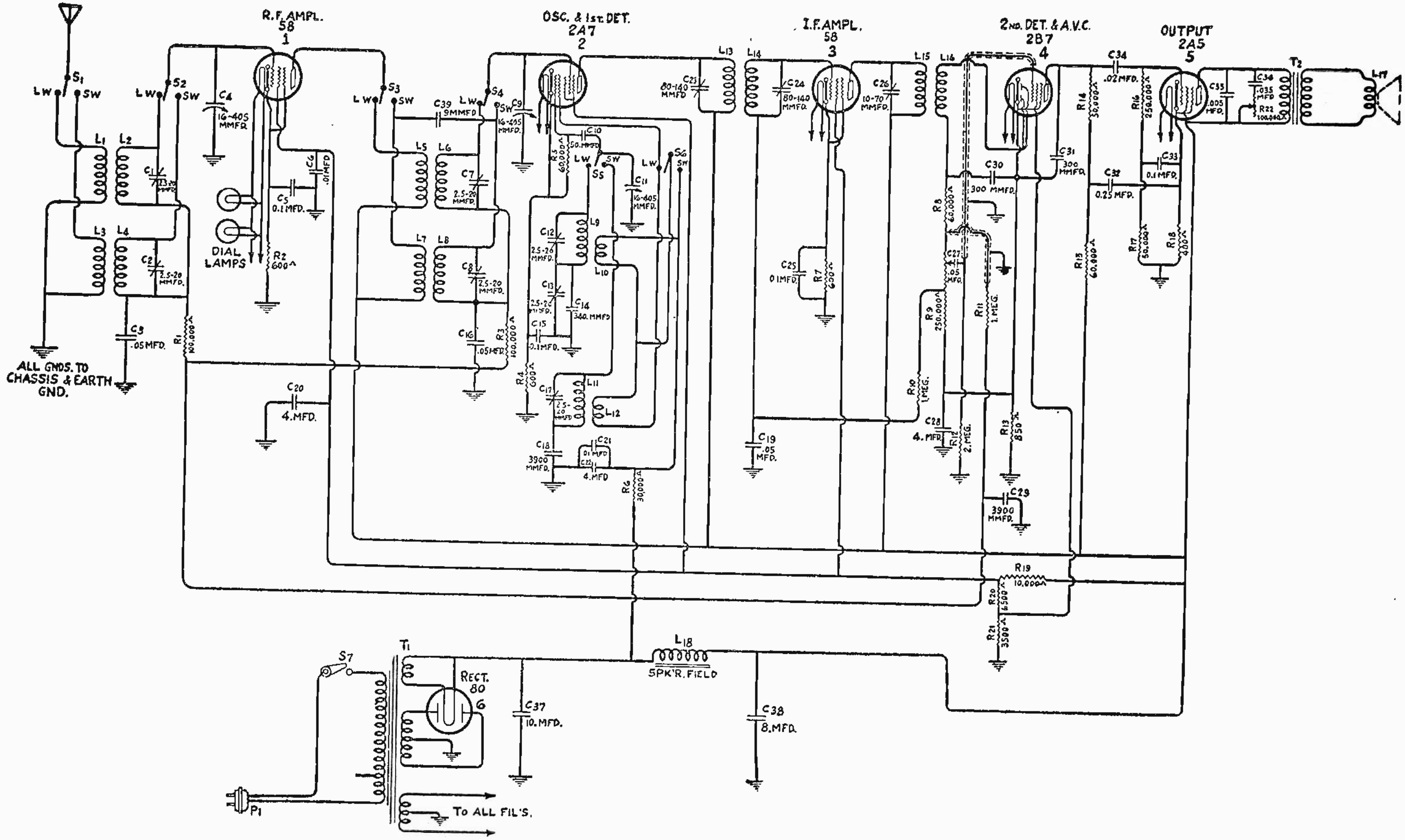


FIGURE 1


R.F. AMPL. 58 1
OSC. & 1st DET. 2A7 2
I.F. AMPL. 58 3
2nd DET. & A.V.C. 2B7 4
OUTPUT 2A5 5
DIAL LAMPS
ALL GNDS. TO CHASSIS & EARTH GND.
RECT. 80 6
SPK'R. FIELD
TO ALL FIL'S.

METERS FOR MEASURING CURRENT

THE CATHODE RAY OSCILLOGRAPH

28FR-2

PIONEER HOME STUDY RADIO SCHOOL

NRI

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

GETTING ALONG WITH PEOPLE

"Diplomacy" is another of those words that can be defined in various ways. Often we think of diplomacy as being a sort of undercover scheming such as statesmen and politicians use when they want to get something without seeming to ask for it.

But in the better sense of the word, diplomacy is not much more than a high degree of courtesy and a true diplomat is one who, in all his associations with his fellowman, shows a deep appreciation of the other fellow's feelings.

A diplomat knows when to agree with you—and how to disagree. He will not come to blows with you on some trivial matter but he will win your good will by yielding to you. But when it comes to something important, he will bring you to his way of thinking—painlessly. He will be able to get you to do what he wants you to do—or to believe what he wants you to believe—without your realizing that your will is being influenced by his.

Now turn matters around—and you be the diplomat. No matter what you are doing—your job calls for diplomacy. If you are an employer, an employee, or if you are in business for yourself and working alone—learn diplomacy.

In conversation, ordinary or business, try to gauge the other fellow. Be considerate of his feelings—his pet beliefs. Don't contradict people flatly—they might have more basis for their stand than you have for yours. If you are sure you are right and the other fellow wrong, be reasonable about it. Explain your position in a friendly way.

There are some few people who can be frank, say exactly what is in their minds, and get away with it. For the most part, however, people just tolerate this sort of person and call him a "character"—possibly "not all there."

People like the man who thinks before he talks—who doesn't make rash or crude statements. And if you can get people to like you, you can count on them to help you—to give you the sort of cooperation that will mean success for you.

So learn diplomacy—and practice it in all your contacts with your fellowmen.

J. E. SMITH.

NATIONAL RADIO INSTITUTE

WASHINGTON, D. C.

1936 Edition

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Meters for Measuring Current

ELECTRICAL QUANTITIES

The knowledge of *how great* or *how small* a thing is, is of just as much importance in radio as in any other phase of life. If you go to the carpenter and tell him to make a table for you, he will ask you how long you want it, how high it should be, how much weight it must be able to bear, and so on.

Immediately you think of a foot-rule, or a yardstick, or some other length-measuring instrument with which you are familiar. You tell the carpenter that the table must be 6 feet long. You are unconsciously comparing the length which you desire the table to have with the length of a piece of wood you have at home, which you call a foot-rule. What you really mean when you tell the carpenter that the table is to be 6 feet long is that it should be six times as long as that particular piece of wood.

It is clear from this that all measurements are really *comparisons.* The thing which you wish to measure is compared with some other thing with which you are familiar. Everything has a certain property or characteristic which we call quantity. Length, weight, velocity, resistance, capacity, time, current, voltage, density—all these are quantities. All these are measured by comparing them with a certain standard which we call a *unit.*

The *foot* is a unit of length; the *second* is a unit of time; the *pound* is a unit of weight; the *henry* is a unit of inductance; the *ohm* is a unit of resistance, and so on almost indefinitely.

Sometimes we have several units for the same property. For example, the unit of length may be the *inch,* the *centimeter,* the *mile,* etc. But this all amounts to the same thing, because we know that there must be certain simple relations between these various units. The inch is equal to 2.54 centimeters; if we measure a length and find it to be 10 inches long, we know immediately that if we had used a centimeter scale instead of an inch scale, our measurement would have given us 25.4 centimeters as the length. In other words, the length may be considered as so many times any standard unit. If measurements are made by different persons using different systems of measurement, then the relation between the two systems must be known.

All practical measurements are *comparisons.* Some comparisons may be *direct* and some may be *indirect.* For example, by laying a foot-rule along a certain pencil line, we compare the length of line with the length of the rule, a direct comparison. But we can't measure the speed of a train in any such way. First we have to measure a certain distance with our foot-rule, or by some other convenient means; then as the train runs over this distance, we measure the time it takes it to do so with a stop-watch. This involves another comparison; we compare the time which the train takes with the time it takes the hand of the clock to travel around the face of the watch, which in turn is compared with the time the earth takes to revolve completely around on its axis. Then, knowing the distance and the time, we simply say that the train has passed over so many miles in so many minutes, and we have a third unit which is called *miles-per-minute*. This unit measures speed. This is an indirect measurement or comparison. We must measure two quantities in order to know the third.

Although the foot-rule divided into inches and fractions of an inch, and the watch, are common everyday measuring equipment, they are not the standards, as we call them. The absolute* standards of time and length are carefully guarded by the National Bureau of Standards, in Washington, the Nation's Capital. Here the standard foot is kept and your rule will be compared with this standard by the Bureau at a nominal fee. Over years of use, manufacturers of rulers are able to produce rulers with considerable exactness, but after all, they are only *secondary* standards, whereas the standard at the Bureau of Standards is the *primary* standard.

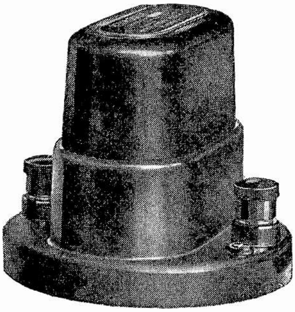
Twice each day, at 12 noon and 10 p. m. Eastern Standard Time, the Government sends out time signals, which are determined by astronomical means. And these time signals afford a means of regulating clocks and watches so they become accurate devices to measure time, in seconds, minutes, and hours; and they become the secondary standards of time.

Now let us turn to electrical and radio units. To be sure, you may buy a one ohm resistor which has been checked to be very nearly equal to the one in the Bureau of Standards; or you can purchase a coil with an inductance of one henry; or a condenser with a capacity of one microfarad. Even though they may have been compared to similar standards held by the Government, are the latter the primary standards? They are not, as the primary standards are obtained in a different manner. For example, an *ohm* is really a unit to measure a property of a conductor and by definition it is the resistance property that a conductor has when it allows only one ampere to flow when an electric pressure of one volt is applied. But how much is a volt or an ampere? Scientists have many procedures of determining the absolute values of voltage and current, but these are not the practical standards. At the Bureau of Standards you will find a small wet cell capable of generating exactly 1.01865 volts, determined by the absolute methods known to scientists; it is the primary standard. When kept under rigid atmospheric conditions, especially temperature, its voltage hardly varies. Yet you can buy a secondary standard cell, as shown in Fig. *1a*, which has been checked against the primary standard.

* It is a fact known to scientists that such basic qualities as *amperes, volts, ohms, henries, farads, pounds, etc.*, may be expressed in units of *length, time* and *mass*, which are referred to as the *absolute units* and any measurements in terms of absolute units are known as *absolute measurements.*

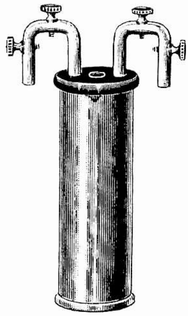
Even though an ohm represents the unit property of a conductor, it is now customary to have a definite size and kind of conductor to represent the *standard ohm.* Incidentally it happens to be the resistance of a column of mercury 106.300 centimeters long of uniform cross-section, the mercury weighing 14.4521 grams, at the temperature of melting ice. But for practical use, secondary standards as shown in Fig. *1b,* made of special resistor wire are used. Given a standard volt and a standard ohm, by Ohm's law the standard current can be produced for purposes of comparison. Again we measure two quantities in order to know the third.

However, we can only measure current by what it will do. What we may do is this: we construct a movable coil system, suspended in a constant magnetic field, and when we pass a current through the coil work is done, the coil moves and by attaching an indicator the amount of movement can be observed. This movement is a measurement of the



COURTESY WESTON ELECTRICAL INSTRUMENT CORP.

FIG. 1a



COURTESY LEEDS & NORTHRUP CO.

FIG. 1b

current. The exact current is known because the ohms in the circuit and the volts applied to it are easily compared to secondary standards. Thus we produce a secondary current indicating standard.

Now all that I have said about absolute, primary and secondary standards is of no great concern to the practical radio man, if the following ideas are clearly understood. If you understand that the meters you use in testing are only approximately correct, that they can only be considered more correct by comparing to secondary standards, which in turn are checked against a primary standard, which from time to time is checked by absolute methods, you get the whole scheme of measurements by the means of comparison. Remember this: a practical measuring instrument is calibrated by comparing it with an accepted secondary standard.

In radio and electrical design, research, maintenance and servicing we definitely depend on our ability to measure electrical quantities, and the important units are:

Amperes	units of current
Volts	units of potential difference
Watts	units of power
Cycles per second	units of frequency
Ohms	units of resistance, reactance or impedance
Farads	units of capacity
Henries	units of inductance

As practical men we have need for measuring instruments that will simplify the measurement of any of these quantities. And the question constantly arises, what instrument shall I use to measure this or that quantity? You must select this instrument fully aware of what it will or will not do. For example, every ammeter cannot be used to measure one ampere of high frequency current. There is a correct type to use, and the ability to select the proper type only comes from a knowledge of meters and how or why they work. Instrument design involves com-

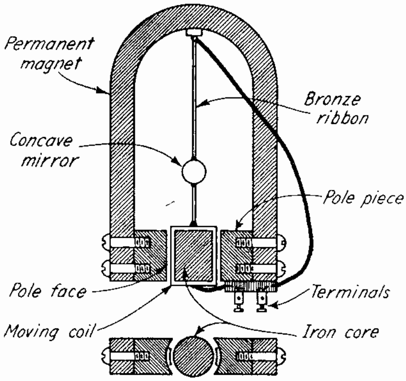


FIG. 2

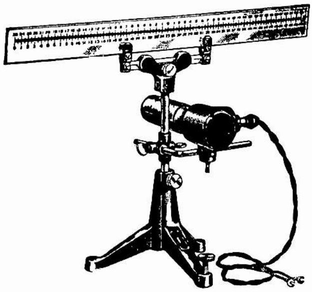

Scale and lamp for semi-portable galvanometer

FIG. 3

plex mathematical work, hence our study will be limited solely to the practical side, their construction, operation, and limitation. As the current meter is essentially the basic instrument, it will be studied first.

THE D'ARSONVAL GALVANOMETER

The D'Arsonval galvanometer is by far the most important D.C. current-measuring device. In this type of instrument we have a moving coil suspended in a permanent magnetic field, the indicating device being a small concave reflecting mirror attached to the coil system, as shown in Fig. 2. The coil is small, very light in weight, and rectangular in shape. It consists of a number of turns of very fine, copper wire, and the entire coil is suspended on a thin, flat, phosphor-bronze ribbon. The suspension is such that the coil can rotate at right angles to the magnetic lines of force from one pole face to the other. The small mirror shows its movements by the change in the direction of light reflected from it onto a graduated scale.

The current to be measured is made to flow through the coil. Then the magnetic field set up about the coil reacts with the permanent magnetic field, forcing the coil to rotate in one direction or the other, depending on the direction of current. The tendency of the coil to rotate is opposed by a counter-twist of the flat suspension ribbon. Therefore, the coil will turn until the torque (twisting force) due to the current is equal to the counter-torque of the suspension. At this point the indicating device will remain fixed, and the position is a measure of the current flowing through it.

Of course, it isn't difficult to realize that a meter of this type can be made extremely sensitive by using a very strong magnetic field, a large coil, a large number of turns and a weak repelling force in the galvanometer suspension.

The sensitivity of this type of galvanometer can be greatly increased by a special method of magnifying the movement of the indicat-

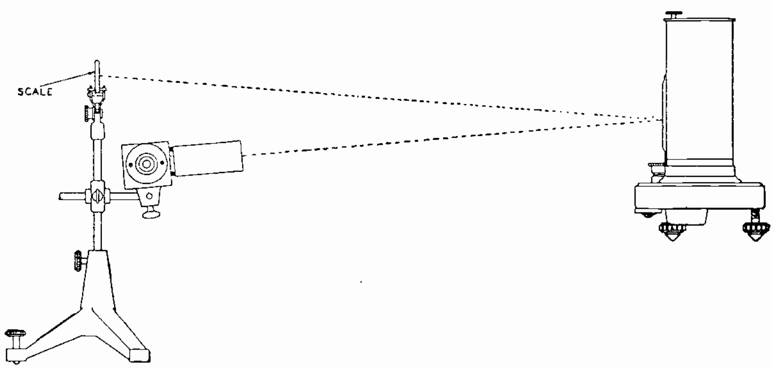


FIG. 4

ing device. The additional equipment is shown in Fig. *3*, and how it is used is shown in Fig. *4*—there being a long-filament lamp in front of the concave mirror of the galvanometer so the image of the filament is reflected and magnified by the mirror onto a frosted semi-transparent scale. Then the least rotation of the galvanometer will show up on the enlarged scale.

The scales may be laid off in any convenient manner and each unit divided into ten equal parts. With this arrangement we can compare currents by the amount of deflections produced on the scale.

CALIBRATING A GALVANOMETER

A galvanometer, as you have probably suspected, is merely a current indicating device. To be sure, a current indicator is quite valuable, especially when radio or electric circuits are adjusted or balanced so zero current (no meter deflection) exists. But the greatest use for a current indicating device is its ability to indicate how much current exists, and to do this a galvanometer is calibrated. When it is calibrated it becomes a current meter, or ampere meter. We usually refer to calibrated current meters as ammeters; if they indicate values of 1/1000 of an ampere they are called milliammeters; if they measure microamperes, they are called microammeters. Calibrating a galvanometer is quite simple if you have secondary standards. The meter manufacturer who makes the testing instruments for use has the facilities to calibrate his product.

To calibrate the galvanometer shown in Fig. *4*, we need an accurate source of voltage and precision resistors. We first would determine roughly how much current will make the galvanometer read full scale. We could take a 10 volt source, connect it to the galvanometer using a variable high resistance in series; gradually decrease the resistance until full scale reading is obtained. Suppose 10,000 ohms give full scale deflection. Obviously 10 ÷ 10,000 (Ohm's Law) or .001 amperes gives full scale deflection. We say that the galvanometer has a 1 milliampere full scale range.

For an exact calibration, the circuit shown in Fig. *5* would be assembled. Let us say that the galvanometer scale is divided into 100 divisions, and that the resistance of the meter is about 15 ohms. We would proceed to adjust the variable resistor until the reading was 100 divisions—and we find that this is roughly 10,000 ohms. How much resistance does it take to produce scale deflections of 90, 80, 70, 60, etc.? In determining these resistor values you are taking the initial steps in the calibration. Suppose the values we got were as follows, where D is the divisions on the scale, R the resistor value in ohms, easily read from the variable standard:

D	R	I_1	I_2	D	R	I_1	I_2
100	10,000	.001	1000	50	20,000	.0005	500
90	11,100	.0009	900	40	25,000	.0004	400
80	12,500	.0008	800	30	33,300	.0003	300
70	14,000	.0007	700	20	50,000	.0002	200
60	16,700	.0006	600	10	100,000	.0001	100

Knowing that the voltage is 10 volts, we can by Ohm's Law ($I = E \div R$) determine the exact current flowing for each deflection.* The current values are shown in units of amperes under I_1 and in units of microamperes under I_2 in the above table.

Of course, a graph or calibration curve is far more useful than a table, for it is easier to determine the current for odd deflections like 63, 27, etc. A calibration curve is shown in Fig. *6*. Notice how straight the calibration curve is. We say that the meter has uniform or linear response. And this characteristic is quite valuable in a meter, and the

* In this case the meter resistance may be neglected. If it happened to be a larger value, for example 522 ohms, the meter resistance (furnished by the maker) would have to be included.

device is designed to have this property whenever possible. Now when a meter has this property we may say that the current for a definite deflection is the *deflection* (scale reading) *times a number*, and the latter is called the *meter constant*. Expressed as a formula we say: $I = K \times D$. The meter constant (K) is easy to determine: Divide the amount of current (in the units you wish to use) known to exist at any scale division by the number shown on the scale at the point you selected. The reading at full scale deflection is generally used. Let us say we want to use the meter as a microammeter. The amount of current known to exist at 100 on the scale is .001 ampere, or 1 milliampere, or 1,000 microamperes. In our case it is 1,000 (we are selecting microamperes) divided by 100, and the meter constant is 1,000 $\div$ 100 equals 10. Hence, if the calibrated galvanometer is used to measure current in units of microamperes and a reading of 63 is obtained, we know at once it is 630 microamperes.

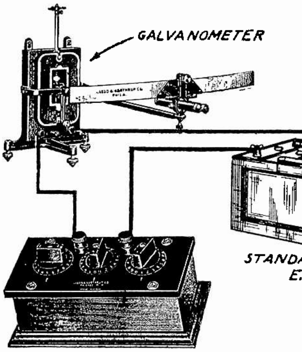


Fig. 5

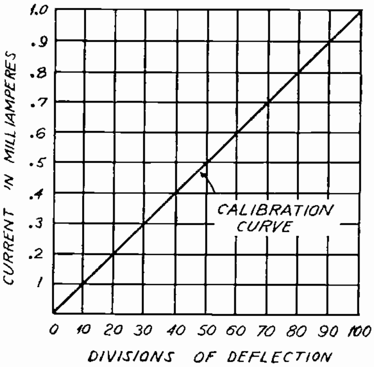


Fig. 6

Now all this is quite important because you may have a current meter or a galvanometer that you may wish to calibrate, and this is one way it may be done if you have no standard meter to compare it with.

D. C. AMMETERS AND MILLIAMMETERS

The D'Arsonval calibrated galvanometer principle was used by Edward Weston in 1888 in the development of what might be considered the first practical, modern, portable galvanometer. Details of the construction of the Weston galvonometer are shown in Figs. 7 and 8.

There is a small, compact but powerful permanent magnet, with soft steel pole pieces and a soft steel core. The pole pieces are bolted to the permanent magnet and to a non-magnetic support.

The coil is wound of many turns of silk-covered fine copper wire on a non-magnetic metallic frame. The coil is mounted in a pivot arrangement. There is a pivot point at each end of the coil exactly in the center of the core and the pivots themselves are set in polished, hard steel pivot holes, arranged directly above and below the exact center of the core. In modern high grade meters, jewel pivot sockets are used.

To the coil is attached a long needle which swings over an indicating scale. It is conventional for zero on this scale to be at the extreme left and maximum deflection to the right. In some cases zero is in the center of the scale and the indicating needle swings either to the right or left, depending on the direction of the current through the meter.

The air gap in which the coil rotates is made as small as possible so that the magnetic field through it will be strong. If linear response is important the distribution of flux in the area through which the coil moves must be uniform and the coil must not be allowed to swing beyond the point of uniform field, or beyond the curvature in the pole pieces. A coiled ribbon spring is connected to the pivot and anchored to an arm which is a part of the end piece holding the bearing. The arm is adjustable so that the tension of its spring can be changed. The

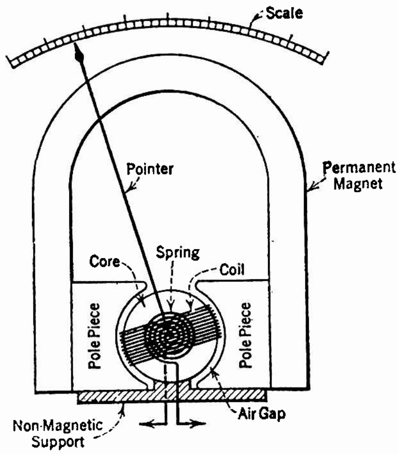


FIG. 7

needle is adjusted for zero in the same way. A spring coil is also used on the lower pivot, both springs being of phosphor-bronze. They provide the electrical connection to the coil windings provided the springs are led to insulated terminals.

A current flowing through the coil sets up a magnetic field which reacts with the permanent field, forcing the coil to rotate until the twist is balanced by the tension of the coil spring. The amount of current flowing can be calculated from the same formula we used with the D'Arsonval galvanometer ($I = K \times D$).

SHUNTS TO EXTEND THE CURRENT RANGE

3 You probably know that the range of an ammeter may be extended by using a resistor shunted across the meter terminals, as shown in Fig. *9*. Thus part of the current to be measured passes through the shunt and

some through the meter. Of course, the shunt must be selected so a definite proportion of the whole passes through itself and the meter. Only precision resistors, two types of which are shown in Fig. *10,* should be used as shunts, to insure the greatest accuracy. As a rule they will have extremely small ohmic resistance, and carry the bulk of the current to be measured—you do not want the basic meter to overheat.

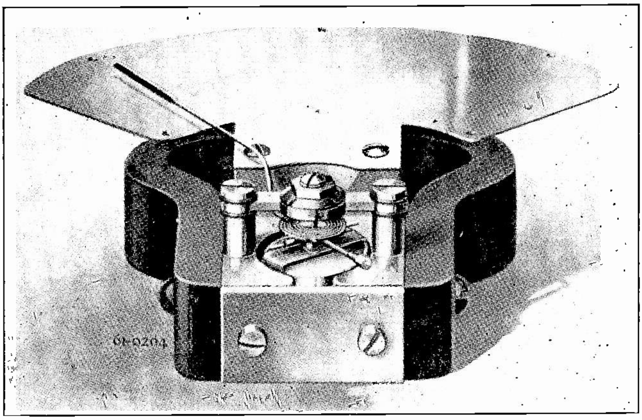


FIG. 8. D'Arsonval D.C. ammeter with case removed

Let us follow through the calculation of several shunts on a typical meter that you as a Radiotrician may constantly use. The meter selected has a range of from 0 to 1 milliampere and its coil has a resistance of 12 ohms. The scale is divided into 10 divisions, and each of these is divided into 10 smaller divisions. Each small division represents 10 microamperes and each large division .1 milliampere (ma.). As there are 100

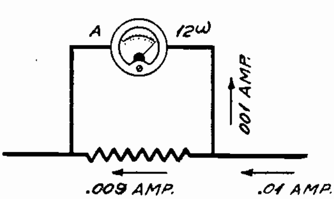


FIG. 9

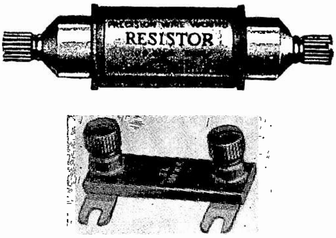


FIG. 10

divisions on the scale and as these hundred are designed to represent 1 ma., K will be in this case $1 \div 100$ or .01.

By the use of shunts of various values, this basic milliammeter can be used to read from 0–10 ma., 0–20 ma., 0–100 ma., etc. The shunt to be used can always be calculated from Ohm's law. For example, suppose we want this 0–1 milliammeter to read from 0 to 10 ma. We must use a shunt which, in parallel with the 0–1 milliammeter will allow only .001 ampere to flow through the instrument and .009 ampere through the shunt—at the new maximum current range. This simple circuit is shown in Fig. *9*. Knowing this distribution of current and the resistance of the basic current meter, calculating the correct shunt is simple.

The voltage drop across the milliammeter is 12 × .001 or .012 volt. The same voltage exists across the shunt. The resistance of the shunt must be such that, with that voltage across it, only .009 ampere will flow. The value of this resistance, from Ohm's law, is:

$$R = \frac{E}{I} = \frac{.012}{.009} = 1.33 \text{ ohms.} \tag{1}$$

Suppose we wanted to adapt our meter to read from 0 to 20 ma. Of course, full scale deflection will mean that 1 ma. flows through the

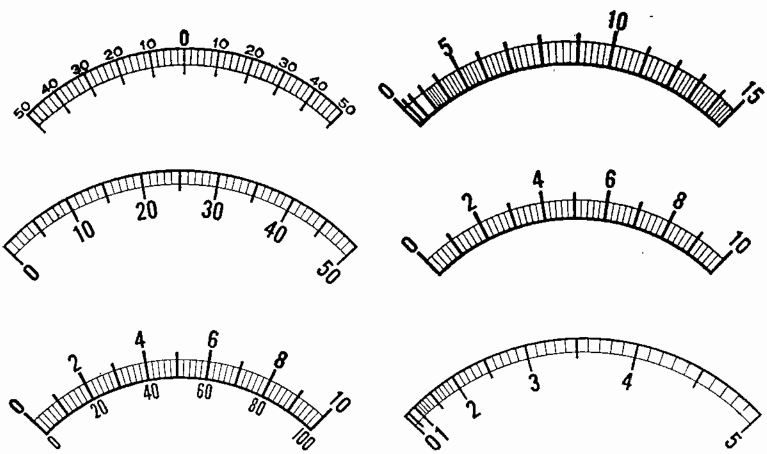


Fig. 11

meter and 19 ma. through the shunt—and the total current measured will be 20 ma. Again the voltage across both meter and shunt is .012 volt. The resistance of the shunt required is equal to $\frac{.012}{.019} = .63$ ohm.

For a 0–100 mil. range R will have to be $\frac{.012}{.099} = .121$ ohm.

The procedure just shown may be presented in a form to enable you to calculate a shunt for any current meter. It is as follows:

$$\textit{Shunt Resistance} = \frac{\textit{Meter Resistance} \times \textit{Its Current Range}}{\textit{Current the Shunt Must Pass at the New Maximum Range}} \tag{2}$$

where: Resistance is in ohms, Currents are in the same units.

PRACTICAL METER CALIBRATION

Assume that you had a meter which no longer gave accurate readings, or one you "picked up" somewhere. How would you go about, in a practical way, to get a new scale? To be sure, you could send the instrument to its maker for a new scale or adjustment, but let me tell you how you can do it. Although the following method will apply to a D.C. meter, it may be employed for other types, provided the correct type of current and secondary standards are used.

The first step is to remove all shunts and determine how much current is necessary to read full scale. This I have already shown. It is quite obvious that this represents the lowest possible range. Inspect the scale. Typical scales are shown in Fig. *11*. If one of the scales reads 0 to 10, or 0–15, or 0 to 100, or 0 to 150, a very satisfactory series of ranges can be adapted without the need for drawing a new one, provided in the case of a 0 to 10 or 0 to 100 scale, maximum reading is less than 1, or 10, or 100 milliamperes; and in the case of the 0 to 15 or 0 to 150

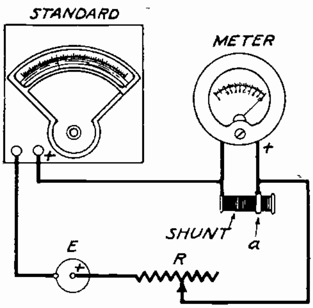


FIG. 12

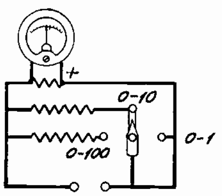


FIG. 13

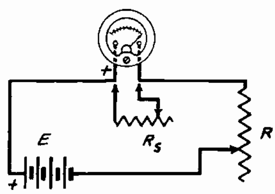


FIG. 14

less than 1.5, or 15, or 150. Simply because a shunt will permit us to bring the meter to exactly full scale for the maximum value selected.

First you need a meter with an equivalent current range to be used as the standard of comparison. If you do not have one among your meters, borrow one from a fellow technician. Connect the standard and the instrument in series with *E*, a voltage source, and *R*, a variable resistor, as shown in Fig. *12*. Be sure to select *E* and *R* so *E* divided by the maximum value of *R*, is a little larger than the maximum current range of the meter to be calibrated. Get a 0 to 100 ohm rheostat and shunt it across the meter, setting it to a low ohmic value. Vary *R* until the standard reads the desired full scale value. Now adjust the shunt rheostat until the meter being calibrated reads full scale. Readjust *R* and the shunt rheostat until both the standard and the meter read the desired full scale value. The resistance in the rheostat in use represents the shunt required. Measure the exact amount of resistance with a serviceman's ohmmeter, or by visual inspection judge how much there is in use. For example, if about 1/10th is used, the shunt must have a resistance of about 10 ohms. Now procure a regular fixed wire wound resistor of a slightly higher resistance value; connect it permanently to the meter, as shown in Fig. *12,* and either move the sliding contact, or remove turns, or connect other resistors in parallel, or short out turns with solder until: the meter reads full scale and the standard reads the desired full scale value. When the exact shunt resistor is found, secure all connections.

Shunts to extend the meter range may be made in exactly the same manner, using, of course, a high range standard, and suitable values of E and R are chosen. The shunts so determined are connected to a selector switch as shown in Fig. *13.*

If the scale on the meter happens to be unsuitable for the basic range of the meter, procure a suitable scale 0 to 10 or 0 to 15 or some multiple of this range from the meter maker. You may, of course, with a compass and pen draw a suitable scale on a piece of high grade drawing paper cemented over the existing scale. For radio use, a basic milliammeter of 0 to 1, 0 to 1.5, and 0 to 3 milliamperes is recommended. In drawing or selecting scales, you will find those shown in Fig. *11* are the best. They are easy to read between numbers shown. In extending a range, extensions of 2, 5, and 10 times are wise, and they are easy to read if the scales are mentally read in the following manner. When extended
4 twice multiply the basic reading by 2; when extended 5 times, mentally divide by 2 and add a zero (0); and when extended 10 times merely add a zero (0).

One more practical method of extending the range of meters when a standard for comparison is not available, but you are reasonably sure the basic range is correct. Connect the basic ammeter in series with a source of voltage E and high ohmic variable resistor, as shown in Fig. *14.* The value of R must be at least 100 times greater than the meter resistance. In the case of D'Arsonval milliammeters, a 0 to 1 milliampere meter will rarely have a resistance more than 30 ohms. Hence, R should have a value of at least 3,000 ohms. With this resistance two dry cells in series, giving 3 volts, will cause 1 milliampere to flow in the circuit. Adjust R until the meter reads full scale—exactly. (If the meter reads above full scale, add 500 to 1,000 ohms to the circuit.) Now without adjusting R add the shunt R_s and vary its value until the meter reads exactly one-tenth the full scale. A permanent resistor of this value will serve as a shunt to extend the range 10 times. For an extension of 5, adjust the shunt until the meter reads one-fifth full scale; for an extension of 2, adjust the shunt until the meter reads one-half full scale. It is not wise to make an extension greater than 10 in this manner. For greater extensions use a standard for comparison.

HOT WIRE AMMETERS

Until recent years the hot wire ammeter was extensively used in measuring radio frequency currents. Today, the thermocouple ammeter has almost universally replaced them. However, the operation of the hot wire ammeter is important as you will still find many of them in daily use.

Figure *15a* shows the working mechanisms of the hot wire ammeter. There is an alloy wire of platinum and silver, or platinum and iridium, stretched between A and B. The tension on the wire may be increased or decreased by adjustment of the set screw S. Between C and E there is a phosphor-bronze ribbon. From point D on this ribbon, around a cylinder to a coil spring F, is wound a silk cord. When a current is passed through wire AB, an I^2R loss takes place and the wire becomes hot. Naturally the wire expands and sags. The sag is transmitted to FP through the action of the spring, causing the cylinder P to rotate. An indicating needle attached to P moves over a convenient scale. As the resistance of the hot wire remains substantially constant in value,

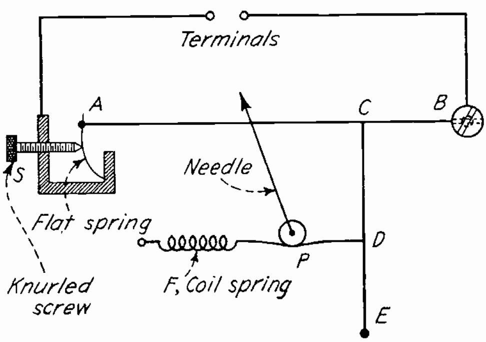


FIG. 15a


FIG. 15b

the sag in the wire, hence the deflection of the needle depends on the current squared (current times current). For that reason, low current readings are "bunched" together as you can see by looking at the hot wire ammeter scale shown in Fig. *15b*.

As D.C., A.C., or R.F. currents will produce heat and the resistance of a straight wire is essentially the same for any frequency of current, the hot wire ammeter may be calibrated on D.C. or A.C. and safely used to measure high frequency currents. Unfortunately, a hot wire ammeter is not a very sensitive meter, and ranges of 0 to 20 milliamperes are extremely difficult to make, besides are very fragile. Their use is generally limited to current ranges of one ampere and more.

THERMOCOUPLE AMMETERS

For the reasons just explained, hot wire ammeters are not practicable for the measurement of currents much smaller than 20 ma. But R.F. currents that have to be measured are often of the order of a few microamperes. It is for measuring these small R.F. currents that thermocouple ammeters must be used; in fact, the thermocouple ammeter has replaced the hot wire ammeter for almost all current ranges.

It is known that two dissimilar metals, like copper and iron, or copper and constantan (a special alloy), when joined together at one end and heated at the joint will produce a D.C. voltage across the open ends. This is the principle used in thermocouple ammeters. Any kind of current to be measured causes the joint between two dissimilar metals to heat up, and a D.C. voltage appears across the ends of these metals which can be measured by a D'Arsonval needle type galvanometer. As D.C. indicators can be made in any degree of sensitivity (ranges as low as 0 to 1 microamperes are not uncommon), a correspondingly sensitive A.F. or R.F. thermocouple ammeter is readily obtained.

Figure *16a* shows the working principle of a thermocouple ammeter. Two short, fine pieces of wire, one steel and the other constantan, are twisted together as shown. High frequency current is led to the terminals T_1 and T_2. The resistance of T_2JT_1 is perhaps 1 or 2 ohms and heats up due to the I^2R loss in it. The heat developed is concentrated at point J. Wires G_2J and G_1J act as a thermocouple with J as the heated point.

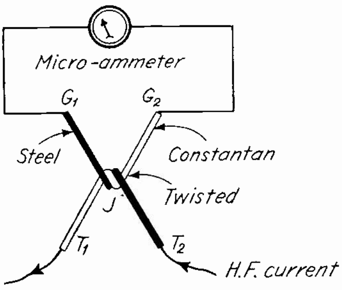


FIG. 16a

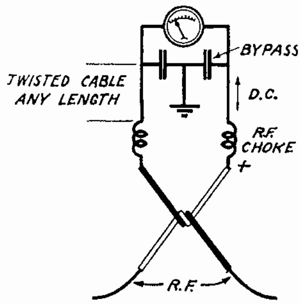


FIG. 16b

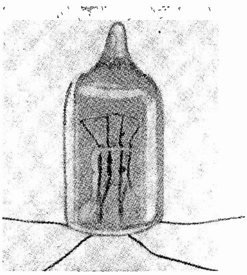
(Note. The H.F. current does not flow through meter)

In one type of thermocouple, a 25 ma. flow of high frequency current from T_2 to T_1, results in a .5 ma. of D.C. through G_2 and G_1 when an ordinary 0 to .5 ma. D'Arsonval meter is used.

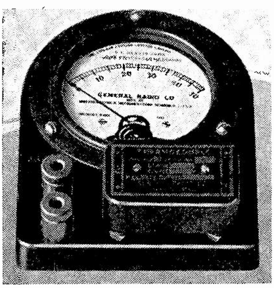
In using a thermocouple meter, it is essential that no R.F. currents get into the D.C. meter. Even though an R.F. current will not produce a meter deflection, enough R.F. current will burn out the coil. For ordinary laboratory work where low R.F. currents are measured, no precautions are generally required, provided reasonable care is taken to shield the D.C. meter from stray R.F. currents. In transmitters where the couple and the meter may be many feet apart, the following precautions are taken. The couple, of course, is located at the point where the current to be measured is present. A twisted cable connects the couple to the meter. To prevent R.F. from the source measured from getting into the cable leads, R.F. chokes are used. Quite often the D.C. meter is shunted with two low loss condensers and the center tapped to ground, as shown in Fig. *16b*. When one R.F. terminal to the couple is at ground

R.F. potential, the chokes and by-passes may be omitted, as the meter will be at a low R.F. potential.

A typical thermocouple unit is shown in Fig. *16c*, the elements held by a glass press and in a vacuum. The couple is then mounted in a moulded box with four prongs as terminals. Figure *16d* shows a D.C. galvanometer (0 to 500 microamperes) designed to take any of several thermocouples. Calibrations are required for each couple used and thermocouple ammeters, although intended for R.F. or A.C. uses, may be calibrated on D.C. That is, a circuit similar to Fig. *5* or Fig. *12* may be used, the standard resistors and the source being D.C. devices, but the meter to be calibrated a thermocouple ammeter. In calibrating a thermocouple ammeter it is wise to reverse the battery connections, as a difference in contact resistance of the joint may cause the readings to differ. An average value is taken. Several points on the scale should be so checked and a calibration curve drawn, as a thermocouple meter is not a linear indicator.



COURTESY GENERAL RADIO CO.
FIG. 16c



COURTESY GENERAL RADIO CO.
FIG. 16d

MAGNETIC VANE AMMETERS

For power line frequencies, that is commercial A.C. power, which we obtain at the outlet in our homes, offices and factories, more substantial types of current meters are available. One of them is the magnetic vane ammeter. Its low cost of construction, its ruggedness and its fair precision have led the serviceman to accept this type of ammeter for line current measurements of 25, 40, and 60 c.p.s. current as well as D.C. The principle of operation is rather simple.

Suppose a solenoid is fed with D.C. current. If a *soft, annealed* iron plunger is placed near an open end, it will be sucked in, even against the action of a spring which may tend to pull it out. The greater the current in the solenoid, the greater the pull. What happens is that the plunger becomes a magnet under the influence of the solenoid electromagnetic action. Now, if the D.C. current is reversed, the sucking-in action will continue. The polarity of the plunger reverses with the polarity of the solenoid. So, even by feeding low frequency A.C. to the solenoid wires, the action of pulling in the plunger continues in spite of the comparatively rapid reversal of current. However, there is a limit to increasing the frequency, and at a high audio frequency the current in the solenoid would have no effect on the plunger. Magnetic vane ammeters which employ this principle are usually designed to read current correctly with frequencies below 133 c.p.s. They are inaccurate at higher frequencies or may not deflect at all.

Some of the inexpensive meters—D.C. as well as A.C.—use the principle applied in the manner illustrated in Fig. *17a*. From our previous explanation, no trouble should be experienced in understanding how this simple ammeter acts. A scale is attached to the instrument, and by comparing to various known values of A.C. current, the instrument may be calibrated. The coil should be shielded from heavy magnetic fields of dynamo-electric machinery, dynamic loudspeaker fields and power choke coils; and this shield is built into the meter.

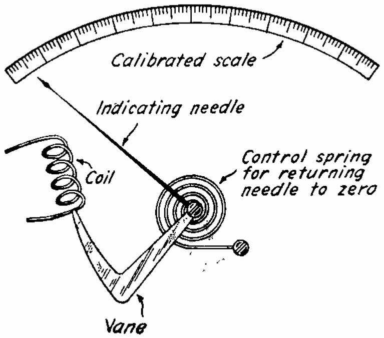


FIG. 17a

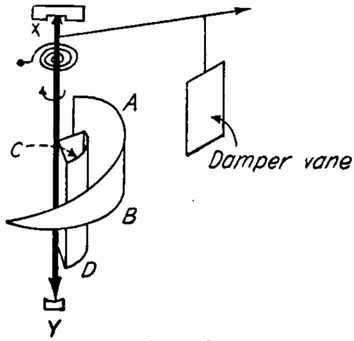


FIG. 17b

The original magnetic vane instrument invented by Weston is shown in Fig. *17b*. A thin piece of soft iron, *AB*, of triangular shape, is bent to cylindrical form, and placed firmly within a solenoid. Another piece of thin iron, *CD*, rectangular in shape but bent into a slightly smaller cylinder, is centered coaxially within *AB*, that is, having the same axis *XY*. The vane *CD* is rigidly attached to *XY*, which has a pointer also controlled by a restoring spring. When a direct current flows through the solenoid, both pieces of iron become magnetized. Edges *A* and *C* are of the same polarity and edges *D* and *B* are alike in polarity. Naturally they repel, and the only motion possible is in the direction of the arrow. The twist continues until balanced by the restoring spring. It will take a greater flux strength and more current in the solenoid to force a greater rotation. The fixed element *AB* is shaped to give as nearly as possible a uniform meter scale.

Figure *17c* shows the internal construction of an actual meter. Rigidly affixed to the needle is a flat rectangular aluminum damping vane which rotates in, but without touching, an airtight box. This air friction damper keeps the needle steady, on much the same principle as a tight-rope walker uses a large fan or umbrella to steady himself. As the current rises, falls and reverses, the damper keeps the needle pointing to the r.m.s. or effective value of current.

Because the current flows through a solenoid, a magnetic vane ammeter will have inductance as well as resistance. If the inductance is sufficiently large it will have a definite effect on its frequency range, and the method of extending its current range. For example, a typical high grade 0 to 1 ampere magnetic vane meter has a resistance of 1 ohm and an inductance of .0001 henries. At 60 c.p.s. its inductive reactance will be about .038 ohms. This is about 3 per cent of the resistance. For ordinary radio use this may not seriously upset the meter calibration. At 600 c.p.s. the reactance becomes .38 ohms, sufficient in itself (not considering the magnetic field response at this frequency) to throw the

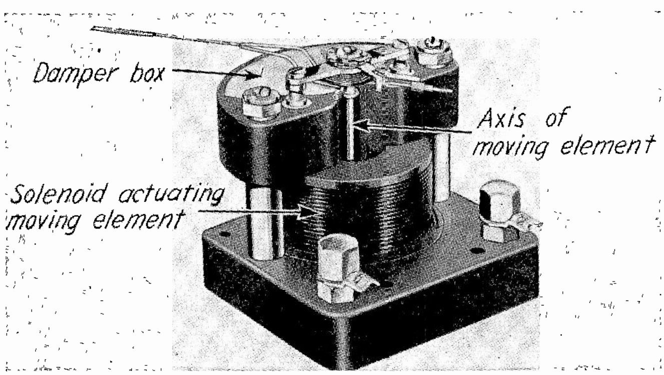


FIG. 17c

calibration off a considerable amount. An ammeter of the type shown by Fig. *17a* would have more of this inductive effect.

With these facts in mind, a shunt may be used at any low frequency, determined in a manner identical for a D'Arsonval unit, provided the inductive reactance is less than 4 per cent of the resistance and high precision is not required. Of course, a shunt may be used at any frequency with any ammeter, provided a special scale is supplied for that frequency and shunt. But in general, it is wiser to use step-down or so-called current transformers where the original scale times a multiplying factor is to be used in current range extensions. In general, a magnetic vane ammeter may be used on D.C. and A.C. up to 133 c.p.s. without much change in the calibration. As there are many modified magnetic vane ammeters in daily use, it is wise to follow the maker's limits of frequency and current range. However, they are all made to read correctly for 25, 40, and 60 c.p.s. currents.

ELECTRODYNAMOMETER A.C. AMMETERS

Although the electrician and radiotrician will generally, for high current measurements, use the magnetic vane type of instrument for commercial frequencies, at times an electrodynamometer ammeter may be of advantage. A typical construction is shown in Fig. *18*. Wattmeters operate on a similar principle, as well as the better grade of meters used for direct measuring of capacity and inductance. It is the laboratory A.C. meter. The principle of its action is quite simple.

The coil *A,* in Fig. *18,* which may be either circular or rectangular, is fixed. Within it is a similar coil, smaller, of course, so that it may rotate without touching, but yet quite close. Both coils are in series. When a current flows through coil *A*, a magnetic field is set up; the same current flowing through coil *B,* whose magnetic field is in the opposite direction, causes the movable coil to swing away. The larger the current, the greater the repulsion and the more the turning torque. Naturally the pointer moves until the magnetic twist is balanced by the back torque of the spiral springs. A damping vane, enclosed in a damper box, prevents the pointer from vibrating to and fro when a measurement is made.

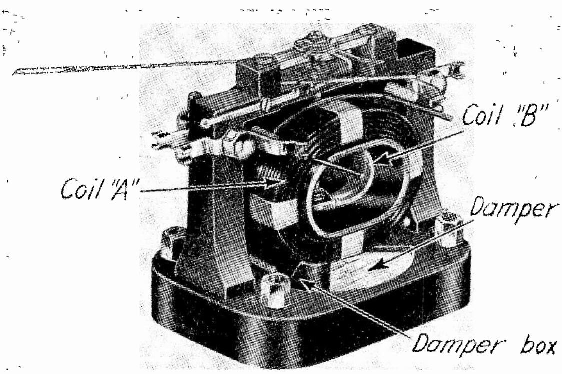


FIG. 18

When an A.C. current flows, the magnetic field will first be in one direction and then in the other. But the coils are in series, and the same current flows through each and repulsion always exists. Consequently, the turning torque is always in the same direction. Electrodynamometer ammeters *always* read r.m.s. values. Like the magnetic vane ammeter, they are only for commercial frequencies of 0–133 cycles and almost always are calibrated for 60 cycles per second. They must also be shielded from outside magnetic fields and be kept away from large steel construction work.

No iron is used in the moving system, consequently no magnetic hysteresis or eddy current losses take place. No magnetization of iron is necessary and fairly sensitive ammeters may be built. One manufacturer will supply electrodynamometer ammeters from 15 milliamperes to 10 amperes in semi-precision models. A 0–1 ampere model may have a resistance of ½ ohm and a 0 = 15 ma. meter a resistance of 1,400 ohms. As these ammeters are generally of the precision type, only current transformers may be used to extend their range. A typical current transformer is shown in Fig. *19,* and they do not differ in construction from ordinary transformers. They are merely designed to have negligible effect on the current to be measured, that is, have a definite turn ratio.

COPPER OXIDE RECTIFIER AMMETERS

Perhaps the copper oxide rectifier, plus a D.C. ammeter, is the most widely used device by servicemen and radio technicians, for A.C. measurements. You are well acquainted with the fact that half- and full-wave rectifiers will convert A.C. to pulsating D.C., and a D.C. meter will

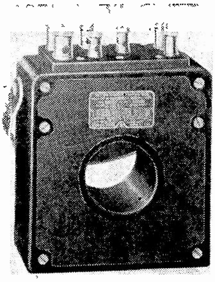


FIG. 19. A portable current transformer. Designed to be used on any A.C. 0 to 5 ampere ammeter with errors of less than ½% in the range of 25 to 60 c.p.s. Ammeter connects to the upper right two terminals. In the group of five posts, one is a common terminal of an internal tapped primary winding. The other four posts also connect to this primary winding and permit current extensions of 10, 20, 50 and 100 amperes. The internal primary winding is not used for currents greater than 100 amperes but by running one external loop of wire through the center opening which is carrying the current to be measured, the range is extended to 1,200 amperes; two turns extend it to 600 amperes; three turns extend it to 400 amperes; four turns extend it to 300 amperes; six turns extend it to 200 amperes.

record the average D.C. value. The tube is commonly used for this purpose, and the vacuum tube meter will be considered in another lesson. A crystal detector, of the fixed carborundum type, may also be used. But as the crystal is very unstable, these types are used without calibrated scales as A.C. current indicators rather than as accurate current meters. The copper oxide rectifier, which is used extensively in converting A.C. to D.C. for low voltage D.C. sources, is readily designed to have fair stability and similar sizes are readily duplicated in quantities. Typical meter rectifier units are shown in Fig. *20.* Of course, rectifiers can be obtained to handle any amount of A.C. current, but the usual radio practice is to design them for low current (1 to 5 milliamperes) and use them in combination with a sensitive D.C. microammeter for use as low current A.C. meters. For example, with the rectifier shown, when 1 milliampere of A.C. is fed to the rectifier, sufficient D.C. current is obtained to make a 0–500 D.C. microampere meter read full scale. The combination then is useful as a 0–1 milliampere A.C. meter. In fact, this is the usual set-up for basic milliammeters used in radio work, higher ranges obtained by the use of shunts.

The most commonly used connection is the full-wave arrangement shown in Fig. *20c*. During each alternation of the A.C. cycle, two elements allow current to pass, while one of the other two block the current flow in that portion of the rectifier. It is important that every element has the same resistance, otherwise unequal half waves will be rectified. The practical connections are shown in Fig. *20b*. The end and center terminals are the D.C. meter connections, the two terminals off center are for the A.C. connections. Extreme care must be exercised in soldering to lugs if supplied as in Fig. *20a*. Heating the elements destroys their resistance and rectifying characteristics.

A copper oxide rectifier may be made to work on any frequency, and if it were not for its capacity (capacity between adjacent elements) frequency would have no effect, that is, it would not introduce meter errors. In fact, elements as small as ⅛-inch diameter have been made which work well at 2,000 k.c. For radio work, the copper oxide rectifier meter is generally used for power frequencies (25 to 133 c.p.s.) and audio-frequencies (35 to 10,000 c.p.s.). The unit shown in Fig. *20a* has been

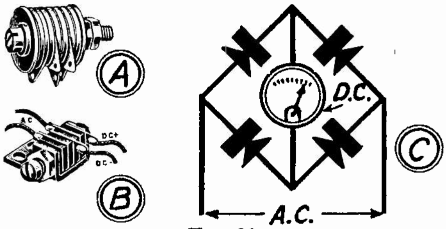


FIG. 20

designed for power line frequencies, but may be used at audio frequencies if only comparative readings are desired. The unit shown in Fig. *20b* is only about ¼-inch square and an ammeter calibrated on 60 c.p.s. may be safely used on any frequency up to 10,000 c.p.s. if 5 per cent accuracy will suffice.

The instrument must be used at ordinary room temperature. As heat has an appreciable effect on the calibration, it must be kept away from parts radiating heat. As the rectifier merely changes A.C. to pulsating D.C., and the D.C. meter reads average value, the copper oxide rectifier meter must be used to measure current of the same wave form
8 used in its calibration. Sine wave currents are used in calibration, and if you measure A.C. currents with distorted wave forms only, rough measurements are provided. Correct readings are possible on commercial power currents, as they are invariably sine wave. Copper oxide rectifier meters, if used for measurements, should be checked at least twice a year, and the correction required noted and used in subsequent measurements. If too far off, it should be returned to the maker for correction. For precision measurements of A.C. power currents where precision of 2 per
6 cent or better is required, magnetic vane and electrodynamometer meters should always be used.

As you probably know, the basic instrument in the multimeter used by servicemen is a 0–1 A.C. or D.C. milliammeter. A single D'Arsonval needle type microammeter and a copper oxide rectifier may be used. Using shunts and series resistors, extended current ranges and various voltage ranges are possible. The 0–1 D.C. milliammeter may also be used in the ohmmeter. Figure *21* shows a basic A.C.-D.C. milliameter circuit. A double-pole double-throw switch is used to change from A.C. to D.C. measurements, and one of the test leads is changed. When changing from A.C. to D.C., the full current passes through the meter, and a shunt, R_1 is used to reduce the sensitivity of the D.C. meter. This is done to have both A.C. and D.C. scales nearly alike and equal in range, a matter of simplicity in use. Resistor R_2 is used to prevent the low resistance of the D.C. meter placing too much of a load on the copper oxide rectifier, and reducing the load tends to make the A.C. scale more uniform. As all rectifiers of similar make do not have the same resistance when assembled, resistor R_3 is used in practice to make up for any

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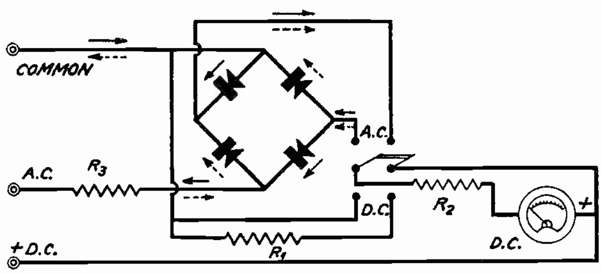

FIG. 21

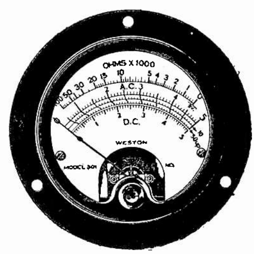

FIG. 22

difference in the desired total ohmic value of the entire meter circuit. A typical universal meter is shown in Fig. *22,* the meter incorporating only the copper oxide rectifier, with the associated resistors and controls provided in kit form.

The Cathode Ray Oscillograph

It is well to remember that the D.C. milliammeter, in fact, all D.C. meters measure average current; A.C. meters, such as the hot wire, the thermocouple, the magnetic vane and the electrodynamometer ammeters, are calibrated to read root mean square (that is effective) current values; and the rectifier type ammeters read average values of the rectified A.C. current they are intended to measure, but are calibrated to read in root
9 mean square values. In radio work, there are conditions where it is equally as important to know the current wave form, as its average, root mean square and peak values. For this purpose the cathode ray oscillo-

graph is perhaps the most useful and the most flexible instrument for use by the radio servicemen, laboratory or design technician. It is important that you know how it works.

It is a well-known fact that electrons are readily controlled by an electric field, and when electrons are in motion they may also be controlled by a magnetic field. Furthermore, it is well known that when a screen made of such material as calcium tungstate (a chemical also called willemite) is bombarded with high-speed electrons, the spot hit will emit light, simply because the energy of impact readily causes the electrons in the atoms on the screen to vibrate and emit by its own accord light peculiar to the material used (usually a green light). The screen is said to be fluorescent. Braun, prior to the year 1900, suggested a tube having a source of free electrons, which are sped up by an electrode, into a beam, and directed to a fluorescent screen. The beam is made to move over the screen influenced by the voltage to be analyzed,

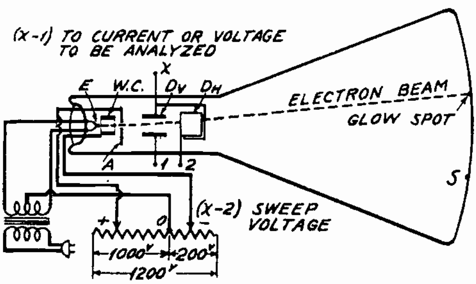

FIG. 23

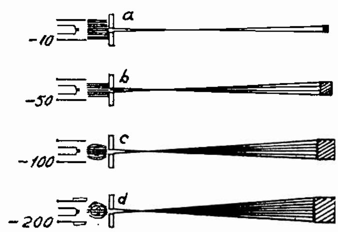

FIG. 24

and thus the wave form is traced. The beam will follow practically any variation regardless of its frequency, because it has negligible mass. In other words, the beam is a pointer of negligible weight. A modern cathode ray tube is nothing like the original Braun tube, even though the basic idea remains the same. Let us study the action of two modern cathode ray oscillographs.

The tube itself looks like a large glass funnel, totally closed, the air removed to a reasonable vacuum and in some cases a little argon gas introduced. Thus we have gas and vacuum type cathode ray tubes. The reason for the gas will be shortly explained. Although there are many types of cathode ray tubes, those used in the testers designed for servicemen may be considered as having: *1,* an electron emitter E (see Fig. *23*); *2,* an electron beam concentrator $W.C.$; *3,* an accelerating electrode or anode A; *4,* a vertical (up and down) set of deflecting plates D_V; *5,* a horizontal (side to side) set of deflecting plates D_H; and *6,* a fluorescent screen S. Although Fig. *23* shows one type of tube made and extensively used in the U. S. A., another popular make will shortly be considered in Fig. *27*.

The electron emitter *E* in Fig. *23* is a regular filament with its tip twisted or coiled, the tip covered with barium or strontium oxide which you should know emits electrons when heated. These small negative particles are drawn out by the anode *A* which is at a high positive potential, and the intensity of the beam (the space current) is increased by raising the anode or plate voltage. If the two sets of deflecting plates have no voltage difference applied, the beam will pass straight through the tube, impinge on the fluorescent screen (usually calcium tungstate) which then emits a green glow. The spot will be quite large and means are provided to control its size and brilliancy. This tube has a small amount of argon gas, which is ionized by the passage of the electrons. The freed electrons join the stream, leaving the heavy positive gas ions. Any of the electrons that stray from the beam combine with the positive ions, making neutral argon. Thus the beam is concentrated or held in a close bundle. The gas effect is fixed by the tube designer.

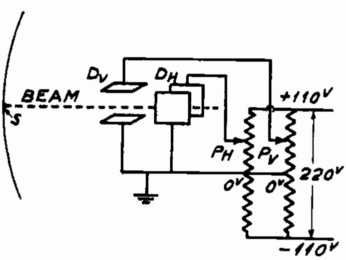

FIG. 25

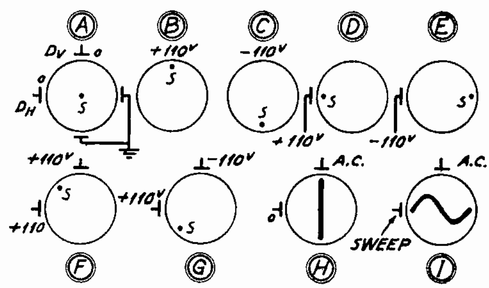

FIG. 26

The intensity of the beam may be increased by raising the anode voltage and such a control is often provided. To adjust the size of the spot a special electrode *W.C.* is introduced. It is a little cylinder which surrounds the electron emitters; its ends are open. Technicians call it a "Wehnelt" cylinder after its originator. This tube is made negative and the greater the negative charge the larger the spot and the greater the spot brilliancy. The negative charge converges the beam through the hole in the anode, as illustrated in Fig. *24*.

It was previously said that the deflecting plates are used to move the spot on the screen. Everything else said so far is primarily to obtain a sharp distinct spot on the screen. The deflecting plates do the work that makes the cathode ray tube so useful. Suppose a circuit as suggested by Fig. *25* is connected to the deflecting plates. If variable contacts P_V and P_H are placed at *0*, the electron beam will suffer no attraction or repulsion and the beam will impinge at the center of the screen as shown in Fig. *26A*. As P_V is adjusted to +110 volts, the spot will move upward and reach a maximum as shown in Fig. *26B*, because the electrons in the beam are attracted by the positive charged plate. If the upper plate is made negative by sliding P_V below *0*, then the spot will move down. Various positions are shown in Figs *26A to 26G* for various potentials on D_V and D_H, and the effects produced should be perfectly clear.

On the other hand, if a 60 c.p.s. voltage, 110 volts peak is connected to the D_V plates while no voltage is connected to the D_H plates, the spot will rapidly move up and down and appear as a line, as shown in Fig. *26H*. Because the up and down action is rapid, 60 complete cycles per second, a band or line instead of a movable spot as you might expect is seen. This condition exists because the eye cannot follow a change of more than 8 per second, although at least 15 changes per second are best for no flicker. This phenomenon is called persistence of vision. Now, with the 60 c.p.s. voltage applied to D_V, if you were to rapidly swing P_H from +110 to —110 in an irregular manner, by wiggling the knob, the spot which previously formed a straight line would also move sideways, and you would observe a series of confusing waves. But if you would produce a voltage that would rise uniformly from +110 to — 110, exactly 60 times a second, a single stationary cycle would appear

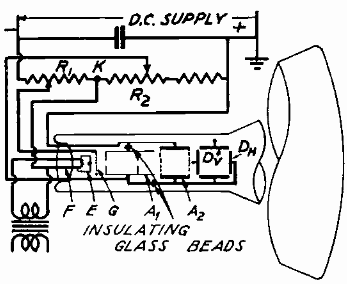

Fig. 27

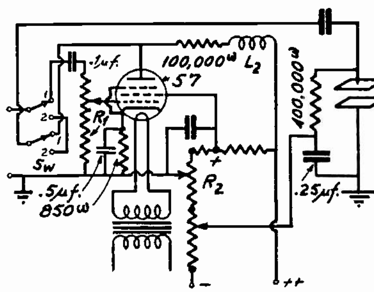

Fig. 28

on the screen as shown in Fig. *26I*. This uniformly rising voltage which is applied to D_H for the purpose of moving the spot sideways is called the sweep voltage and when the pattern stands still you have synchronized or locked the sweep voltage with the analyzed voltage which is applied to D_V. The method of producing the regularly changing sweep voltage will be discussed shortly, but now for a description of the other popular cathode ray tube.

Figure *27* shows a high vacuum cathode ray tube and the basic electrodes and controls. Again an electron emitter is used, but in this case a small ferrule with a recess covers the filament. Barium and strontium oxides are placed in the recess at *E*. The electrons are drawn out of the emitter by two anodes lettered A_1 and A_2. The latter are of special construction. They are two cylinders placed end to end. A_2 is larger than A_1. The first anode has two circular discs, one near each end. When these anodes are positively charged, they create an electrostatic field which bends the beam into a close bundle, and if either voltage is regulated the bundle of electron rays converge to a point on the fluorescent screen. This is referred to as electrostatic focusing and is quite often compared to a camera lens in action. Hence the anodes accelerate the electron stream and focus it to a point on the screen. Either anode voltage could be regulated, although A_1, which operates at a lower voltage than A_2, is usually controlled. R_2 in Fig. 27 is the focusing control.

The brilliancy of the spot is varied by the voltage applied to a circular disc with a centrally located hole called a grid placed near the electron emitter and between the latter and the first anode. By varying the negative bias (R_1 in Fig. 27) the space charge surrounding the cathode is aided or neutralized and the amount of electrons drawn over by the anode is under control. The vertical and horizontal deflecting plates are the same in action as for the first tube described.

Clearly the deflection of the spot on the screen from its center position is dependent on the voltage applied to the deflecting plates. In the average cathode ray tube made for service work the deflection is one

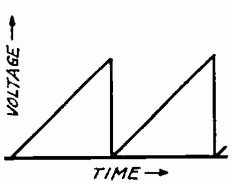

Fig. 29

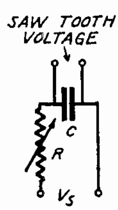

Fig. 30

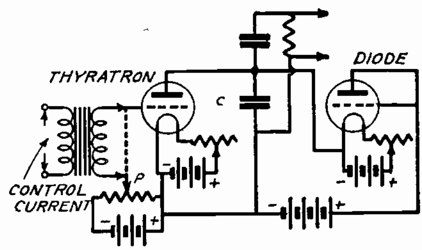

Fig. 31

inch for every seventy-five volts applied. As a matter of fact, this is the sensitivity rating of a tube. If the screen of the tube is about 1½ inches in radius, then voltages of 1.5×75 or 112.5 volts may be measured. If the spot could be initially moved down to the bottom by applying an initial 112.5 negative bias, then a voltage of 225 could be measured. As a rule, we want to measure A.C. voltages so we are limited to only one-half the total swing, or a peak value of 112.5 volts. Of course, deflections of ⅛-inch would be just about distinguishable, and this corresponds to about 10 volts. When we come to measuring the R.F. voltages in the I.F. stages, and the A.F. voltage at the output of the second detector of an ordinary receiver, especially when a small receiver input signal is applied, 10 volts is a large value. So some amplifying device is required in conjunction with the regular cathode ray tube.

To increase the sensitivity of the ordinary cathode ray tube, an amplifier for each pair of plates is needed. It is referred to as the horizontal or vertical amplifier, depending on which set of plates it feeds.

The usual amplifier is of the type shown in Fig. *28,* and contributes a voltage gain of about 40. With this amplifier the sensitivity of the cathode ray tube becomes 2 volts per inch, and voltage peaks of .25 volt are readily detected.

The circuit shown is one that is used in a popular cathode ray oscillograph tester. As you will recognize upon tracing the circuit, a resistance-capacitance coupler is used, the circuit designed to have linear amplification from 20 to 90,000 c.p.s. When switch *S.W.* is placed on contacts *1–1,* the amplifier is employed; when placed on contacts *2–2* the amplifier is not used. The potentiometer controls the degree of amplification, while R_2 is one means of shifting the spot for centering it on the screen.

To sweep the spot horizontally from left to right we need: *a,* a bias set the spot to the left (this is the usual practice); and *b,* a constant varying potential, as shown in Fig. *29,* which will rise in a regularly increasing manner from 0 to about 215 volts, then return to zero value immediately. Such a sweep voltage is called a saw-tooth voltage. The frequency of this saw-tooth wave should be variable from 15 to 20,000 c.p.s. for analyzing audio frequencies. Furthermore, whatever system is selected to produce this saw-tooth voltage should have some means of keeping it in step (synchronizing it) with the voltage or current we are analyzing.

A simple way of getting a fairly true saw-tooth voltage is to connect a condenser *C* and a resistor *R,* as shown in Fig. 30 to a D.C. supply. The condenser charges up, the process limited in time by the presence of resistor *R.* The rising voltage is tapped off of *C.* The time to reach about 60 per cent of the applied voltage is determined by the time constant of *RC* (*C* in microfarads times *R* in megohms). By varying either *R* or *C* the time to reach this value may be controlled. Now we must introduce an automatic condenser shorting switch to stop and start the process over and over again.

The solution to this problem is to be found in the modern gas triode, otherwise known as the thyratron or grid glow tube. When shown in a circuit diagram this tube is not distinguishable from an ordinary heater type triode, although the cathode is designed quite differently to withstand heavy bombardment of the gas ions produced. What is its unusual behavior which permits it to be used as an automatic switch? Assume first that it is connected in the usual way and with a fixed *C* bias. As the plate voltage is raised from zero, the plate current remains at zero until a critical plate voltage is reached. Then the plate current rises sharply and the plate-cathode resistance becomes very low. Now when the plate-cathode of a gas tube is connected to the charging condenser, the latter will be shorted at the critical voltage which is supplied by the condenser. What has the grid bias to do with this critical voltage? An important effect. If the grid bias is raised, so is the critical breakdown plate voltage; if it is lowered, then the critical breakdown voltage is lowered. Furthermore, once the breakdown takes place, the grid has no further control on the plate current until the next cycle starts.

A basic control and sweep circuit is shown in Fig. *31*, following the ideas just outlined. Condenser C is charged by battery B (or some D.C. supply) through the diode which is nothing more than a variable resistor, whose ohmic value is controlled by its filament current. The diode and the condenser control the basic frequency of the sweep. If the bias control P is varied so the negative bias is increased, it takes a larger plate voltage to break the tube down, consequently, the amplitude across C is increased and the frequency of operation is reduced. The peak voltage is limited by the D.C. supply. Furthermore, if the gas tube circuit is only

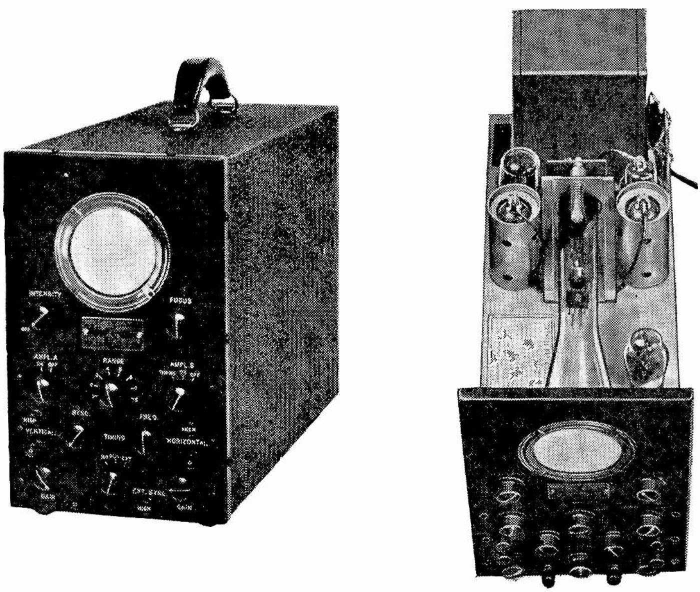

FIG. 32

adjusted for an approximate frequency (usually by adjusting its bias and plate voltage and altering the condenser capacity, the plate load resistor), the frequency of oscillation of the saw tooth voltage may be stabilized or synchronized exactly, by introducing into the grid bias circuit a small amount of the signal voltage to be analyzed. The sweep frequency is then controlled by the applied signal, all other factors essentially controlling the sweep voltage amplitude.

It should be mentioned that the diode in Fig. *31* is used as an automatic variable resistor that serves the same purpose as R in Fig. *30* to make the sweep voltage curve more linear than using a wire wound resistor. Usually an R.F. pentode is employed, the cathode and plate acting as the terminals of what is called a saturated tube resistance, and its value of resistance controlled by varying the C bias applied to its grid. In other cases a tube type resistor and a regular resistor are used together, the latter variable.

The modern cathode ray oscillograph, a practical portable type as shown in Fig. *32,* is nothing more than a compact assembly of the cathode ray tube, amplifier and sweep circuits each with the essential controls. In general, the voltage, or voltage obtained across a series
10 resistor representing the current to be analyzed, is connected to the vertical plates, and when synchronization is obtained a true picture of the wave is seen. By using a wire or transparent ruled paper screen over the end of the cathode ray tube, current and voltage measurements are readily made.

TEST QUESTIONS

Be sure to number your Answer Sheet 28FR-2.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your course, and the best possible lesson service.

1. How is a practical measuring instrument calibrated?
2. What is an ammeter made to indicate 1/1000 of an ampere called?
3. How may the range of an ammeter be extended?
4. If a meter has been extended five times, how would you mentally read the meter scale?
5. Would you use a hot-wire or thermocouple meter to measure R.F. currents of less than 20 milliamperes?
6. For measurements of A.C. power currents where precision of 2 per cent or better is required, would you use a copper oxide rectifier or magnetic vane ammeter?
7. Draw the circuit diagram of a basic A.C.-D.C. milliammeter circuit incorporating a copper oxide rectifier.
8. If a copper oxide rectifier meter is calibrated on sine wave currents, what accuracy would you expect when measuring A.C. currents having distorted wave forms?
9. What instrument is used when it is important to see the current wave form?
10. Is the voltage representing the current to be analyzed applied to the vertical or horizontal plates of a cathode ray oscillograph?

VOLTAGE MEASURING DEVICES AND THEIR USE

29 FR-1

PIONEER HOME STUDY RADIO SCHOOL

NRI

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

"WISHERS" AND "DOERS"

How often have you said, "I wish I had more money?" Thousands of times, possibly. But do you realize that if you are living in a town of, let us say, 5,000 inhabitants, there are exactly 4,999 others in your town who have said exactly the same thing about the same number of times?

And yet of these 5,000 "wishers," only about 100 are going to do something about it. The others are going to continue being "wishers."

Now, any man who shows enough "get-up-and-go" spirit to undertake this Course proves that he is not a mere "wisher." When you enrolled you showed that you wanted to be a "go-getter." Your job now is not to yield to the temptation to relax. You must spur yourself to new efforts every day—to new achievements. You must keep going forward on the Road you have mapped out for yourself.

Every lesson in this Course, every Radio job you have to work hard to get, is a step along this Road. So don't let yourself wish that the lessons were easier, or that you could become successful without studying, or that Radio jobs would come looking for you.

Stay out of the class of the "wisher" and stay in the class of the "Doer."

Don't forget that the "wisher" is a very unhappy individual because he is constantly thinking and worrying about what he does not have. The go-getter is so busy getting what he wants that he doesn't have time to be unhappy.

J. E. Smith.

WASHINGTON, D.C.

Revised 1932, 1933

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Voltage Measuring Devices and Their Use

VOLTMETERS

The voltage across any resistance can easily be determined if we know the current through the resistance and the value of the resistance. From Ohm's law, voltage is equal to current multiplied by the value of the resistance. Thus we have a direct method of calculating the potential difference (P.D.) between any two points in a circuit, regardless of the kind of voltage, D.C., or A.C. of any frequency, provided always there is no source of e.m.f. connected within the two points.

From all of this we can derive a very simple method of measuring voltage—that is, by placing a known resistance in series with a calibrated milliammeter, across the voltage difference to be measured.

Fig. 1 shows a supply delivering current to a load. It can be any kind of a supply delivering current to any kind of a load—a motor, a resistance or a resonant circuit. Naturally there is a voltage across the load. Let us say we want to measure it. Its resistance or impedance is not known; therefore an ammeter in series with it would not enable us to compute the voltage. However, by placing between the two terminals whose P.D. is to be measured, a known high resistance in series with a milliammeter, we can obtain sufficient information to compute the P.D. Of course a D.C. milliammeter must be used for D.C. voltages and an A.C. milliammeter for A.C. voltages.

We know that the voltage across the load is the same as the voltage across the resistance R in series with the milliammeter. But we know the value R, and our meter will indicate the value of the current I. The voltage is simply $I \times R$.

A voltmeter is nothing more than an arrangement of this sort. Sometimes you hear a voltmeter referred to as a "potential galvanometer" because all it amounts to is an ammeter used to measure potential differences.

Any milliammeter may be used as a voltmeter, provided the combined resistance of the meter and the external known resistance is high enough to prevent all but a negligible amount of current flowing between the two terminals from being "sidetracked" through the meter. When measuring D.C. potentials, a D'Arsonval type of ammeter is used. When measuring A.C. voltages, an electrodynamic ammeter is usually used, although magnetic vane types of instruments may be used. For audio frequency voltages, a thermocouple or oxide rectifier ammeter is frequently used, while for measuring R.F. voltages a hot wire or thermocouple milliammeter is commonly used. These various types of voltmeters will be discussed separately in the following pages.

D.C. VOLTMETERS

One of the most important things to remember in connection with voltmeters is that, when a voltmeter is connected across two terminals, the voltage across them is not the same as it was before the voltmeter was connected. A consideration of a resistance load with a definite value of current flowing through it as in Fig. 2 will show why this is true. Let us say the load is a 1,000 ohm resistance and there are 100 milliamperes flowing through it—that is, the meter A indicates .1 amp. The P.D., from Ohm's law, should be .1 × 1,000 or 100 volts.

But suppose a voltmeter having a resistance 5,000 ohms

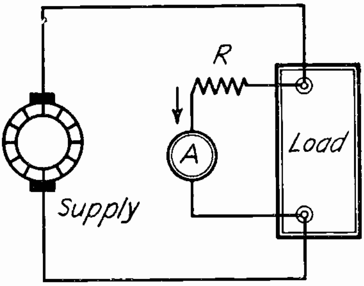

Fig. 1

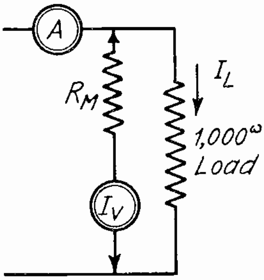

Fig. 2

is connected across this load. What will be the voltage across the load? We are going to assume that the current has not changed—that A still reads .1 amp. This current divides between the voltmeter and the load, 5/6 of it going to the load and 1/6 through the voltmeter. Then $V = 1/6 \times 5{,}000 \times .1 = 83.3$ volts—and our reading is approximately 17 per cent off.

On the other hand, if the voltmeter had a resistance of 100,000 ohms, the part of the total current going through the load would be equal to 100 ÷ 101 and the part through the voltmeter would be 1 ÷ 101. In this case $V = \frac{1}{101} \times 100{,}000 \times .1$ or 99.1 volts and the error is less than 1 per cent.

Now what does all this mean to us? It means simply that for close voltage measurements, our voltmeter should have an extremely high resistance in comparison to the resistance of the circuit in which the potential difference is being measured.

A voltmeter of the type commonly used by Radio-Tricians for measuring D.C. voltages is shown in Fig. 3a. This is a portable type of voltmeter. The panel type of voltmeter is illustrated in Fig. 3b. Meters of this sort are designed for use in measuring voltage across voltage dividers of power packs and C bias resistors and are designed to have a resistance of 1,000 ohms for every volt on the scale.

You will note in Fig. 3c that the voltmeter has four terminals, one marked minus (–), one +10 volts, one +250 volts and the other +750 volts. The (–) terminal is a common terminal. Thus connecting two points of a circuit whose potential difference is to be measured across this terminal and the +10 terminal, we can read voltages up to 10 volts. Between (–) and +250, we can measure up to 250 volts. And between (–) and 750 we can read up to 750 volts.

FIG. 3a

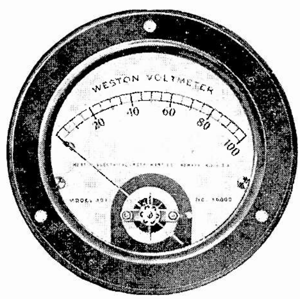

FIG. 3b

2 When the 0–10 volt scale is used, the voltmeter resistance is 10 × 1,000 or 10,000 ohms; when the 0 – 250 volt scale is used, the resistance is 250,000 ohms and, for the 750 volt scale, the resistance is 750,000 ohms. For every volt in the range there is a resistance of 1,000 ohms. By using Ohm's law we can immediately see that the meter is a 1 milliampere (.001 amp.) meter, for:

$$.001 \times 250{,}000 = 250 \text{ volts, etc.}$$

The voltages read with a meter of this type would be only 1 per cent off if the resistance of the load across which measurements are taken was 1/100 the resistance of the meter. Therefore, to maintain this degree of accuracy for the various scales, the 0–10 scale should not be used when measuring across loads greater than 100 ohms; the 0–250 range should not be used when measuring across loads greater than 2,500 ohms and the 0–750 range should not be used on loads greater than 7,500 ohms. Incidentally, a typical, well-made, modern voltmeter is guaranteed to be accurate within 2 per cent when measuring voltages of the order of 100^{v}—that is, if the meter reads 98 or 102 volts, the meter is as accurate as it is guaranteed to be.

Knowing this, you can easily see why it is not correct to measure the voltages across very high resistances, such as detector resistors, C bias and plate resistors, with a voltmeter of this type.

Anyone can adapt a milliammeter for use as a voltmeter by the use of the proper external resistance.* For best results a 0–1 milliammeter is used, having a resistance between 10 and 15 ohms. Its scale should preferably be divided into 100 divisions. Now suppose we wish to read 0–10 volts. What is the value of the resistance we shall have to use with it?

When placed across 10 volts a current of 1 milliampere must pass through it for full scale deflection. Then the required voltmeter resistance will be calculated from the formula $R = \frac{E}{I}$

3 In this case $R = \frac{10}{.001}$ or 10,000 ohms. As the meter has only 10 or 15 ohms resistance, this can be overlooked and the external resistance may be made exactly 10,000 ohms. However, should the meter resistance be above 15 ohms, say for example 500 ohms, it would not be negligible and the external resistance would have to be in this case (10,000-500) 9,500 ohms.

If the voltmeter is to read from 0–250 volts, the external resistance would be (neglecting the meter resistance) $R = \frac{250}{.001}$ or 250,000 ohms. If we already have a 10,000 ohm resistor connected to the 10 volt terminal, we can connect a 240,000 ohm resistor in series with this as shown in Fig. 3c (resistor R_{250}.) Then the additional resistor is called a *multiplier*. In Fig. 3c, three multipliers are shown — R_{10} = 10,000 ohms; R_{250} = 240,-000 ohms, and R_{750} = 500,000 ohms. All these resistors are standard precision devices. With the use of these multipliers the meter has three scales, a 0–10 scale in which case each main division represents 1 volt, a 0–250 volt scale in which case each main division represents 25 volts, and finally a 0–750 scale in which each main division represents 75 volts.

It is essential when using multipliers to measure high volt-

* By the use of the proper shunts and multipliers, a single 0–1 milliammeter can be made to measure various ranges of current and voltage.

ages that the resistance be not concentrated in one bobbin as in Fig. 4, but that it be spread out—and for this purpose several bobbins in series are used. This makes it easier to insulate the resistance wires from each other.

In order to prevent moisture from entering the coils, they are boiled in wax. And to prevent sparking when the terminals of the voltmeter are removed from the circuit under test, the resistances are non-inductively wound. This is accomplished by winding two wires, side by side, from two different spools. The resistance is started by cleaning the insulation from the end of both wires at one end and soldering them together. Then the correct amount of wire is wound on the form and the two open ends form the terminals of the multiplier. The resistance, of course, is twice the resistance of one length of wire.

Very similar construction methods are used in building non-inductive resistance units for A.C. voltmeters.

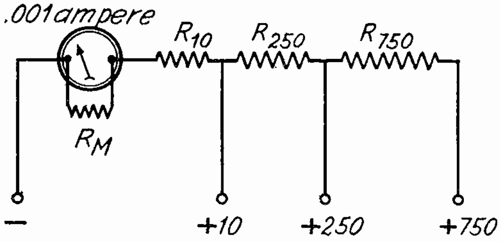

Fig. 3c

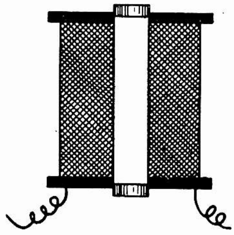

Fig. 4

ELECTRODYNAMOMETER VOLTMETERS (A. C.)

The A.C. voltmeter is basically an A.C. milliammeter. There are several types of A.C. milliammeters that may be used, but the most desirable for accurate measurements is of the electrodynamic type. Here we meet new problems, for the electrodynamic meter has inductance besides resistance and this must be taken into consideration in calculating the series resistance required.

When a resistance is placed in series with an inductance, the voltage across the system is equal to:

$$V_M = I_M \times \sqrt{R^2 + (2\pi f L_M)^2}$$

where V_M is the voltage across the arrangement

I_M is the current through the voltmeter indicated by the milliammeter

L_M is the inductance of the meter
R is the resistance of the voltmeter and the multiplier's resistance (non-inductive)

In the formula the expression $2\pi f L_M$ is the reactance of the milliammeter, and, if it can be made small in comparison with R, we can neglect it. In the design of an A.C. voltmeter, this is always made as small as possible.

An electrodynamometer milliammeter designed to have very little inductance may be connected in series with precision multipliers. However, instruments of this kind are expensive and are not used for ordinary radio work. They are generally used in laboratories and wherever precision is essential.

In radio work for measurement of A.C. power supplies, A.C. voltmeters having comparatively low sensitivity are used. The D.C. permanent magnet voltmeter discussed in the previous pages has a sensitivity of 1,000 ohms per volt. A typical precision electrodynamometer voltmeter designed to read from 0 to 300
4 volts has a total resistance of approximately 6,600 ohms—that is, a sensitivity of 22 ohms per volt. And so measurements cannot be made on high resistance loads without considerable error. While satisfactory for measuring filament and line voltages, these instruments are not sufficiently accurate for high voltage measurements across power pack transformers.

Electrodynamometer voltmeters are suitable only for low frequencies—up to about 150 c.p.s. Beyond this frequency the inductance, the resistance, eddy currents and capacity effects in the coils alter the calibration and readings are not reliable.

Fig. 5 shows a typical electrodynamometer voltmeter of the precision type. This instrument is shielded from external magnetic disturbances and the needle is damped. The moving coil system is attached to a fan-shaped aluminum disc which revolves between two permanent magnets. The eddy currents that are induced in it tend to keep the needle deflection steady.

A.C. voltmeters are built to measure up to 750 volts r.m.s. Where higher voltages must be measured, a step-down "potential" transformer is universally used.

MAGNETIC VANE VOLTMETERS

A magnetic vane voltmeter is nothing more than a magnetic vane milliammeter in series with a known resistance. However, the presence of iron in the center of the solenoid affects the inductance of the milliammeter considerably. Therefore instruments of this type are calibrated at known A.C. voltages of a certain frequency and are designed only for use at that frequency. In general, however, it is true that a 60 c.p.s. meter may be used with frequencies from 25 to 130 c.p.s. with little error.

Moving vane voltmeters for high voltage measurements are

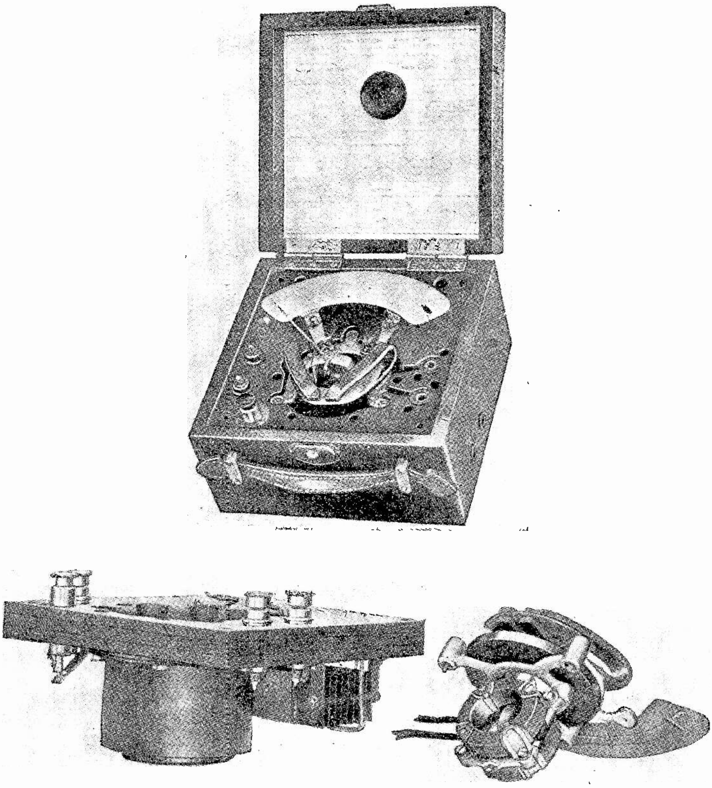

Fig. 5

fairly sensitive. A typical A.C. voltmeter of this type commonly used in radio work is shown in Fig. 6. A 0–4 A.C. voltmeter has a sensitivity of 10 ohms per volt; a 0–300 voltmeter has a sensitivity of 166 ohms per volt.

In cases where meters of this type are designed for sensitivity at large voltages, the exciting solenoid is wound with many turns of wire. For very high voltages a step-down transformer is used.

The A.C. voltmeters in most set analyzers are of the magnetic vane type. It should be remembered that they are not intended for use as D.C. voltmeters. Furthermore, they are intended to measure voltages only at commercial power frequencies.

COPPER OXIDE A.C. VOLTMETERS

A copper oxide milliammeter, in series with one or more known resistances, provides a valuable A.C. voltmeter. This type of instrument is used chiefly for measuring A.C. voltages where great sensitivity is desired. It consists of the copper oxide rectifier system arranged in a diamond (bridge) formation, feeding a sensitive D.C. microammeter connected across the bridge. The other two ends of the diamond, in series with a

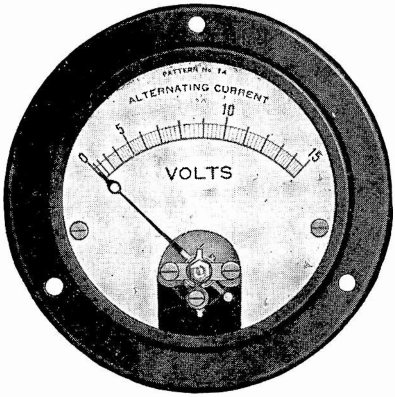

Fig. 6

resistor or resistors, connect across the load whose potential difference is to be measured. A typical arrangement is shown in Fig. 7. With properly chosen multipliers connected as shown, the device would measure voltages from 0–900 in convenient steps. For radio work this type of A.C. voltmeter is replacing all other types.

For ordinary frequencies, 25 to 500 cycles, the impedance of the milliammeter system is negligible and the series resistances merely serve to drop the voltage across the milliammeter bridge arrangement to a given value. As the A.C. current being measured is full-wave rectified as shown in Fig. 8, the D.C. microammeter reads the average value of the half sine wave. Therefore calibration should be made with the use of pure sine wave generators and not on ordinary A.C. unless it is known to have a sine wave. Voltages read with an instrument of this sort are always r.m.s.

Although instruments of this type are very sensitive, they are subject to considerable error. As they are calibrated on pure sine waves, the presence of harmonics in the current being measured will tend to throw the readings off. Then, too, the rectifying property of the copper oxide element decreases with increasing frequency at the rate of 1 per cent for every 2,000 c.p.s. And the rectifier is affected by room temperature. However, if the wave form of the current being measured is a fairly pure

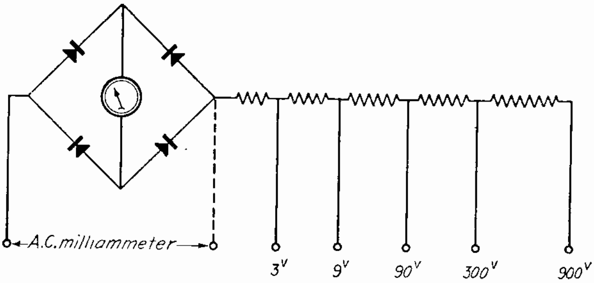

FIG. 7

sine wave, accuracy will be within 5 per cent of full scale reading.

A sensitivity of 1,000 ohms per volt is possible with this type of meter.

By a simple switching arrangement the D.C. meter can be disconnected from the rectifying system and used for D.C. measurements. In this case a different scale will have to be used, or a

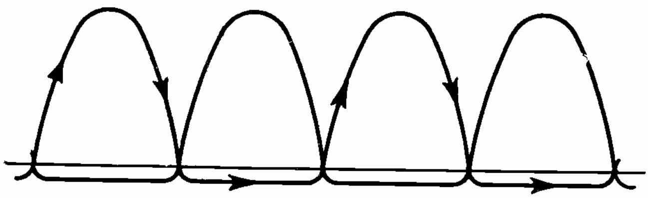

FIG. 8

resistance must be placed in shunt with the meter to compensate for the r.m.s. calibration.

THERMOCOUPLE VOLTMETERS

When it is required to make exact measurements of A.C. voltages at audio or radio frequencies, the thermocouple voltmeter is the best device to use. A voltmeter of this type is simply a thermocouple milliammeter in series with a non-inductive, non-capacitive resistance which limits the current flow through the meter to a value sufficient to provide full scale deflection.

For R.F. and A.F. measurements, a thermocouple milliammeter is generally used without any multipliers and the voltage is measured in the following manner: The meter is placed in series with the resistance load across which the voltage drop is to be measured—the value of the resistance must be known. By multiplying the value of current flowing by the resistance of the load, the voltage can be determined. If the square of the current measured is multiplied by the resistance, the power output is obtained.

The meter is calibrated in milliamperes for convenience and voltages must be calculated. A meter of this sort is especially useful for measuring hum output or the signal output of power audio tubes. The connections for this purpose would be as shown in Fig. 9.

Radio men who do considerable experimental work usually find it advisable to invest in a thermocouple milliammeter having a range of 0–120. There are available several instruments of this type that are accurate to within 2 per cent on all frequencies ranging from commercial A.C. to radio frequencies. The resistance of these instruments is around 5 ohms. Then an r.m.s. voltage of .6 volt ($.120 \times 5 = .6$ volt) will give full scale deflection.

For exact laboratory work where R.F. voltages of the order of a few millivolts must be measured, microammeters must be used. Fortunately, suitable microammeters are available, and these, too, work on the principle of the thermocouple.

HIGH VOLTAGE MEASUREMENTS

Where potentials of 2,000 volts and more are to be measured, it is general practice to use capacity (electrostatic) voltmeters.

Although voltages this high are seldom used in ordinary radio work, it is well worth understanding the underlying principles of the devices used to measure them.

As you know, when a condenser is charged, one plate is positive and the other is negative. You also know that opposite charges attract. And here you have the principle of the electrostatic voltmeter, as illustrated in Fig. 10.

The force existing between the two plates, one fixed, the other movable and attached to the indicating needle, depends on the voltage and the capacity of the attracting system.

Voltmeters of this type are calibrated by means of voltages whose r.m.s. values are known.

In Fig. 10, terminals T_1 and T_2 are for low range readings. The multipliers used to extend the range are condensers. For each multiplier a separate calibration is necessary.

One big advantage capacity voltmeters have is that they

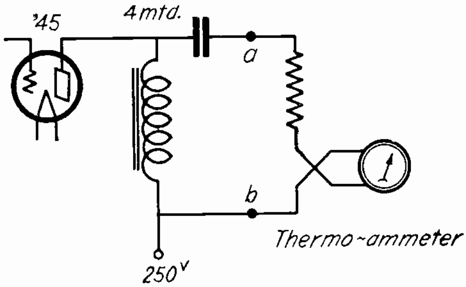

FIG. 9. For exact power measurements the resistor in series with meter should equal the recommended load for the tube whose output is measured. For relative output indication a value of 2 to 4 thousand ohms will suffice in most cases.

require little or no current after the initial deflection and they eliminate the necessity for step-down potential transformers. They may be used for A.C. or D.C. measurements over wide frequency ranges.

It might be mentioned that extremely delicate capacity voltmeters for low voltage work have been built, but their use is confined to laboratory work.

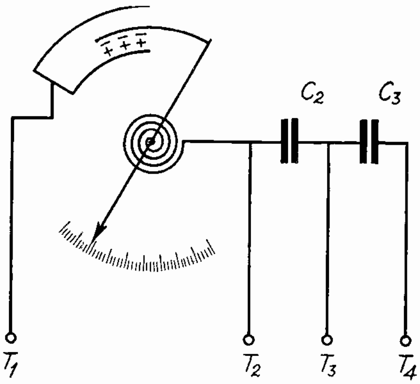

FIG. 10

Another device for the measuring of extremely high voltages, of the order of 10,000 to 200,000 volts (10 to 200 kilovolts), makes use of a spark gap. For voltages from 50 kv. to 200 kv. the spark gap consists of two spherical brass electrodes. The distance between the spark gap at the break-down point can be measured and the voltage determined from a calibration curve.

Then corrections for certain weather conditions, temperature, and humidity should be made for closer results.

Devices of this sort fill a practical need in the making of insulation tests. Extremely high voltages are required—higher than can be measured by the ordinary voltmeter. In practice the gap is adjusted so that it will break down at a certain high voltage. Then the voltage is stepped up by means of transformers until the gap breaks down, which is then an indication that the voltage is sufficiently high for use in testing insulation and dielectric resistance.

The spark gap breaks down at the peak voltage and not the r.m.s. Remember that the peak voltage is 1.41 times the r.m.s. value.

For voltages between 10 and 50 kv., a spark gap of which the electrodes are two No. 00 sewing needles may be used. When these are 11.9 millimeters apart, the gap will break down when 10 kv. are impressed across it. When break-down occurs with the electrodes 41 millimeters apart, 30 kv. are indicated; and when 118 millimeters apart, 60 kv. are indicated.

HOT WIRE AND OSCILLOGRAPH VOLTMETERS

The universal practice of using non-reactive resistors in series with a milliammeter for voltage measurement applies also to the hot wire milliammeter and the oscillograph milliammeter when used for voltage readings. When the reactance is negligible, the voltage V is always equal to $I_a \times (R_m + r_a)$—that is, the sum of the ammeter and the multiplier resistance multiplied by the current through them. Remember this fundamental rule and you will never have any difficulty in determining the proper type of voltmeter to use for any particular purpose.

The hot wire milliammeter in a voltmeter arrangement is used for the same purposes as the thermocouple voltmeter—for audio and radio frequency measurements. Voltmeters of the hot wire type, however, are much less expensive than thermocouple voltmeters, and for this reason they are used much more extensively in ordinary servicing work.

Voltages can be photographed or actually "seen" by the use of a sensitive oscillograph galvanometer in series with a pure resistance.

Neither the hot wire nor the oscillograph voltmeter requires a more complete discussion here than has been given, for in a previous lesson we studied the hot wire ammeter and the oscillograph galvanometer in detail. Their adaptation for use as voltmeters requires merely that they be connected across the potential difference, in series with a known resistance.

It should be perfectly clear by this time that most voltmeters and ammeters are current indicating devices; the only difference is that one is calibrated to read in volts, the other in amperes.

VACUUM TUBE VOLTMETERS

One of the most valuable devices for use in radio laboratories and at the service bench is the vacuum tube voltmeter, often called the "thermionic" voltmeter. It is as important a piece of equipment as the thermocouple milliammeter.

The great advantage of the vacuum tube voltmeter is that it draws negligible current from the circuit in which a potential difference is being measured, which makes it especially valuable for measuring voltages in the grid circuits of R.F. ampli-

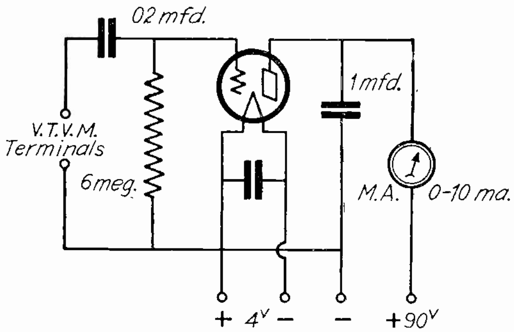

Fig. 11a

fiers, or voltages across resonant circuits having extremely small current outputs. The ordinary V.T.V.M. (vacuum tube voltmeter) will read A.C. voltages over a range of 0 to 12 volts. On the other hand, voltmeters of this type can be made to read 1 or 2 microvolts, and by the use of shunts they can be used to indicate current values. Just recently announcement was made of the development of a V.T.V.M. that will measure a current flow as small as 60 electrons per second. The sensitivity of this device can be appreciated if we recall that sixteen million, million, million electrons flowing through any cross-section of a wire per second constitute only one ampere of current flow.

6

Basically the V.T.V.M. is an A.C. detector tube operated with a *C bias* or a *grid leak-grid condenser* control. The grid leak type is more sensitive than the C bias type of V.T.V.M.—it may be adjusted to read from a few microvolts to 7 or 8 volts.

Fig. 11a shows the schematic diagram of a typical *grid leak-grid condenser* V.T.V.M. In operation the filament is kept at 4 volts in order to prolong the life of the tube. The filament voltage is kept constant by means of a filament ballast or by manual adjustment (a rheostat and a D.C. voltmeter).

While the V.T.V.M. circuit shown in Fig. 11a is not extremely sensitive, it is quite rugged and extremely useful.

A V.T.V.M. is usually calibrated on 60 cycle current by the drop wire method. A toy transformer with a 110 to 10 volt step-down is used to supply the calibrating potential. Across the secondary is connected a low resistance potentiometer. Between the slider contact of the potentiometer and one of the other terminals is connected a 0 to 10 volt r.m.s. 60 cycle voltmeter. See Fig. 12. The V.T.V.M. to be calibrated is connected to the two free terminals. Then by adjustment of the potentiometer arm, the voltage fed to the V.T.V.M. can be changed in known steps, and for each voltage, the plate current of the tube is noted and recorded. A calibration curve is then made from the recorded values as shown in Fig. 11b.

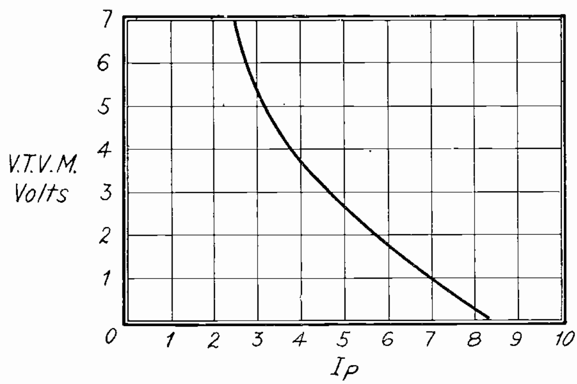

FIG. 11b

Notice the low plate current when high A.C. voltages are measured. The explanation of this is that as the A.C. voltage applied to the grid swings positive, electrons are drawn to the grid. During the negative swing the electrons which have not escaped make the negative swing greater than it would be normally. This causes the plate current to drop and results in a decrease in the average plate current. The grid leak is provided to allow the extra electrons to leak off.

In very sensitive V.T.V.M.'s, microammeters are used to

measure the plate current. In this case it is very important that the D.C. component of the plate current be balanced out so that the microammeter records only current changes. The manner in which this is accomplished is shown schematically in Fig. 13. The meter used is a 0 to 100 microammeter. A shunt should be
7 used in connection with this meter to make it less sensitive until the steady plate current is exactly balanced out.

A 0 to 8 D.C. voltmeter is necessary for checking the fila-

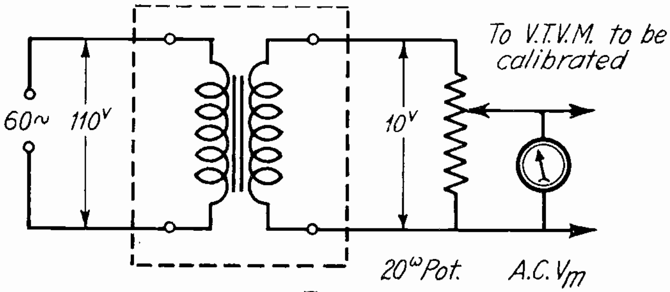

FIG. 12

ment voltage which should be kept always at constant rated value. A 45 volt B supply is used, connected through the meter in the plate return. Between the $B-$ and the $A+$ connections there are a variable 10,000$^{\omega}$ resistor, a 10,000$^{\omega}$ fixed resistor and a 400$^{\omega}$ variable resistor. This arrangement supplies a voltage which bucks the plate voltage and provides a means of balancing out part of the D.C. plate current.

The variable resistors are adjusted so that with no A.C.

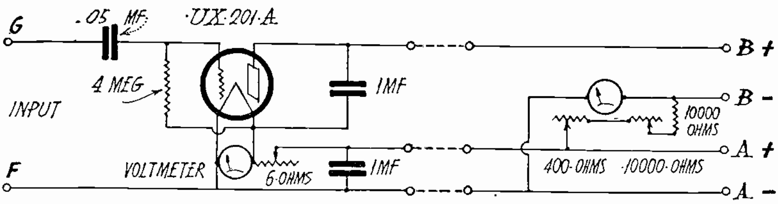

FIG. 13

applied to the input of the device and with a shunt connected across the meter, approximate zero microammeter reading is obtained. Then the shunt is removed from the meter and the 400$^{\omega}$ variable resistor adjusted so that the microammeter reads exactly full scale, in this case 100 μa.*

* If the meter is adjusted originally to zero, actual calibrations and readings should be made with the meter terminals reversed. Otherwise the meter will read down-scale.

After most of the D.C. plate current has been balanced out in this way, the V.T.V.M. is ready for calibration. This should be done by the use of known A.C. voltages. The same arrangement is used as in Fig. 12 except that a fixed drop wire is connected between the vacuum tube voltmeter and the low voltage side of the transformer. Fig. 14 shows the details. Notice the 100 ohm resistor in series with a 900 ohm resistor. Of course the voltage across the smaller resistor will be 1/10 the total voltage—that is, 1/10 of a volt if the total voltage is 1 volt. A 1 ohm resistor in series with a 999 ohm resistor will (a 1000^{ω} resistor will be satisfactory) reduce the voltage to .001 volt.

Naturally, as the grid swings positive, some grid current will flow and the measurement of terminal voltages will be slightly affected. For ordinary purposes, however, the current drawn is negligible. The calibration curve will be like Fig. 11b.

Where it is absolutely essential that the grid shall draw no

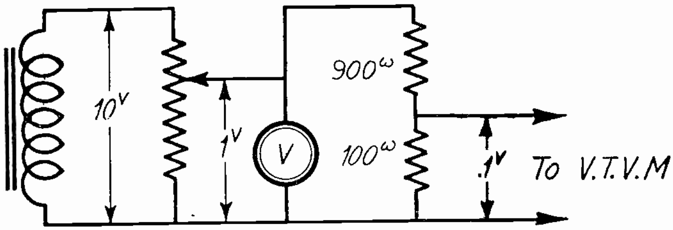

FIG. 14

grid current, the *C bias type* of tube rectifier is used. Fig. 15 shows how the apparatus used in Fig. 13 can be adapted for use as a C bias V.T.V.M. In order to prevent grid current flow, the bias must always be greater than the peak value of the voltage being measured. It is always safe to assume that the C bias should be 1½ times the r.m.s. value of the measured voltage. For example, if we want our V.T.V.M. to measure up to 4 volts r.m.s., the C bias should be 1.5 $\times$ 4 or 6 volts. In this case the bucking adjustment is made so the meter reads *zero* when no A.C. voltage is applied to the V.T.V.M. The calibration curve will show increased plate current as the applied measured voltage is increased.

Higher voltages may be measured by using larger grid biases and larger plate voltages. The relation of C bias voltage to plate voltage should always be such that the tube operates at the point of greatest curvature of its E_g-I_p characteristic. The use of less sensitive meters as shown in Fig. 11a will increase the range up to the limit set by the bias voltage.

The range of a V.T.V.M. may be extended by using a drop wire * as shown in Fig. 16. A 99,000 ohm non-inductive, non-capacitive resistor is placed in series with another resistor of 1,000 ohms. The V.T.V.M. is connected across the 1,000 ohm resistor while the terminals 1 and 2 are connected to the termi-

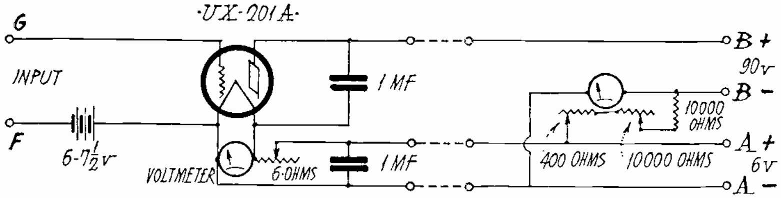

Fig. 15

nals at which the voltage is to be measured. If the V.T.V.M. normally reads up to 10 volts, with the drop wire the range will be extended 100 times (100,000 ÷ 1,000) ; that is, it will now read up to 1,000 volts.

If in any A.C. circuit there is a resistance, whose ohmic value is known at the frequency of operation, the current through that circuit may be measured with a V.T.V.M. by measuring the

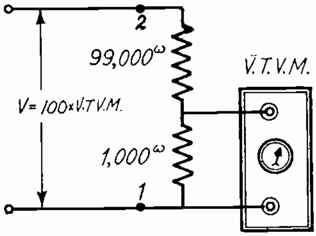

Fig. 16

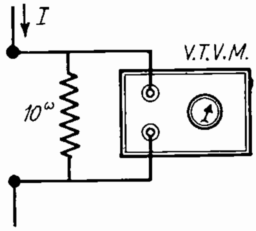

Fig. 17

voltage across the resistance in the circuit and calculating the current by Ohm's law. A known resistance may be introduced if it does not materially alter the circuit condition. For example, if a sensitive V.T.V.M. is shunted across a 10 ohm resistor in the circuit, as in Fig. 17, and a reading of .01 volt obtained, the current in the circuit will be from Ohm's law I = .01/10 or .001 ampere.

If vacuum tube voltmeters are properly by-passed, they can be safely used to measure voltages at either audio or radio frequencies with little error, even though they were originally calibrated at 60 cycles.

* Another expression for a voltage divider.

MEASURING RESISTANCE

If a voltage of known value is connected across a resistor whose value is not known, and the current through the resistance is measured, the resistance in ohms can be calculated from Ohm's law. See Fig. 18a for the set-up. A D.C. supply is used, and the meters are also D.C. instruments. It is not essential that the voltmeter have a very high resistance or that the ammeter have a very low resistance if the proper corrections are made.

It should be noted in Fig. 18a that the voltmeter does not read the true voltage across the resistance although the ammeter does read the correct value of current flowing through it. The true voltage across the resistor is equal to $V-(I \times R_1)$; that is, the voltmeter reading minus the current through the meter multiplied by the meter resistance. Of course, if the meter

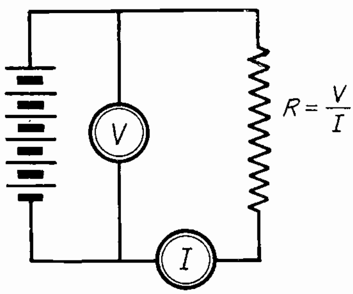

FIG. 18a

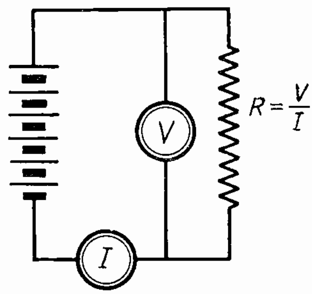

FIG. 18b

resistance is known, it is possible to measure the total voltage drop across R and the meter, calculate the total resistance, and subtract the resistance of the ammeter. To make the necessary corrections the resistance of the ammeter will have to be known or measured. Then the value of the unknown resistor will be the total resistance, calculated from the voltmeter reading, minus the ammeter resistance.

An alternate method of measuring resistance is shown in Fig. 18b, where the voltmeter is connected directly across the unknown resistance and the ammeter is placed next to the voltage supply. In this case the voltage reading will be the true voltage across the resistor, but the ammeter will not read the true current through the unknown resistor for the voltmeter is in parallel with it. That is, the ammeter will read the current through the resistor plus the current through the voltmeter To find the true current, subtract the voltage reading divided by the voltmeter resistance from the ammeter reading. In other words, the true $I = I_{AM} - \frac{V}{R_{VM}}$.

Most voltmeters have a resistance of from 200 to 1,000 ohms per volt. If you are using the 10 volt scale of a 200 ohm per volt meter, the voltmeter resistance will be this factor multiplied by 10—in the case mentioned, 200×10 or 2,000 ohms.

The resistance is always the true voltage across the resistor divided by the true current through it.

In Fig. 18a, if a low resistance ammeter is used, the error is negligible and correction is not necessary. In Fig. 18b, if a high resistance voltmeter is used, the error will be negligible and correction unnecessary. When both low resistance ammeters and high resistance voltmeters are used, either connection 18a or 18b may be used and corrections are unnecessary.

For measurement of widely varying values of resistance,

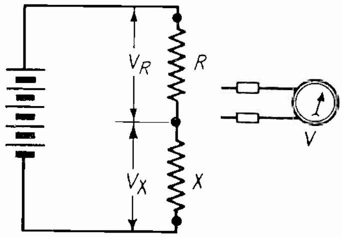

FIG. 19a

FIG. 19b

multi-range meters are necessary. In this case, the range which permits ¾ to full-scale deflection should be used.

Fig. 19a illustrates what is known as the double voltmeter reading method of measuring resistances. A single high grade multi-range 1,000 ohm per volt voltmeter is used in conjunction with precision resistors of various values—1, 10, 100, 1,000, etc., ohms. The known resistor R and the unknown resistor X are connected in series across the voltage supply. Voltmeter readings are taken across both resistors. Let these readings be represented by V_R and V_X. Then the value of the unknown resistor is:

$$X = R \times \frac{V_X}{V_R}$$

For exact measurement, R should be chosen as near the value of X as possible—that is, V_X and V_R should be approximately equal.

Fig. 19b shows an external view of a typical non-inductive precision resistor, commonly used by service men when measuring resistors by this method.

Often in practical work it is sufficient to determine only the approximate values of resistances. For example, at the service work bench it is not often necessary to be able to measure resistances exactly, but a means of making rapid measurement is desirable. For this purpose ohmmeters are used. As shown in Fig. 20, an ohmmeter is simply a milliammeter calibrated to read directly in ohms. Incidentally, any milliammeter can be used as an ohmmeter by means of a calibration curve made by plotting meter readings against known values of resistances.

The ohmmeter shown in Fig. 20 consists of a 0–1 milliammeter of the D'Arsonval type in series with a 3 volt source of e.m.f. (usually a flash-light battery) and a 4,000 ohm rheostat. Two test prods are included.

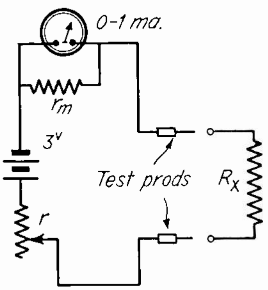

Fig. 20

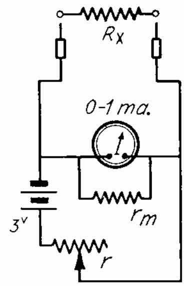

Fig. 21

When the test prods are held together, the meter, the variable resistor and the 3 volt battery are all in series. With the variable resistor adjusted for 1 mil.* of current flow, assuming the battery voltage is exactly 3 volts, the combined resistance of the circuit, including that of the resistor, the meter and the battery, will be 3 ÷ .001 or 3,000 ohms. Now when the prods are connected across a resistor to be measured, the current that flows will be equal to 3 ÷ (3,000 + R_X). and as we are interested in computing the resistance R_X, we may arrange this in formula form:

$$R_X = \frac{3}{I} - 3{,}000$$

For example, if I is .8 mil. (.0008 amp.), a 750 ohm resistor is indicated. If I is .5 mil. (.0005 amp.), 3,000 ohms are

* Milliampere.

indicated. If .2 mils. (.0002 amp.), 12,000 ohms; .1 mil., 27,000 ohms, etc. With this information we can plot a calibration curve or the scale of the meter may be calibrated directly in ohms.

Because of the circuit arrangement, the ohmmeter in Fig. 20 is called a series type ohmmeter. It is an ideal ohmmeter for measuring large resistances.

For measuring low resistances rapidly and with a fair degree of accuracy, a shunt type of ohmmeter is used, shown schematically in Fig. 21. The meter used is a milliammeter.

Assuming that a 0–1 milliameter is used, when the prods are separated the resistor r should be so adjusted that 1 mil. of current flows and the meter needle deflects full scale. As r will

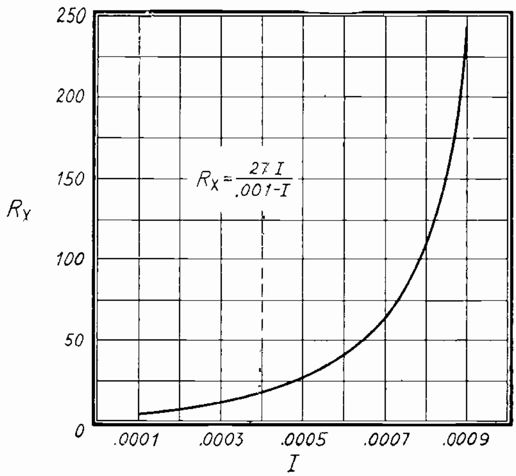

FIG. 22

be about 3,000 ohms and r_m, the meter resistance, will be about 25 ohms, it is evident that the prods can be held together, shorting the meter, without affecting the current flowing in the circuit—it will still be .001 amp.

Knowing this, we can work out the principle of the operation of our shunt-ohmmeter. The voltage across the meter will be $r_m \times I$—that is, the resistance multiplied by the current indicated by the meter. This voltage will also act across the unknown resistor R_X which is connected between the prods of the ohmmeter and will be equal to the resistance R_X multiplied by the current flowing through R_X. Knowing that the main line current is .001 amp., the current through R_X will be .001 less the current through the meter. Therefore its voltage is

$(.001-I) \times R_X$, and this is, of course, equal to $I \times r_m$. From this we develop the formula:

$$R_X = \frac{r_m \times I}{.001 - I}$$

A calibration curve for an ohmmeter using a Weston 0–1 ma. type 301 panel milliammeter which has a resistance of 27 ohms, is given in Fig. 22.

MEGGERS

The name "megger" is simply a contraction of "megohm meter." Thus meggers are devices for measuring resistances in terms of megohms—that is, extremely high resistances such as leakage resistances and resistances of insulating material.

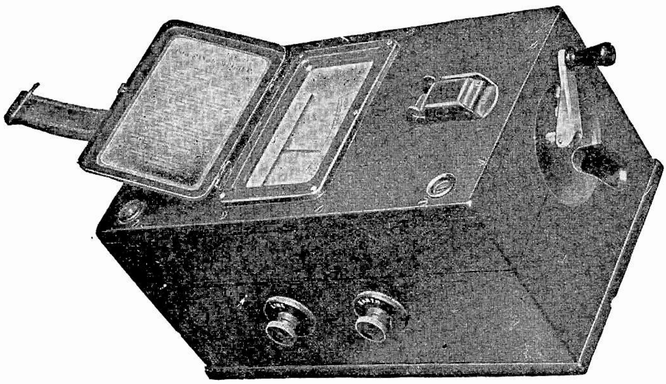

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FIG. 23

These measurements are often extremely valuable as in the case of paper condensers, in which the measurement of the leakage resistance is an indication of the useful life of the condenser. The windings of power chokes must be well insulated from the iron cores. In transformers the primaries must be well insulated from the secondaries. The leakage resistance of an insulating bushing on a variable condenser is an indication of the efficiency of the support.

The "megger" insulation testing and high resistance measuring instrument shown in Fig. 23 consists essentially of a special direct reading ohmmeter of the permanent magnet-moving coil type, mounted in a suitable case along with a hand driven generator.

The diagram in Fig. 24 shows details of the magnetic circuit and electrical connections. *M* represents permanent bar magnets. Between the poles at one end is the armature *D* of the hand-driven generator, and between the poles at the other end is the moving system of the ohmmeter.

There are three coils, *A*, *B* and *B'* (in Figs. 24 and 25), fastened rigidly together. The assembly is free to rotate about the axis. There are no controlling springs, but current is led to the coils by flexible copper leads having the least possible torsion, so that the pointer "floats" over the scale when the generator is not in operation.

Coils B and B' are connected in series with resistance R across the generator potentials. They constitute the "control" element of the ohmmeter and give the instrument the property of indicating correctly, regardless of the exact value of the generator potential or the strength of the permanent magnet. These coils are so connected that when a potential is applied they tend to turn the axis in a counter-clockwise direction until they assume a position where their rate of cutting the magnetic flux is zero—that is, directly opposite the gap in the C-shaped iron core about which B' moves. The pointer then indicates infinity on the scale. This is the reading obtained when a megger is operated with nothing connected across the terminals marked *earth* and *line*.

The moving coil A, which for the most part is in a uniform electromagnetic field, is in series with the generator, the ballast resistor R' and the unknown resistance which is connected to the terminals earth and line. The electrical connections are such that this current tends to turn the axis in a clockwise direction, in opposition to that of B and B'. When the earth and line terminals are

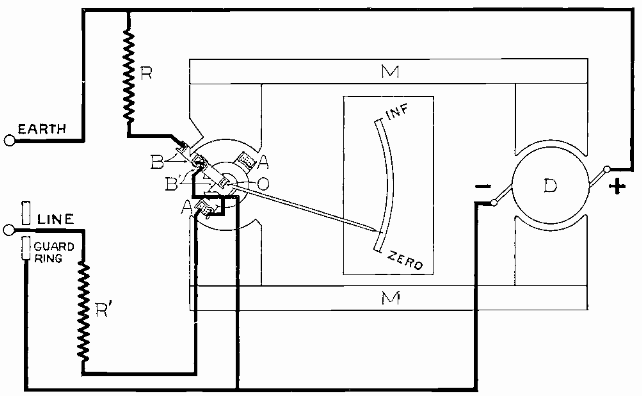

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FIG. 24

short circuited, the current produced by A overpowers that of B and B' and the pointer stands over the point marked zero.

Now if a high resistance is connected across the external terminals, the current from the generator has two paths over which it can flow. Therefore it divides, part passing through the control coils B and B', and part through coil A in series with the resistance under test. The result is that the opposing currents of the two elements balance one another at a point on the scale corresponding to the value of the resistance under test. In this way, also, by using known values of resistance, the scale can be calibrated.

The ordinary megger operates at a voltage of 500^v, which is kept fairly constant even though it is supplied by a hand driven generator, by means of a special control. When necessary, the voltage supply to the device under test may be reduced by increasing the resistance of R' (by means of a rotary switch). However, with each change of R', the scale readings change. For simplicity, these scales are usually arranged so that readings are 1/10 and 1/100 of the original scale values. A typical megger reads from 2 to 1,000 megohms with alternate scales from .2 to 100 megohms or 20,000 ohms to 10 megohms.

There is on the market a small portable megger which has been proven highly useful in the installation of centralized radio systems, sound recording and amplifying systems, public address and sound picture equipment. In many cases, proper testing of insulation resistances will mean a saving of considerable time and trouble.

MEASURING POWER

Determination of the power delivered to a load in a D. C. circuit is a comparatively simple matter. All we have to do is to measure the voltage across the load, the current through it, multiply these two values together, and we have the power in watts. Of course the voltmeter used should have a very high resistance as compared with the resistance of the load of which measurements

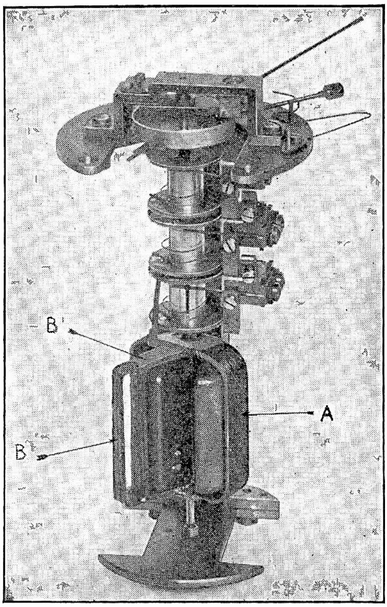

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Fig. 25

are taken, and the ammeter must have a very low resistance so that the values read are true values. Thus power in watts is always equal to the true I multiplied by the true V.

In A.C. circuits, however, the determination of power is not so simple. The volts multiplied by the amperes as measured between two terminals do *not* represent the power used by a load or delivered by two terminals because the *power factor* must be taken into consideration. As you know, the power factor corrects for phase conditions.

If you measure the A.C. voltage across a load in an A.C. circuit, and the current through the load, the product of the two ($I \times V$) is the *apparent* power—not in watts but in volt-amperes (V.A.) or kilovolt amperes (KV.A.). For example, if a voltage of 110 was measured and the current was found to be 1.5

amperes, the apparent power delivered to the load or absorbed by the load would be 1.5 × 110 or 165 volt-amperes (.165 KV.A.).

To find the power in watts, the apparent power must be multiplied by the power factor. That is, $P = V \times I \times \text{P.F.}$

In Fig. 26 the voltage V leads the current I by a certain number of degrees which we call θ. The actual power is $I_E \times V$. I_E, you will observe, is obtained

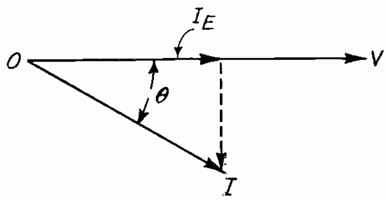

FIG. 26

by drawing a perpendicular line from the end of line I to the line OV. The ratio of I_E to I is the power factor; that is, $\text{P.F.} = I_E \div I$.

Unless we know the power factor exactly, to measure the real power we must use a wattmeter, an instrument almost identical in appearance and construction to an electrodynamic ammeter.

Fig. 27 illustrates the working principle of the wattmeter. There are two coils, one within the other. These coils are only inductively coupled. The

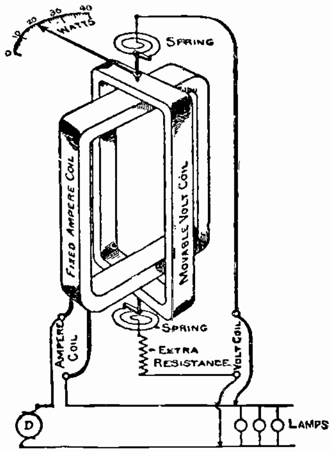

FIG. 27

inner coil is made of very few turns of relatively heavy wire. The outer coil is made of many turns of fine wire and is in series with a high resistance. When a device of this sort is used to measure power delivered to a load, the inner coil is connected in series with the load and its magnetic field will be proportional to the current through the load. The current that flows through the outer coil will be proportional to the voltage of the load and its magnetic field will be proportional to the load voltage.

The two coils are set at right angles to each other. When current flows through them, their magnetic fields interact. The outer coil is free to move and, when the magnetic fields about both coils interact, the outer coil is twisted; that is, it is given a mechanical torque, to a degree depending on the relative intensity of the two fields. The twist is balanced by a coil spring and the deflection of the outer coil is indicated by a pointer moving over a graduated scale.

As the "twist" is proportionate to the product of the magnetic field of one coil and the magnetic field of the other, and as these fields are determined by the voltage across and the current through the load, naturally the amount of the twist indicates power in watts.

10

The device is so designed that only *effective* current and voltage contribute to the twisting effect. Therefore the wattmeter is a true power indicator. When an instrument of this sort is magnetically shielded and provided with air or magnetic eddy current dampers, it can be used to measure either D. C. or A. C. power up to 150 cycles with little error.

The wattmeter is hand calibrated against known powers. These instruments are obtainable in ranges of a few watts to many kilowatts. Milliwatt meters are also available for the measurement of small powers. Of course any wattmeter must be designed to carry the voltage and the current of all loads to

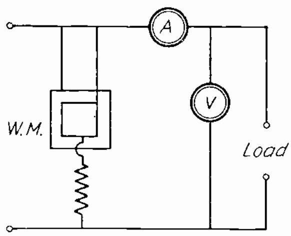

FIG. 28

be measured. For testing the A.C. power delivered to a radio receiver, a wattmeter capable of withstanding a voltage of 150 and capable of carrying 3 amperes maximum current is required.

Sometimes it is necessary to determine the power factor of an A.C. supply. To find the power factor, a set-up as shown in Fig. 28 must be used. There is a wattmeter, an A.C. voltmeter and an ammeter connected as shown. The voltmeter and ammeter will enable us to calculate the apparent power and the wattmeter will tell us the true (effective) power. Then the power factor will be found from the formula:

$$\text{P.F.} = \frac{\text{effective power}}{\text{apparent power}} = \frac{W}{V \times I}$$

OUTPUT INDICATORS

Often in testing at the service work bench or in the laboratory it is necessary to measure the power output of a radio receiver. In the early days of Radio about the only check on the power output was obtained by listening to the output of the loudspeaker. But since then Radio has advanced to become an extremely exact science, and exact methods of measuring the power output were developed.

Along with A.C. receivers came the problem of hum, and in the development of means to reduce the hum output it became necessary to have accurate means of measuring the amount of hum in the receiver output.

We will now explain to you how power output and hum measurements are taken. Let us work with a typical output stage—a pair of '45 type tubes in push-pull. As a loudspeaker is not a constant impedance device, we disconnect it and connect in its place a suitable resistor.

As the total tube impedance is 2 × 1,750 or 3,500 ohms, a 3,500 ohm resistor connected across the output will result in maximum power output. It is this output we want to measure.

A single 45 tube will deliver a maximum of 1.6 watts of power and two in push-pull deliver about 4.0 watts. The current through the load resistance may be calculated from the formula $P = I^2R$—the power to be wasted as heat. With a maximum output of 4 watts,

$$I = \sqrt{\frac{P}{R}} = \sqrt{\frac{4.0}{3{,}500}} = .032 \text{ amp., approximately (32 ma.)}$$

From this we can see that a 0 – 50 milliampere thermocouple ammeter in series

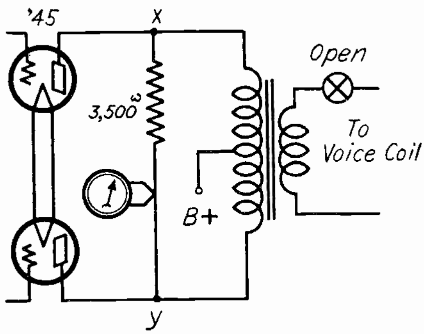

Fig. 29a

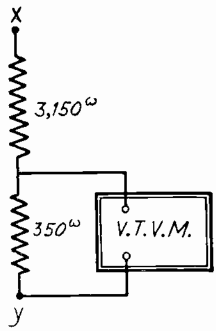

Fig. 29b

with the load resistance or a vacuum tube voltmeter will indicate the current through it and enable us to calculate the actual power output up to the maximum value.

The output voltage is $I \times R$; and the power output will be I^2R. A thermocouple ammeter or a V.T.V.M. should be used as these are the only instruments that can be used with precision on low and high frequencies and in this case the frequencies may be as low as 60 cycles or as high as 10,000 cycles.

When measuring hum output a 0–1 milliampere meter should be used as the amount of hum that should be present is less than .15 volt. When hum measurements are taken, it is absolutely essential that the antenna and ground be disconnected so that no R.F. signals are picked up.

Thermocouple ammeters are expensive and extremely delicate. For this reason the vacuum tube voltmeter is a more practical device for measuring output powers. Fig. 29b illustrates the use of a V.T.V.M. which may be connected across the output of two '45 tubes in push-pull (terminals x and y). With a V.T.V.M. connected as shown across only 350 ohms of the 3,500 ohm load resistor, the V.T.V.M. will read 1/10 the entire voltage across the resistor. Our vacuum tube voltmeter will be of the type that will read from 0 to 15 volts, and its readings will have to be multiplied by 10 to give the true voltage.

The power lost in the load will be equal to $E^2 \div R$.

A vacuum tube voltmeter is accurate at any audio or radio frequency.

Often it may be desired to get a rough approximation of the power output with the receiver in operation. In this case a vacuum tube voltmeter can be connected directly across the voice coil of the speaker. A 0–5 volt instrument may be used.

Another simple method involves the use of a fixed carborundum detector in series with a 0–10 milliammeter. When this method is used, a high variable resistance should be connected in series with the meter to prevent the meter needle from flying off scale. A device working on this principle serves only as an output indicator, and measurements are not accurate.

A copper oxide voltmeter may also be used, but here, too, results will not be very accurate, due to the presence of harmonics. A device of this sort used in laboratory testing where single frequencies are measured will be accurate to within 5 per cent.

TEST QUESTIONS

Be sure to number your Answer Sheet 29FR-1.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and the best possible lesson service.

1. How can a milliammeter be used to measure voltage?
2. Suppose you have a 0-5 milliammeter having a resistance of 200 ohms and you want to use it to read 0-10 volts, what value of *external* resistance (in ohms) would you use?
3. What do we call an external resistance used with a voltmeter to increase its range?
4. Explain why an Electrodynamometer voltmeter is not suitable to measure high A.C. frequencies.
5. Show by a diagram how a thermocouple voltmeter is connected in a circuit for output power and hum voltage measurements.
6. Name the two types of V.T.V.M.'s.
7. How can the V.T.V.M. be used to measure current in an A.C. circuit?
8. What is an ohmmeter?
9. What type of ohmmeter would you use for measuring low resistances?
10. What instrument would you use to find the true (effective) power in an A.C. supply circuit?

RESISTANCE, CAPACITY, INDUCTANCE AND FREQUENCY MEASUREMENTS

30FR

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

THE VALUE OF HAVING VARIED INTERESTS

Don't go stale! Keep a fresh, active interest in everything you do. Only by doing this can you get your full measure of benefit from your work, from your play, from exercise, from study.

When you work or when you play—work hard, play hard. When you study, throw your whole brain, every part, into your studies.

Then when you stop working, or playing, or studying—let go. Drop it. Forget about it. Turn to something else.

Not everybody knows that the best vacation is merely a complete change from what you have been doing. Loafing is not a vacation—it is merely boredom.

There is nothing better for an office worker after hours than a brisk walk, a swim or a round of tennis. There is nothing better for an outdoor worker than a quiet hour with a book or a good newspaper, or listening to the Radio.

Exactly *what* you do is not important provided it is *different*. Change your pace. Don't do the same thing all the time. Vary your life as much as you can. Vary your interests. Cultivate a general, intelligent interest in the world of which you are a part. You will find it helps you to keep a fresh and alert outlook on life.

Keeping alert keeps you young. Keeping interested keeps up your energy. Interest creates energy in you. A curious mind learns more readily than one with a narrow outlook. The more you learn, the more easily you learn.

Study your Course—but keep room in your mind for other things. Concentrate on Radio—but concentrate on your regular work, on your play, on your other desirable or necessary activities when it is time for them. Keep a fresh outlook. Keep growing. Don't go stale.

J. E. Smith.

WASHINGTON, D. C.

Revised 1932, 1933, 1935

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Resistance, Capacity, Inductance and Frequency Measurements

WHEATSTONE BRIDGE

Where precision is desired in measuring resistance, methods more exact than the ohmmeter or the voltmeter-ammeter methods are needed. A "differential" arrangement of comparing resistances has been known for over a century and today it is applied not only to the measurement of resistance, but inductance and capacity, for conditions of direct current flow, as well as A.C. of high and low frequencies. There are many suc-

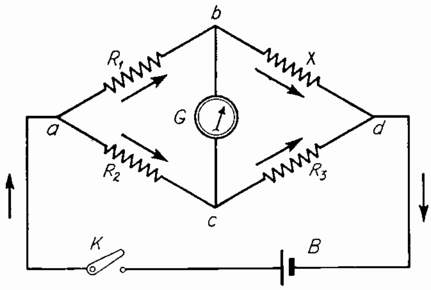

FIG. 1

cessful adaptations of the basic Wheatstone Bridge, as the original method is called.

Study closely Fig. 1. Four resistances are arranged in diamond or elongated rectangular formation. Three of these resistances are precisely known values which we shall refer to as R_1, R_2 and R_3; the fourth is the unknown which is to be measured. Resistances R_1, R_2 and R_3 are variable resistors but are not like rheostats which are so common in practical radio work. We shall see how these are constructed and arranged shortly. One or more dry cells, B, are in series with a key K, and connected to terminals a and d of the diamond formation. Between b and c, a sensitive D.C. galvanometer or microammeter of the portable or laboratory type is connected. For the sake of convenience and as a protection, various adjustable shunts (not shown in Fig. 1) are connected across the galvanometer so that the latter may be made less or more sensitive.

When key K is depressed, a current flows from a through R_1, through X, to d and into the battery line again. Likewise a current flows from a through R_2 to c through R_3 to d and joins the other current when entering the battery line. A potential difference, or a voltage drop if you prefer, exists across R_1 and across R_2. If they are of different values, a current will flow through the galvanometer G. Resistance R_3 is now adjusted until the galvanometer reads zero, when the key is closed, thus indicating the Wheatstone bridge is perfectly balanced, because at zero reading the voltage across R_1 equals that across R_2 and the voltage across X is equal to that across R_3. No current flows through G and the current I_{ab} through R_1 is equal to that which flows through X; while the same amount of current I_{ac} flows through R_2 and R_3.

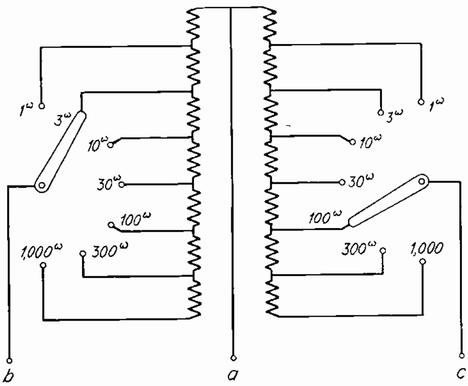

FIG. 2

The voltage across each resistance is the current multiplied by the resistance in ohms. Therefore,

$$I_{ab} \times X = I_{ac} \times R_3 \tag{a}$$

also

$$I_{ab} \times R_1 = I_{ac} \times R_2 \tag{b}$$

With the aid of simple algebra, we divide equation (a) by equation (b), and with the current cancelled out, the equation of the Wheatstone bridge when *balanced* is obtained. For those who are not familiar with algebra, the following equation (1) should be memorized along with Fig. 1.

$$X = R_3 \times \frac{R_1}{R_2} \tag{1}$$

For example, if at balance, which is indicated when there is no deflection on the galvanometer, R_3 was 227 ohms, R_1 was 10 ohms and R_2 was 100 ohms, the unknown resistance X would equal

$$227 \times \frac{10}{100} = 22.7 \text{ ohms.}$$

You may have already observed the possibility of measuring extremely large and small resistances in a single bridge. Notice that the unknown resistance is always R_3 multiplied by the ratio of R_1 *to* R_2. This reveals the possibility of making a convenient variable bridge by changing the ratio of R_1 to R_2, as for example, 1/1, 10/1, 100/1 and 1000/1 and 1/10, 1/100, 1/1000. By the use of a simple 1 to 1 ratio of R_1 and R_2 the value of X can be approximately obtained. Then X will be equal to R_3 at the proper setting of R_3. Afterwards, for more exact measurement, a ratio of 1/10, 1000/1 or 1/100, or any ratio that allows a more complete

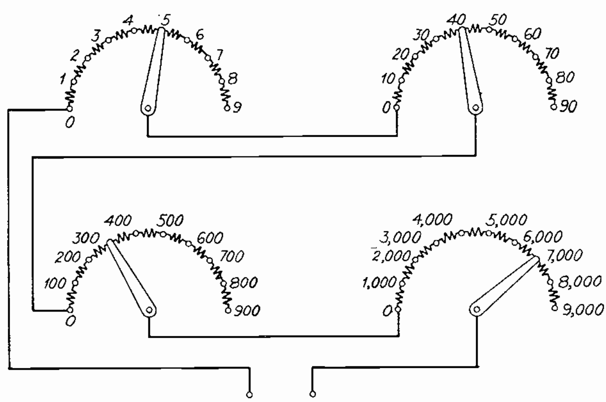

FIG. 3

use of R_3 may be used. Figure 2 shows how these ratios may be prearranged. The important factor in connection with R_1 and R_2 is not their exact value, but rather the ratio of R_1 to R_2.

The value of resistance R_3 must be known exactly for every setting, and it must be variable in a very simple and convenient manner. What is known as a "decade" arrangement is used as R_3 in Fig. 1. A *decade resistance* arrangement is shown clearly in Fig. 3. Each switch arm moves over ten contacts which make connection with nine equal resistors in series. There are usually four variable tap-arm arrangements, the first for the nine equal 1000^{ω} resistances, the second for the 100^{ω} section, the third for the 10^{ω} section, and the fourth for the 1^{ω} section. They are all in series, so that a value of resistance up to 9999 ohms may be readily obtained by setting the four switch arms at maximum. Thus at maximum setting of the switch arms and with the ratio arms set at 1000/1, a resistance measurement up to 9,999,000 ohms—practically 10 megohms—is possible, and at the minimum setting, a low value of .001 ohm can be measured. However, the lowest resistance measurable with any precision is ½ ohm.

A typical portable Wheatstone bridge is shown in Fig. 4. It is surprising how quickly a resistance can be measured with it. The unknown resistance is connected to the binding posts provided for quick connection and a single dry cell is connected to $B+$ and $B-$. When the approximate resistance is known, the

FIG. 4
Leeds and Northrup Type S Portable Wheatstone Resistance Bridge

procedure is simple. For example, if you know the resistance to be measured is somewhere near 250^{ω}, R_3, the decade group is set as follows. The "thousand" section would be set at 2000, and the hundred section at 500. The ratio switch at the extreme rear left of the bridge $\frac{R_1}{R_2}$ would be set at 1/10 (.1), which will reduce the measured values by one-tenth.* The key in this instrument (a contact button) would be pressed and the decade switches (0–10 and 0–1) adjusted until the galvanometer needle reads zero or as near to zero as possible. At first the shunt

*Of course, the decade box could have been set for 250^{ω} and a ratio of R_1 to R_2 of 1 to 1 used. However, under these circumstances, the full sensitivity of R_3 would not be utilized.

across the galvanometer would be used and then entirely removed. This precaution is essential in order to protect the meter. Further sensitivity can be had by the use of 2 or 3 dry cells in series as the source of e.m.f.

When the resistance to be measured cannot be estimated, the ratio arm is set at 1 and the decade resistor section adjusted, using a shunt across the meter until the change of a small resistance value will cause the needle to read first to the right and then to the left of zero. This gives a close approximation to the final value.

This bridge is intended for close D.C. resistance measurements and must be made with great care. Each unit, whether 1000 ohms or 1 ohm, is non-inductively wound in the form of a bobbin. Fig. 5 shows a typical construction. A layer of silk is

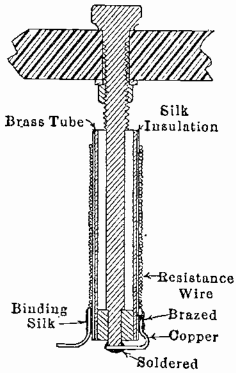

FIG. 5

wound on a brass tube. This is then shellacked and baked. The insulated resistance wire, usually "manganin," is doubled, and the looped end used as the starting end. The two wires are wound side by side, usually in a single layer. The two free ends are brazed to metal terminal lugs. The coil is then shellacked and baked for about 10 hours at 140° Centigrade, after which it is paraffined to exclude moisture. Thus the resistance unit is made moisture proof and is free from temperature effects.

THE A.C. WHEATSTONE BRIDGE

For ordinary purposes the A.C. resistance of a device used in commercial and audio frequency circuits may be assumed to be the same as the D.C. resistance as measured in a D.C. bridge. No hard and fast rule can be set, however, and we must be guided by the design and use of the device. Quite often the device may have associated with it an inductance or a capacity or it may really be an inductance coil with an associated resistance. The A.C. resistance of such parts will vary with frequency and may involve varying power losses. Then an A.C. bridge is required for precise measurement.

An A.C. bridge used to measure A.C. resistance would be arranged in the same manner as the D.C. bridge in Fig. 1. Instead of a battery, an A.C. source of e.m.f. would be used, that is, an audio oscillator with a range of 400 to 10,000 c.p.s. The D.C. D'Arsonval microammeter would be replaced naturally by an A.C. indicating device. A sensitive thermocouple microammeter or a microvolt V.T.V.M. would be an appropriate indicator for bridge balance, and well adapted for use at all frequencies.

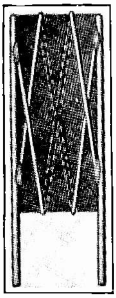

FIG. 6

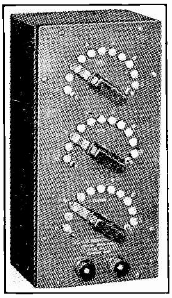

FIG. 7

Considerable testing is done at audio frequencies, particularly at 1000 c.p.s. Therefore a telephone headset can be used in place of an A.C. meter, a balance being obtained when minimum or no sound signal is heard through the phones.

The resistances R_1, R_2 and R_3, if used at frequencies from
7 zero to 1,500,000 c.p.s., for any degree of precision, must be made with an absolute minimum of distributed capacity, inductance and its ohmic resistance must not change with temperature.

An alloy wire, manganin, is used as it is practically unaffected by normal room temperature changes, and its resistance will not change with age. As a matter of fact, some laboratory instrument manufacturers age resistance units six months before adjustment for final exact value.

To make the resistance units independent of frequency changes, special methods of construction are employed to eliminate capacity and inductance effects. The Ayrton-Perry method is a common one. A thin bakelite form is used. A single wire is first wound on with a space between turns equal to the diameter of the wire. In parallel, electrically, a second wire is wound on the form in the spaces between the turns of the first winding. The winding direction of the second wire is opposite to that of the first, so that the currents result in two magnetic fields which cancel each other. This method of winding keeps down the distributed capacity to that of a single layer coil, which is quite negligible. A schematic of the winding is shown in Fig. 6.

A precision of .1 per cent on D.C. to 5 per cent at 1,500,000 cycles is possible, with a bridge of this kind. An error of only

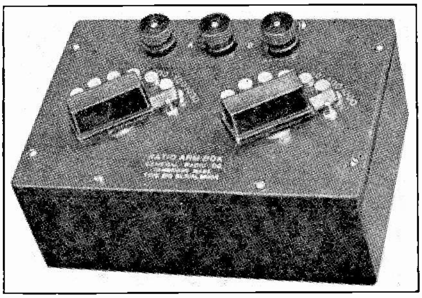

FIG. 8

5 per cent is quite good as R.F. measurement tolerances of 10 per cent are common.

A typical decade resistance box is shown in Fig. 7 (forming R_3 in Fig. 1) and a ratio arm box is shown in Fig. 8 (constituting R_1 and R_2 in Fig. 1). They both use the high frequency resistance feature just described and are valuable in radio and audio frequency bridge measurements.

CAPACITY BRIDGES

There are innumerable capacity bridges, each having its particular value. The most commonly used is the one shown in Fig. 9, having a diamond arrangement of two A.C. resistance decade boxes, a known fixed metal-plate mica-dielectric condenser and the unknown capacity to be measured. R_1 and R_2 are 0 to $10{,}000^{\omega}$ decade resistance boxes of the kind illustrated in Fig. 7. C_s is the standard condenser and for measuring ordinary radio capacities of .001 to 10 mfd., it has a capacity of .050 mfd. Notice that the audio oscillator supplies A.C. voltage through a coupling transformer. This is good practice, as it prevents any D.C. current from flowing through any leak that may be present in either condenser. It is also advisable to use a coupling transformer ahead of the phones, having a large primary impedance and secondary turns to match the impedance of the phones.

R_1 and R_2 are adjusted until minimum hum is heard in the phones and the capacity X is found from equation:

$$C_x = C_s \times \frac{R_2}{R_1} \tag{2}$$

If the unknown capacity of C_x is near the value of C_s, the

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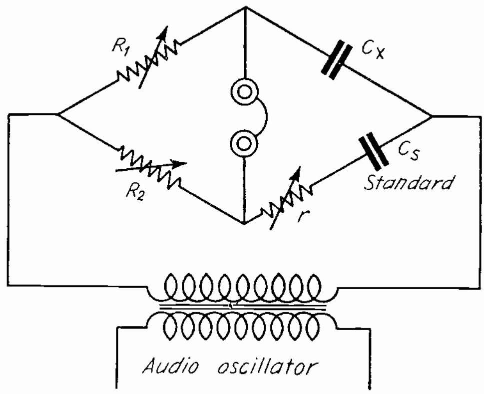

FIG. 9

standard, the settings of R_1 and R_2 will be practically the same. The greater the value of R_1 and R_2 used, the greater will the precision of measurement be. If C_x is small in comparison to the value of C_s, R_1 will be much higher than the value of R_2. Likewise, when C_x is large, R_2 will be larger than R_1 for balance. In permanent capacity bridges the arm R_1 is not always a variable decade box but may be a group of resistances which can be adjusted in steps of 10 ohms by means of a tap switch. Values of 10, 100, 1,000 and 10,000 ohms are all that are needed. This allows capacity measurements of 20 microfarads down to .005 mfd. with fair precision by setting R_1 and adjusting decade box R_2.

It is not possible to reduce the hum in the phones to nothing merely by adjusting R_2. We must not overlook the fact that C_x and C_s have inherent resistance and this must be balanced out. The standard C_s is usually selected with great care for low losses, and in general its series resistance will be much lower than the series resistance of C_x. A calibrated variable rheostat r of 0 to

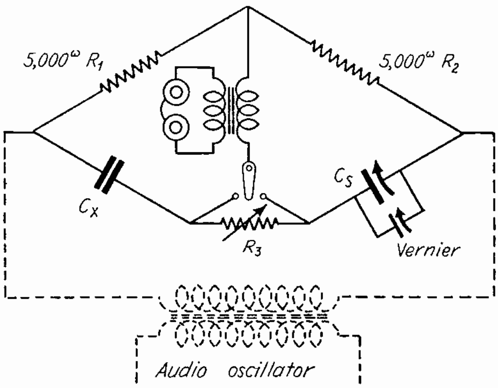

Fig. 10

200 ohms is placed in series with the standard condenser. This is adjusted for no hum by balancing out the series resistance of C_x. It may be necessary to readjust R_2 and then r again before absolutely no signal is heard in the phone. This last value of R_2 is used in calculating C_x.

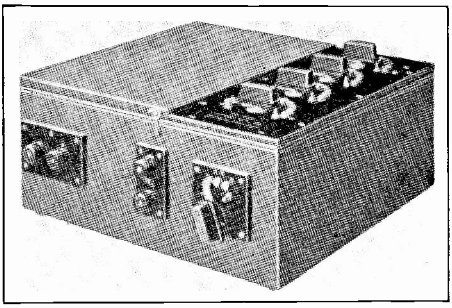

Fig. 11

The equivalent series resistance of the unknown condenser can be measured and will be $R_x = r \times \frac{R_1}{R_2}$. This method is very valuable in testing by-pass, filter, and coupling condensers for equivalent series resistance. The power factor of the condenser is then quickly calculated from the formula:

$$\text{P.F.} = 2\pi f R_x C \tag{3}$$

Where the service man or laboratory technician builds most

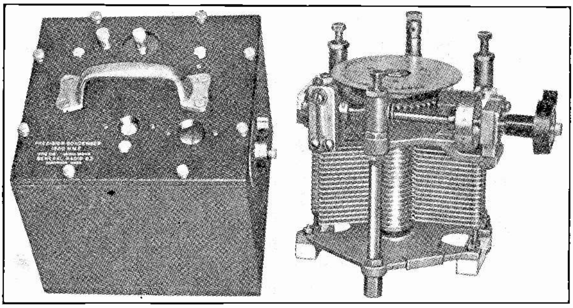

FIG. 12

of his own apparatus, the condenser bridge merits a prominent place along with an audio oscillator, an R.F. signal generator, and other laboratory equipment.

When measuring radio condensers of small capacities hav-

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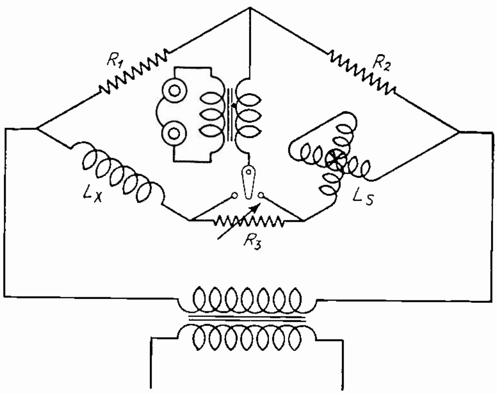


FIG. 13

ing low losses, considerable care must be exercised. All parts of the bridge must be shielded—each section from the other.

Fig. 10 shows the usual bridge arrangement when the resistance arms, R_1 and R_2, are fixed and equal. A precision variable condenser is connected at C_s and the unknown is placed at C_x. An audio oscillator feeds an A.C. e.m.f. across the bridge and C_s is varied until minimum hum signal is heard. R_3—a decade resistor box—is connected in series with either C_s or C_x for final hum balance. Using equal arms of resistance—that is, with R_1 equal to R_2—the unknown capacity equals the known value of C_s. R_1 and R_2 are shown as 5,000$^\omega$ each. C_s may be a 1,500 micro-microfarad direct reading variable standard. If R_2 is 500 ohms, the values of C_x will be 1/10 of C_s and the largest capacity that can be measured is 150 $\mu\mu f$; if R_2 is 50 ohms, the value of C_x will be 1/100 of C_s and the largest capacity that can be measured is 15 $\mu\mu f$.

Fig. 11 shows a typical capacity bridge with fixed ratio arms, using a precision variable condenser like the one shown in Fig. 12. A tuning fork oscillator emitting a 1,000 c.p.s. sine wave is used as oscillator.

INDUCTANCE BRIDGES

Inductances are also measured by means of a bridge circuit only they must have at least two inductance arms. Fig. 13 shows

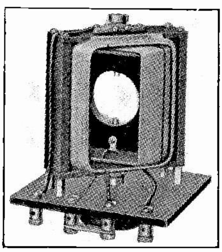


FIG. 14

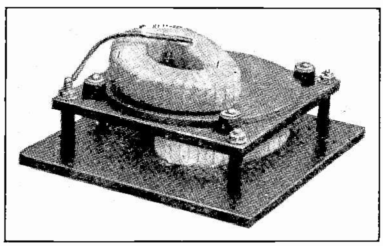
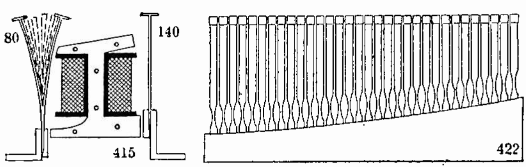


FIG. 15

an ideal inductance bridge arrangement. L_s, a standard inductance, is used, and the unknown inductance L_x takes the place of C_x. If the resistance arms are equal, L_x will be equal to L_s, which is usually a variable inductance (variometer). A typical laboratory instrument is shown in Fig. 14. It is obtainable in sizes from .02 to .4 millihenry; .10 to 4 mh.; and .4 to 18 mh. Obviously, varying the ratio of R_1 to R_2 allows larger or smaller inductances to be measured.

The bridge shown in Fig. 13 can be used as a universal bridge for measuring resistance, capacity and inductance. R_1 is a decade box having .1, 1, 10, 100$^\omega$ sections and R_2 is a tapped resistance with values of 1, 10, 100 and 1,000 ohms in individual will not change its speed of rotation when a load is added, and whose speed is dependent solely on the frequency of the supply current, operates a clock mechanism. This clock must not deviate at any time from the naval standard. The speed of the power house generators is so regulated that they maintain absolute agreement with the standard.

Where no attempt is made to supply power for electric clock operation, the power company may use several methods of keeping fairly constant frequency. Each alternator will deliver rated frequency at a definite speed of rotation. It then remains to maintain the speed at that specific value. Small automobile magnetos are often used for this purpose. In general, they produce 10 volts when driven at 1,500 r.p.m. They consist of a small armature such as used in D.C. generators, but have a magnetic field produced by 4 to 6 large, well-aged, permanent magnets.



B

Fig. 17

The magneto is connected to a variable speed motor and the output of the magneto connected to a suitable range voltmeter (a low resistance type will do). Next the magneto-voltmeter combination is calibrated. At various speeds of rotation the voltage is recorded; a curve is drawn between voltage and speed in revolutions per minute. Likewise a plot of cycles per second against voltage could be drawn for use when the combination is permanently attached to the A.C. generator.

The speed of the calibrating motor which is directly coupled to the magneto is determined by means of a stop watch and a revolution counter. The latter is usually set at a simple number such as 0000, or 1000 or 3000 and, holding the stop watch in one hand and the counter in the other, the stop watch is started at the same moment the counter is inserted into the countersunk center of the motor shaft. After exactly one minute the counter is removed—the counter reading is the r.p.m. Several readings are taken and the average of them all used. A watch with a second hand can be used by a careful observer.

The calibrated magneto and voltmeter are connected to the main generator. If the latter is running at the proper speed, the voltmeter connected across the magneto will read a constant correct value. Should the voltage increase or decrease, it is an indication that the speed of the generator has changed and consequently its frequency. Then the main driving motor is adjusted to drive the generator at the proper speed.

Another method of keeping a check on frequency in the power house, and one that is used even more often than the magneto method, involves the use of a low frequency meter.

It is well known that a tuning fork (an instrument which sends out a definite frequency of sound when tapped) goes into violent vibration when brought near a solenoid having an A.C.

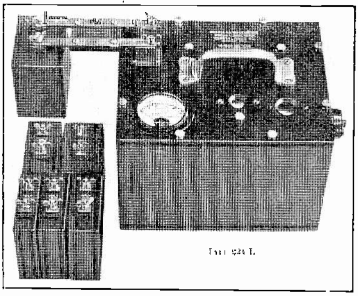


Fig. 18a

current flowing through it whose frequency is the same as the frequency of the tuning fork. This principle is made use of in the Hartmann and Braun frequency meter. In this instrument, there are small steel reeds (*B* in Fig. 17) firmly anchored in the base. Each reed is of a different length and therefore has its own period of vibration. On the top of each reed is a rectangular cap painted white. These caps are weighted so that the reeds will vibrate at exactly the proper frequency.

The electromagnet of the meter, which has a high resistance winding, is connected across the supply whose frequency is to be measured. As the reeds do not retain magnetism, they will be attracted twice during each cycle and the A.C. power will cause that reed to vibrate violently whose frequency is twice that of the current measured. If the reeds have been previously calibrated, we have a direct reading frequency meter. A variation of 50 per cent in the amplitude of reed vibration will result if the supply frequency is altered one-half cycle. Thus if two reeds vibrate, let us say the one marked 60.5 quite prominently and the one marked 61.0 less prominently, the indication is that the frequency is between 60.5 and 60.7 c.p.s.

There are various other types of frequency meters, but they cannot all be discussed here. In many cases the principles are too involved for elementary study. However, all are as simple to use as a voltmeter should you at any time need to use them.

HIGH FREQUENCY METERS—WAVEMETERS

The use of a radio frequency coil shunted by a variable condenser to form a resonant circuit is not new to us. We have met resonant circuits many times in our study of radio principles. When excited by a buzzer or an A.C. power source a

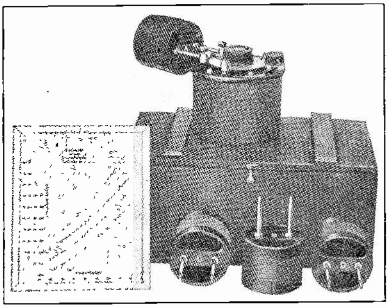


FIG. 18b

modulated high frequency is obtained; when connected into a tube oscillating system an A.C. tube generator is available. The resonant frequency is $f = \frac{1}{2\pi\sqrt{LC}}$, where f is in c.p.s. and L and C are in henries and farads respectively. Thus A.C. can be generated or measured from commercial to high frequency values.

The measurement of radio frequencies is important and a simple radio frequency meter consists primarily of an R.F. coil shunted by a variable condenser. Two commercial radio frequency meters are shown in Figs. 18a and 18b, the former a precision device, accurate to ¼ of 1 per cent and the latter accurate to 1 per cent.

These instruments can be calibrated by comparison with standard known frequencies. We should bear in mind that fre-

10 quency meters and wavemeters are one and the same, the only difference being in the calibration. In order to find the wavelength corresponding to a definite frequency in cycles, divide the latter into 300,000,000—the velocity of radio waves—and the wavelength in meters will be known.

Now let us see how a frequency meter indicates when its natural frequency is in resonance with the source being meas-
3 ured. We require an indicating device in addition to the coil and variable condenser. The simplest device is a thermocouple galvanometer (see Fig. 19a) connected in series with L and C. The meter may be a 0-100 ma. milliammeter; a more sensi-

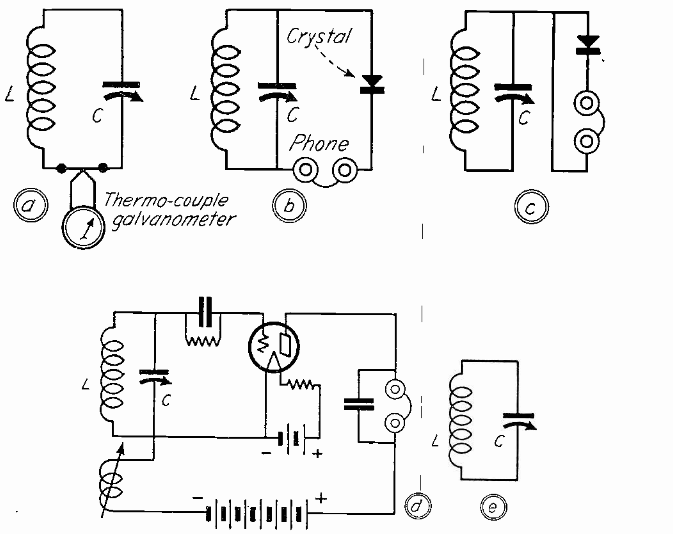


FIG. 19

tive meter of course means that less powerful sources can be measured. The coil is coupled by bringing it near to the circuit where the current is to be measured for frequency. The condenser C is varied until the meter shows maximum deflection. In place of the galvanometer a small flash-light bulb having a low resistance can be used. Lamps having more than one or two ohms resistance should not be used because of broad tuning effects, so that exact resonance is not easily determined. At exact resonance the bulb lights up most brilliantly. These arrangements are for use with transmitters, and powerful signal generators, *not* radio receivers. The method can be applied to modulated or continuous R.F. currents.

Various other types of frequency meters are shown in Figs. 19b to 19e. In the circuits shown in Figs. 19b and c, you will note that phones are used in conjunction with a crystal detector. These methods can be used only to measure the frequency of modulated radio frequencies.

5

The connections shown in *b* result in a more sensitive device than that in *c;* in fact the first is about 8½ times as sensitive as the second. In both cases the condenser *C* is a precision calibrated condenser. In practice *C* is adjusted for maximum earphone response. Then the frequency is calculated from the condenser setting, or, if the condenser is calibrated in kilocycles, it can be read directly.

The frequency meter shown in Fig. 19d has a regenerative detector. Thus it can be used with unmodulated as well as modulated R.F. This is also a rather sensitive frequency meter.

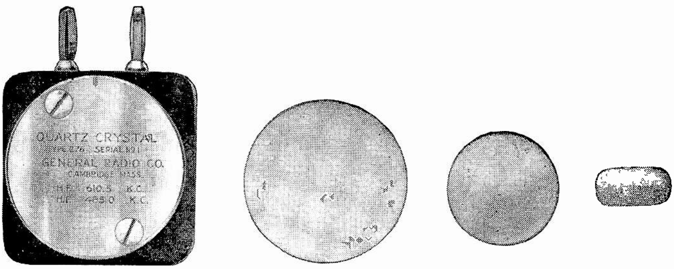


FIG. 20a

Surprising as it may seem, the coil and condenser alone as in Fig. 19e form quite an efficient frequency meter. Suppose the circuit containing the unknown frequency has an R.F. indicator, a meter in the case of an oscillator, a loudspeaker in the case of a receiver. When the coil of the frequency meter is brought near the circuit to be investigated and the capacity is varied, a sharp drop in meter reading or a decrease in sound output will be evident when the two circuits are resonant, that is, at the same frequency. The frequency meter is then read.

PIEZO OSCILLATORS

Various crystals such as Rochelle salts, tourmaline and quartz have what are known as "piezo electric properties," that is, properties involving the production of electricity by pressure. If any piezo electric crystal is mechanically pressed, an e.m.f. will be developed across two of its sides. Then when the pressure is removed, the crystal naturally expands, but, acting as though it were resilient, it expands beyond its normal size and again an e.m.f. is developed across two of its faces, this time, however, of opposite polarity.

If we cause a piezo electric crystal to vibrate in some way or other, it will generate an A.C. e.m.f.—*at a constant frequency,* determined by the size, shape, structure, and temperature of the crystal.

Piezo electric effects can be obtained electrically, and in practice the crystal is always made to vibrate by electrical means. Suppose we placed a rectangular shaped, carefully faced piece of quartz crystal between two metal plates and we applied a source of D.C. to them. The crystal would actually con-

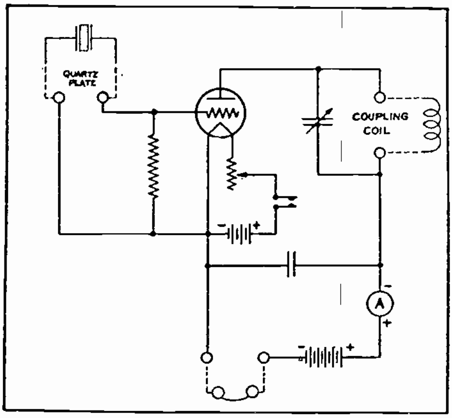


FIG. 20b

tract and expand (vibrate) for a short while immediately after the D.C. was applied, each vibration being smaller than the preceding one.

What effect does this have on current flow? Of course the only D.C. current that flows is that required to charge the condenser formed by the two plates. But the vibration of the crystal results in an A.C. e.m.f. having a damped wave form—each cycle smaller than the preceding cycle—and a small A.C. current will flow through the circuit. The frequency of this A.C. will be determined by the size, shape and structure of the crystal.

Now if an A.C. e.m.f. of the same frequency as the crystal is impressed across the plates holding the crystal, the crystal will maintain oscillation indefinitely, at its own frequency. The crystal frequency will not deviate by more than a fraction of one per cent from its natural frequency, provided the temperature of the crystal does not vary.

Fig. 20a shows typical quartz crystals of the kind used in radio work. Quartz is always used, as Rochelle salts are fragile and tourmaline is expensive. These crystals are placed in regular crystal holders consisting essentially of two plates, which, with the crystal as the dielectric, form a condenser.

A typical crystal oscillatory circuit is shown in Fig. 20b. Here the crystal tunes the grid and the *LC* circuit in the plate is tuned to exact resonance with the crystal. Oscillation is maintained in this circuit by the energy fed back from the plate to the grid through the tube capacity. The crystal keeps the frequency of oscillation practically constant. Without it or with a regular *LC* circuit in its place, oscillation could be maintained in the circuit over a considerable frequency variation. With it in the circuit, should the *LC* constants change in any way and the feed back frequency be affected by even a small amount, oscillation will stop.

Crystal frequencies are confined, in practice, to a band between 100 and 2000 kc. High frequencies are obtained by using the harmonics of the crystal frequency; lower frequencies are obtained by using multi-vibrators (frequency reducing devices).

Quartz crystals are used in Radio, for the purpose of maintaining the carrier frequency of broadcasting stations at an absolutely constant level. They are also used in standard oscillators and signal generators because of their excellent frequency stability. In the next paragraphs we shall see how a crystal controlled oscillator operates.

STANDARD AUDIO AND RADIO FREQUENCY SOURCES

In an earlier lesson we studied various devices for producing R.F. and A.F. current—signal generators and oscillators. When well built and properly calibrated, these are valuable tools for the service man and the laboratory technician. For ordinary purposes, signal generators are calibrated by means of frequency meters. But this leads us to the question, "How are the frequency meters calibrated?" Of course, you might say that these are calibrated from other frequency meters, but for the original calibration we must always go back to a primary standard.

While you may never come in contact with a primary frequency standard, you should know, and you will be interested to know, how this standard is obtained and maintained. Standard frequency devices are to be found in the Bureau of Standards at Washington, D. C., and in a few of the larger experimental laboratories throughout the country.

The device consists primarily of a 100 kc. crystal oscillator controlling a couple of multi-vibrators one working at 1,000 cycles. This thousand cycle current is used to operate a synchronous motor type of clock. The time kept by this clock is checked against an absolute standard of time, as, for example, the time signals sent out at 10 P. M. and 12 o'clock each mid-day by the government station NAA.

If the synchronous clock keeps exact time over a period of twenty-four hours, to the second, it is shown that the crystal is oscillating at exactly 100 kc. Thus the multi-vibrator system and the synchronous clock provide an exact check of the crystal.

As we said, two multi-vibrators are used. The first multi-vibrator operates at 10 kc., the other at 1 kc. or 1,000 cycles. The first or 10 kc. multi-vibrator is controlled at its 10th harmonic by the 100 kc. crystal oscillator, and the 1 kc. multi-vibrator is controlled by the first multi-vibrator at 10 kc. How this is done is explained as follows:

A multi-vibrator is nothing more than a resistance coupled amplifier circuit with its output connected to the input. It has no *LC* circuit but its frequency of operation is determined mainly by the values of *R* and *C*. The oscillation thus is comparable to motor-boating in the audio system of a receiver.

A multi-vibrator will supply a signal rich in harmonics, but the frequencies are not constant. If a constant signal of the same frequency as the fundamental or any harmonic frequency of the multi-vibrator is fed to the multi-vibrator, the latter will assume the stability of the introduced signal. Usually in primary signal sources, a piezo crystal oscillator is used to provide the controlling signal, and is usually of a frequency equal to the tenth harmonic of the multi-vibrator.

After the crystal is known to generate a frequency of exactly 100 kc., various standard frequencies can be obtained from it. Directly from the multi-vibrators can be obtained frequencies in steps of 10 kc. and 1 kc. A third multi-vibrator is supplied in commercial units, whose fundamental frequency is the fundamental frequency of the crystal oscillator. Thus accurate frequencies above 1,000 kc. are obtained.

Higher frequencies could be obtained by an ordinary *LC* oscillator carefully monitored by the harmonics of the crystal oscillator, or the multi-vibrator.

It is interesting to know that this very same elaborate frequency standard may be made to give standard audio frequencies. It is to be realized that the synchronous motor driving the clock mechanism revolves exactly in step when fed with 1000 c.p.s. If two synchronous motors were operated as synchronous generators by reduction gears, one 10 to 1 and the other 100 to 1, the generated frequencies would be 100 and 10 c.p.s. If these frequencies including the 1000 c.p.s. driving source are amplified by an amplifier having a large bias, harmonics up to the 10th may be obtained. Again audio frequencies from 10 to 10,000 can be obtained in steps of 10 c.p.s.

Primary standards of this sort are extremely costly and, for general calibration purposes, secondary standards calibrated from the primary standards are used. Fig. 20b shows the diagram of a piezo oscillator extensively used in laboratories as a secondary standard. A complete commercial oscillator of this type is shown in Fig. 21. The tube in this circuit is a type '12A. Large tubes are not advisable as quartz crystals cannot handle large R.F. powers. All A and B batteries are housed within the cabinet.

A milliammeter (D.C.) indicates when the circuit is in oscillation. The phone jack permits connection to other apparatus or to amplifiers or, if the device is used as a frequency meter and coupled to the source to be measured through the coil, a pair of phones is inserted to enable the operator to hear the beats. The crystal and coils may be replaced with ones of different values by a convenient plug-in arrangement and a complete calibration in small steps within the fundamental or harmonic band can be made.

In order to obtain useful power at a harmonic frequency, it is general practice to set up a local oscillator whose fundamental frequency is the same as the desired harmonic frequency of the crystal. That is, its fundamental is adjusted for zero beat with the crystal harmonic, and the oscillator is at exactly the desired frequency and will deliver the required output power.

MAGNETOSTRICTION OSCILLATORS

In much the same way as a small, carefully cut disc of quartz will vibrate when an alternating e.m.f. is applied to its faces, rods of certain metals vibrate when subjected to a varying magnetomotive force. Such metals are said to have magnetostrictive properties.

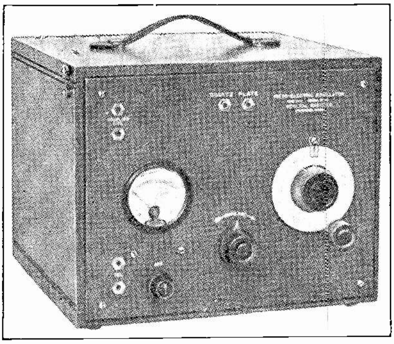
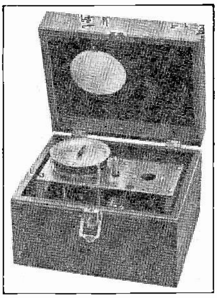


FIG. 21

Surprisingly enough, the more magnetic metals do not show magnetostrictive properties to as great an extent as metals that are less magnetic. For example, iron and steel which are highly magnetic show only feeble magnetostrictive properties. Pure nickel, alloys of nickel and iron, such as invar metal which is 36 per cent nickel and 64 per cent iron, cobalt and iron,



1000 c.p.s. Synchronous Clock

chromium, nickel and iron, all of which are practically non-magnetic, show large magnetostrictive effects.

Suppose we have a magnetostrictive bar and we inserted it into a solenoid. Current flowing through this solenoid would cause the bar to extend its length. When the current was removed the bar would return to normal length. If the current through the solenoid were reversed, the bar would also be extended in length. Accordingly, if an A.C. current is made to flow through this solenoid, the bar will vibrate at a frequency twice that of the exciting current.

Of course we have been assuming that the shape and size and structure of the magnetostrictive bar are such that the frequency of the exciting current will cause the rod to vibrate.

If a magnetostrictive bar is placed within a double solenoid, one part of which is fed with an A.C. current and the other with a D.C. current in such a way that the e.m.f. never actually reverses its direction, the frequency of the A.C. can be made the same as the frequency of the bar.

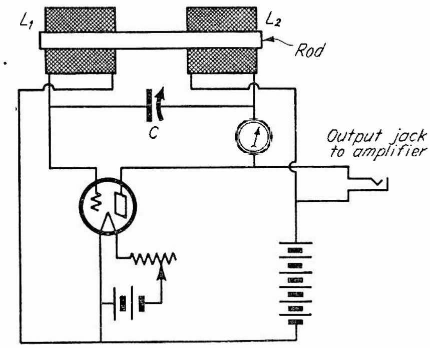


FIG. 22

An arrangement of this sort can be connected in a "hi mu" vacuum tube circuit to provide a standard frequency generator. In this case one of the coils is connected across the grid and cathode of the tube and the other across the plate and cathode of the tube. When the circuit oscillates at the frequency of the magnetostrictive bar, this frequency will remain constant within very narrow limits.

The magnetostriction oscillator is shown in Fig. 22 and a commercial standard frequency generator of this type is shown in Fig. 23. The coils are shunted by a variable condenser so that the *LC* constants can be adjusted to the fundamental frequency of the rod used.

As the condenser *C* is tuned to resonance with the rod, the milliammeter current rises rapidly. When this current is at a maximum it can be used as a signal power control without affecting the circuit frequency. Changes in filament current and plate voltage have extremely small effect on the circuit frequency, which depends solely on the length and structure of the rod. The longer the rod the lower the frequency.

An oscillator of this kind is a valuable secondary source of standard frequencies from 5 to 50 kc. and, as it is a rich producer of harmonics, frequencies of several million c.p.s. are easily obtained. Various fundamental frequencies are obtained by replacing the rod with others of various sizes. Thus the device may be used as a frequency generator or meter.

R.F. COIL MEASUREMENTS BY RESONANCE METHODS

Special resonance methods are used in measuring the inductance, R.F. resistance and distributed capacity of R.F. coils.

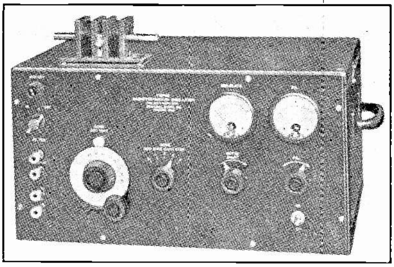


FIG. 23

For making these measurements, the resonance method is best because this is the only method by which actual operating conditions can be gauged, as the various quantities differ greatly at high and low frequencies.

From the formula $L = \frac{1}{39.5f^2C}$ $\left(\text{derived from } f = \frac{1}{2\pi\sqrt{LC}}\right)$ it can be seen that, knowing the value of f and C, it will be a simple matter to calculate the inductance of a coil in a resonant circuit. We can use this formula as the basis of a simple inductance measuring device.

The coil whose inductance is to be measured is connected in series with a precision variable condenser having negligible R.F. resistance, and a thermocouple milliammeter. Then the coil is weakly coupled to an R.F. signal of known frequency, which should be very close to the frequency the coil is to handle. The next step is to adjust C for maximum milliammeter reading.

At this setting of C, its capacity value is read and as the frequency is known, we have sufficient information to calculate L.

Now suppose we want to find the R.F. resistance of L. If we knew the voltage across L at resonance we could find r from Ohm's Law, for the current I is read on the milliammeter. Unfortunately only I is measurable. But we can insert a known R.F. resistance, as shown in Fig. 24. Now the current through the milliammeter is reduced by the resistance of the standard resistor (R) as well as by the resistance of the coil (r). Then the new current is I_1 and:

$$I_1 = \frac{E}{r + R} \qquad \text{(a)}$$

Of course we still do not know the value of E, but we do know that it is equal to $I \times r$. Therefore we can restate formula (a) as follows:

$$I_1 = \frac{I \times r}{r + R} \qquad \text{(b)}$$

Solving formula number (b) for r we get the working formula:

$$r = R \div \left(\frac{I}{I_1} - 1\right) \qquad (7)$$

It is obvious now that as we know R and we can measure I and I_1, we can easily calculate the value of r, the R.F. resistance of the coil.

Suppose, for the sake of a practical example, that we used a standard resistor of 20 ohms and we measured I as 110 ma. and I_1 as 55 ma. Substituting in formula (7) we get:

$$\begin{aligned} r &= 20 \div \left(\frac{110}{55} - 1\right) \\ &= 20 \div (2 - 1) \\ &= 20 \div 1 \\ &= 20 \text{ ohms} \end{aligned}$$

If we have a decade box available, it is a much simpler matter to measure the R.F. resistance of a coil. We merely insert the decade box at R, and adjust it so that the current through the milliammeter is reduced to exactly one-half. Then we would read the value of R and the coils R.F. resistance (r) would be exactly equal to R.

We have thus far determined two important factors of an R. F. coil; its inductance and its R.F. resistance. Another important factor is its distributed capacity. With the circuit shown in Fig. 24 this may also be quickly obtained.

Tune the condenser C to resonance with the fundamental frequency produced by the signal generator. This we have already done when we measured L. Let us call the value of the precision condenser at this setting C_1. The generator no doubt

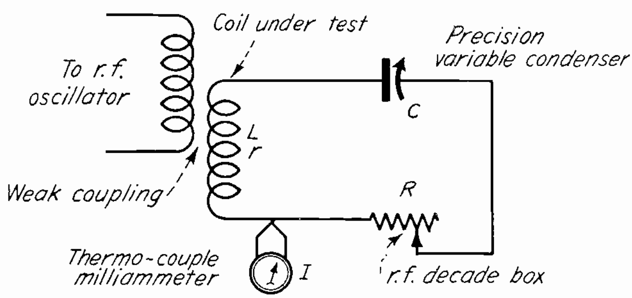


FIG. 24

has a prominent second harmonic and with the original coil it will require a condenser setting about ¼ of C_1 to bring L and C to resonance with it. Call this setting C_2. If it were not for the distributed capacity of the coil, C_1 would be four times C_2. The distributed capacity C_0 is then found from the formula:

$$C_0 = \frac{C_1 - 4C_2}{3} \tag{8}$$

and if C_1 and C_2 are measured in microfarads, the formula will give C_0 in microfarads.

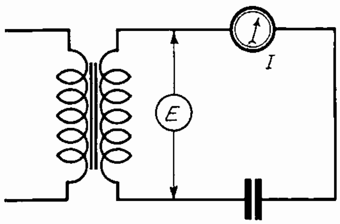
APPROXIMATE CAPACITY OF FILTER CONDENSERS

The usual radio service bench is equipped with a low range A.C. milliammeter, either of the thermocouple, moving vane or electrodynamometer type. A step-down transformer is connected to the 110 volt 60 cycle power supply. To its secondary terminal are connected the condenser to be measured and the A.C. milliammeter, in series. If there is any doubt about the secondary voltage, measure it with a voltmeter, then the capacity in microfarads will be:

$$C = \frac{1000}{2\pi f E} \times I$$

where I is in milliamperes
$2\pi = 6.28$
$f = 60$
E is in volts.

The method is only for approximate measurements, as the transformer may distort the wave form and the current read-



Condenser under test

Fig. 25

ing will not be true. The impedance of the ammeter will be included in the measurement. If the voltmeter is placed across the capacity, the ammeter will read both the current through the capacity and the voltmeter. Correction should be made for the latter. If an electrodynamometer milliammeter of low resistance and inductance is used, or a V.T.V.M. is used as the ammeter, or a thermocouple meter is employed, the arrangement in Fig. 25 will be fairly accurate.

A permanent set-up can be made and the ammeter dial actually made to read in microfarads, in which case we have a capacity meter. The ammeter may have several shunts so as to measure a wide range of capacities. In general the system is good for ranges of .01 to 10 mfd. However, it is usually far more satisfactory to measure capacity in a bridge measuring circuit.

TEST QUESTIONS

Be sure to number your Answer Sheet 30FR.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and the best possible lesson service.

1. What is a decade resistance?
2. When a Wheatstone bridge is perfectly balanced, what will the galvanometer reading be?
3. If you placed an *LC* resonant circuit as shown in Fig. 19e, near the antenna coupling coil of a receiver, carrying signal current, how would you know when the *LC* circuit resonated to the frequency of the incoming signal?
4. Draw a diagram of a bridge circuit for measuring inductance, using a standard variable inductance (variometer).
5. Would you use the frequency meter shown in Fig. 19b for measuring an unmodulated R.F.?
6. What particular advantage does the piezo crystal oscillator have as a signal generator?
7. What precautions must be taken when making precision resistors for frequencies from zero to 1,500,000 c.p.s.?
8. How can a 1 kc. standard frequency be obtained from a 100 kc. crystal oscillator?
9. Draw a diagram of a simple capacity meter having a range of .01 to 10 mfd.
10. What is the difference between a wavemeter and a frequency meter?

14 CIRCUIT DIAGRAMS EACH WITH TESTING INFORMATION

31 SS

SERVICE MANUAL

PIONEER HOME STUDY RADIO SCHOOL

NRI

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

FOREWORD

This booklet is one of a series of service manuals which contain service sheets giving typical information on radio receivers. Each service sheet shows the circuit diagram in the usual symbolic form for that radio receiver. Many of the service sheets will contain such special service information as space will permit.

By studying each service sheet, you will gradually develop the ability to read any diagram or manufacturer's service manual and learn the usual methods of set adjustment. Enough typical receivers have been selected to give you quickly a good insight to the entire radio problem.

In reading a circuit diagram, learn to trace independently the power supply and the signal circuits. Then locate the special control circuits, such as the automatic volume controls, tuning indicators, manual volume controls, etc. Detailed information on power, supply, signal and control circuits, as well as set servicing, is given in the course, to which reference should be made.

J. E. SMITH.

WPC3M-1136 Printed in U.S.A.

RADIO-TRICIAN
REG. U.S. PAT. OFF.
Service Sheet
Compiled Solely for Students and Graduates

NATIONAL RADIO INSTITUTE, WASHINGTON, D.C.

ATWATER KENT 91, 91B, 91C, 188, 188F, 260, 260F, 469, 469F

TUBE	CIRCUIT	91 91-B 91-C	188 188-F	260 260-F 1ST TYPE	260 260-F 2ND TYPE	469 469 F
R. F. TUBE	FILAMENT PLATE SCREEN GRID	6 130 80 2	2.4 130 75 3	2.4 200 90 2	2.4 250 70 1	2.4 125 110 2
1ST-DET. TUBE	FILAMENT PLATE SCREEN GRID	6 125 75 5	2.4 130 75 1	2.4 200 20 1	2.4 250 60 2	2.4 160 100 5
I. F. TUBE	FILAMENT PLATE SCREEN GRID	6 130 85 2	2.4 130 75 4	2.4 200 90 2	2.4 250 70 1	2.4 125 110 2
2ND-DET. TUBE	FILAMENT PLATE SCREEN GRID	6 60 — 9	2.4 95 55 4	2.4 ** ** **	2.4 ** ** **	2.4 170 — 15
1ST-A. F. TUBE	FILAMENT PLATE SCREEN GRID	6 130 — 3	2.4 205 215 3	2.4 115 — 2	2.4 110 — 1	2.4 230 235 15
2ND-A. F. TUBE	FILAMENT PLATE SCREEN GRID	6 127 130 12	— — — —	2.4 230 235 15	2.4 225 230 15	— — — —
OSC TUBE	FILAMENT PLATE GRID	6 100 *	2.4 85 *	2.4 35 *	2.4 40 *	2.4 75 *
CONTROL TUBE	FILAMENT PLATE GRID	6 5 2.5	2.4 40 10	2.4 ** **	2.4 ** **	2.4 14 10

VOLTAGE TABLE
91, 91-B, 91-C, 188, 188-F, 260, 260-F, 469, 469-F

The voltages listed in this table are only approximate and are measured values, not actual operating values.

Use 250-volt scale of a 1000-ohm-per-volt voltmeter.

TONEBEAM ADJUSTMENT FULL COUNTER CLOCKWISE; RANGE SWITCH AT LOCAL.

All plates, screen and grid measurements are made from cathode in heater-type tubes, and from —F in plain-filament-type tubes.

LINE VOLTAGE = 110 VOLTS

VOLTAGES ACROSS BLEEDER AND BIAS RESISTORS

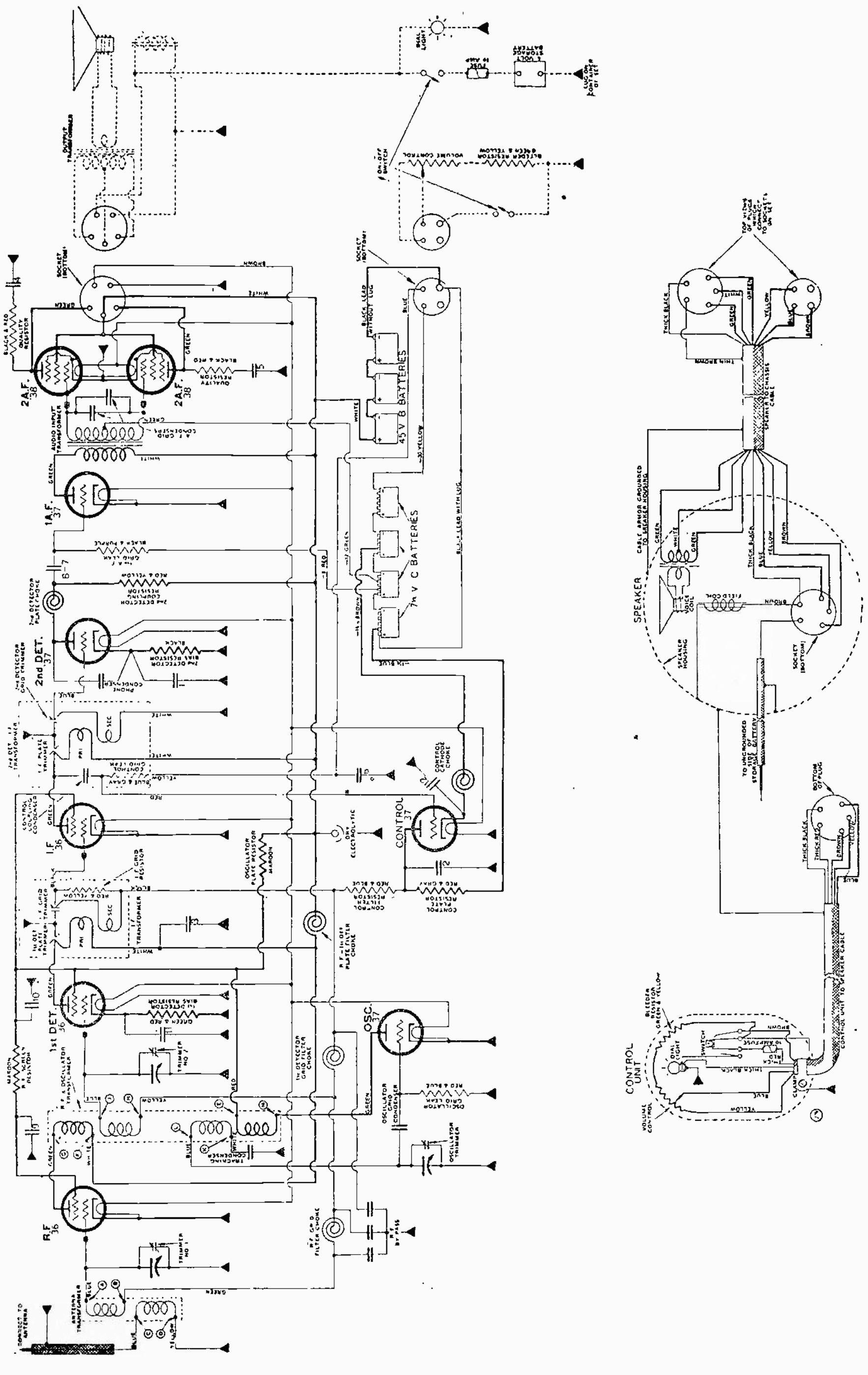
RESISTOR	188 188-F	260 260-F 1st type	260 260-F 2nd type	469 469-F
Bleeder No. 1	50	92	90	50
Bleeder No. 2	85	108	75	110
Bleeder No. 3	70	73	55	8
Bleeder No. 4	11	20	15	12
Bleeder No. 5	—	88	30	Slight
Bleeder No. 6	—	50	85	35
Bleeder No. 7	—	—	—	55
1st-detector bias	5	2	1	3
R. F.-I. F. bias No. 1	Slight	4	6	1
R. F.-I. F. bias No. 2	7	2	2	—
2nd-I. F. bias	—	Slight	Slight	—
2nd-detector bias	5	—	—	15
1st-A. F. bias	—	5	5	—
A. F. bias	12	15	15	15
Tonebeam adjustment	—	95	120	65

* The measured oscillator grid voltage will vary dependent on several factors. In some cases, no reading will be secured for grid bias. In other cases, the reading will be only slight, or it may be as high as 10 volts.

** In Model 260 and 260-F, the 2nd-detector also functions as automatic-volume-control tube. The voltages that can be read at this socket are as follows: 1st type, cathode to ground 20 volts, grid to ground 7 volts. 2nd type, cathode to ground 15 volts, grid to ground 5 volts.

ATWATER KENT MODEL 91, 91B AND 91C MOTOR CAR RADIO

(Intermediate Frequency, 260 Kilocycles)



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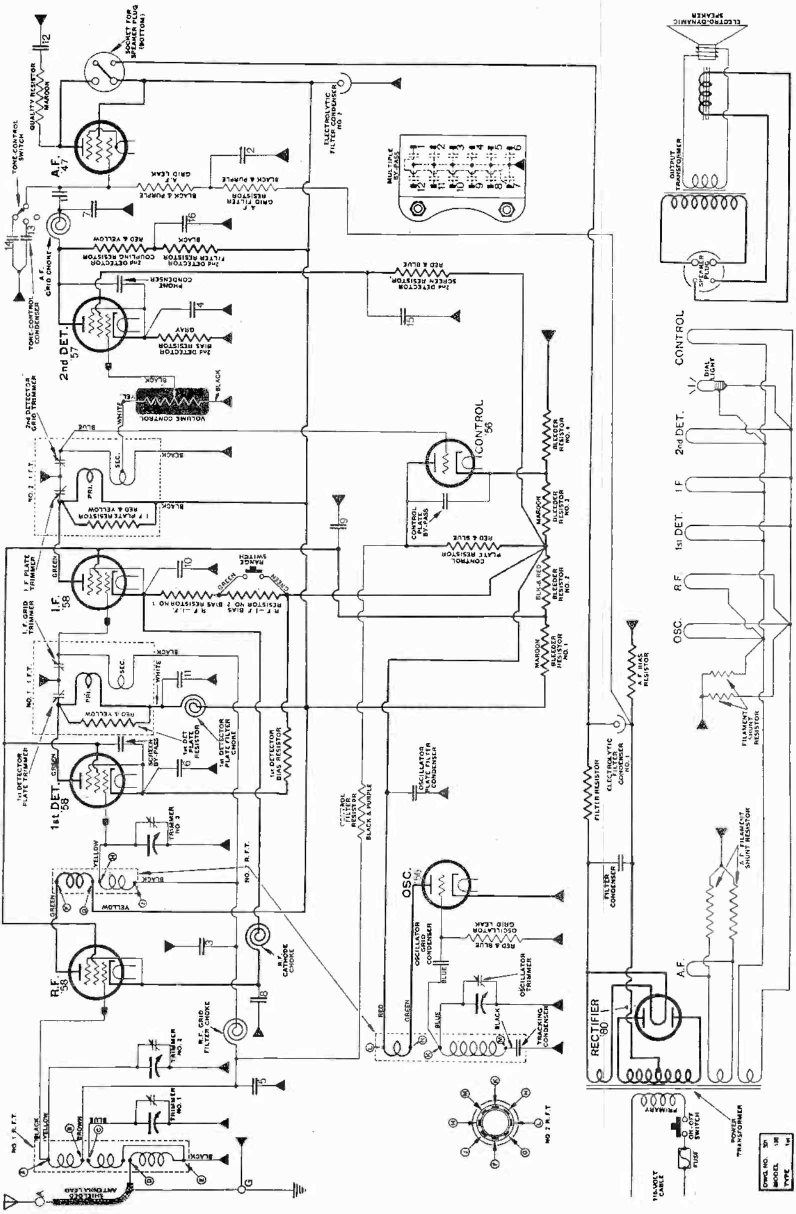
ATWATER KENT RADIO MODEL 188

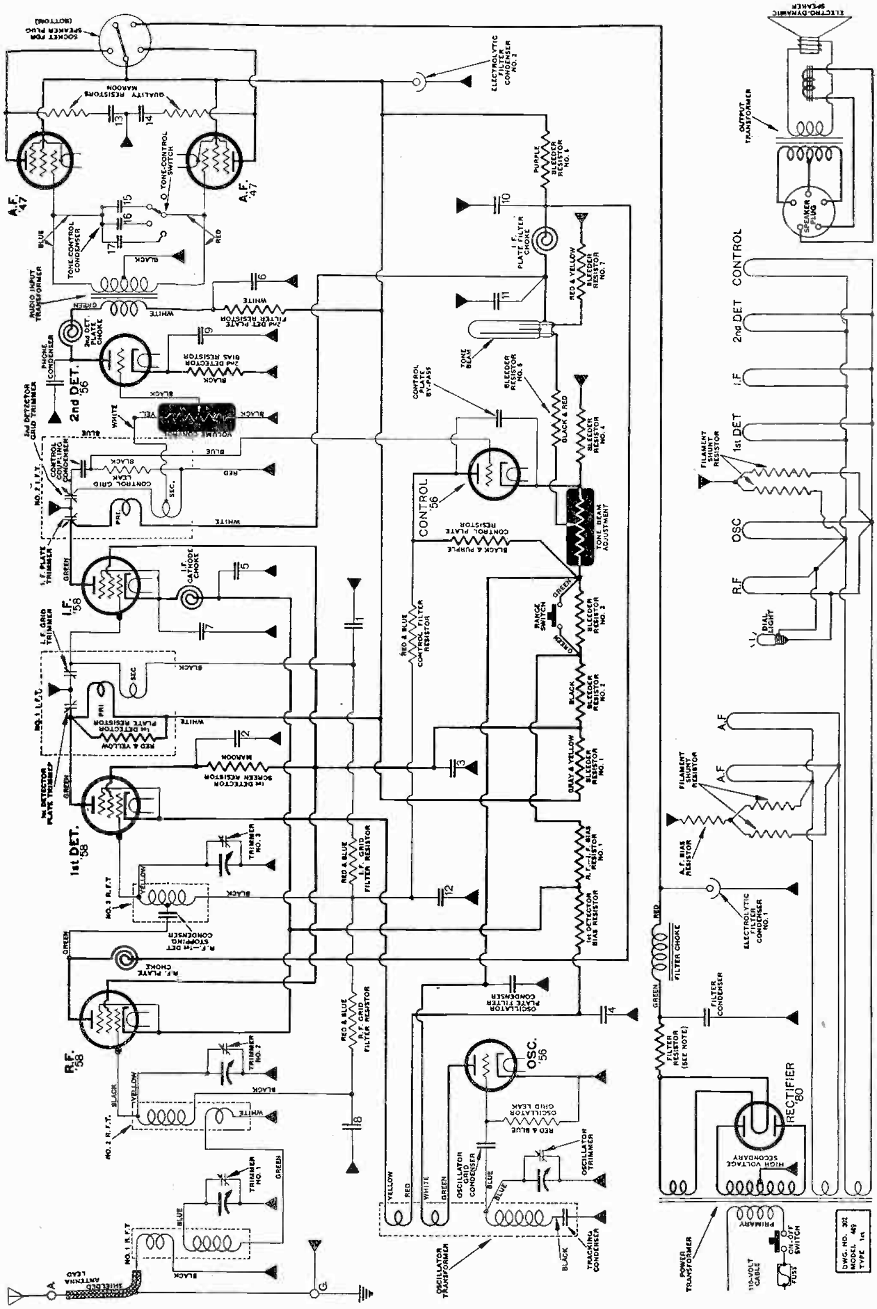


In late-type sets, bleeder No. 2 is black. In late-type Models 188 and 188-F, the oscillator grid winding on No. 2 R. F. T. is split into two separate sections, thus making five coils instead of four on this transformer. Also, a small compensating condenser (No. 16360) is connected across contacts K and M of No. 2 R. F. T.

The late-type No. 23028 R. F. transformer group, which incorporates these changes, supersedes the early-type group. The early-type group is not supplied for service. When installing the late group in place of an early group, it is essential to remove the early-type 1st detector bias resistor No. 21030, and install in its place a late-type 1st detector bias resistor No. 16320. A No. 16320 flexible resistor is provided for this purpose with each No. 23028 R. F. transformer group.

It is also necessary to connect the blue lead from the oscillator grid condenser (125 mmf.) to the extra terminal at the side of No. 2 R. F. T. instead of to terminal K. The extra terminal is the center tap of the oscillator grid coil.

ATWATER KENT MODEL 469, 469F



Early-type Model 469 receivers employed a T-12-A power transformer which necessitated the use of a filter resistor (No. 19180-X) as shown above. Later types of this model use a T-23 power transformer which does not require the filter resistor. The T-12-A transformer is not supplied for service, being superseded by the T-23. When installing T-23 in place of a defective T-12-A, it is necessary to remove or short circuit the filter-resistor.

In late-type 469, the 2nd detector filter resistor is sealed inside the audio input transformer, which has six leads: The white lead is for connection to condenser 6, and a yellow lead is for connection to plus B. When replacing an early-type audio input transformer, with the late-type, it is necessary to remove the external 2nd-detector filter resistor,

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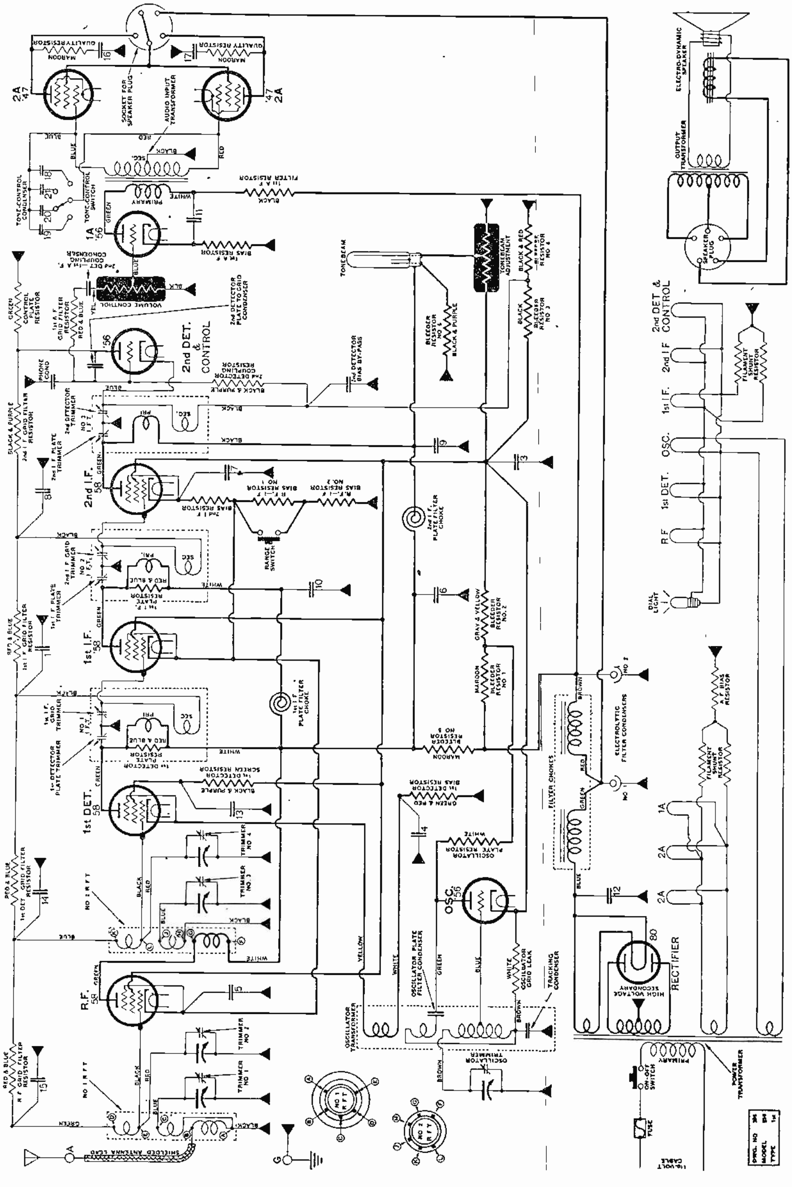
ATWATER KENT MODEL 260, 260F (First Type)

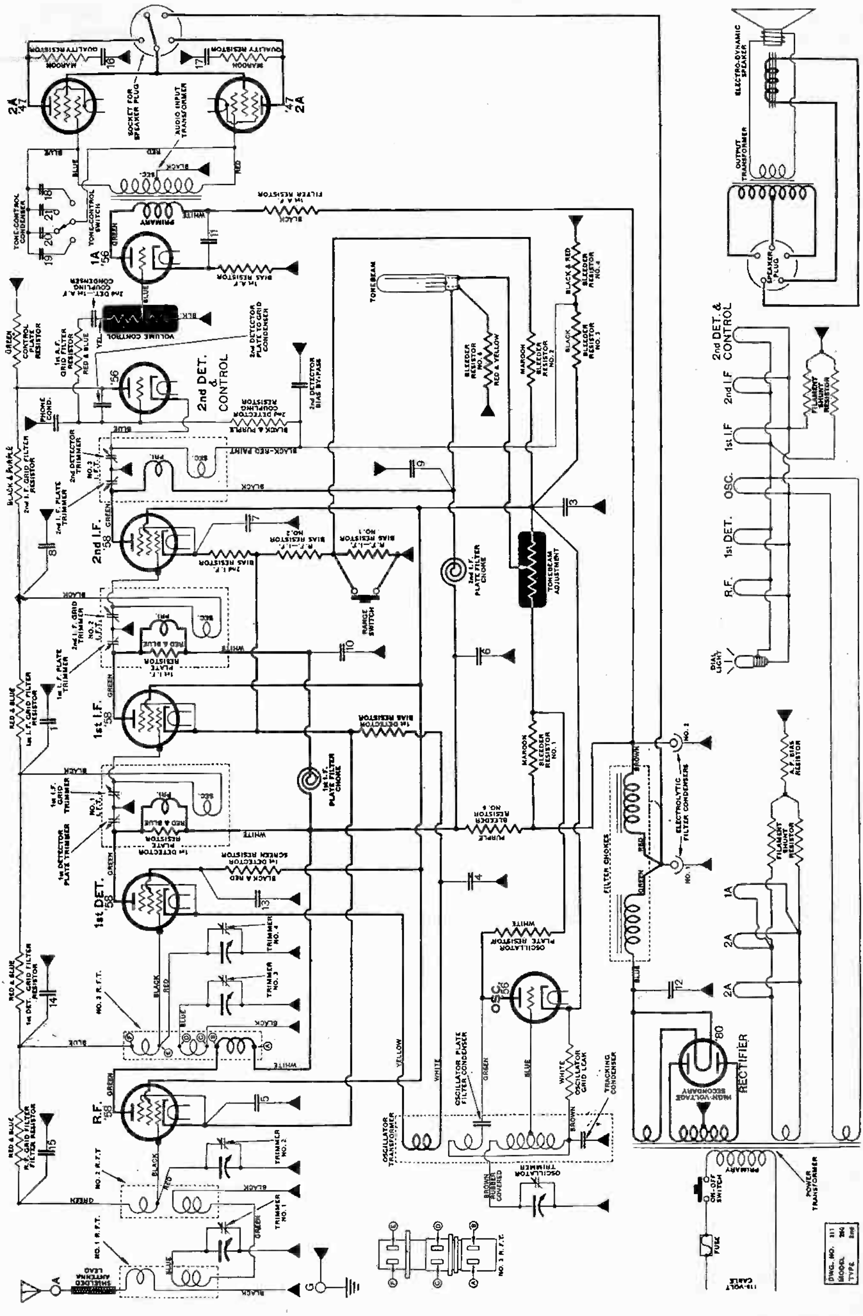
Below Serial No. 8422101



Ak260

ATWATER KENT MODEL 260, 260F (Second Type)

Above Serial No. 8422101



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Sparton Model 14 Super-Heterodyne
Schematic Diagram and Voltage Analysis

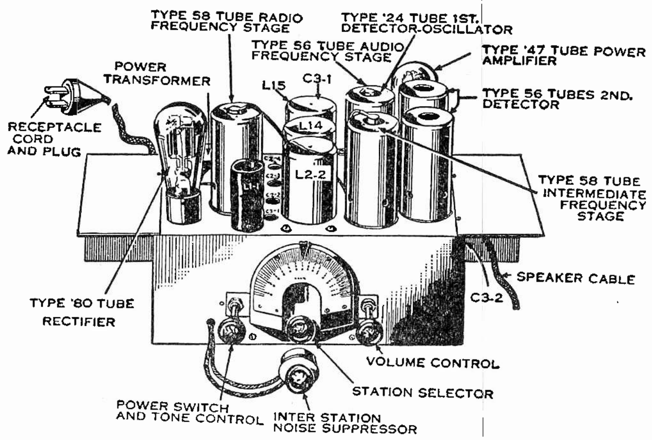
VOLTAGE ANALYSIS

Line Voltage 115—Position of Voltage Compensator 100-115—Position of Volume Control Full

Tube	Location	Heater or Filament	Plate	Control Grid —	Screen Grid +	Plate Current M. A.
58	R. F. Stage	2.2—2.5	218—242	2—4	95—105	5.5—7.0
'24	1st Det.-Osc.	2.2—2.5	218—242	——	95—105	0.7—8.0
58	I. F. Stage	2.2—2.5	218—242	2—4	95—105	5.5—7.0
56	2nd Det.-AVC	2.2—2.5	*	*	——	*
56	2nd Det.-AVC	2.2—2.5	*	*	——	*
56	A. F. Stage	2.2—2.5	20—40	Zero	——	0.5—0.7
'47	Power Stage	2.2—2.5	205—225	†18—20	218—242	20—24
'80	Rectifier	4.5—5.0	315—345	——	——	19–23 per Plate

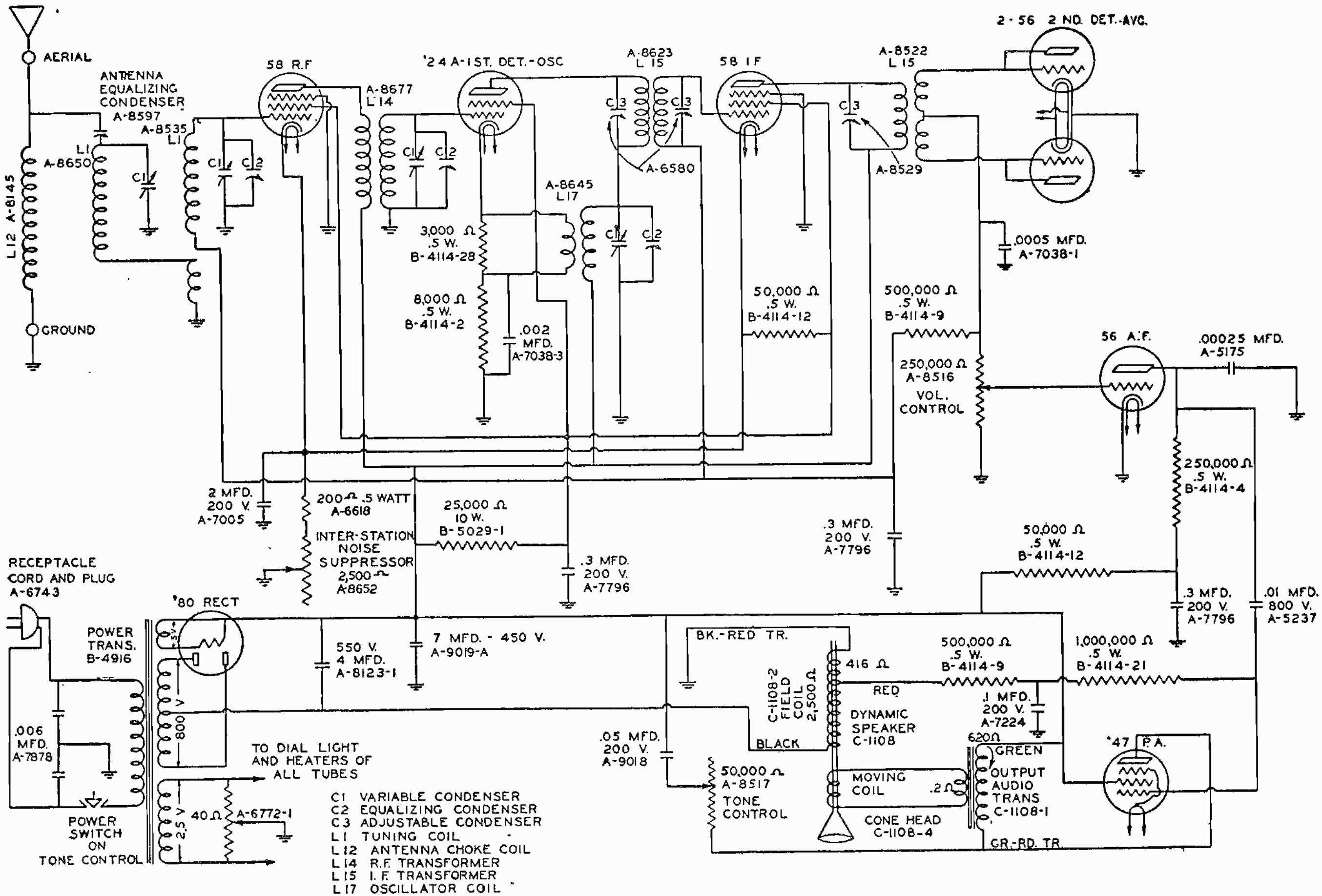
* Present only when signal is applied.
† Measured from tap on field coil to ground.

MODEL 14 CHASSIS



C2-1 Antenna Equalizing Condenser
C2-2 R. F. Stage Equalizing Condenser
C2-3 1st Detector Equalizing Condenser
C2-4 Oscillator Equalizing Condenser
C3-1 I. F. Input Stage Adjustable Condenser
C3-2 I. F. Output Stage Adjustable Condenser
L1 1st Tuning Coil
L2 Second Tuning Coil
L14 R. F. Transformer
L15 I. F. Transformer

SPARTON MODEL 14 SUPER-HETERODYNE



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Sparton Model 18 Super-Heterodyne Schematic Diagram and Voltage Analysis

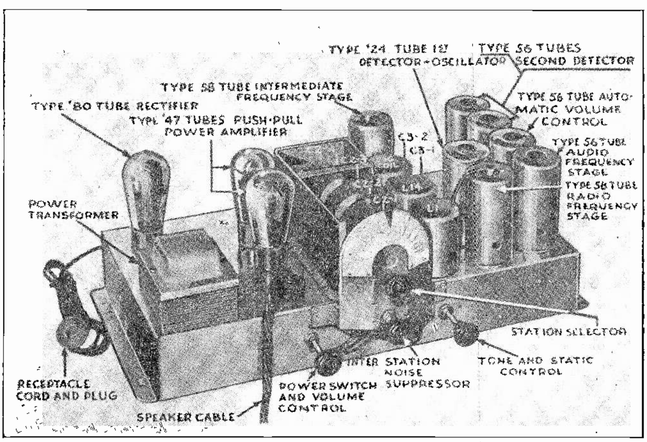
VOLTAGE ANALYSIS

Line Voltage 115—Position of Voltage Compensator 100-115—Position of Volume Control Full

Tube	Location	Heater or Filament	Plate	Control Grid —	Screen Grid +	Plate Current M. A.
58	R. F. Stage	2.2—2.5	260—305	1.9—2.5	70—88	4.5—8.0
'24	1st Det.-Osc.	2.2—2.5	260—305	5—9	70—88	0.8—1.4
58	I. F. Stage	2.2—2.5	260—305	1.9—2.5	70—88	4.5—8.0
56	2nd Det.	2.2—2.5	*	*	——	*
56	2nd Det.	2.2—2.5	*	*	——	*
56	A. F. Stage	2.2—2.5	245—285	10—14	——	4.5—8.0
56	AVC	2.2—2.5	35—50	40—50	——	Zero
'47	Power Stage	2.2—2.5	250—295	19—25	260—305	18—25
'47	Power Stage	2.2—2.5	250—295	19—25	260—305	18—25
'80	Rectifier	4.2—5.0	360—440	——	——	33—45 per Plate

* Present only when signal is applied.

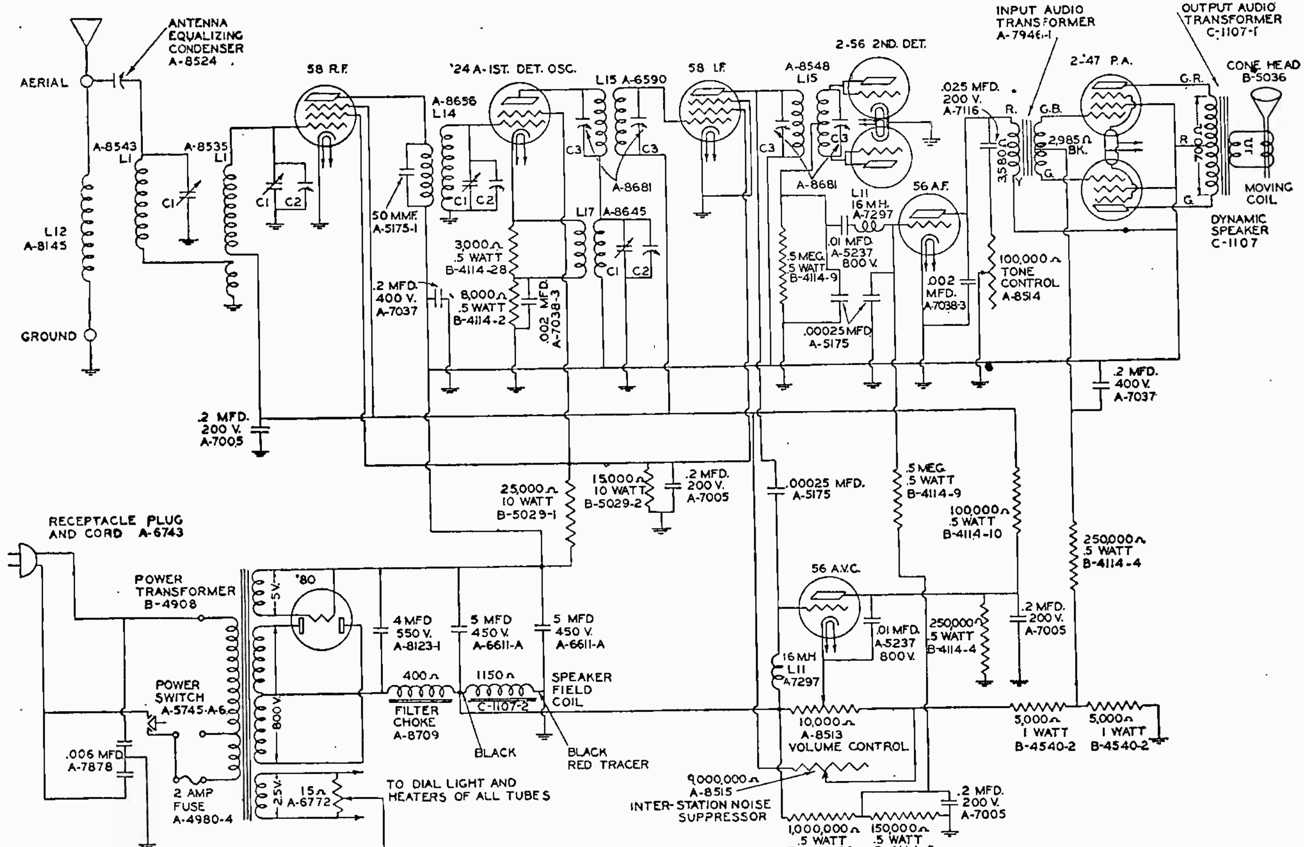
MODEL 18 CHASSIS



C2-1 Antenna Equalizing Condenser
C2-2 R. F. Stage Equalizing Condenser
C2-3 1st Detector Equalizing Condenser
C2-4 Oscillator Equalizing Condenser

C3-1 I. F. Input Stage Adjustable Condenser
C3-2 I. F. Output Stage Adjustable Condenser
L1 1st Tuning Coil
L14 R. F. Transformer

SCHEMATIC DIAGRAM
SPARTON MODEL 18 SUPER-HETERODYNE



C1 VARIABLE CONDENSER
C2 EQUALIZING CONDENSER
C3 ADJUSTABLE CONDENSER
L1 TUNING CO
L11 DETECTO TE CHOKE COIL

L12 ANTENNA CHOKE COIL
L14 R.F. TRANSFORMER
L15 I.F. TRANSFORMER
L17 OSCILLATOR COIL

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PHILCO SCREEN GRID, MODEL 76

Voltage Readings for Model 76

Tube Type	Tube Circuit	Filament Volts	Plate Volts	Screen Grid Volts	Control Grid Volts	Cathode Volts	Plate Milli-amperes	Screen Grid Milli-amperes
224	1st R.F.	2.3	145	90	3	13	3.5	.4
224	2d R.F.	2.3	145	90	3	13	3.5	.4
224	Detector	2.3	36*	30†	1.4	12	0	0
227	1st A.F.	2.3	140		1	10	3	
245	2d A.F.	2.2	230		46		30	
245	2d A.F.	2.2	230		46		30	
280	Rectifier	4.5					50	

All readings taken with antenna disconnected and ground on. Volume control on full. Local-Distance Switch in Distance position.

*Read with a 250.000-ohm voltmeter.

†Read with a 100,000-ohm voltmeter.

Power Transformer Voltages for Model 76

Terminals	A. C. Volts	Secondary
1		Center Tap for 280 Plate
2		Center Tap for 245 Tubes
3- 4	2.67	Heaters of 224 and 227 Tubes
5- 6	2.68	Filaments of 245 Tubes
8- 9	5.00	Filament of 280 Tube
7-10	750	Plate of 280 Tube
Red Wire		Center Tap for 224 and 227 Tubes
Red Wire		Primary } Through panel together
Red Wire		Primary } Through panel together

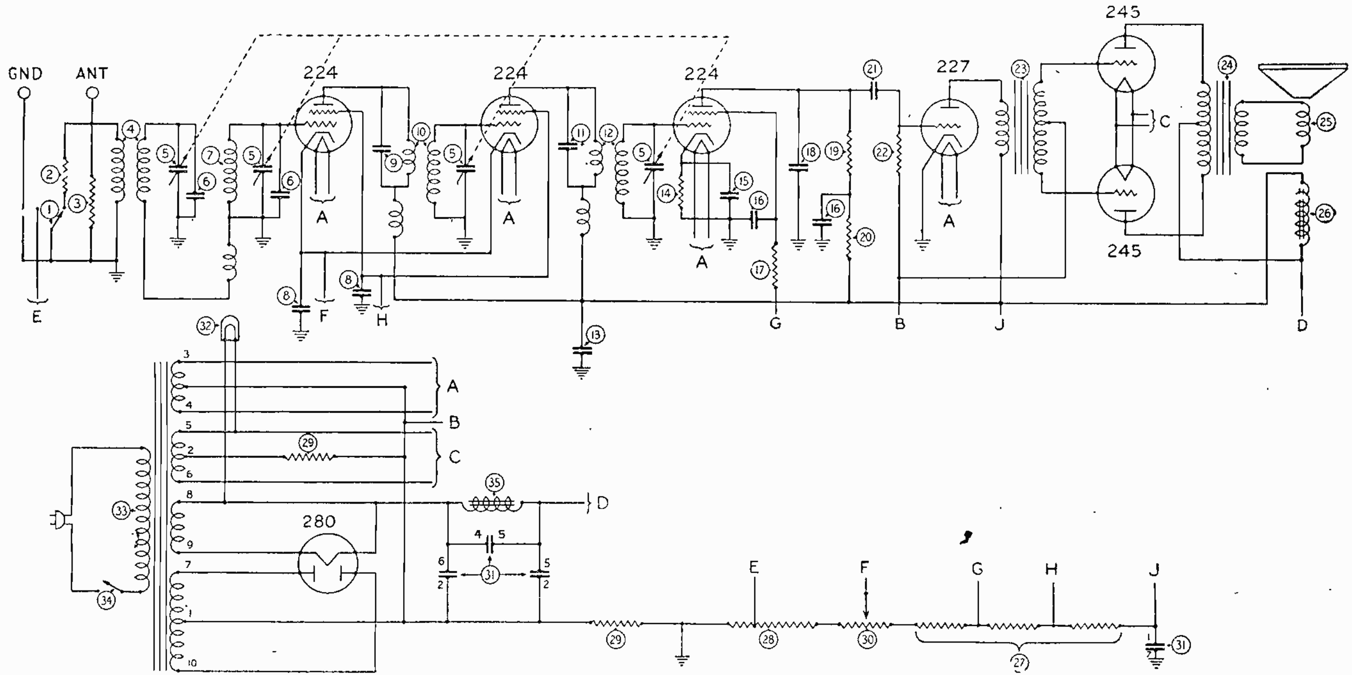
Resistor Data for Model 76

Number From Diagram on Page 5	Resistor Terminal	Ohms Resistance	Voltage Drop
	1-2	1,400	40
(27)	2-3	1,500	40
	3-4	2,000	55
(29)	1-2	250	11
	2-3	800	46
(2)		20	
(3)		5,000	
(14)		100,000	
(17)		250,000	
(19)		500,000	
(20)		100,000	
(22)		500,000	
(28)		125	

Condenser Data for Model 76

Lugs No.	Capacity	D. C. Volts With Receiver Turned On
1-7	2.0 MF	145
4-5	.15 MF	21*
2-5	2.0 MF	295
2-6	2.0 MF	310

*Read with a 250,000-ohm voltmeter.



Schematic Diagram of Model 76.

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PHILCO SCREEN GRID, MODEL 95

"B" Filter Condenser Block for Model 95

Lugs No.	Number From Diagram on Page 7	Capacity	D.C. Volts With Receiver Turned On
1-11	(48)	1.00 MF	155
4-11	(48)	.50 MF	.7
6-11	(48)	1.00 MF	90
7-11	(48)	1.00 MF	110
8- 9	(48)	.15 MF	18
3- 9	(48)	2.00 MF	300
3-10	(48)	2.00 MF	338
5-11	(48)	.015 MF	5.3

Condenser Data for Model 95

Number From Diagram on Page 7	Capacity	D.C. Volts With Receiver Turned On
(6)	.015 MF	*
(8)	.050 MF	110
(10)	.050 MF and 250 Ohm Resistor	110
(11)	.050 MF and 250 Ohm Resistor	155
(12)	.015 MF	*
(15)	.050 MF	155
(16)	.015 MF	300
(19)	.0005 MF	*
(24)	.500 MF	**
(27)	.0025 MF	*
(28)	.0025 MF	*
(31)	.050 MF	66
(32)	.015 MF	30
(37)	.015 MF	*
(46)	.250 MF	**
(50)	.015 MF	*

*No voltage reading will be obtained across these. Check for break-down with a voltmeter with battery in series

**Voltage reading will be obtained even if condenser is open. Unsolder condenser and check with meter and battery for break-down.

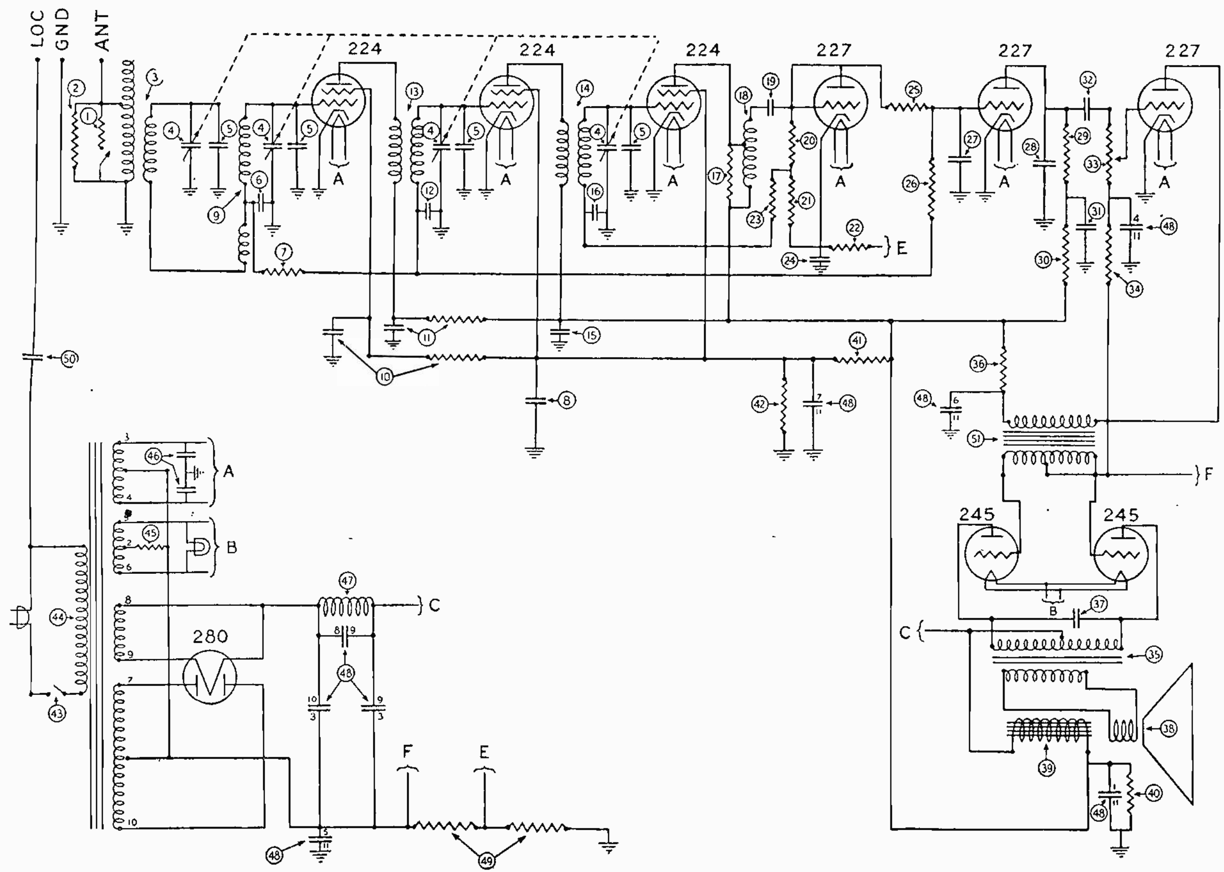
Voltage Readings for Model 95

Tube Type	Tube Circuit	Filament Volts	Plate Volts	Screen Grid Volts	Control Grid Volts	Cathode Volts	Plate Milli-amperes	Screen Grid Milli-amperes
280	Rectifier	4.5					43/Plate	
224	1st R.F.	2.15	155	95	0	5.3	4	.8
224	2d R.F.	2.15	155	95	0	5.3	4	.8
224	3d R.F.	2.15	155	95	0	5.3	4	.8
227	Detector	2.15	0		—.5	.7	0	
227	Det. Amp.	2.15	27		—.5	5.5	0	
227	1st A.F.	2.15	85		—2.0*	5.5	2.5	
245	2d A.F.	2.2	250		41		28	
245	2d A.F.	2.2	250		41		23	

*This is read with Volume Control off. With it on the reading will be .2 volt.

NOTE: Do not allow receiver to oscillate while taking readings. Keep R.F. shield on and tune to eliminate oscillation. Have antenna and ground connected.

Ph95



Schematic Diagram of Model 95

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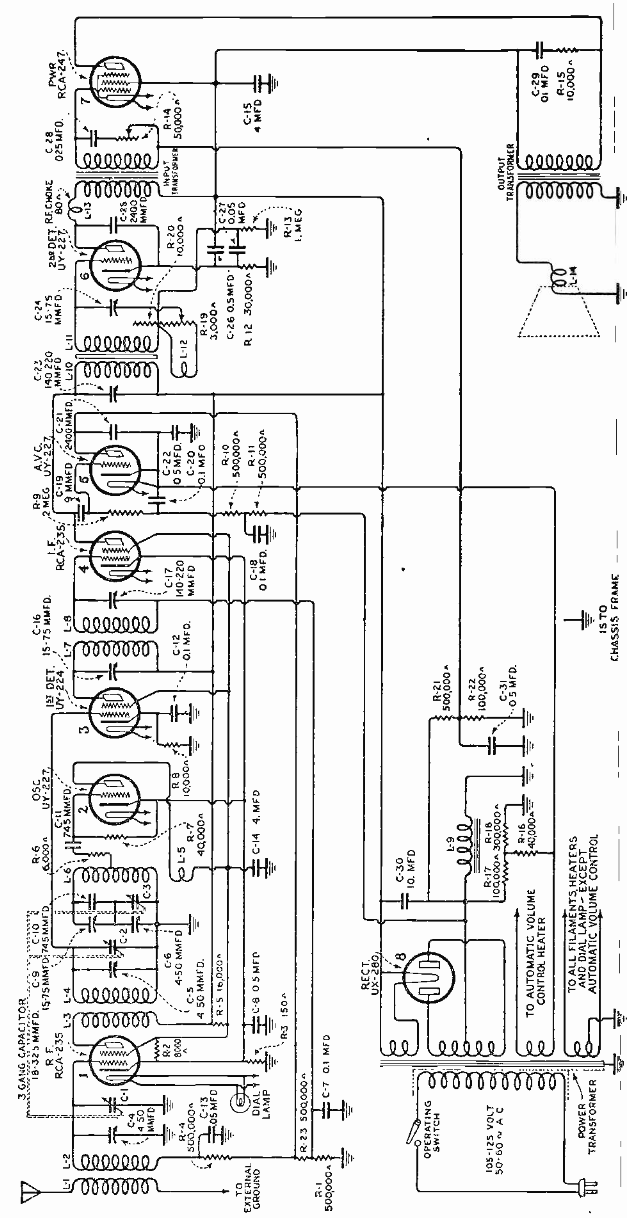
R. C. A. VICTOR MODELS—R-8, R-12, AND R-20



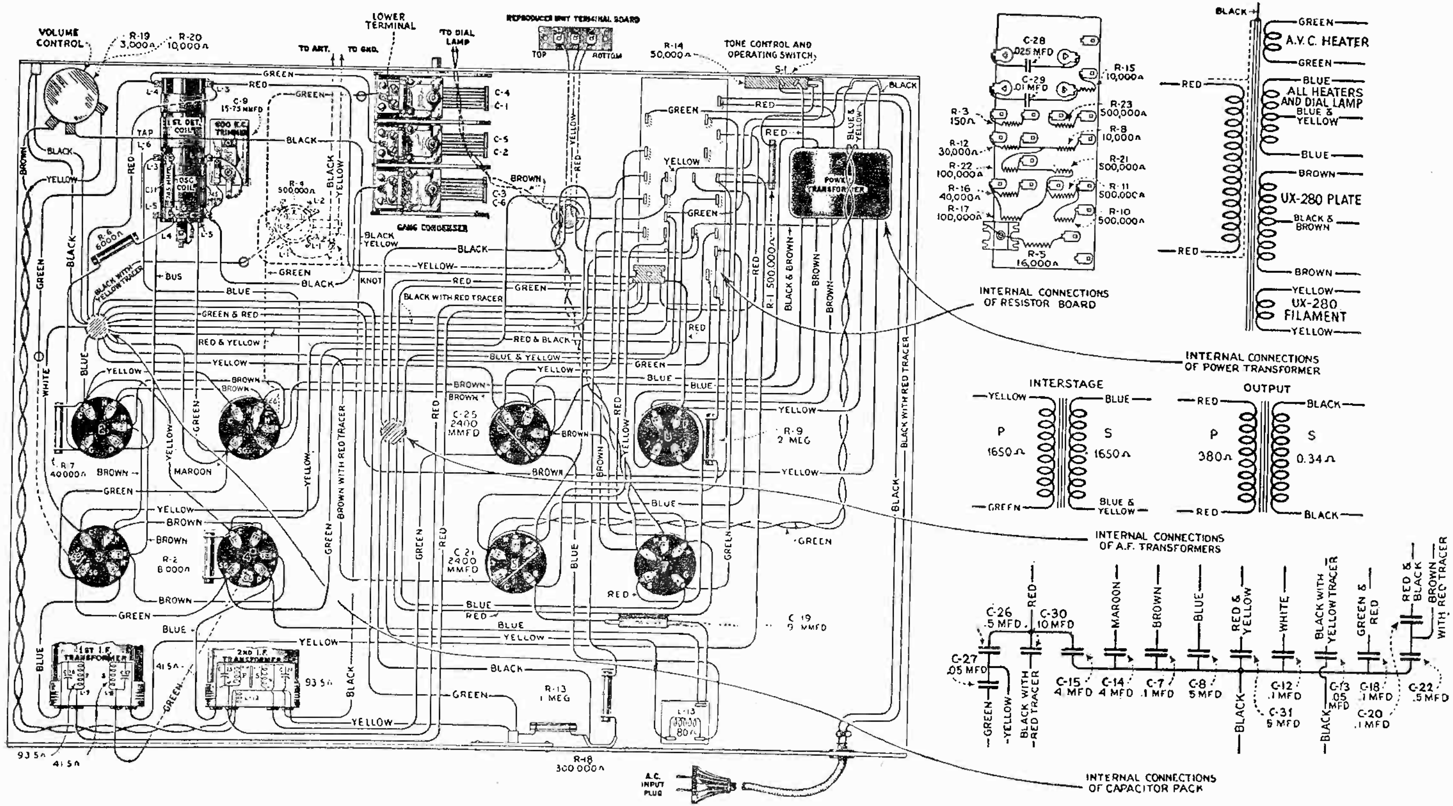
RADIOTRON SOCKET VOLTAGES

120 VOLT LINE

VOLUME CONTROL DOES NOT AFFECT VOLTAGES

Radiotron No.	Cathode to Heater Volts, D. C.	Cathode or Filament to Control Grid Volts, D. C.	Cathode or Filament to Screen Grid Volts, D. C.	Cathode or Filament to Plate Volts, D. C.	Plate Current M. A.	Screen Current M. A.	Heater or Filament Volts, A. C.
1. R. F.	4.0	0.5	70	260	4.0	0.5	2.66
2. Osc.	4.0	0	—	65	6.0	—	2.66
3. 1st Det.	7.0	6.0	70	260	0.75	0.1	2.66
4. I. F.	4.0	4.0	70	260	4.0	0.5	2.66
5. 2nd Det.	28.0	10.0	—	250	1.0	—	2.66
6. A. V. C.	0	0	—	25	0	—	2.66
7. Power	—	10.0	290	280	35.0	—	2.66

R. C. A. VICTOR MODELS—R-8, R-12, AND R-20



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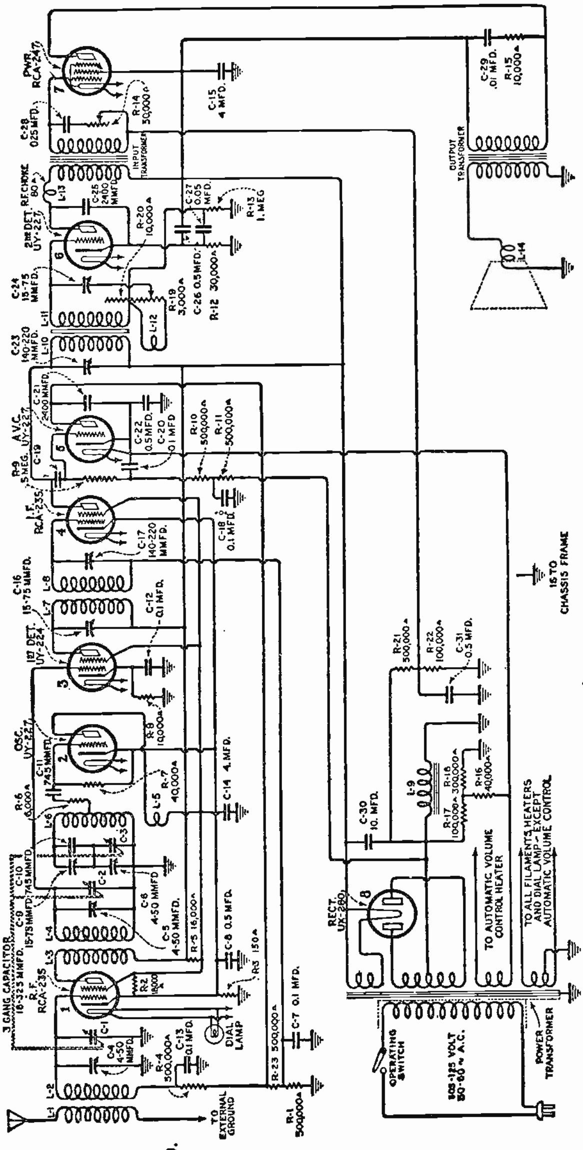
R. C. A. VICTOR CONSOLE, R-10



C-19 9 MMFD.

C-13 3-5 MFD.

RADIOTRON SOCKET VOLTAGES

110 VOLT A. C. LINE

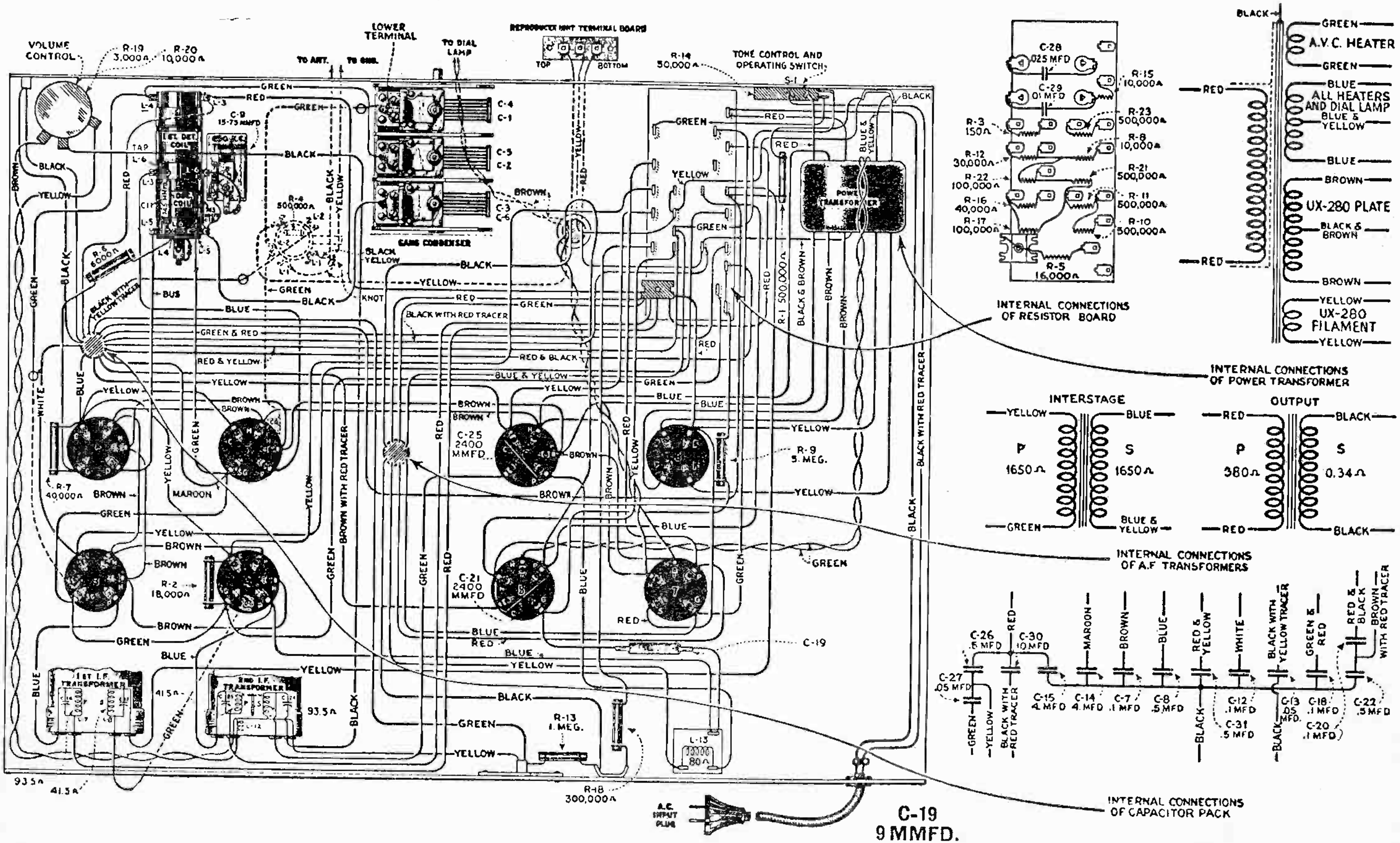
(Volume Control Setting Does Not Affect Voltages)

Radiotron No.	Cathode to Heater Volts, D. C.	Cathode or Filament to Control Grid Volts, D. C.	Cathode or Filament to Screen Grid Volts, D. C.	Cathode or Filament to Plate Volts, D. C.	Plate Current M. A.	Screen Current M. A.	Heater or Filament Volts, A. C.
1	2	*0.1	75	210	5.0	0.5	2.2
2	8	0	—	60	5.0	—	2.2
3	7	7.0	70	205	0.5	0.1	2.2
4	2	*0.1	75	210	5.0	0.5	2.2
5	0	0	—	30	0	—	2.2
6	20	*8.0	—	185	0.5	—	2.2
7	—	10	210	210	25	—	2.2

*Not true reading due to resistance in circuit.

RCA10

R. C. A. VICTOR CONSOLE, R-10



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RCA-VICTOR MODEL 221; GENERAL ELECTRIC M-65; CANADIAN RCA-VICTOR 221

LINE-UP CAPACITOR ADJUSTMENTS

I.F. Adjustments—Two transformers comprising four tuned circuits are used in the intermediate amplifier. These are tuned to 370 K.C. and adjustment screws are accessible as shown in Figure D. Proceed as follows:

(a) Short-circuit antenna and ground terminals and tune receiver so that no signal is heard. Set volume control at maximum and connect a ground to chassis.

(b) Connect oscillator output between first detector control grid and chassis ground. Connect output meter across voice coil of loudspeaker and adjust oscillator so that, with receiver volume contral at maximum, a slight deflection is obtained in output meter.

(c) Adjust secondary and primary of first and then the second I. F. transformers until maximum deflection is obtained. Keep oscillator output at low value so that only slight deflection is obtained on output meter at all times. Go over adjustments a second time, as there is a slight interlocking of adjustments. This completes I.F. adjustments.

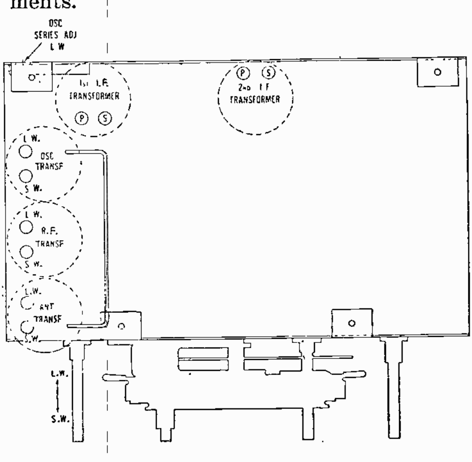
R.F. and Oscillator Adjustments—R.F. line-up capacitors are located at bottom of coil assemblies instead of their usual position on gang capacitor. They are all accessible from bottom of chassis except the 600 K.C. series capacitor, which is accessible from rear of chassis. Proceed as follows:

(a) Connect output of oscillator to antenna and ground terminals of receiver. Check position of indicator pointer when tuning capacitor plates are fully meshed. It should be coincident with radial line adjacent to dial reading of 540. Then set Oscillator at 1400 K.C., dial indicator at 1400 and oscillator output so that slight deflection will be obtained in output meter when volume control is at maximum.

(b) With Range Switch at "in" position, adjust three trimmers under three R.F. coils, designated as L.W. in Figure D, until maximum deflection is obtained in output meter. Shift Oscillator frequency to 600 K.C. Trimmer capacitor, accessible from rear of chassis, should now be adjusted for maximum output while rocking main tuning capacitor back and forth through signal. Then repeat 1400 K.C. adjustment.

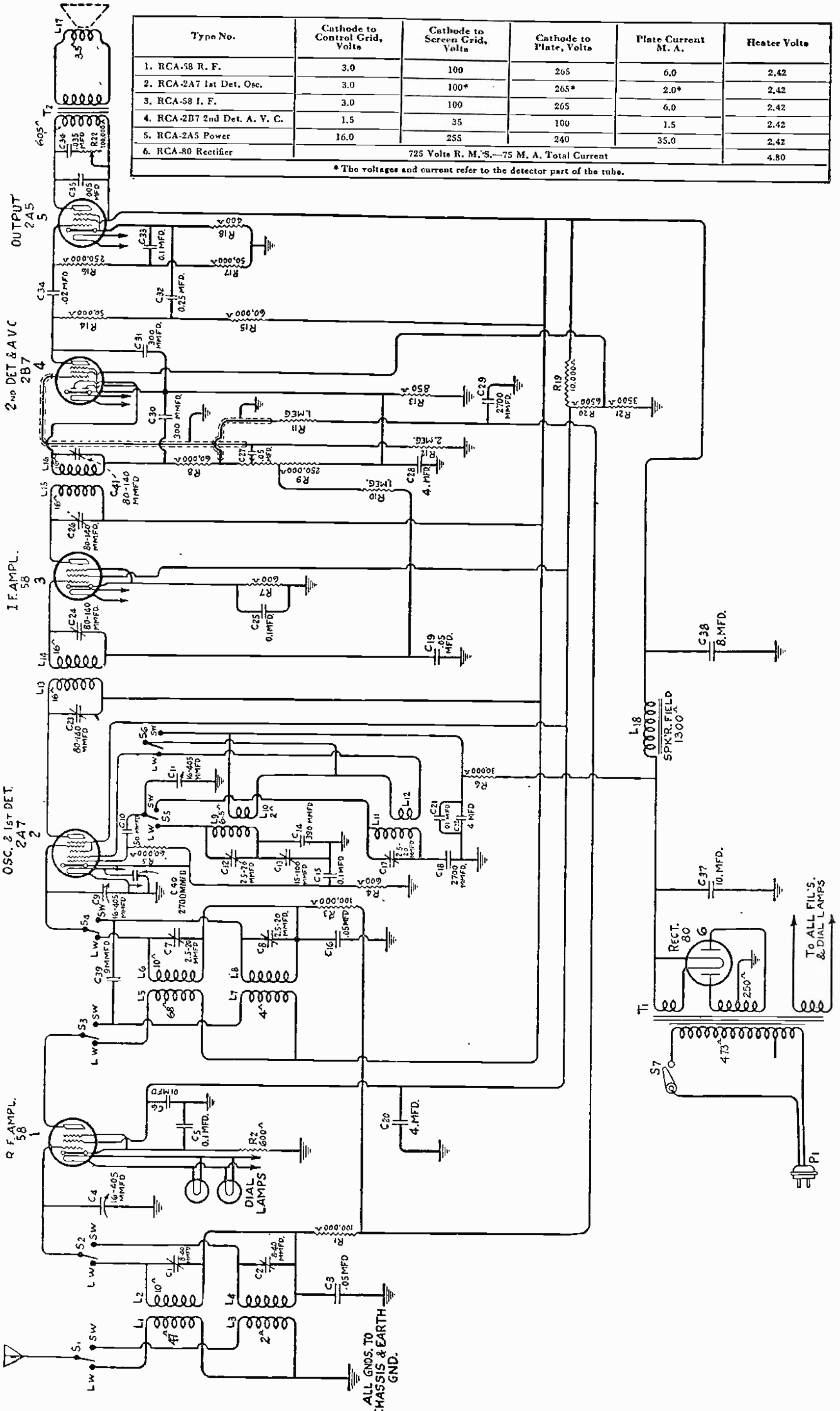
(c) Now place Range Switch at "out" position, shift Oscillator to 15,000 K.C. and set the dial at 15 on megacycle scale. Adjust three trimmer capacitors designated as S.W. in Figure D for maximum output, beginning with oscillator trimmer. It will be noted that oscillator and first detector trimmers have two positions at which signal will give maximum output. The position which uses lower trimmer capacitance, obtained by turning the screw counter-clockwise, is proper adjustment for oscillator, while position that uses a higher capacitance is correct for detector. Both of these adjustments must be made as indicated irrespective of output. The R.F. is merely peaked. In conjunction with detector adjustment, it is necessary to rock main tuning capacitor back and forth while making adjustment. This completes line-up adjustments.

Important points to remember are need for using the minimum oscillator output to obtain deflection in output meter with volume control at maximum position and manner of obtaining proper high frequency oscillator and detector adjustments.



Type No.	Cathode to Control Grid, Volts	Cathode to Screen Grid, Volts	Cathode to Plate, Volts	Plate Current M. A.	Heater Volts
1. RCA-58 R. F.	3.0	100	265	6.0	2.42
2. RCA-2A7 1st Det. Osc.	3.0	100*	265*	2.0*	2.42
3. RCA-58 I. F.	3.0	100	265	6.0	2.42
4. RCA-2B7 2nd Det. A. V. C.	1.5	35	100	1.5	2.42
5. RCA-2A5 Power	16.0	255	240	35.0	2.42
6. RCA-80 Rectifier	725 Volts R. M. S.—75 M. A. Total Current				4.80

* The voltages and current refer to the detector part of the tube.



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Stewart-Warner Model R-116 Chassis

CIRCUIT DESCRIPTION

The Stewart-Warner Model R-116 chassis uses a five-tube superheterodyne circuit. The incoming signal goes to the tuned first detector circuit and then beats with the oscillator output to produce a 456 K. C. intermediate frequency signal. This particular frequency is chosen to prevent image frequency interference.

The 456 K. C. signal is amplified by a high-gain I. F. stage and is then rectified by the diodes of the 75 tube which are connected in parallel. The audio component of the rectified signal is impressed across the 500,000 ohm potentiometer through condenser No. 15. The volume is controlled by selecting any desired portion of the A. F. voltage with the moving arm of the potentiometer which is connected to the grid of the 75 tube. The triode section of this tube acts as a high-mu audio amplifier, resistance-coupled to the type 42 output tube. This method of coupling produces excellent tone quality.

The necessary A. V. C. operating voltage is secured by smoothing out the modulated drop across resistor No. 8 by a resistance-capacity filter consisting of resistor No. 5 and condensers No. 3 and 6, and applying the voltage to the grids of the 6A7 and 78 tubes. Thus the bias of these tubes increases and drops in proportion to the strength of the received signal and tends to maintain the audio output at a practically constant value.

For the reception of short wave signals, portions of the antenna coil primary and the oscillator grid coil are shorted and a condenser is connected across part of the antenna coil secondary. This reduces the inductance of the coils and thus permits tuning to higher frequencies.

The R-116 A, H, and L are designed for operation on 115 volt 60 cycle power circuits while the R-116 X, XH, and XL are adaptable for use with voltages of 115, 125, 230, 240, or 250 at any frequency from 25 to 60 cycles. To permit this flexibility of operation, the power transformer has two separate tapped primaries. The connections for the various line voltages are shown on the tag attached to the transformer. All X models are also wired for operation with a high impedance phonograph pick-up. The R-116 AL and XL chassis are used in console cabinets with 8 inch speakers. The others are used in table models with 6 inch speakers.

ALIGNING THE R-116 CHASSIS

Before attempting to align a set, the service man should remove the chassis from the cabinet and become familiar with the general layout and with the function and location of the various alignment trimmers. The following discussion briefly explains how each circuit is affected during the various steps of alignment.

The first detector and oscillator circuits are aligned by the two trimmers located on the two-gang variable condenser and are kept in exact step by the special shape of the rotor plates of the oscillator section. This shaping of the plates makes it unnecessary to use a padding condenser for low frequency alignment.

The I. F. transformers, located on the top of the chassis in front of the 75 and 78 tubes, are the tuned-input, tuned-output type, with each winding tuned by a separate trimmer condenser. The four I. F. adjustments are reached through holes in the tops of the I. F. transformer shields.

PRELIMINARY STEPS

A high-grade modulated oscillator and a sensitive output meter are necessary for correct alignment of the Model R-116 receiver. It must be possible to reduce the oscillator output to a very low value or the signal will cause the A. V. C. circuit to function making it difficult to secure exact alignment. The output meter must be sufficiently sensitive to give a satisfactory reading with the low signal.

All aligning adjustments should be made with the **volume control full on but with no broadcast signal being received.** The output meter should be connected between the plate of the 42 and the chassis through a .25 mfd. condenser or across the speaker voice coil, depending upon the type used.

ALIGNING PROCEDURE

The step-by-step routine given below should be carefully followed after reading the preceding instructions.

1. The modulated oscillator should be tuned to a frequency of 152, 228, or 456 K. C. to align the 456 K. C. I. F. amplifier. **Do not use the oscillator calibration curve to determine this frequency but check the oscillator harmonics against broadcast stations which are required to be on their assigned frequency.** First check the accuracy of the broadcast dial by noting whether stations come in at the correct setting. With the oscillator set at 152 K. C., the third harmonic is used for aligning while the fifth harmonic can be tuned in on the broadcast dial. It should come in at exactly 760 K. C.

To be sure that you have the harmonic of the 152 K. C. signal, tune in the other harmonics on the broadcast dial. These should come in 152 K. C. on either side of the original setting. With a 228 or 456 K. C. oscillator signal a similar procedure can be followed using 910 K. C. (The exact frequency to be used is 912 K. C. but 910 will be satisfactory.)

2. Connect the oscillator output from the grid cap of the 6A7 to chassis. Turn the tuning condenser of the set to some point where it has no effect upon the signal strength.

3. Adjust the oscillator output to give about one-half full scale deflection of the output meter.

ADJUSTING THE I. F. CIRCUIT

1. Adjust all four I. F. trimmer condensers, in each case tuning carefully to make sure that maximum deflection is obtained on the output meter. It is desirable to use an all-bakelite screw driver for this purpose although one with a small metal point may be used.

No inward or sideward pressure should be applied to the alignment tool, or the condenser may spring back to a different setting as soon as the tool is removed.

2. Go back and repeat all four adjustments, since the changing of each I. F. trimmer affects the others to a certain extent, thus necessitating readjustment.

ADJUSTING R. F. AND OSCILLATOR CIRCUITS

1. Connect a .0001 mfd. condenser from the blue aerial wire to the output of the oscillator, and ground both set and oscillator. Adjust the oscillator frequency to 1400 K. C. and carefully tune the receiver to give maximum output. Set the oscillator output to produce about half-scale deflection on the output meter.

2. Carefully adjust the 1st detector trimmer which is the front one on the gang, to give a maximum output meter reading. Retune the set and again adjust the trimmer. The rear section which tunes the oscillator, should not be touched unless the set is out of calibration at the high frequency end of the dial.

If the set is out of calibration it can be re-calibrated as follows: Disconnect the test oscillator, connect an aerial and set the tuning dial at the frequency reading of some broadcast station between 1000 and 1500 K. C., whose exact frequency is known and which can be picked up without any difficulty. Adjust the oscillator trimmer (rear) until this station is brought in with maximum volume. Re-connect the modulated oscillator and output meter and again adjust the front trimmer for maximum output meter reading. This is necessary because the first detector circuit is always affected by any change in the oscillator tuned circuit.

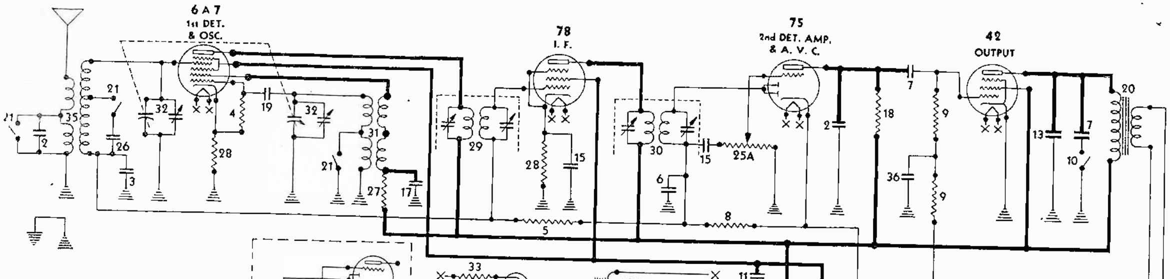
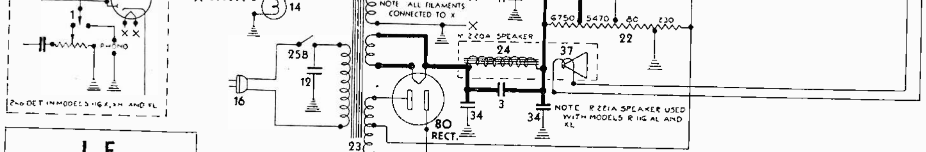
HUM AND NOISE ELIMINATION

Hum in early R-116 table model chassis may be reduced by reversing the two speaker field coil leads. This may be done underneath the chassis where these leads connect to the two electrolytic condensers. The green field coil lead should go to the front electrolytic condenser, and the white lead to the rear electrolytic. Later production chassis already have the connections made in this way. All console model chassis are already wired for least hum with the white lead connected to the front electrolytic and the green to the rear electrolytic.

Excessive hum may also be due to the fact that the A. C. line lead is too close to the .05 mfd. 100 volt condenser No. 15 which is hooked in series with the volume control. The remedy is to separate the two as far as possible.

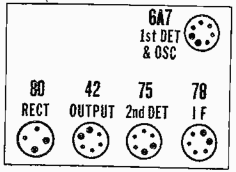
Another cause of hum is poor contact at the grounding lug of the voltage divider. This may be caused by the grounding screw being loose or may be at the point where the resistance wire is soldered to the terminal strap on the resistor. To eliminate hum from this cause, first tighten the grounding screw and solder to the chassis. If the hum continues, the 230 ohm negative end of the voltage divider should be replaced by a 230 ohm wire wound resistor. The two wires connected to the negative end of the voltage divider should be unsoldered and hooked to one end of the new resistor. The other end should be soldered to ground, preferably to the lug located just below the short wave switch.

Intermittent or noisy operation especially noticeable when the dial is turned or when the variable condenser is jarred, is frequently caused by metal particles shorting the variable condenser. This trouble can be eliminated by cleaning with a blast of air or by running a pipe cleaner between the plates.

TUBE LOCATIONS

FRONT OF SET



I. F. FREQUENCY 456 K. C.

VOLTAGE TABLE

Line Voltage 115 A. C. — Volume Control Full On

Type of Tube	Position in Circuit	Filament Voltage	Plate Voltage	Screen Grid Voltage	Control Grid Voltage	Cathode (Bias) Voltage
6A7*	1 Det & Osc.	6.15	240	90	0	2.7
78	I. F.	6.15	240	90	0	2.4
75	2nd Det.	6.15	110		0	1.3
42	Output	6.15	227	240	-1.5†	0
80	Rect.	5.0	320 Volts D. C. From Filament to Ground			

* Oscillator plate voltage, 130; Oscillator grid voltage, —7.5.

† Actual bias voltage on type 42 tube is 17.0 volts measured across 230 ohm section of voltage divider.

Speaker field voltage, 85.

All D. C. voltages are to be measured with respect to ground, using a high resistance voltmeter of 1000 ohms per volt. Readings will vary, depending upon voltage range of meter, being higher for higher range instruments. This variation is most marked for second detector plate voltage.

Readings taken with set analyzers will be different because such instruments generally measure voltages with respect to cathode instead of ground.

R-116 PARTS LIST

Diag. No.	Part No.	Description	List Price
1	73689	Phonograph Switch (Used in R-116X, XL, and XH)	
2	81158	.0001 Mfd. Mica Fixed Condenser	
3	81630	.1 Mfd. 100 volt Fixed Condenser	
4	81681	29,000 ohm. ¼ watt Carbon Resistor	
5	81682	1.1 megohm. ¼ watt Carbon Resistor	
6	81812	.00051 mfd. Mica Fixed Condenser	
7	83007	.02 Mfd. 600 volt Fixed Condenser	
8	83072	510,000 ohm, ¼ watt Carbon Resistor	
9	83082	260,000 ohm, ¼ watt Carbon Resistor	
10	83179	Tone Control Switch	
11	83214	.25 mfd. 250 volt Fixed Condenser	
12	83216	.02 mfd. 1000 volt Fixed Condenser	
13	83219	.01 mfd. 600 volt Fixed Condenser (Used in models R-116-AL and XL only. See No. 83352 for R-116-A, AH, X and XH)	
14	83278	6.3 volt Pilot Light Bulb	
	83352	.015 mfd. 600 volt Fixed Condenser (Used in Models 116A, AH, X, and XH only)	
15	83353	.05 mfd. 100 volt Fixed Condenser	
16	83406	Power Cord and Plug	
17	83440	.1 mfd. 400 volt Fixed Condenser	
	83435	Diaphragm and Shell Assembly (for R221A Speaker used in Models R-116AL and XL)	
18	83538	260,000 ohm. 1 watt Carbon Resistor	
19	83539	.00026 mfd. Mica Fixed Condenser	
20	83541	Output Transformer for R-220A Speaker (Used in Models R-116 A, AH, X and XH. See No. 83625 for R-116, AL and XL)	
21	83542	Range Switch	
22	83543	6750-5470-80-230 ohm Voltage Divider	
23	83544	Power Transformer. 115 volts, 60 cycles. (Used in R-116A, AH, and AL only. See No. 83620 for 115-250 volt, 25-60 cycle)	
24	83548	Field Coil and Housing for R-220A Speaker. (Used in R-116A, AH, X, and XH. See No. 83635 for R-221A Speaker Field Coil	
25-A, 25-B	83551	500,000 ohm Volume Control / Line Switch — In one unit.	
26	83554	.0011 mfd. Mica Fixed Condenser	
27	83555	21,000 ohm, 1 watt Carbon Resistor	
28	83556	310 ohm, ¼ watt Carbon Resistor	
29	83557	1st I. F. Transformer Complete	
30	83558	2nd I. F. Transformer Complete	
31	83559	Oscillator Coil	
32	83565	Variable Condenser	
33	83566	10 ohm Wire Wound Resistor	
34	83613	8 mfd. 440 volt Dry Electrolytic Condenser	
	83620	Power Transformer. 115-250 volts 60 cycles. (Used in Models R-116X, XH, XL)	
	83625	Output Transformer for R-221A Speaker. (Used in Models R-116AL and XL only)	
35	83631	Antenna Coil	
36	83632	.5 mfd. 100 volt Fixed Condenser	
	83635	Field and Hum Bucking Coils (for R-221A Speaker used in R-116 AL and XL)	
37	83662	Diaphragm and Shell Assembly for R-220A Speaker. (Used in R-119A, AH, X and XH only. See No. 83435 for R-221A Speaker)	

MISCELLANEOUS PARTS NOT SHOWN ON DIAGRAM

Part No.	Description
83447	Range Switch Knob
83470	Speaker Cable (Used in R-116 AL and XL)
83560	Tube Shield
83574	Pilot Light Socket and Bracket
83577	Escutcheon (Used in R-1161 and R-1162)
83579	Knob for R-1161-2-3-4
83580	Dial & Bushing (Used in R-116A.AL.X.& XL
83581	Volume Control Dial and Bracket (Used in R-116A, AL, X, and XL
83590	Volume Control Dial and Bracket (Used in R-116AH and XH)
83593	Escutcheon (Used in R-1163-A)
83603	Dial and Bushing (Used in R-116AL & XL)
83637	Escutcheon (Used in R-1165)
83638	Knob for Model R-1165
R-220A	Dynamic Speaker (6 inch used in Models R-116A, AH, X, and XH)
R-221A	Dynamic Speaker (8 inch used in Models R-116L and XL)

RADIO-TRICIAN
REG. U.S. PAT. OFF.

Service Sheet

Compiled Solely for Students and Graduates

NATIONAL RADIO INSTITUTE, WASHINGTON, D.C.

General Electric Model A-53

ALIGNMENT PROCEDURE

I. F.	Broadcast	Short-wave
465 kc.	580 kc. 1500 kc.	6000 kc.

In order to properly align this receiver, it will be necessary to have the following service tools:

1. Test Oscillator capable of producing the above alignment frequencies.
2. Non-metallic alignment screwdriver.
3. Output meter.

I. F. Alignment. The I. F. amplifier should be tuned to 465 kc.; set the oscillator dial at this frequency. Set the volume control at maximum and short-circuit the antenna and ground leads. Tune the receiver to a point where no signal comes in and ground the chassis.

Connect the test oscillator output between the 6A8 converter tube grid and the chassis. Connect the output meter across the cone coil of the speaker and adjust the oscillator output until a small deflection is observed in the output meter.

The three I. F. trimmers are adjusted in the following sequence:

1. Secondary trimmer on second I. F. transformer.
2. Secondary trimmer on first I. F. transformer.
3. Primary trimmer on first I. F. transformer.

Throughout all adjustments output should be maintained at a low level by decreasing the test oscillator output as the various stages are brought in line. After these adjustments have been made the same procedure should be repeated as a final check. The I. F. alignment will then be complete.

R. F. Alignment. The R. F. and oscillator transformers are aligned at 580, 1500, and 6000 kc. With the tuning condenser plates fully meshed, line up the pointer and dial by adjusting the dial set screws so that the line at the extreme end of the dial is indicated.

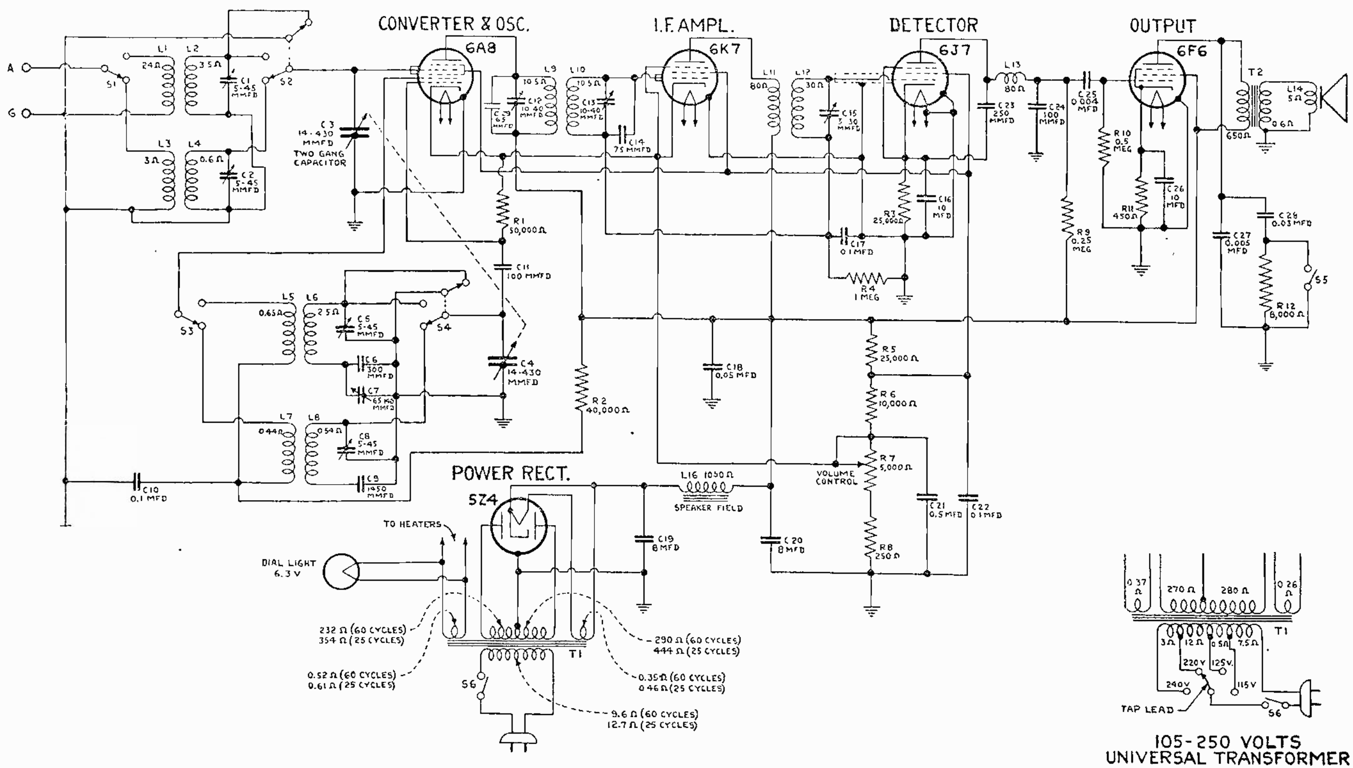
Broadcast Band. With the band switch in the clockwise position, set the tuning dial to 1500 kc. Set the test oscillator at 1500 kc. and adjust the oscillator trimmer for the broadcast band for maximum output. Next, set the R. F. trimmer for maximum output, taking care that the output from the test oscillator is not high enough to overload any part of the set. After these adjustments, tune the set and the test oscillator to 580 kc. Adjust the broadcast padding capacitor for maximum output while rocking the tuning condenser back and forth until maximum output is obtained. The dial setting after this adjustment may not agree exactly with the frequency, but this is not important.

To complete the broadcast band line-up, repeat the adjustment at 1500 kc. as before.

Short-wave Band. With the frequency band switch in the counter-clockwise position, set the receiver dial to 6.0 mc. Set the test oscillator at 6000 kc. and adjust the short-wave oscillator trimmer for maximum output. Next, set the short-wave R. F. trimmer for maximum output. Repeat these adjustments a second time. After aligning the S. W. band, turn the test oscillator to approximately 6930 kc. with the receiver dial still at 6mc. Increase the test oscillator output until a signal is heard in the neighborhood of 6930 kc. This is the image frequency and if the set has been properly aligned the sensitivity at this point will be much less than at 6000 kc. In the event the image frequency cannot be found, the alignment should be rechecked at 6.0 mc. It will be noticed that the oscillator trimmer will have two positions at which the signal will give maximum output. The position which gives the lower trimmer capacitance obtained by turning the trimmer screw counter-clockwise is the proper adjustment.

When these adjustments have been completed the receiver will be in alignment.

General Electric Model A-53



RADIO-TRICIAN
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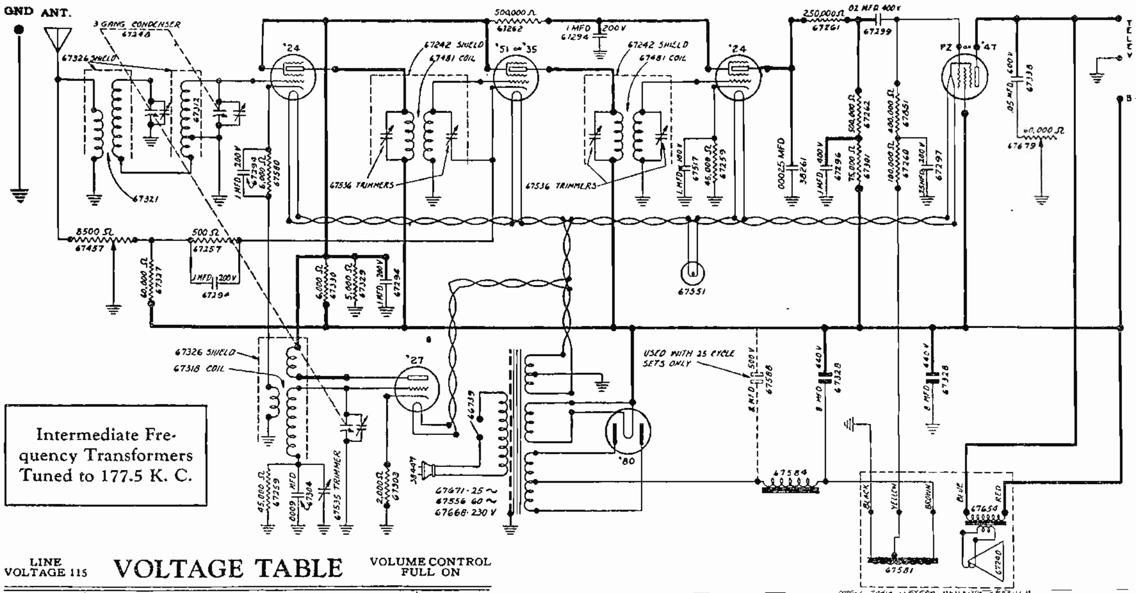
Service Sheet

Compiled Solely for Students and Graduates

NATIONAL RADIO INSTITUTE, WASHINGTON, D.C.

Circuit Data of Stewart-Warner Models R-102-A, B & E.*



Intermediate Frequency Transformers Tuned to 177.5 K. C.

LINE VOLTAGE 115 **VOLTAGE TABLE** VOLUME CONTROL FULL ON

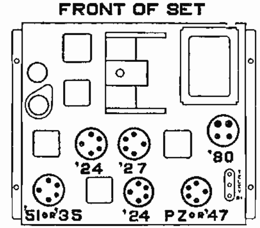
Type of Tube	Tube Circuit	Filament Voltage	Plate Voltage	Screen Grid Voltage	Bias Voltage
'24	1st Det.	2.45	250	95	6.5
'27	Osc.	2.45	95		9
'51	I. F.	2.40	250	95	3
'24	2nd Det.	2.45	70	30	7
P. Z. or '47	Output	2.45	230	250	15 ‡
'80	Rect.	4.8	170		

All D. C. voltages measured with respect to ground, using high resistance voltmeter of 1000 ohms per volt. Readings will vary, depending upon voltage range of meter, being higher for higher range instruments. This variation is most marked for second detector screen grid and plate voltages.

‡ This reading obtained between ground and yellow speaker lead. Direct reading from grid to ground or reading taken with a set tester will show about 3 volts because of high resistance in grid circuit.

USED IN MODELS 500A; 503A; 505A; 507A; 509A

FRONT OF SET

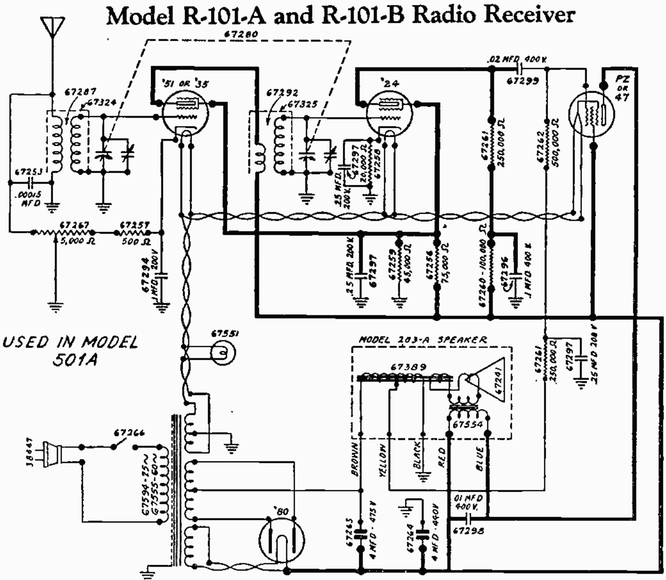


TUBE LOCATIONS

*This data sheet applies to the following serial numbers only:

Model 102-A, 34,000 upwards
Model 102-B, 10,500 upwards
Model 102-E, 10,200 upwards

Service Data on Stewart-Warner Model R-101-A and R-101-B Radio Receiver



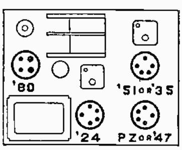
VOLTAGE TABLE

Type of Tube	Tube Circuit	Filament Voltage	Plate Voltage	Screen Grid Voltage	Bias Voltage
'51	R.F.	2.4	243	68	2.75
'24	Det.	2.4	80	68	6
PZ or '47	Output	2.4	228	243	16 •
'80	Rect.	4.8			

• This reading obtained between ground and yellow speaker lead. Direct reading from grid to ground or reading taken with a set tester will show low voltage because of high resistance in grid circuit.

All D.C. voltages are taken between socket terminals and ground with high resistance voltmeters having resistances of 1000 ohms per volt.
Line Voltage—115.
Volume Control full on.

FRONT OF SET



TUBE LOCATIONS

Circuit Data of Stewart-Warner Short Wave Converter R301-A, B, and E

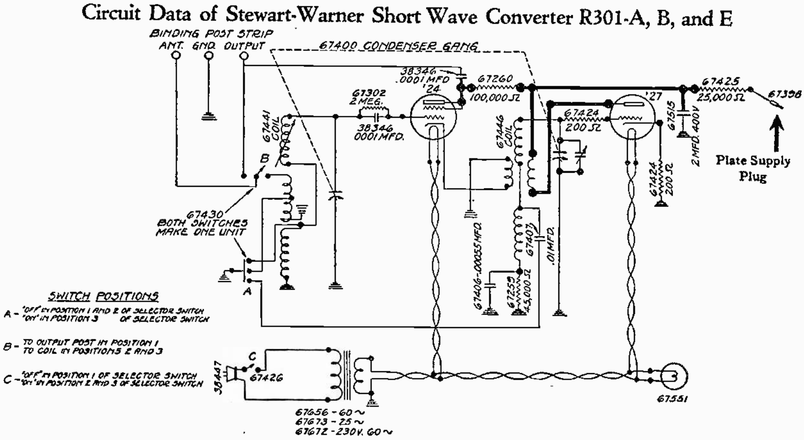


Plate supply plug (#67398) must be connected to some source of filtered D.C. at a potential of 180 to 280 volts. Recommended voltage is 250.

The Ground Post of the converter is the negative return and must be connected to the negative side of the external plate supply. The table below gives plate voltages at both tubes for three different plate supply voltages.

Plate Supply Voltage	'24 Plate	'27 Plate
180	26	70
250	34	93
280	37	102

RADIO-TRICIAN
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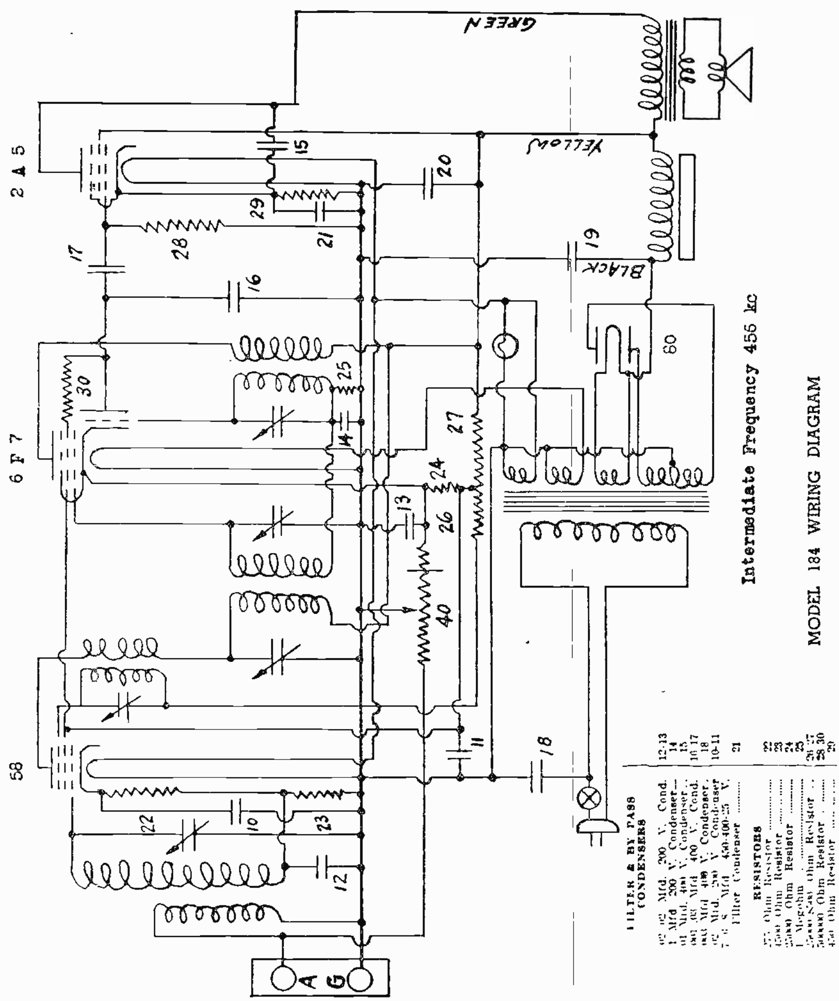
Service Sheet

Compiled Solely for Students and Graduates

NATIONAL RADIO INSTITUTE, WASHINGTON, D.C.

CROSLEY MODEL 184



Tube	Position	Plate	Screen Grid	Cathode	Supp. Grid.	Filament
58	Oscillator-modulator	165	82	22	0	2.5
6F7	I. F. & Detector	165	82	2	0	2.5
2A5	Output	158	165	10		2.5
80	Rectifier	295				4.9

Voltage limits are plus or minus 10% of values given.

Line Voltage 117 A. C.

CROSLEY MODEL 182

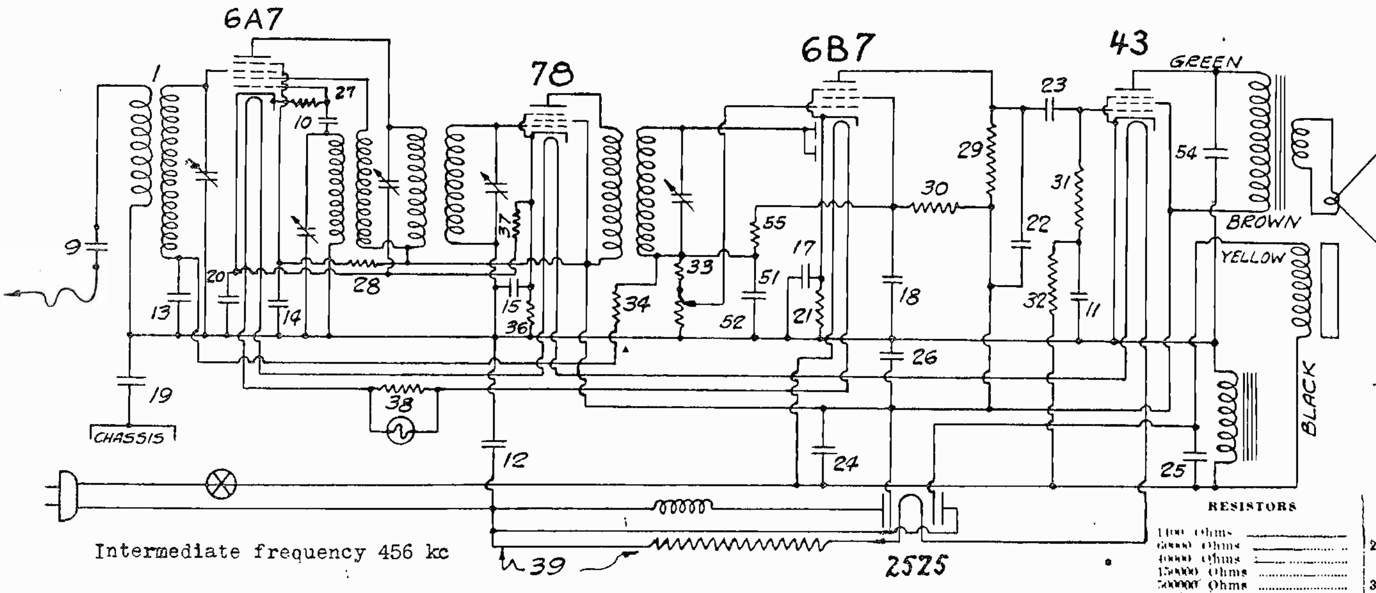
Tube	Position and Use	Plate	Screen Grid	Cathode	Supp. Grid	Filament
		Voltages				
6A7	Oscillator	120		-8		
	Modulator	120	50	3		6.5
78	IF Amplifier	120	120	2 5	2 5	6.5
6B7	Diode and AF Amplifier	20	30	3	3	6.5
43	Output	115	120	0		25.1
25Z5	Rectifier			120		25.1

Voltage limits are plus or minus 15% of values given.
On DC operation, voltages are approximately 90% of those given above.
Output bias voltage is obtained by using drop across filter choke which is 20 volts.

Line voltage 117 A.C.

FILTER & BY-PASS CONDENSERS

0.003 Mfd. 200 Volt	9
0.0005 Mfd. 400 Volt	10
0.26 Mfd. 200 Volt	11
0.02-0.02 Mfd. 400 Volt	12-13
0.02 0.02 Mfd. 200 Volt	14-15
0.1-0.1 Mfd. 200 Volt	18-19
0.02 Mfd. 200 Volt	20
0.00017-0.006 Mfd. 200 Volt	22-23
0.0001 Mfd.	51
0.023 Mfd. 200 Volt	54
6. Mfd. 25 Volt	17
25.-8. Mfd. 125 Volt	24-25
16. Mfd. 110 Volt	26



Intermediate frequency 456 kc

RESISTORS

[illegible] Ohms	21
[illegible] Ohms	27 33
4000 Ohms	28
15000 Ohms	29
[illegible] Ohms	30-31
300000 Ohms	32
1 Megohm	34
165 Ohm	36
75 Ohm	37
[illegible]	38
[illegible]	55

MODEL 182 WIRING DIAGRAM

RECEIVER REFINEMENTS

31 FR

PIONEER HOME STUDY RADIO SCHOOL

NRI

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

COURTESY

Courtesy is the oil which takes the friction out of your daily life. Friction means wear and tear. Friction creates heat and retards forward motion. You want to get where you are going with the least resistance.

Make full use at every opportunity of the magic oil of courtesy. A quiet word in the right place can accomplish more than a thousand impassioned ones. A simple, thoughtful deed of kindness will get you further than weeks of arduous striving.

Courtesy is a sign of strength. Truly big men are always courteous. It is only "small" men, men with inferiority complexes, who are rude or thoughtless. And smaller than small are those who are over-courteous to their superiors and intentionally rude to those over whom they have some authority.

Practice courtesy in all your contacts, business as well as social. Be courteous even to those you might think much beneath you in social standing. Establish courtesy as one of your life habits. Practice it until it becomes second nature.

The best place to test yourself is right at home. Are you always courteous to the members of your immediate family or do you shout at them on the slightest provocation? Are you considerate of their feelings or do you delight in saying things and doing things you know will hurt them?

About 99 per cent of people are entirely different persons away from home. If you are now in this 99 per cent, try treating the members of your family with the same consideration you would show strangers or ordinary friends. They might think for a few days that you are ill, but they will soon become accustomed to your new attitude and everyone will be much happier.

More than that, if you develop the habit of courtesy to your folks, your away-from-home courtesy will ring true. It won't appear "put-on" as is so often the case when a man reserves his courtesy for only special occasions.

J. E. Smith.

Revised 1932, 1933

1936 Edition

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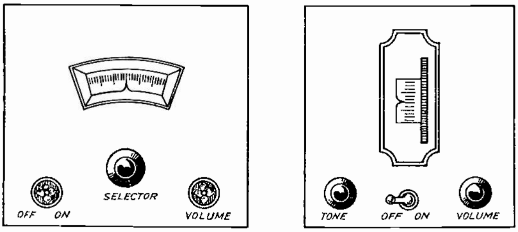
Printed in U. S. A.

Receiver Refinements

SINGLE DIAL CONTROL

The modern radio receiver, besides having satisfactory performance characteristics, must be designed for ease of operation and adjustment. Station selection, control of volume and tone quality adjustments must all be simple. And for ease of operation there should be only one knob for each control and its action must be positive as well as fixed between definite limits.

Figs. 1a and 1b show typical panel fronts. Note the three knobs, one for each of the adjustments mentioned and a switch to turn the receiver "on" and "off." Some commercial receivers may have more adjustments, such as a vernier condenser to align the first antenna coils and a regeneration control for the detector stage, but these are in the minority. On the other hand, some



(a) (b)

FIG. 1

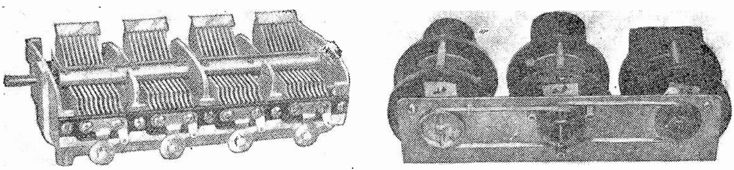
modern receivers have all the control knobs pyramided so that any control may be manipulated without moving the hand from the center of the panel.

The subject of single dial control has already been taken up in earlier lessons, as was the subject of tone control and manual volume control. In this chapter we are going to study single dial control from the viewpoint of the factors which make station selection with a single dial possible.

First we must give credit to the designers and manufacturers who have developed methods of constructing radio parts that are mechanically and electrically perfect. Without perfectly constructed variable condensers and radio frequency coils, single dial operation would be impossible. When variable condensers are ganged together, each must track with the other—as the capacity of one is varied, the capacity of the others must be changed to exactly the same degree.

Figs. 2a and 2b show typical ganged variable condensers. They are sturdy and matched with the greatest precision. One section is like the others to the slightest detail. Note that all the rotors are connected together—they are either mounted on a steel rod or are connected by means of a phosphor-bronze belt—an electrical conductor. This at once indicates that the rotors are connected into their circuits so that they are always at the same potential, usually B minus or ground. This is brought out in Fig. 3 which shows the stators of the ganged variable condensers connected to the grids of the tubes, while the rotors are grounded.

There are a number of receivers in which the plate circuits are tuned. In this case the ganged condensers are mounted on a



(a) (b)

FIG. 2

steel chassis frame and special R. F. ground connections are made as we shall see. Modern variable condensers are made in a sort of metallic tray which is electrically integral with the rotor. The stator plates are insulated from the condenser frame but the rotor system bearings are built into it and therefore the rotor itself is electrically connected to it. Fig. 4 shows the connection. One terminal of the coil L is connected with the stator side of the condenser and then directly to the plate of the first tube. The condenser rotor therefore, must be electrically connected to both the plate supply and ground. Of course it is impossible that there be a direct connection, otherwise the B supply would be shorted. A fixed by-pass condenser C_1, having a capacity of .1 to .25 mfd., is inserted between the rotor (in this case the ground) and $B+$. This isolates $B+$ and prevents a D.C. short circuit, at the same time providing a short path for Radio frequency current in the L-C circuit. C_1 must be 50 to 100 times larger in capacity than C so that its capacity will not affect the L-C value of the resonant circuit. C_2 is a blocking condenser, about .00025 mfd. which is used to prevent the D.C. from reaching the grid of the following tube. R is a grid leak of about 500,000 ohms. The bias on these tubes must be definitely set so that they will not act as detectors.

A very important condition must be satisfied before single dial control is possible. L and C of one stage must "track" with L and C of the other tuned stages, over the entire frequency range from 1,500 to 500 kc. An exact matching of coils is just as necessary as exact matching of condensers.

Suppose for example all sections of a gang condenser track with the greatest precision over the entire range of the tuning dial.* Let us suppose also that at one stage we have a shielded coil, in another an unshielded coil, and in a third a criss-cross wound coil. At 550 kc. the inductance of each may be exactly

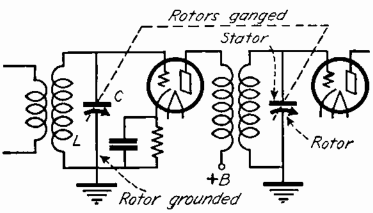


FIG. 3

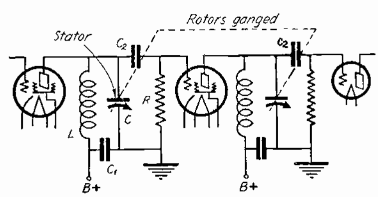


FIG. 4

250 microhenries. But what happens when the dial is rotated from 550 to 1,500 kc.? All the coils will have different distributed capacities and their high frequency resistance will vary so that at 1,500 kc. their apparent inductances may be far from 250 microhenries.

In a previous lesson it was shown that if some of the R.F. stages were adjusted slightly off resonance, it was possible to obtain a flat top resonance characteristic. You will remember, however, that this is possible only when each stage is extremely selective. In production receivers the chances are that even though the stages are perfectly lined up there will be a slight variation so that tuning will be quite broad. Therefore it is important that each stage be adjusted as closely as possible to the same resonant frequency as the other stages in order to obtain maximum sensitivity and selectivity.

2

* Condensers can be matched to a precision of ¼ of 1%, from the maximum to the minimum setting.

trouble manufacturers of receivers will go to match these parts as perfectly as possible, we can realize that more than ordinary importance is attached to simplicity of operation.

As exact matching of both L and C in three or four tuned circuits requires very critical adjustment and as a perfect adjustment can very easily be upset by vibration and changes in temperature, provisions are made for readjustment. Obviously nothing can be done to make a coil conveniently adjustable. Therefore these are made to the closest precision possible and matched in sets of three or four as required. The only means for readjustment that can be provided is in connection with the gang condensers and the individual sections of these are provided with small trimmer condensers for this purpose. These trimmer condensers are shown in Fig. 5a. Another method of providing means for readjustment is shown in Fig. 5b in which case the end rotor plate of each section is slotted so that there are six to ten radial sections. Then at six to ten settings of the tuning dial, readjustment for exact matching can be obtained by slightly bending the section one way or the other. This is the more satisfactory method of readjustment over the complete tuning range.

Quite often you will find both methods used on gang condensers. The trimmers in Fig. 5a are midget vernier condensers attached to the side gang frame. Their capacity at minimum setting is 5 $\mu\mu f$. and, maximum, 20 $\mu\mu f$.

The readjustment for matched resonance over the entire tuning range is called aligning the R.F. stages. There are two possible methods of accomplishing this. In the one we listen to the output of the loudspeaker using our ears as the indicating device, making adjustments for maximum sound output, or we use an output meter in place of the loudspeaker and make adjustment for maximum output. In the second method we use a tuned grid R.F. oscillator having a 0—1.5 milliameter in its grid circuit. Each stage is successively connected in the grid circuit of the oscillator through a 20 $\mu\mu f$. variable condenser. Then when the R.F. stage is in resonance with the oscillator, it will draw energy from it and the grid meter will "dip"—read down. This method is a very sensitive indicator of resonance. The type of oscillator used has already been described.

In either method, the general procedure is to tune to the highest frequency and adjust each trimmer for maximum output.

In the "grid-dip" method with the trimmer condensers adjusted for about one-quarter capacity, the oscillator is tuned to resonance and connection is made to the stator of one section of the gang. At resonance the meter needle will dip sharply. Next, without changing the adjustment of the oscillator connect it to the stator of the next section and adjust its trimmer to obtain a sharp dip. This same procedure is followed for all the sections of the gang. If a condenser is found which requires excessive reduction in trimmer capacity, this condenser should be used as the reference section, and all the other sections adjusted to it. In general, this adjustment is made for differences in coil construction. Even comparatively large changes in capacity at the high frequency end will have very little effect on the low frequency resonance, as was seen by our previous calculations.

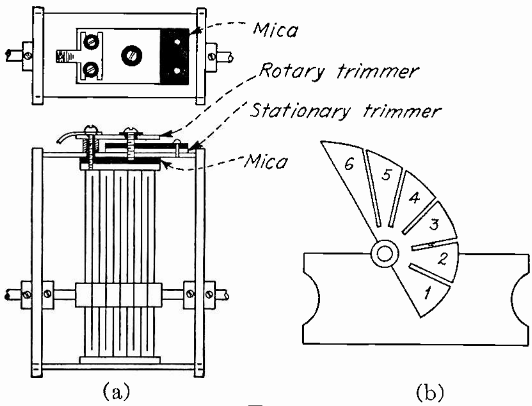


FIG. 5

Similar adjustments are made at about five different positions of the tuning dial. If the rotor end plates are radially cut, adjustments are made with the various radial sections just meshing with the stator plates, as in Fig. 5b. In this case alignment is made by tuning the oscillator to a reference section, the same one at all times.

In condensers having flat end plates, the end rotor plate may be bent, using a very thin, flat nose pliers. It must be remembered however, that if the coils are too greatly mismatched it will be impossible to align the R.F. stages properly. In the same way, a perfect match is impossible if poorly constructed variable condensers are used in the set.

In some cases, the rotors may have to be reset for exact mid-and it is quite possible that the frequency will still be more than 175 above 1,500 kc. In general, therefore, a small adjustable vernier condenser of 0 to 10 $\mu\mu f$ is shunted across C. This is C_3 in Fig. 7d by which adjustment at zero dial setting is made for the exact 175 + 1,500 kc. local oscillator signal.

The general procedure for aligning an arrangement like 4 Fig. 7d is as follows: At a dial setting of 50, C_2 is adjusted for maximum output signal, using of course a signal oscillator as a source of supply. Then at 1,500 kc. (zero on the dial), C_3 is adjusted for maximum signal, and at 550 kc. (100 on the dial) C_2 is readjusted for maximum signal strength. If these adjustments are carefully made, the ideal conditions shown in Fig. 6 can be closely approached.

Fig. 8 shows a specially shaped plate that has been proposed for use in the oscillator section of a gang condenser. It is designed so that at any dial position the oscillator condenser will tune to a resonant frequency above that of the other condensers by exactly the amount of the intermediate frequency. The disadvantage of this plate is that it cannot be adjusted once installed except by adjusting all the rotors of the other sections.

REMOTE CONTROL AND AUTOMATIC TUNING

By remote control is meant the ability to adjust the volume and to vary the station selector at will from a distance. More and more are we demanding the greatest comfort and simplicity in receiver operation. In some radio installations the Radio set is placed in an obscure position in a room or house with more than one speaker in various places which can be turned off or on.

We may think of the single dial receiver as the height of simplicity, but we find people who demand even greater ease in the selection of broadcasting stations. To answer this need, the automatic station selector was invented, so that by pushing a button, or pushing down a lever, a favorite station is tuned in without fuss or added adjustment.

The modern remote control panel combines two features—automatic preselected tuning for tuning in as many as 6 to 10 favorite stations, and remote control for DX or "signal fishing" as it is often called. These mechanical or electrical attachments add nothing to the electrical performance of the receiver, only convenience in tuning. Yet for many individuals they may result in greater receiver satisfaction.

Both of these additions demand a receiver having absolute single dial operation, no vernier or tuning adjustments, and absolute smooth volume control regulation. The underlying principle of remote control is the operation of the shaft of the volume control or the shaft of the selector by means of a miniature A.C. motor geared down through silent reduction gears. Although this seems easy to say there are many obstacles in the way of its successful adaptation. Much yet remains to be done in the development of remote controls.

To begin with it is not a simple matter to design an A.C. motor which will rotate in either direction, although an A.C. series motor may be used. A motor in rotation creates magnetic disturbances which are heard in the loudspeaker. Pressing a button does not endow the motor with the intelligence to move in the right direction. Condensers in general can only be operated through 180 degrees, although they may be designed to revolve completely. Motors have mechanical inertia; they take time to

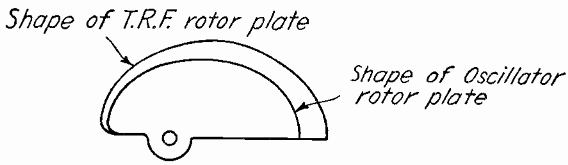


Fig. 8

start and time to stop. When the button is released at resonance with a particular station, the driving force of the motor is removed, but it tends to continue rotation. Sudden stopping is essential or a correction must be considered.

The accepted practice is to provide at the radio receiver an independent knob to select DX stations. The main driving shaft of the ganged variable condenser is extended and geared to the motor and on the same shaft is attached some selective system, which allows the motor to start and stop in a predetermined manner. These selective systems may vary in many ways. A possible method is shown in Fig. 9. This system is an imaginary remote control to illustrate possible features.

Fig. 9a shows the general layout. There is a ganged variable condenser on which is mounted the regular visual dial and its hand control knob. The main shaft continues to the motor which is connected through a high ratio step-down gear. This gear mechanism is so arranged that when the shaft has been turned 180 degrees to a stop, the gear reverses or the motor reverses the rotation for 180 degrees in the opposite direction. Between the motor and the dial on the long shaft is rigidly fitted a hollow metal tubing, but insulated from the shaft. Six to ten individual

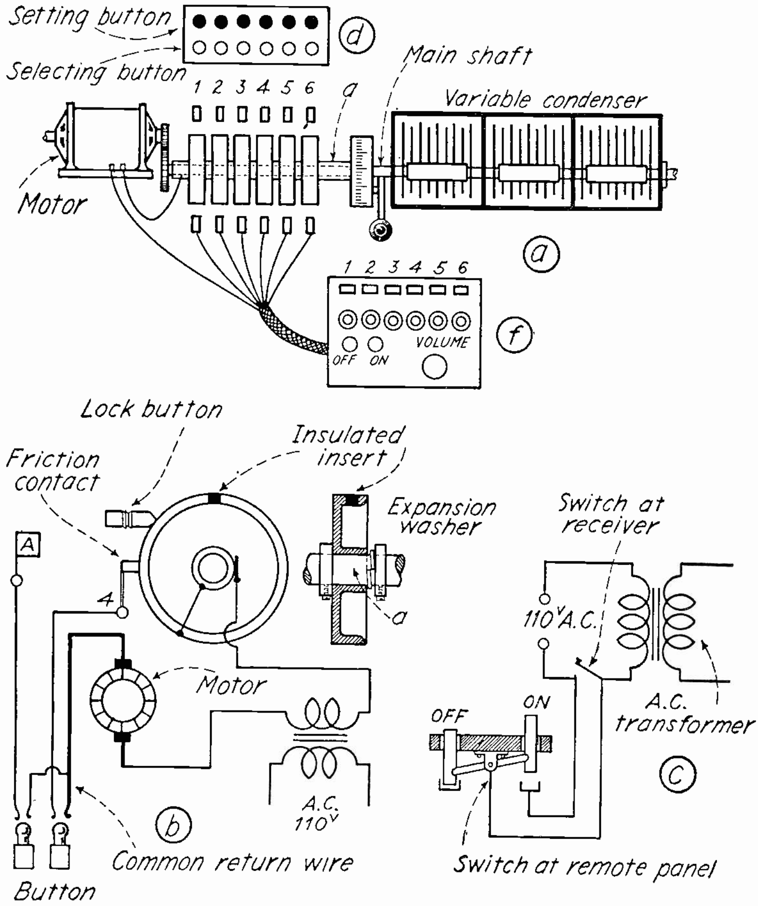


FIG. 9

metal drums are mounted on this shaft as shown. Each drum has an insulating insert as shown in "b." The drum is held to the metal tube *a* (in Fig. 9b) by a strong side friction washer. All six drums will rotate unless held by some impeding medium.

Note in Fig. 9b the friction contact held lightly against the drum by spring action. Trace through the electrical circuit and observe that when the push button connected to this contact and drum is pushed down, the motor is set in rotation and continues to run until the friction contact is fully over the insulated insert. At this point the power to the motor is automatically turned off and a mechanical brake at the motor brings it to an instantaneous stop. Pressing any of the other buttons will result in a similar action.

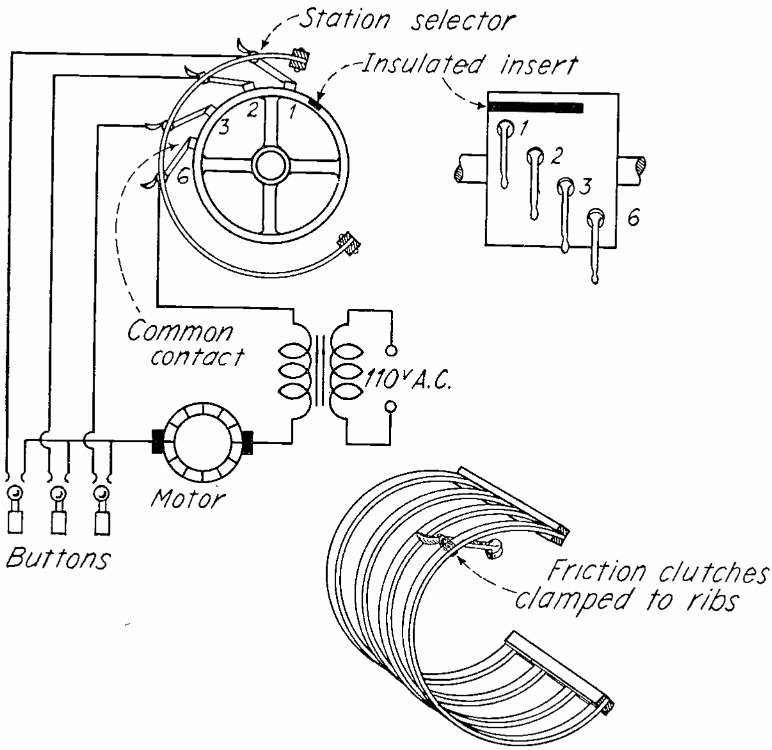


Fig. 10

How are these drums pre-set for favorite stations? The selecting mechanism is close to the panel of the receiver. An additional series of buttons is brought out to the panel, those in the lower row in Fig. 9d. The selecting buttons are in parallel with the remote control buttons, and allow automatic selection at the chassis. Above these are setting buttons or lock buttons as indicated in Fig. 9d. Suppose a button is to be set to a given signal. It would be pressed until the tuning system came to a stop, then the lock button would be depressed holding its drum while the entire remaining mechanism is allowed to rotate. The hand dial is now used to tune in the desired signal, and at resonance the lock button is released. Thereafter when the selector button is pressed, the motor will rotate the tuning system to this point. The insulating insert is the guide.

Note that this arrangement permits the use of any button for any frequency from 1,500 to 500 kc. In some instances it may require only a small rotation to bring in a given station, in other cases rotation continues in its original direction until the end of the 180 degree point and then reverses to the proper position.

As it would be rather unpleasant to hear one station after the other "crash" in and out while in the process of remote control tuning, an A.C. relay could be provided in the circuit

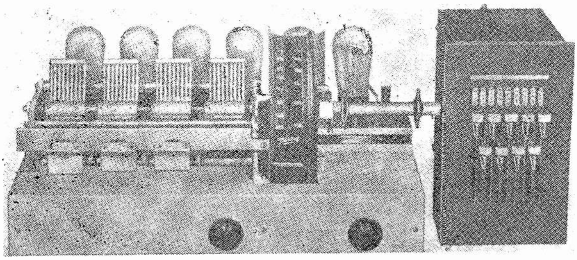


Fig. 11 (a)

which would open or short circuit the loudspeaker while in operation.

Another scheme which might be used is shown in Fig. 10. Instead of six drums one large one is employed, arranged as indicated. The station selecting contacts may be set for a given station by changing their positions on the ribs. The procedure would be as follows: Tune in the desired signal manually, move contact to be used until locked in the insulated insert. The insert should be undercut slightly. Lock the selector brush firmly and the station will always appear when its associated button is pressed. Provisions for DX and silent tuning can be arranged.

Do not overlook that these, although only imaginary remote controls, are perfectly feasible and are included to teach you underlying principles of automatic tuning. Variations are and will be many.

ZENITH AUTOMATIC TUNING

A very ingenious system is employed in Zenith receivers to tune in various stations automatically. We are merely concerned, at the present, with the principle rather than the actual construction. Fig. 11a shows a picture of the general appearance of a Zenith automatic control. This arrangement is, in no sense, a remote control as it is located in the same cabinet with the remainder of the equipment. The automatic feature does not interfere with the ordinary method of manual tuning—in this case by means of a drum dial. However, whenever the owner wishes to listen to a certain, predetermined station, it is only necessary to push down the corresponding button and adjust the volume control and vernier knobs on the machine. This is, of course, provided the station is "on the air."

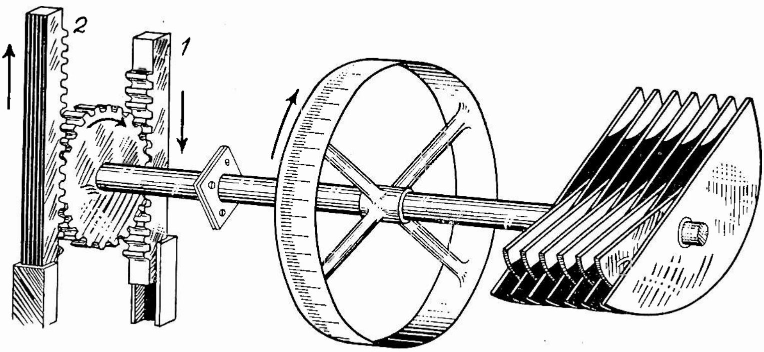


Fig. 11 (b)

Fig. 11b will give you a general idea of the mechanical structure. The main shaft of the condenser connected to the drum dial is extended through a flexible coupling and is connected mechanically to a gear. Vertically upward and in mesh with this gear are two pinion racks. If the drum dial is turned in the direction indicated, a close study will show that the gear turns in the same direction and forces pinion rack 1 down and pinion rack 2 up. Conversely, if pinion rack 1 is pushed down, the gear will be rotated and likewise, the drum dial and associated tuning condensers. Fig. 12 shows a side view of the gear with a key and a pawl used to press the rack down. You can see that if we press this key, we will cause the gear to move in the direction indicated by the arrow. If we continue to push the key down until *A* and *B* touch the pawl, no further pressure on the key will produce an additional movement in the pinion racks and consequently in the gear.

The pawl is held rigidly in its position. When the pressure on the key is released, it comes up to its former position but the

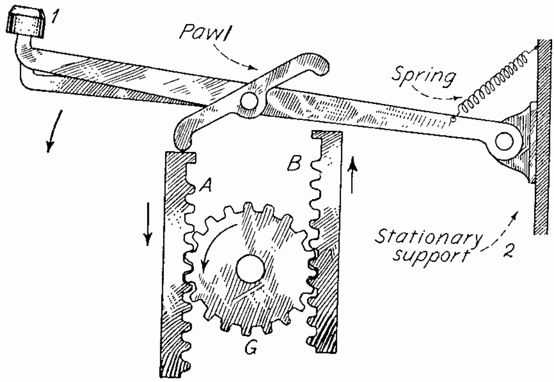


FIG. 12

racks do not move. No matter what position the racks are in, they will always be returned to this spot by pressing down the key.

All we need now is a method of setting the pawl in such a position that when pressed down, it will turn the condensers to

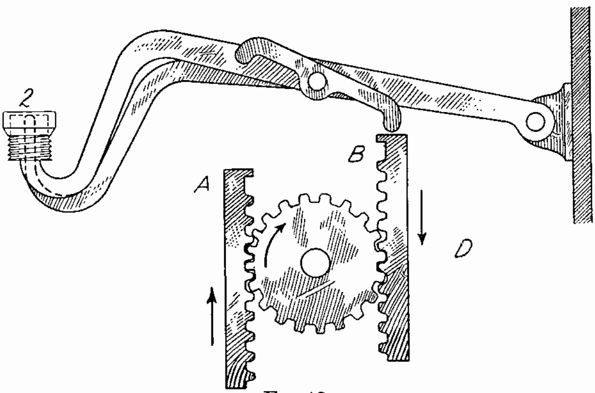


FIG. 13

the position where a desired station is ordinarily received. From Fig. 13, which by the way, shows the same kind of a key but in this particular instance the type used for the lower row of keys, you can see that the key arm is made in two parts; one is movable and pivots from the extreme right. The other rotates within this arm but is firmly affixed to the pawl. They both come together at the key and are screwed together in position. To set this particular key for a definite signal, unscrew the key tip, adjust manually the desired station and press the key down until it stops. Be sure that the station is still in resonance and screw the two arms together by means of the key knob. Now whenever that particular key is depressed, that station will be tuned in automatically.

The system may be applied to the preselection of one or more stations by the use of additional sets of gears and pinion racks, one for each key, or a mechanical system may be devised by which various levers act directly on one gear and pinion rack system.

REMOTE VOLUME CONTROL

Although some manufacturers use a motor remote volume control, the greater majority use the adjustable grid bias. We

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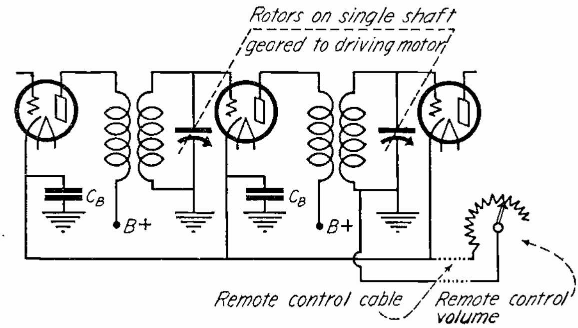


FIG. 14

have seen this principle used before in commercial broadcast receivers. Through the remote control cable two wires are run, one wire common to one or more radio frequency tube cathodes and the other wire connected to ground. A variable rheostat is mounted at the remote control panel (see Fig. 14) and when adjusted to have a large resistance the C bias will be great and when low in value the C bias will be reduced. A high bias means low volume, a low bias maximum volume. Condensers C_B by-pass possible R.F. current at the chassis and only D.C. plate current passes through the cable, without any detriment to the R.F. system.

The DX fan may want to have a remote control button.

An extra wire could be added to the cable which would connect an extra DX button to the motor. Connections to the relay which affect the loudspeaker must be such as to be unaffected when this button is pressed. This button would allow DX reception from one end of the dial to the other without reversing until the end was reached. With a reversible motor and a double DX start and stop button, a more convenient arrangement would be had (no insulation insert is used in this particular case).

Fig. 9c shows the off and on switch at the remote panel, and how it is connected in parallel with the chassis switch. The volume control used in this system is identical to the scheme shown in Fig. 14. A DX button is easily provided by using a ring without an insulated insert. Two or more remote controls can be run in parallel, the limit of length being set by the resistance in the volume control leads.

AUTOMATIC VOLUME CONTROL

Automatic volume control which is being featured in many of the better receivers today, is an interesting development of a principle that has long been known. We all know that volume can be controlled by changing the grid bias on the R.F. tubes. The smaller the negative bias, the larger the plate current and the greater the volume. Of course, the bias must not be allowed to become so low that the signal causes the grid to swing positive.

Now if we can connect our grid bias to a supply that increases in value as the signal increases and decreases as the signal decreases, volume will be controlled automatically.

6 The basic method of obtaining an automatic volume control is to use a rectifier connected to the plate of the last R.F. tube through a coupling condenser. This rectifier changes the A.C. component of the plate current to pulsating D.C., the average value of which changes with the intensity of the signal voltage. The output of the rectifier is used to bias the R.F. tubes.

A typical automatic volume control circuit is shown in Fig. 15.* C_1 is the coupling condenser (about .0001 mfd.) placed between the plate of the last R.F. tube and the grid of the automatic control tube (*A.V.C.*).

Although the plate of the A.V.C. tube is at ground potential it is at a positive potential with respect to its cathode. Note that the plate of the control tube is connected to the $-B$ or

* It is not advisable to attempt to adapt factory built receivers for automatic volume control because of the design difficulties involved.

ground terminal of the voltage divider XY. The cathode of the tube is connected to a point on the voltage divider ($-B_1$) which is more negative than the ground. In order to operate the tube as a C bias rectifier it is necessary that the grid be at a more negative potential than the cathode. To accomplish this, the grid is connected through the leak R_1 to a point on the voltage divider ($-B_2$) which is more negative than $-B_1$.

With no signal picked up by the receiver, the current through R_2 and R_3, the A.V.C. tube plate load, will be small due to the negative bias on its grid. When a signal is received, the R.F. signal in the last R.F. tube not only feeds the detector, usually a power or C bias detector, but also the A.V.C. tube

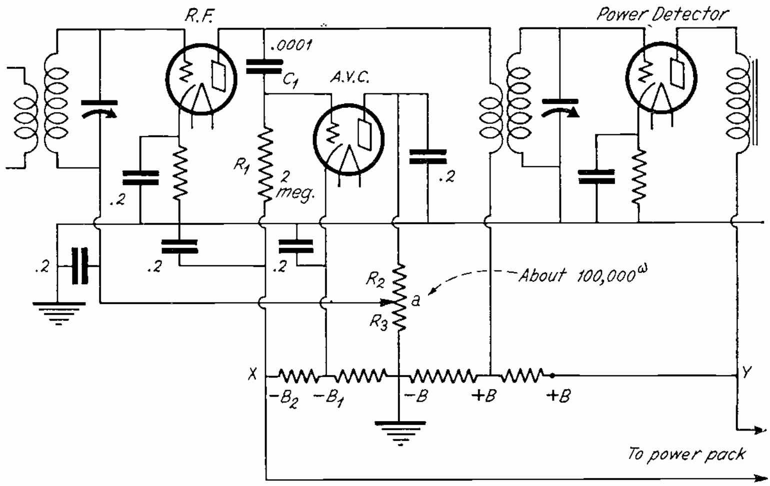


FIG. 15

through condenser C_1. The signal is rectified and amplified by the A.V.C. tube and the D.C. current through the R_2 and R_3 increases.

The potential of point a, with no signal picked up, is slightly negative with respect to the ground. Note that a is connected to the grid of the R.F. tube, thus making the bias on this tube greater than the C bias introduced by the resistor between its cathode and the ground. Now when a signal is received, the increased drop through R_3 makes a more negative with respect to the ground than previously, with the result that the R.F. tube negative bias increases. This we know will decrease the amplifying ability of the tube and the signal will be weakened.

Weak signals will be affected but little by the action of the A.V.C. tube; strong signals will cause large C bias increases in the R.F. tube so that the signals fed to the detector are kept at a normal constant level, regardless of the strength of the picked up signals. By varying the position of *a*, the normal signal level is established. Point *a* may be connected to the grids of two or more tubes. By means of an automatic volume control, the same audio output level may be maintained for signals from 100 to 100,000 microvolts applied to the input.

Manual control of volume is obtained by making point *a* variable or by the use of a potentiometer in the input to the last audio tube.

Fig. 16 shows part of the R.F. system, the volume controlling "diode" and the detector of one of the late Philco screen

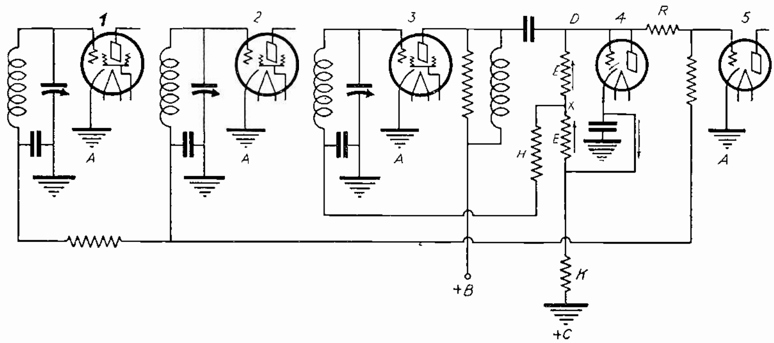


Fig. 16

grid models. Tube No. 4 is the control tube. There is no D.C. applied to the plate of this tube—it is actuated solely by the R.F. which passes from the plate to the cathode. The original signal passes on to the detector tube (No. 5) after causing a flow of current between the cathode and plate of tube No. 4. The plate current flowing in the output circuit of tube No. 4 is as shown by the arrows. It flows through resistor *E*, causing a voltage drop across *E* equal to the product of *I* and *R*. This voltage drop is used to bias the grids of the R.F. amplifiers.

Point *D*, to which the grid of tubes *1* and *2* are connected, through *R*, is negative with respect to *C* (the ground connection). Note that the grid return of the third R.F. amplifier is connected through H to resistor *E* at point *X*. Thus a varying additional bias is applied to this tube to offset changes in R.F.

signal strength. The fixed bias applied to tube No. 3 is not as great as that applied to No. 1 and No. 2 because X is less negative than point D. Resistor K is a stabilizing resistor used to prevent the bias on the R.F. amplifiers from becoming zero at any time.

In any method of automatically controlling volume, the "time constant" is an extremely important factor. By time constant we mean the amount of time that elapses before the automatic control operates.

7 The main advantage of automatic volume control is in its effect on fading. When a signal fades of course its strength decreases. When automatic volume control is used, a fading signal will be accompanied by a decrease in grid bias on the R.F. tubes which will tend to keep the volume constant. Fading is a gradual process and as far as fading is concerned the automatic volume control will not have to operate extremely rapidly. In some cases, however, rapid operation is desirable. Here we run into trouble for if the time constant is too high, that is, if there is too small a lapse of time between a decrease in signal strength and a decrease in grid bias, the control would be operated by the modulation of the carrier wave, instead of by changes in signal strength.

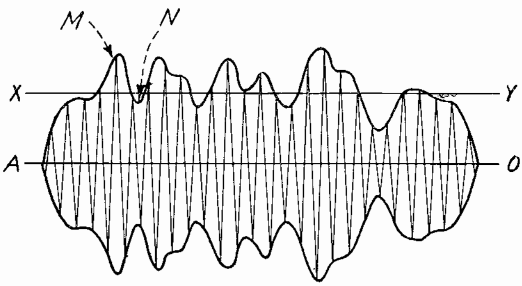


FIG. 17

Refer to Fig. 17. Here we have a representation of a typical continuous wave modulated at audio frequency. Suppose line XY represents the regular strength of the signal. When a peak such as M is reached, the control would at once bring the volume down to XY. Likewise, when the signal strength is at N, the volume would be raised to XY. Should this happen, we would not receive any signals—only the carrier wave.

However, if the resistors and condensers used in connection with the automatic volume control are of the proper values, the time constant can be made such that relatively fast audio changes will not affect it. The time constant is equal to the resistance times the capacity. Therefore if these values are increased, the time constant will be made larger, and if these values are decreased the time constant will be made shorter.

The main advantage of the automatic volume control has already been mentioned—its tendency to offset fading. There are other smaller advantages, such as the fact that with the manual control set at a certain level, tuning can be done over the entire broadcasting spectrum without any possibility of a "local" suddenly blaring out as we tune past it. Any stations picked up by the set will come in with the same volume. However, there is this disadvantage, that a receiver equipped with automatic volume control will tune rather broadly on local stations.

VISUAL TUNING WITH AUTOMATIC VOLUME CONTROL

In the operation of a receiver equipped with automatic volume control, it is quite difficult to tell just when the receiver is exactly tuned to resonance. This is because the same volume will be obtained with the receiver slightly off-resonance. In other words, the resonance curve of the receiver will be flat topped and not peaked as it would be if it were not for the automatic control.

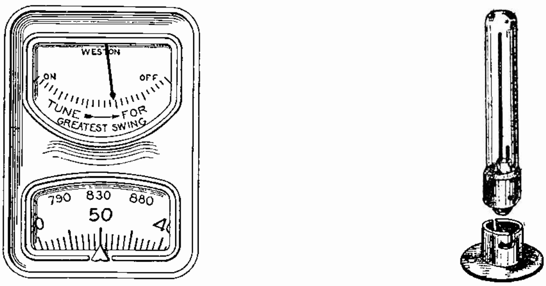
It is easy to see why this should be the case. As the set is tuned to resonance, a strong R.F. signal causes the rectifier tube to increase the bias on the R.F. tubes and signal gain drops. On the other hand, when tuned off-resonance the bias on the R.F. tubes decreases and the signal strength remains constant.

In the older automatic volume control equipped sets, the only guide for exact tuning was the noise level. When tuned off-resonance the weaker signals would be amplified more, but at the same time, the static would be amplified more. Then exact resonance would be indicated by minimum static noises and maximum signal strength.

This was not as satisfactory as some manufacturers would like to have it and so in several of the latest receivers we find visual resonance indicators, used in conjunction with automatic volume control and the variable mu tubes. This is nothing more than a milliammeter placed in the plate circuit of an R.F. tube, or in series with the grid bias. In some cases it is even placed in series with the plate supply to all the R.F. tubes in which case it cannot be placed in series with the grid bias unless there is a common resistor supplying the biases for all tubes.

Then when tuning to a desired station, as the resonance peak is reached, the plate current decreases. When minimum deflection is obtained on the resonance indicating meter, the receiver is tuned to exact resonance. Exact resonance can easily be determined by moving the tuning dial back and forth for no increase or decrease in deflection.

In some modern sets a neon tube is employed for visual tuning. When tuning the receiver, at the approach of a station, the neon tube indicator sends a rising glow of light upwards. When the light has reached its highest point for that station the receiver is sharply and accurately tuned to the station frequency. Typical visual resonance indicators are shown in Figs. 18(a) and (b).



(a) Visual Tuning Meter (b) Visual Tuning Neon Tube

FIG. 18

A typical visual resonance indicator installed in a commercial receiver is shown in Fig. 18.

PHONOGRAPH PICKUPS

While radio receivers very effectively replaced the old phonograph as a home entertainer, there were many people who found it rather unsatisfactory to rely on radio broadcasts for the type of entertainment they might want at a particular time. To meet this situation, radio manufacturers incorporated in their receivers electrical phonograph devices so that, when desired, the set could be used as a phonograph and musical selections recorded on regular phonograph records could be reproduced with the same fidelity as radio programs and with absolute freedom from interference.

Electrical phonographs owe their present high standard of performance to the development of good loudspeakers, power audio amplifiers, new standards of electrically producing records, and that small, insignificant yet most important device, the phonograph pickup.

The pickup is nothing more than a small A.C. generator deriving its mechanical motion from a record. At the next opportunity, examine one of these electrically transcribed records and observe the spiral cut grooves starting at the circumference and winding toward the center. Under a simple magnifying glass you will notice the irregular cut in the sides of the grooves. They are "lateral cut" records. These irregular cuts cause a needle which is held firmly in the phonograph pickup, to vibrate from side to side as the record revolves at a constant speed. See Fig. 19.

The needle is attached to the pickup armature, causing it to rock or vibrate between two north poles (N_1 and N_2) and two

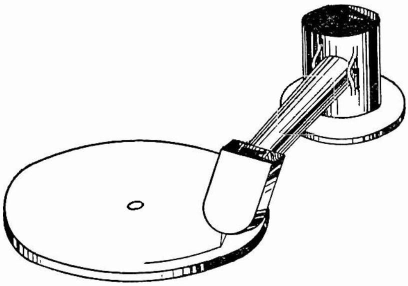


FIG. 19

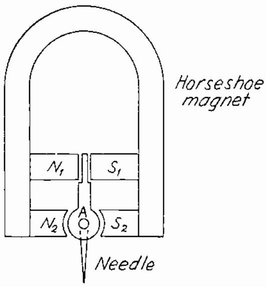


FIG. 20

south poles (S_1 and S_2), as in Fig. 20. When the armature is in the neutral position or exact center, the magnetic flux flows directly from N_1 to S_1 and from N_2 to S_2 and no flux moves up or down the armature A. As the needle is forced to the right by the cut on the record, the armature takes an off position, as you can readily imagine, and the flux moves from N_1 to S_2 because of the decrease in magnetic reluctance. For the same reason, when the armature is pushed to the left, the flux flows from N_2 to S_1.

There is a coil wound on the armature A. Then when the flux through A is caused to alternate in direction by the swinging of the armature, a voltage will be induced in the coil. For this reason the unit can be considered a generator. The voltage induced in the armature coil is then impressed on the input of an audio amplifier which brings it up to the proper level to operate a loudspeaker.

As most electrical pickup devices are of the magnetic type, we shall consider them alone. Two types are shown in cross-section in Fig. 21.

10 Magnetic pickup devices differ principally in the design of the armature and the method by which the armature is pivoted between the pole pieces.

In both Figs. 21a and 21b, the armature A is a small piece of high quality soft iron. It may be silicon, special magnetic Armco, or very carefully annealed soft iron. The armature is fulcrumed in the lower pole pieces and as the needle in the armature rides over the grooves on the phonograph record, the armature is made to vibrate from side to side, inducing a voltage in bobbin *C*.

The pole pieces marked *B* are made of soft iron like that used in the armature. All the parts are very carefully machined

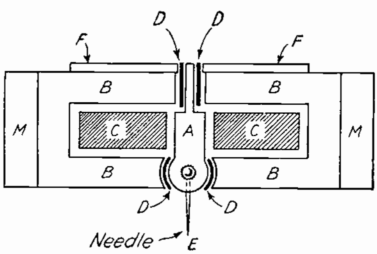


FIG. 21 (a)

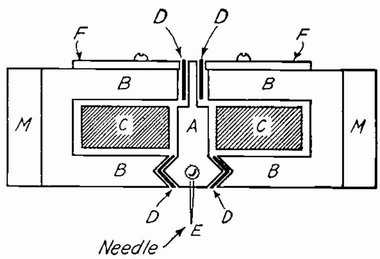


FIG. 21 (b)

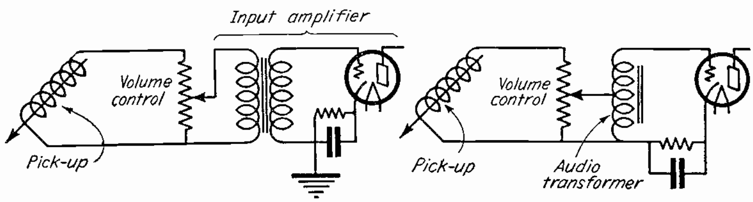
and the pole tips and sides of the pole pieces next to the magnet, must fit closely to provide the proper magnetic reluctance.

The bobbin *C* consists of several hundred turns of fine wire. *D* represents the rubber dampers which are placed between the pole pieces and the armature at the top and at the fulcrum position. The dampers serve two purposes—they centralize the armature between the pole pieces and they damp the armature movement so that it will not have any mechanical resonance peaks. This rubber must be of the highest quality, free from sulphur, in order that it will not deteriorate rapidly.

A standard phonograph needle *E* is set into the armature and held in position by a convenient set screw.

In magnetic pickups, the armatures must be exactly centralized to prevent "freezing" of the armature against the pole pieces. For this purpose an adjustable holder *F* for the upper rubber is provided. This may be set either to the right or left and the upper portion of the armature centralized. Adjustments are made externally.

Because of the manner in which they operate, magnetic pickups must be small and light. Thus there is little room for the permanent magnet, and, as in magnetic horn or cone reproducers, the permanent magnet used must be as strong as



(a) Fig. 22 (b)

possible. For this reason a special high grade of steel, cobalt-chrome is used which retains magnetism longer than tungsten or chrome magnetic steel. In most pickups, the magnet is in the form of a small horseshoe.

A potentiometer type of volume control, usually having a resistance of 25,000 to 50,000 ohms is connected across the output terminals of the pickup. The output is fed directly to the primary of the input transformer of the audio amplifier through

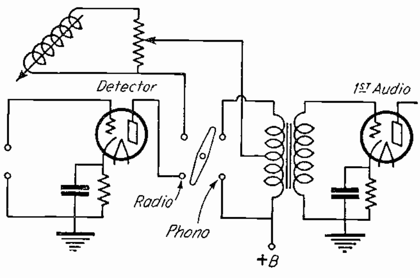


Fig. 23

the potentiometer. Fig. 22a shows a schematic of the pickup system feeding into a step-up transformer and Fig. 22b shows a similar system feeding into an auto-transformer.

As in the case of any device supplying an e.m.f., for maximum results, the device must feed into an impedance which matches the impedance of the device. The impedance of an electrical pickup ranges from 4,000 to 8,000 ohms and as this impedance is too low to match the high input impedance of the tube, it must be fed through an impedance correcting transformer. In many cases where there is transformer coupling between the plate of the detector and the first audio amplifier in a radio receiver and a phonograph pickup is inserted as in

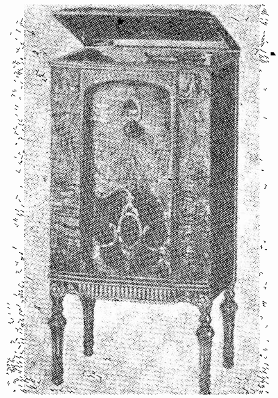


FIG. 24
A typical combination of radio-phonograph

radio-phonograph combinations, the primary winding of the input transformer is tapped. There are two taps, one for 4,000 to 6,000 ohms impedance to match the phonograph pickup and the other, 10,000 to 15,000 ohms to match the plate impedance of the detector tube. Where this method is used, there is a radio-phonograph switch as in Fig. 23, so that either the radio or the phonograph may be used at will.

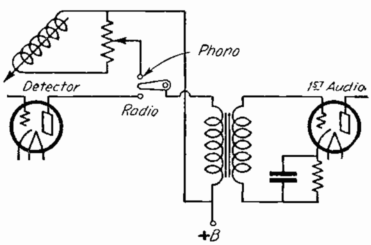


FIG. 25

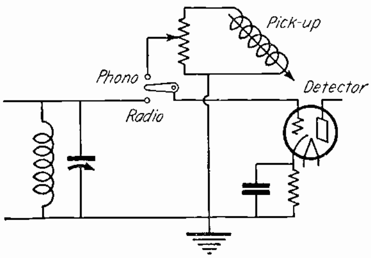


FIG. 26

There are other methods of coupling a pickup to a radio receiver. Fig. 25 shows the simplest, in which however, no attempt is made to match impedances. The switch may be a two-way toggle switch—one way for radio and the other for phonograph. Quite often a panel switch is not provided but the radio receiver is cut off and the phonograph brought into use by turning the station selector dial all the way to the right or to the left. This is usually done in combination radio-phonographs where the electrical turntable and the pickup are built into the cabinet.

A typical combination radio-phonograph is shown in Fig. 24.

The normal pickup delivers about 2 volts as an average. However, there are some phonograph pickups that deliver considerably less voltage and therefore greater amplification in the audio system is required. Pickups of this sort are usually connected to the grid and cathode of the detector as in Fig. 26. A suitable resistor must be shunted across the grid bias resistor so the tube will act as an amplifier instead of a detector. When this method is used the connection between the grid of the detector tube and the phonograph switch or jack must be

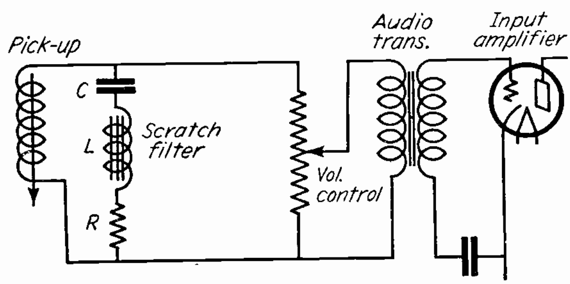


Fig. 27

made extremely short and must be well shielded otherwise it will affect radio reception.

If the audio amplifier used in conjunction with phonograph apparatus is well designed about the only thing to mar a musical selection taken off a phonograph record is the scratching noise made by the needle as it passes over the record. The frequency of this scratch is between 5,000 and 7,000 cycles—unfortunately within the audio frequency range. This scratch can, for the most part, be eliminated by the use of electrical scratch filters as shown in Fig. 27.

9

A scratch filter is nothing more than an inductance in series with a condenser and resistance, connected across the pickup. The constants of the inductance, capacity and resistance are so chosen that they resonate to the scratch frequency, and a series resonant circuit designed to resonate at approximately 6,000

Note.—The values for L and C in Fig. 27 are about 200 millihenries and .004 to .006 mfd. respectively.

cycles per second should absorb a great deal of the scratch frequency from the pickup. Designed to resonate at above 5,000 cycles its effect on the reproduction of music will hardly be noticed.

The amount of background or scratch frequency noise depends on the material of the record, how it is cut, and the sensitivity and frequency range of the pickup device.

TEST QUESTIONS

Be sure to number your Answer Sheet 31FR.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and the best possible lesson service.

1. What two conditions must be satisfied before the tuned circuits of an R.F. amplifier may be ganged together?
2. Why should each R.F. stage in a single control receiver be adjusted to the same resonant frequency?
3. What two provisions are made in each section of the gang condenser for readjustment so that tracking is possible over the complete tuning range?
4. Explain how you would adjust the oscillator section of Fig. 7d using a signal oscillator as a source of supply.
5. Draw a circuit diagram illustrating the use of a remote C bias volume control.
6. What is the basic method of obtaining automatic volume control?
7. What would you say was the main advantage of an automatic volume control and its disadvantage?
8. Draw a diagram showing the connections to a radio-phonograph combination with a switch through which connection is made to a tapped primary for impedance matching.
9. What is a scratch filter and where is it connected?
10. Explain briefly the working principle of a magnetic phonograph pickup.

SHORT WAVE RECEIVERS AND TRANSMITTERS

32 FR-1

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

THE VALUE OF SELF-STUDY

There are any number of books on the market on how to be successful and in every one of them great stress is laid on self-analysis which is just another name for self-study.

Even the ancient Greeks recognized the need of self-study and one of their most familiar sayings was "Know thyself."

No two people are alike—no two people can do the same job in exactly the same way. And we all have our limitations. The important thing for each of us is to know our limitations and to put all our effort where it will do the most good.

For example, a man with the ability to sell and with a great interest in salesmanship, should not hold a full-time job as a Radio serviceman—he should be selling Radios and be putting his technical knowledge of Radio to work in this way.

In the same way, a man with administrative ability should have his own business. He most likely will not be happy or successful, working for someone else. And a man who does not have administrative ability should recognize this limitation and make up his mind to give the very best he has in him to the man who employs him.

Coming down to every-day matters, if you get a job you know is beyond you, it is much better to admit frankly that it is beyond you than to try to bluff it out. For example, let us say you are specializing in Radio Servicing. Already you have handled a number of jobs—all with the greatest success. You are making a name for yourself as a Radio expert. Then a man comes along and asks you to build or supervise the building of a small broadcast station. You are tempted to tackle the job because it would mean real money to you. But be wise! Turn the job down! You are not yet ready to build broadcasting stations. Admit it honestly.

Bluffers don't get very far these days and the man who is honest and will not bluff is deserving of and in ninety-nine cases out of a hundred, gets the respect of all the people with whom he comes in contact. And with the respect of your fellowmen you will find the Road to Success and Happiness smooth and easy under foot.

J. E. SMITH.

NATIONAL RADIO INSTITUTE

WASHINGTON, D. C.

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Short Wave Receivers and Transmitters

SHORT WAVE COMMUNICATION

Not so long ago the wavelengths below 200 meters were considered of no practical or commercial value. Permission was granted to amateurs and experimenters to use any wavelengths below 200 meters that they desired. The ingenuity of these pioneers in short wave development proved very fruitful and the amateur experimenter was soon quite at home below 200 meters. Progress was made with little regard to the theory of Radio but the results showed that the theory applied just as well here as in the broadcast band after the work had been done. Today the short wave bands all the way down to 10 meters, covering over 18 bands as large as the entire broadcast band, are in many respects more valuable than the wavelengths of the broadcast band.

The advantages and disadvantages of short waves are, briefly: as the frequency of a transmitter is increased (wavelength shortened), the effort of its wave on a receiving antenna becomes increasingly greater. This causes short wave apparatus to be very efficient, requiring much less power for greater distance than long wave or broadcast wave apparatus. Short wave apparatus in general is much lighter and more compact than intermediate or long wave apparatus. Unfortunately, short wave communication has many disadvantages. The waves are subject to erratic propagation, producing rapid and severe fading; there are dead signal zones and reception is inconsistent. Any audio modulation which these high frequency waves may carry is subject to selective fading or attenuation, a very displeasing type of distortion.

A full discussion of the theories accounting for these peculiarities will be given in a later text.

THE DETECTOR CIRCUIT

The success of a short wave receiver is largely centered around its detector tube and associated circuit. In short wave receivers other than those of the superheterodyne type, a regenerative detector is almost invariably used. Regeneration is essential for radiophone reception and oscillation is essential for C. W. reception. The difference between regeneration and oscillation in a receiving detector is only one of the degree of feed-back of the circuit. The regeneration of a circuit may be intensified until oscillation starts, after which oscillation may be continuously increased up to the limit of the circuit. There is a "critical point" in the action of the detector above which oscillation starts at its weakest intensity and immediately below which regeneration is strongest. This critical point is referred to in a variety of ways which will be discussed as we progress. The best point of operation of the circuit for phone reception is just a trifle below the critical point, at the point of *strongest stable regeneration,* and the best point for C. W. is just a trifle above the critical point, at the point of *weakest oscillation.*

The critical point varies with filament temperature, plate voltage, frequency of operation and a great number of other things, hence regeneration and oscillation must be controlled. In every case the critical point must be "in reach" of the manual controls on the panel of the receiver. This control is often referred to as the "throttle" control because it may be used to throttle the tendency of the circuit to "break-over" into oscillation.

Now let us look at the several methods of controlling the detector's operation. In Fig. 1, circuit (A) uses the filament temperature method of control. Of course, any operation which the tube may perform can be reduced or stopped by gradually reducing the filament temperature. Thus the circuit will regenerate at low filament current and oscillate at high filament current. This method is not popular and not satisfactory because the life of the tube is impaired and the variation is too fast and intermittent (not continuous or smooth). This method of control would be very impracticable, if not impossible, with a heater type tube ('27 or '24).

Circuit (B) employs a rotating coil in the plate circuit so that the amount of energy fed back can be varied. It may be varied from maximum to zero by turning the coil 90°. In this way oscillation in the circuit may be reduced to regeneration or even to an inoperative point. This method, however, has mechanical disadvantages, in that a rotating connection is necessary. While a good rotating connection can be obtained by the use of flexible pigtails, the necessity for their use is a sufficient disadvantage to make another type of regeneration control preferable. Then, too, shielding an arrangement of this sort is a rather difficult problem.

In circuit (C) the throttle device, a variable resistor, is an energy waster. When adjusted to low values it takes away

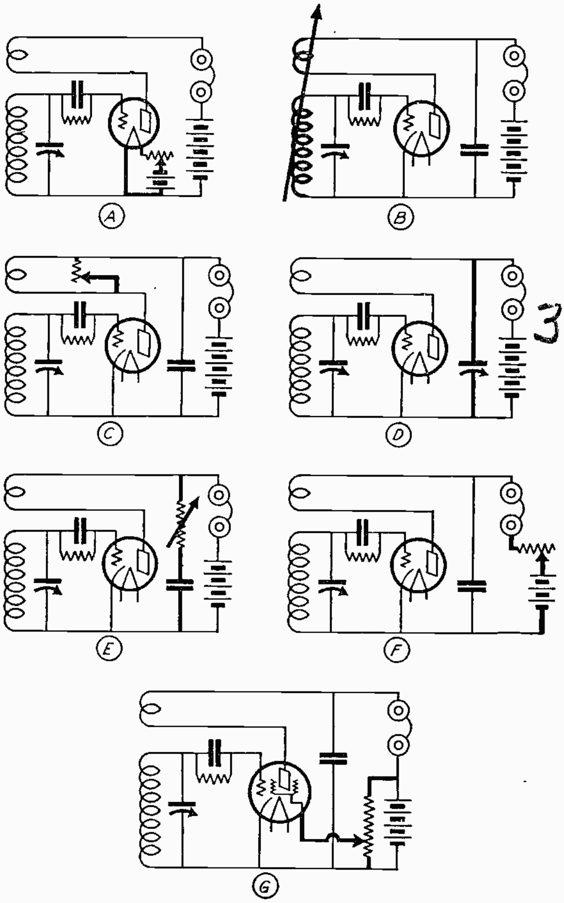


Fig. 1

feed-back energy from the plate coil and thus oscillation may be reduced to regeneration. However, potentiometers of different resistance values are necessary for different coils, making it inconvenient to use the same control for different S. W. coils. Besides this, the circuit is very sensitive to body capacity effects unless special shielding precautions are taken.

All of the other methods are in common use, (D) being most used because of its simplicity and flexibility. The R. F. flowing in the plate coil depends to a large degree on the value of the throttle capacity which acts as an R. F. by-pass across the A. F. input which, in general, offers a large impedance (Z) to the R. F. Where its value is large, a large amount of R. F. can flow in the plate coil and the tube will oscillate. If this capacity is reduced, the impedance to R. F. current flow increases and its intensity is reduced, thus reducing the feed-back. Sufficient reduction of the capacity will reduce oscillation to regeneration.

The R. F. circuit consists of the plate coil, the throttle condenser and the cathode-to-plate resistance of the tube.

This method of throttle control has the inherent fault of changing the frequency of the tuned circuit when its adjustment is changed. Circuit (E) is more or less free from this fault. There is a variable resistor in series with the throttle condenser which in this case is fixed in value. Thus the conductivity of the R. F. circuit is varied by changing the ohmic resistance of the circuit instead of by changing the capacitive reactance. Changing the resistance in this position will not detune the grid circuit appreciably and the circuit can be held at a very constant oscillation or regeneration level throughout the entire tuning range of the grid circuit.

Circuits using methods (F) and (G) are excellent but require more care in construction and operation than method (D). In circuit (F) it will be seen that a series plate resistor is used as the throttle control. The R. F. output of the tube which is responsible for feed-back is almost directly proportional to the plate voltage impressed on the tube, so that by increasing this resistance the plate voltage is reduced, the R. F. is reduced, the feed-back is reduced, and oscillation may be reduced to regeneration.

The internal resistance of a screen grid tube can be varied greatly by varying the screen voltage. Method (G) shows how the screen voltage may be varied by a potentiometer which, of course, is the throttle control in this circuit.

When the screen voltage is high the internal tube resistance is low allowing R. F. to pass and oscillation to take place. But when the screen voltage is reduced, the tube resistance becomes very much higher thus reducing the R. F. in the tickler coil. In this way oscillation may be reduced to regeneration.

CIRCUIT ACTION

In this chapter we will devote our attention to operational details of the detector or regenerative circuit.

To make our study of this circuit easier, the arrangement of the symbols in the diagram of Fig. 2(a) is slightly different from their arrangement in an ordinary diagram. The successful operation of this circuit hinges directly on the amount of radio frequency current flow which can be obtained in coil L_1 (the plate coil). Means must be provided so that the R. F. in this coil can be controlled accurately.

Of course, the coil must be part of a complete R. F. circuit (L_1-C_1). On the other hand, the D. C. plate circuit contains L_1, L_2, L_3, B, and the tube. This D. C. circuit is not intended for an R. F. circuit and is rarely used as such in short wave receivers; its function is simply to supply the plate with

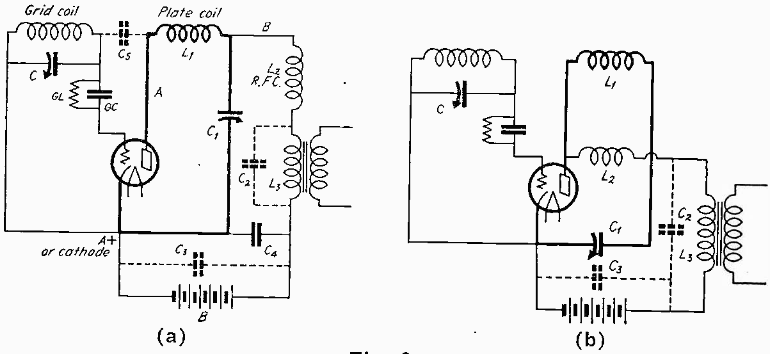


Fig. 2

D. C. at the proper voltage and to convey the modulation from the incoming signal to the audio stages or to a set of headphones.

The plate coil L_1 need not even be in the plate circuit but may be and sometimes is included in a *separate* R. F. circuit as in Fig. 2(b). In both circuits, the R. F. circuit is completed through C_1. The circuit in Fig. 2(a) is a "series-fed" circuit and the circuit in 2(b) is "shunt-fed." Notice that the plate coil and R. F. choke are in series in Fig. 2(a) and in parallel (shunt) in Fig. 2(b). The D. C. plate current flows through the plate coil in Fig. 2(a) but no D. C. flows through the plate coil L_1 in Fig. 2(b). L_1 and C_1 comprise a separate R. F. circuit which is isolated from the plate circuit load but in shunt with it.

The amount of R. F. current flow in the circuit L_1-C_1 depends entirely on the values of C_1 and L_1, provided that the values of the other parts of the circuit remain the same. If the coil L_1 is small, the condenser C_1 should be large, *but no condition of resonance of C_1 and L_1 is desired or expected.* By varying the capacity of C_1, its reactance is varied and thus the amount of R. F. in L_1 can be increased, or reduced, as desired. If L_2 is omitted from the circuit in Fig. 2(a) and there exists enough capacity (represented by C_2) between the turns of the audio transformer primary, and if the B battery is by-passed with a condenser C_3, or if the internal capacity of the battery is high enough, sufficient R. F. may flow to sustain oscillation without C_1.

The circuit is tuned by means of the variable condenser (C) and the grid coil. A grid leak (GL) and condenser (GC) are employed so that the circuit will function as a detector at the same time that it oscillates or regenerates. (C_5) represents the capacity between the plate and grid coils, (C_2) represents the distributed capacity across the primary of the audio transformer primary and (C_3) the capacity of the B battery. (C_4) in Fig. 2(a) is a large by-pass condenser, .1 to .5 mfd., used in this circuit to prevent the "howling" known as fringe howl, at the critical point and other circuit noises arising from the action of the transformer connected in the circuit.

SHORT WAVE COILS AND CONDENSERS

Perhaps the most disconcerting part of short wave work is the design of coils for the tuned circuits and feed-back circuits.

Let us look over our problem. As mentioned we have more than 18 bands as large as the complete broadcast band, between 10 and 200 meters. In some way, the detector circuit must be made capable of oscillating at any frequency between and including 1500 kc. and 30,000 kc.

4

While the entire frequency change in a broadcast receiver is brought about by using condensers having a variable capacity with permanent tuning coils, this cannot be done in a short wave receiver for three important reasons.

1. No matter what tuning capacity would be used its maximum capacity value would have to be *400 times* as large

as its minimum value. Such a condenser would be extremely expensive and commercially impracticable.

2. The ratio L/C could not be held within small limits which is essential for the operation of the tube.

3. The distributed capacities of the circuit would prevent "coverage" of the band at the high frequency end.

The ratio $\frac{C\ max.}{C\ min.}$ for the average .00035 mfd. condenser used in the broadcast receiver, ranges between 8 and 12, depending entirely on its mechanical construction.

For a particular frequency, any value of capacity may be chosen and an inductance value may be found which will form a resonant circuit to that frequency. However, there is an optimum relation between C and L which is most desirable for one circuit. For example, a C of 3500 mmfd. and an L of 25 µh will respond to 550 kc. just as well as 350 mmfd. and 250 µh, or even 3.50 mmfd. and 25,000 µh. (Note that the product of L and C is always the same—they are inversely proportional.) The values 350 mmfd. and 250 mh. are almost invariably used, although sometimes 500 mmfd. and 160 µh or 250 mmfd. and 350 µh are used but these do not represent very great changes in what is known as the LC ratio.

It is evident that a method of tuning must be employed whereby the L and C values may *both* be varied so that the $(\frac{L}{C})$ ratio will be fairly constant and so that a wide range of frequencies may be covered at the same time.

There are four methods of doing this. They are as follows:

1. By the use of a continuously variable inductance in the form of a variometer in the grid circuit and a specially designed tuning condenser which has a large ratio of maximum capacity to minimum capacity. (Note: this method is not used very much because the variometer and condenser must be of special construction.)

2. By the use of "plug-in" condensers for certain bands of frequencies. This method is impracticable because a complicated coupling device will be needed for the condenser shaft and wire connections must be made for the condenser, making exchange of condensers difficult.

3. By the use of plug-in coils. Until recently this was the most desirable method of covering a wide frequency range because it was the simplest, the cheapest and the quickest way.

In shifting from one band to another in the same circuit, plug-in coils of various sizes result in less change in the operating characteristics of the circuit because both the tickler and the grid coil are changed. The same methods of regeneration may be employed, because the effects of frequency change on the regeneration system can be compensated for by the new tickler coil value. See Fig. 3.

5 4. In recent commercial all-wave and short wave receivers, the slight inconvenience of plug-in coils is eliminated by the use of a number of permanently installed coils of various sizes that can be cut into or out of the circuit by means of switches. Of course, the principle is essentially the same as in the use of plug-in coils. The only difference is that the coils are changed, not by removing one and replacing with another, but simply by throwing a switch.

Now what condenser value for a permanent tuning control should be employed so that the greatest band coverage can be obtained, and so that the operating characteristics of the circuit will not be destroyed or become less effective? Further discussion of the regenerative circuit will be necessary before we can answer this question.

There is a certain minimum capacity which always shunts the main tuning capacity and it is formed by a combination of distributed capacities of portions of the regenerative circuit. Among these are the grid to filament capacity of the tube, the capacity between turns of the tuning coil, the minimum capacity of the tuning condenser and others of minor value, totalling for example, 30 mmfd. for a particular circuit.

Regardless of the value of L, the total capacity must be increased four times* to tune the circuit from its original frequency to ½ of this, as, for example, from 7000 kc. to 3500 kc. (40-80 meters approximately). We may call this for convenience, tuning from one frequency to its second harmonic (or over a range of one octave), since 7000 kc. is the second harmonic of 3500 kc. If it were possible to keep this relation, that is, to expect each coil to be tuned in this way, the problem of short wave receivers would be greatly simplified. Unfortunately, however, this convenient relation is upset by the added distributed capacity introduced by the coils used for longer wavelengths.

*That is if the original capacity was 50 uuf, to half the frequency without changing L, increase the capacity to 200 uuf.

Furthermore, the high frequency (short wave) end of the spectrum is affected in an entirely different manner. Because of the distributed capacity, the minimum capacity in the circuit cannot be brought below about 30 mmfd. with the result that the very high frequencies cannot be reached easily without a different circuit design. Thus we can cover one octave in the radio spectrum at about 5000 kc., less than an octave at 2000 kc. and less than an octave at 15,000 kc.

By choosing a capacity slightly greater than 4x30 mmfd. (120 mmfd.) we arrive at values of 140, 150, 160 mmfd., some of which are used in commercial receivers. (A value greater than 120 mmfd. is used to compensate for the "high frequency limiting effect" of a vernier condenser used in conjunction with the main tuning condenser for fine tuning—for while the maximum capacity of the vernier condenser is low as compared with the maximum capacity of the main tuning condenser, at minimum capacity settings, the vernier capacity is not much smaller than the main tuning capacity.)

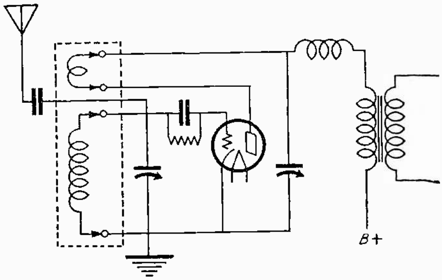


Fig. 3

The exact number of turns of wire for each grid and plate coil for various wave bands will be given later in this book, with other constructional details.

THE AUDIO AMPLIFIER

Fortunately the audio amplifier used with a short wave detector is exactly like any audio amplifier, except in some rare cases. Of course, after detection, the audio signals are the same, whether they had originally been impressed on long wave or short wave carriers. Incidentally, this accounts for the success of short wave adapters. No extensive discussion need be given here on audio amplifiers for short wave receivers for this reason. In general, they consist of one or two stages of transformer, resistance or impedance coupled tubes, either single or pull-push, the latter usually being used only in the last stage.

For continuous wave reception a degree of A. F. selectivity surpassing that of any R. F. system yet developed is sometimes employed so that signals can be easily segregated when their carrier waves are only 100 to 150 cycles apart. One or two audio band-pass filters as shown in Fig. 4 do the trick. It is rare that more than one such stage is used. The LC circuit in the grid circuits are tuned to some audio frequency around 500 cycles.

THE R. F. SYSTEM

Unusual problems present themselves in the direct amplification of radio frequency energy having a frequency much in excess of 3000 kc. The reactance to R. F. current flow offered by the capacity between the grid and the plate becomes very small at extremely high frequencies. Thus some of the high frequency signal energy will be by-passed to the grid

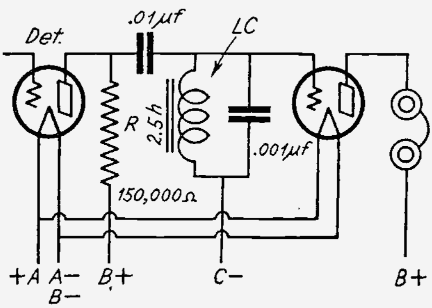


Fig. 4

of a following tube through this capacity and through the distributed capacity of the transformer windings instead of being amplified by the tube in the normal manner. This by-passed energy will be out of phase with the energy passing through the tube in the normal manner with the result that there is considerable cancellation.

Even the internal capacity of the screen grid tube, which is much less than that of any three electrode tube, is far too great for use in a cascade high frequency amplifier. It is for this reason that only a single stage of screen grid R. F. amplification is used in most short wave receivers.

In this connection it must be realized that the complete amplification factor of a screen grid tube can never be obtained in any circuit, and much less in a short wave circuit.

The coupling between the R. F. tube and the detector in a short wave receiver is unusual. The main disadvantage in using the inductive type of coupling that is so universal in broadcast receivers, is that the capacity between the primary and secondary windings of a transformer becomes a major consideration, for through it a large part of the energy is transferred from the R. F. circuit to the detector. This energy is always out of phase with the energy transferred by induction so that the total amount of energy passed on to the detector will be small. Then, too, it is practically impossible to match the R. F. tube impedance with the small primary of the coupling coil which must be used.

Tuned impedance coupling is mostly used and the tuned circuit also functions as the detector regenerative circuit. Figure 5 will show this at a glance. C_1 is the main tuning condenser for the detector grid circuit. C_2 is an "isolating" condenser to isolate the high positive voltage applied to the plate of the R. F. tube from the detector cathode or filament. Its

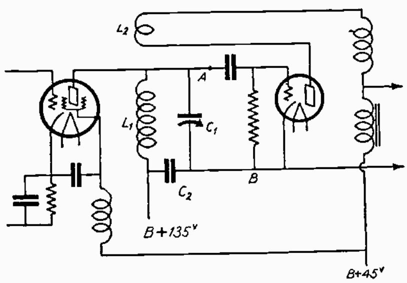


Fig. 5

value is large (.01 mfd. or more) so that the total capacity of C_1 and C_2 will not fall materially below that of C_1 alone. Notice that the plate circuit of the R. F. tube is made continuous through the main grid coil L_1 of the detector circuit. The grid leak must always be returned to the cathode or filament at B rather than to the other side of the grid condenser at A. You can see that this would cause the high positive potential of the R. F. plate to be applied through the grid leak to the detector grid.

The plate of the detector and the screen of the R. F. tube are usually supplied with the same voltage from the same source and thus are connected together. The conventional screen grid by-pass condenser is used and occasionally there is an R. F. choke (about ¼ microhenry) in the screen lead. This, however, is not essential.

Since tuned impedance coupling has been so successful it was conceived by a recent investigator that the tickler coil could be used as the primary of an R. F. transformer, thus carrying the D. C. plate current of the R. F. tube as well as the R. F. which is necessary for regeneration or oscillation.

The circuit is shown in Fig. 6. It has a shunt-fed resistance controlled regenerative detector. (Notice that the feed-back energy is taken from the screen grid circuit of the detector and not from the plate circuit.)

Condenser C_2 isolates the D. C. plate voltage of the R. F. tube from the detector screen while C_3 completes the shunt R. F. circuit. The action of C_3 is similar to the action of C_1 in Figs. 2(a) and 2(b).

The plate of the detector functions independently, handling the rectified audio component only. Any R. F. which may escape into the plate circuit is by-passed by C_4 and

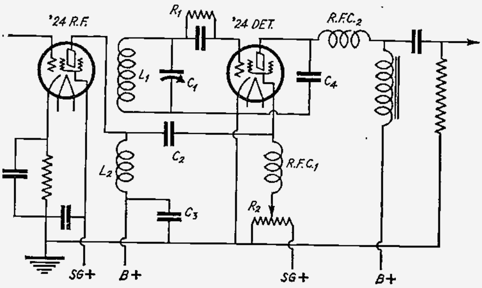


Fig. 6

choked out by R. F. C.2 R. F. C.1 is essential in a shunt-fed arrangement as you have already learned.

There are several methods of bringing the signal from the antenna to the R. F. tube (see Fig. 7). The resistor method (A) is the simplest, the cheapest and the best method. It is not affected by frequency differences, it may be made to match the input impedance of the tube and it has no magnetic effects to be guarded against. The choke coil method (B) is just as good in many respects. Its effectiveness increases with frequency thus allowing more amplification at higher frequencies.

The tuned input method (C) is of least value from a practical standpoint because of the difficulty in keeping the R. F. condenser in line with the detector circuit condenser. It is a greater problem to synchronize these two condensers than any

3 or 4 tuning condensers in a broadcast receiver. Tuning is extremely critical, and very likely to be affected by body capacity. The isolating capacity previously mentioned introduces a further problem into synchronization which is obvious. Figure 7(D) shows the type of input circuit used when the bias is obtained from the voltage drop through a section of the D. C. filament resistor. Methods (B) and (C) can also be used with D. C. tubes.

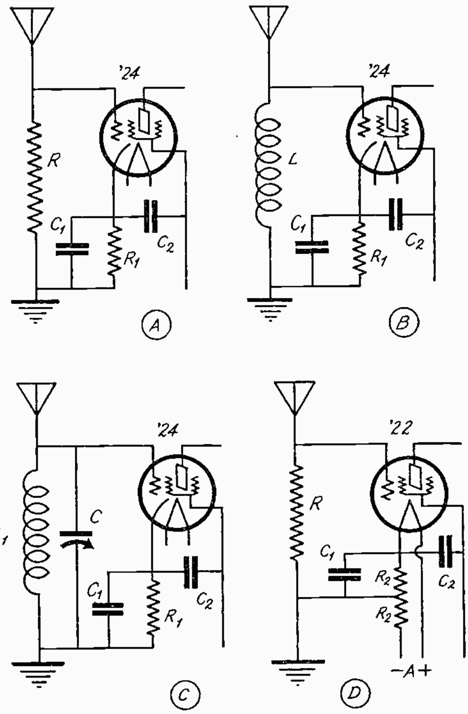


Fig. 7

ANTENNA COUPLING

6 Assuming that no R. F. stage is used ahead of the detector, the antenna circuit must be coupled to the detector in some way. There are two methods of coupling the antenna to the detector of a short wave receiver; capacitive coupling and inductive coupling (see Figs. 8(a) 8(b)). One method is as good as the other. For capactive coupling a .00005 mfd. to .00001 mfd. fixed condenser should be used. There is no advantage in varying this capacity as it would shift the station's position on the main tuning dial, cause the receiver to change its critical

7

point, and in some cases cause "dead spots" on the tuning dial. A dead spot is a section on the tuning dial where the detector tube cannot be made.to oscillate. This must not be confused with failure of the tube to oscillate over the entire dial or even toward either end. A dead spot occurs when the antenna electrical constants are similar to the circuit constants. This condition may be avoided by changing the capacity of the antenna condenser or the length or design of the antenna.

Inductive coupling is to be preferred in most cases to avoid shifting of the station settings for various antennas or operating conditions. Dead spots can result from this type of coupling but they are much less frequent due to the added antenna inductance. They may be avoided as before by changing the antenna length or design or by changing the size or number of turns of the antenna coil.

An actual ground connection is of little value on a short wave receiver having a large metal chassis, or a metal panel and shielding, especially if it is operating at very high frequencies. Usually, little or no difference will be noticed in reception on wavelengths below 50 meters with the ground wire removed.

THE SHORT WAVE SUPERHETERODYNE

By far the most difficult receiver to design is the short wave superheterodyne. The principles involved, such as R. F. amplification signal mixing, detection, I. F. amplication, and audio amplification, are fundamentally the same as in the broadcast band but their application is quite difficult.

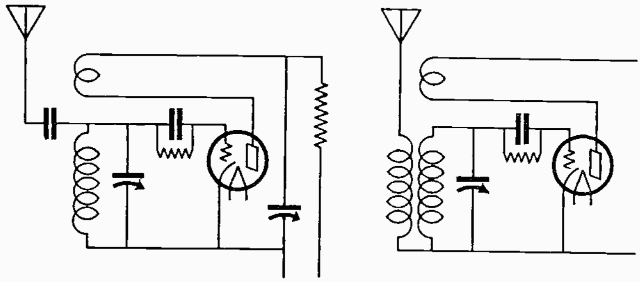
Short wave superheterodynes usually have no tuned R. F. stage or stages but the signal is fed directly to the first detector or mixer, which in many cases employs screen grid A. C. or D. C. tubes. Although these are commonly used in detector and I. F. circuits, a three electrode D. C. or heater type tube is generally used for the oscillator. Standard oscillator circuits with plug-in coils are generally used. The I. F. amplifier usually employs 2 or 3 screen grid tubes in well constructed tuned-plate or tuned-grid circuits responding to high intermediate frequencies; sometimes as high as 450 to 500 kc. or more.

In a short wave superheterodyne, the second detector is usually made so that it may oscillate for continuous wave reception. It oscillates at a frequency of course near the intermediate frequency so that an audible beat between it and the I. F. is formed.

In general, short wave "supers" must be more carefully constructed and shielded than is the case with broadcast "supers." Because of the large change in frequency for a small change in dial position, ganging of tuning condensers is seldom attempted.

SHIELDING THE SHORT WAVE RECEIVER

The frequencies with which we must deal in short wave reception are extremely high. The effects of body capacity and electromagnetic and electrostatic pickup within the receiver cause a great deal more trouble in the case of short wave receivers than in long or intermediate wave receivers. The reason for this is that only a small change in electrostatic capacity between any two wires used to connect the various parts of the



(a) (b)

Fig. 8

receiver will make greater changes in the tuning of the apparatus than they would in long wave circuits. The protection against these effects by shielding is of major importance in short wave receiver construction.

Metal panels are used quite extensively in short wave receivers. In many cases, the receivers are entirely enclosed in a metal box or each stage is in a separate metal compartment. It is not necessary to enclose each audio frequency stage in a separate compartment, as you know from your study of broadcast receivers, but the entire audio system should be isolated from the R. F. system. If the radio frequency stage is not separated from the detector by means of shielding material, the tube should be shielded as well as the control grid lead.

Apparatus such as radio frequency choke coils should either be shielded or should be mounted so that it cannot interfere magnetically with any other piece of apparatus in the short wave receiver. The detector, grid and plate coils should never be shielded because this would introduce too many losses in the operation of the detector as well as introducing serious errors in the coil design. Furthermore, the sockets intended for detector plug-in coils should not be mounted on a metal base because when the coil is plugged into this socket, the metal will be too close to the windings of the coil for efficient operation.

In some types of radio work, the battery cable or the A. C. leads must be thoroughly shielded as well as the telephone or loudspeaker cords. These extra precautions are only taken in particular services such as aircraft radio, police radio and automobile radio.

The shielding problem is a different one for each receiver that is built. To avoid too much useless experimenting, it will be prefectly satisfactory to use a metal panel and space the various parts of the receiver sufficiently far apart so that harmful feed-back effects cannot take place. The apparatus should never be crowded into a small compartment or on a small sub-panel.

Aluminum is used extensively for short wave radio panels and is made in several convenient thicknesses for this purpose.

PRACTICAL SHORT WAVE CIRCUITS FOR THE DESIGNER

Following are shown a number of typical receiver circuits for various short wave services. Complete constructional details are given for each of the following receivers and with this information it should be easy to build any of them.

In some cases the receivers are shown both for A. C. and battery operation. In cases where either the A. C. or D. C. model is not shown, they are practically interchangeable. With a few minor circuit changes with which you are familiar at this point, an '01A tube can be replaced by a '27 tube. The same applies to the type '22 and '24 tubes. Further than this, by changing the A supply voltage or the filament control resistors for a receiver, using type '01A tubes, '12A tubes or '71A tubes, the '30 and '31 type tubes may be used.

In this lesson we don't attempt to show every possible receiver design, for it would take ten textbooks this size to accomplish it. However, you should easily be able to replace a resistance coupled audio amplifier with a transformer coupled amplifier. And you should be able to add push-pull amplification to a single stage amplifier or convert the last stage of any amplifier from a single tube to a push-pull system.

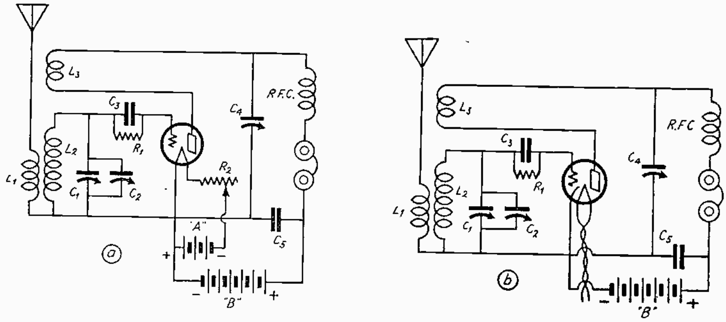


Fig. 9

You should also be able to add a stage of tuned or untuned radio frequency amplification to any of the receivers given here which do not have one, so that with the information given here, you will be able to design your own circuit and build it, if you want to build some variation of one of these circuits.

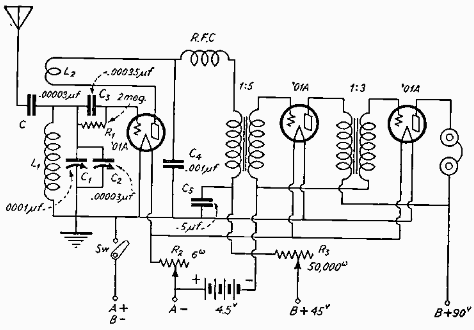


Fig 10

Figures 9(a) and (b) show circuits of a single tube receiver. In Fig. 9(a), the tube may be a type '99, '20, '30, '31, '01A, '12A, or '40. In Fig. 9(b), a type '27 tube must be used. Note carefully the circuit features which distinguish the A. C. set from the D. C. set.

In these receivers the antenna is inductively coupled to the oscillator circuit. A list of parts follows:

List of Parts for Figs. 9(a) and 9(b)

1—set of plug-in coils (5-prong) L_1, L_2 and L_3
1—variable condenser (.00014 mfd.) C_1
1—variable condenser (.00003 mfd.) C_2
1—fixed condenser (.00025 mfd.) C_3
1—variable condenser (.00025—.00035 mfd.) C_4
1—fixed condenser (.5 mfd.) C_5
*1—rheostat (30 ohm) R_2
1—radio frequency choke (R. F. C. ¼ mh)
1—grid leak (2 meg.) R_1
*1—6-volt A battery (A)
1—45-volt B battery (B)
1—tube (see text)
1—"Y" socket (for coils)
*1—"X" socket (for tube)
1—set headphones
1—roll wire (25 ft.)

Additional parts for circuit 9(b).

1—filament transformer (2.5^v—1.75 amp.)
1—"Y" socket for '27 tube.

Through the use of the plug-in coils, either of these receivers can be made to tune from 20 to 200 meters.

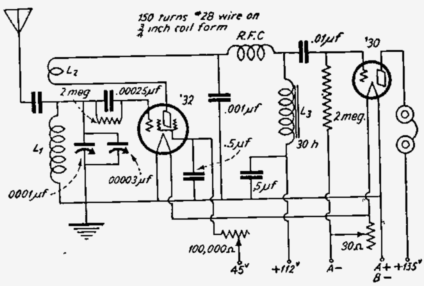


Fig. 11

In Fig. 10 is shown a three tube short wave receiver. This receiver can use 2 volt tubes, 3 volt tubes or 5 volt tubes.

In Fig. 11 is shown a two tube receiver using a screen grid detector.

Impedance coupling is recommended between the detector and first audio in this case although it is not absolutely essential.

If a transformer is used, the primary will replace coil L_3. The other parts of the circuit will be familiar to you.

*Not needed for circuit (Fig. 9 (b)).

Figure 12 shows a four tube receiver circuit which has been found to be very practical in construction and operation.

The following parts may be used in the construction of this receiver. The coil data given here is, of course, applicable

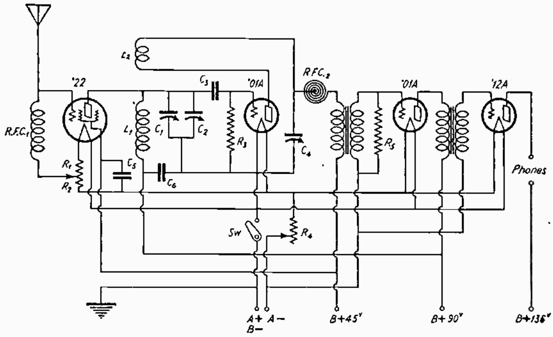


Fig. 12

to any detector circuit using the same tube and responding approximately to the same frequencies.

C_1—.0001 mfd.
C_2—.00003 mfd.
C_3—.00025 mfd.
C_4—.00035 mfd.
C_5—.5 mfd.
C_6—.01 mfd.
R_1—10 ohms.
R_2—10 ohms.
R_3— 2 megohms.
R_4— 6 ohms.
R_5— 2 megohms.
5 "X" Sockets (one for plug-in coils).

R. F. $C._1$ and R. F. $C._2$ ¼ to 3.5 millihenry chokes.

1 type '22 tube.
2 type '01A tubes.
1 type '12A tube.
2 audio transformers (ratio 1—3).
1 filament switch.
4 tube bases (for coils).

Coil Data

Wavelengths	L_1 Turns	L_2 Turns
15- 25 meters	7	8
25- 45 meters	11	12
45- 90 meters	25	15
90-150 meters	45	20

Such parts as binding posts, lugs and hook-up wire are rather indefinite in number or amount as this depends on the particular set design. They are not listed for this reason.

The coils may be wound on 1½ in. coil forms, 1¼ in. coil forms or tube bases. No. 24 to 30 wire enameled, double or single cotton or silk covered may be used. Coils L_1 and L_2 are wound on the same form, the space between windings being from 1/8 to 1/4 in. Both Radio frequency chokes are identical although one is shown in "pie" form. They may be made by winding 150 turns of No. 30 S. C. C. wire on a 1/2 inch diameter coil form.

A complete 5 tube A.C. receiver, using a screen grid R. F. tube, a screen grid detector, and 2 type '45 output tubes is shown in Fig. 13. Excellent results for all wave bands between 20 and 200 meters should be obtained with this receiver.

WINDING COILS

Because of the nature of operating conditions within a short wave detector, coil winding is an art. No two manufacturers use the same type of coil nor are they alike in any respect except that copper wire is used for all. Home-made coils of various experimenters and builders differ just as much, due to this lack of standardization. A discussion of the qualifications of every type of coil would be endless, and it is expected that the set builder design his coils with the following general points in mind:

1. Basket weave coils, "Jumble wound" coils, air wound or any coils of which adjacent turns are not symmetrical or not parallel:
   a. Have indefinite inductance values (hard or impossible to compute).
   b. Have low distributed capacities.
   c. Must be self-supporting or require artificial supporting such as glue or string.
   d. Are unhandy to interchange, bulky and may get out of shape, require careful handling.
2. Space wound coils, coils of irregular shape such as octagon or hexagon coils:
   a. Have indefinite values (hard to compute).
   b. Require special winding forms.
   c. Winding groove or fastening material must be used.
   d. Require careful handling.
3. Bank wound and layer wound coils.
   a. High distributed capacity.
   b. Compact.
   c. Rugged and convenient.
4. Single layer close wound circular coils.

a. Most rugged.
b. Adaptable to accurate evaluation or standardization.
c. Rigid form supported, no fastening material necessary.
d. Usually no winding grooves necessary, easiest to make.
e. Medium distributed capacity effects.
f. Alterations made quickly and easily.

Single layer close wound circular coils have by far the greatest number of advantages from a practical standpoint. The tube base has become the standard coil form for the home constructor. It seems to have only one fault in that it is too

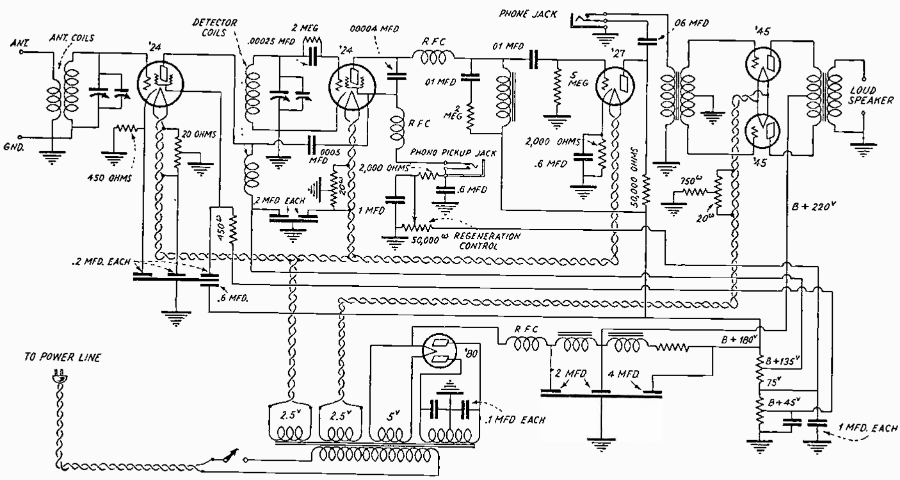


Fig. 13

short to contain all the turns of wire for tuning to wavelengths above approximately 120 meters. This is overcome to some degree by layer or bank winding.

The tube base can be obtained from any burned out X or Y tube, perfect contact is easily and effectively made to its prongs and it is instantly plugged into a standard socket costing only a few cents where it is rigidly held in place by excellent electrical contacts. Knowing the value of the tube base for this purpose, several manufacturers have improved on its length but made no other changes with the exception of a convenient handle on top.

WINDING SHORT WAVE COILS

It should be obvious to the experimenter and constructor that there are a number of methods of winding coils. Some coils for example make use of only two separate windings (grid and plate) whereas others use three (grid, plate and antenna).

First of all we must adopt a rule so that we may know just how these coils are placed with respect to each other. Assuming that the coil is mounted vertically, the plate coil may be above the grid coil or below it. It makes no difference in a "two winding" coil (grid and plate windings) whether the plate coil is above or below the grid coil as long as they are both wound and placed correctly.

Figures 14(a) and 15(a) show methods of placing the windings for two and three winding coils on 4 and 5 prong coil forms, respectively (tube bases may be used). Note that

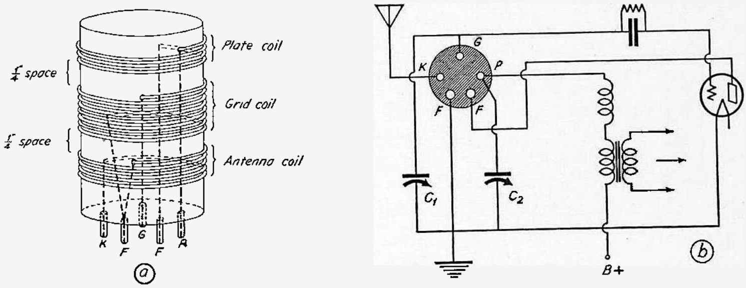


Fig. 14

the plate coil is the upper coil in Fig. 14(a) and when an antenna coil is used, it is placed below the grid coil with its upper end connected to the lower end of the grid coil. In fact, this winding may be simply a continuation of the grid coil with a ground tap to provide a tuning section or grid coil.

The antenna coil may be spaced from the grid coil up to one-half an inch without seriously affecting the coupling between the coils. Usually more turns are used on the antenna coil when it is spaced as far as ½ inch from the grid coil. The antenna coil should always be placed at the grid return (ground) end of the grid coil for the best results with the antenna terminal on the outside end of the antenna coil.

The plate coil should be placed at the grid end of the grid coil with the plate terminal nearest the grid coil and its B+ terminal on the outside. The plate coil is usually spaced ¼ inch from the grid coil but this is not essential as long as sufficient coupling exists between the two coils. More plate turns will be needed if the separation is greater than ¼ inch and less turns if the two coils are nearer than this.

Ordinary 4 and 5-prong sockets are used for mounting these coils and connections from these sockets to the detector circuit and associated apparatus are shown in Figs. 14(b) and 15(b).

There are a number of ways to wind and arrange these coils but the two methods shown are considered standard. As long as the coils are wound correctly and the terminals of the mounting socket are wired correctly to the detector circuit, any method may be used. It would be impossible to show all possible correct methods here.

In Figs. 14(b) and 15(b), C_1 is the grid circuit tuning condenser and C_2 is the regeneration control condenser. The

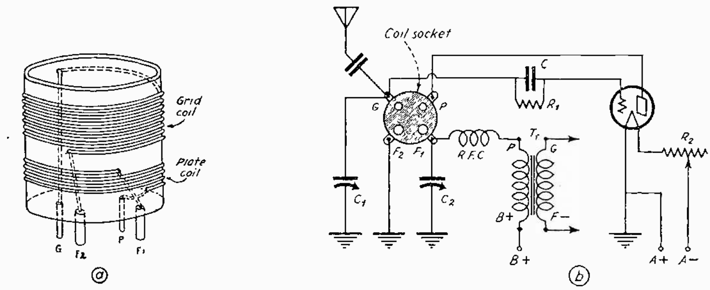


Fig. 15

capacity type of throttle is shown only for simplicity; any method of throttle control previously described may be used. The rest of the circuit components will be readily identified.

SHORT WAVE TRANSMITTERS

No attempt will be made here to explain the theory of short wave transmission but several simple and practical circuits are given as suggestions for the amateur or experimenter who wants to build one.

A simple oscillator coupled to an antenna and arranged in some way so that its R. F. power can be cut off and on by means of a key is a transmitter. Although there are numerous types of oscillators used in various phases of radio reception, none of these oscillators have properties suitable for transmission. And although there are quite a number of types of vacuum tube oscillators which can be used for transmission, only a few of these types have been used extensively.

At the present time the three circuits which have met
8 universal favor both in amateur and commercial radio transmitters are the tuned-plate tuned-grid circuit, the tuned-plate untuned-grid circuit and the Hartley circuit.

Now refer to Fig. 16. Here we have a tuned-plate tuned-grid circuit which is simply an oscillator coupled to an antenna and operated as a complete transmitter.

Oscillation of this circuit results from tube capacity feedback and the frequency of oscillation is determined by both tuned circuits, L_1C_1 and L_2C_2. If the frequency to which the former is tuned differs widely from that to which the latter is tuned, no oscillation can take place. For best results, quite naturally we must obtain as high a grid excitation as possi-

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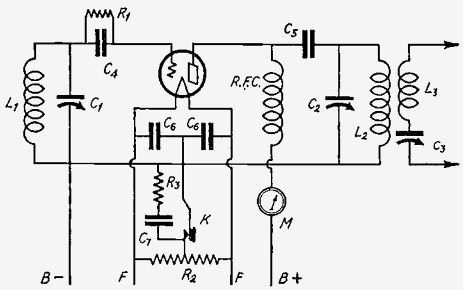

Fig. 16

ble and as much oscillatory current in the circuit C_2L_2 as possible. This is obtained by using a high value of inductance for L_1, a low value of capacity for C_1, a high value of capacity for C_2 and a low value of inductance for L_2. This is called a high-C circuit because C_2 must be as high as possible. We will leave a discussion of the antenna circuit for later.

C_4 is the grid condenser, C_5 is known as the plate blocking condenser, condensers C_6 are the filament by-pass condensers and C_7 is known as the key impact condenser R_1 is the grid leak resistor, R_2 the filament center tap resistor, and R_3 the key impact resistor.

This is called a shunt-fed circuit because the direct current from the plate supply does not flow directly through coil L_2 but through the radio frequency choke R. F. C. The oscillatory circuit is in shunt with the plate circuit.

In Fig. 17, we have a series-fed, tuned-plate tuned-grid circuit wherein the oscillatory circuit is in series with the plate circuit and here coil L_2 carries the direct current of the plate circuit in addition to high frequency alternating current.

With the correct voltage for the A. C. filament supply, this transmitter may be operated with the following tubes: '01A, '71A, '45, '10, '50 and '11. The last tube mentioned is a 50 watt

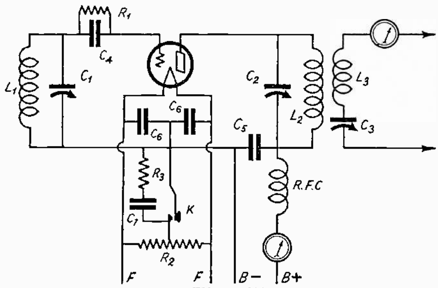

Fig. 17

tube and it is not recommended that a self-excited transmitter, as this one is called, be used with a power in excess of 50 watts. The amount of power to be obtained from these tubes in this circuit is approximately as follows: '01A, '12A, '71A from ¼ to ½ watt; '45, 3 to 4 watts; '10, 7½ to 10 watts; '50, 25 to 30 watts; '11, 50 to 60 watts.

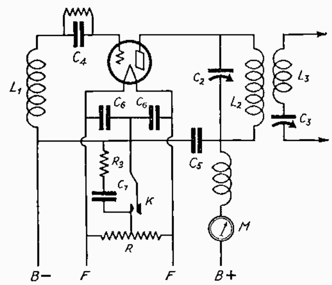

Fig 18

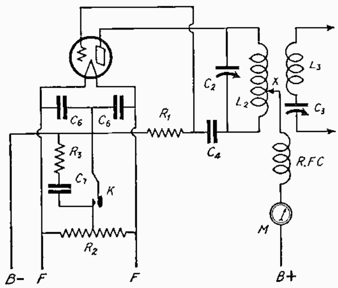

Fig. 19*

Maximum plate and filament voltages are recommended although it is sometimes possible to impress plate voltages 20 to 50 per cent higher than normal on transmitting oscillator tubes.

The tuned-plate untuned-grid circuit, often called the TNT circuit, is shown in Fig. 18. Notice that the only difference between this circuit and the series-fed tuned-plate tuned-grid circuit is that condenser C_1 is missing.

*A by-pass condenser should be placed between point X and the connection between the two condensers C_6.

This circuit has just been developed recently and its success is based entirely on the fact that the coil L_1 is a complete parallel resonant circuit in itself. The distributed capacity between the turns tunes with the inductance value to the frequency desired. Of course, great care must be employed in making this coil. In this way, maximum grid excitation voltage is obtained with minimum feed-back, making the circuit as highly efficient as possible. The same data regarding tubes and parts applies to this circuit with the exception of C_1 which is not used.

Notice that in a shunt-fed circuit such as Fig. 16, C_5 is the plate blocking condenser, and that in a series-fed circuit such as we have just discussed, C_5 becomes the R. F. by-pass condenser placed as shown in Fig. 18. It has the same value in each case (.002 mfd.).

Series and shunt-fed Hartley circuits are shown in Figs. 19 and 20.

In the Hartley circuit, oscillation depends on the voltage set up in the lower section of coil L_2 below the clip X. With the shunt-fed arrangement we have the plate blocking condenser C_5 and with the series-fed arrangement this condenser is not necessary.

The same constants apply to these transmitters as to the ones just described. The filament and keying systems, you will notice, are identical.

A complete parts list giving the transmitter constant follows:

Oscillator Tube	Plate Voltage	Power Supply	Rect. Tubes	Plate Meter D. C. ma.
'01A	200	Battery or B Elim.	'80	0- 25
'12A	200	Battery or B Elim.	'80	0- 25
'71A	200	Battery or B Elim.	'80	0- 25
'45	300	B Eliminator	'80	- 50
'10	550	Power Pack	2-'81's	-100
'50	750	Power Pack	2-'81's	0-100

NOTE: C_1, C_2, C_3, L_1, L_2 and L_3 depend on the operating wavelength desired.

C_4—.00025 mfd.
C_5—.002 mfd.
C_6—.001 mfd.
C_7—.5 mfd.
R_1—10,000 ohms.

R_2—40 ohms (total).
R_3—400 ohms.
R. F. C.—150 turns No. 28 wire D. C. C. wound on ¾ in. form.

There are three ways commonly used to provide a filament center tap. These are shown in Fig. 21 (a), (b) and (c). In (a) a resistor is employed as indicated in all the transmitter diagrams. In (b) the center tap lead is taken directly to the center tap on the transformer winding. In (c) two carbon filament lamps of low wattage are used to obtain a center tap.

ADJUSTMENT AND OPERATION

The tuned-plate tuned-grid circuit is probably the most difficult to adjust for transmission. In this respect the shunt and series transmitters are alike.

With reference to Fig. 22, turn on the filament and plate supply and press the key while varying capacity C_2. Carefully notice the reading of meter M and if its reading varies while changing the capacity C_2 it is an indication that the tube is oscillating. Set the condenser C on the proper wavelength setting of the wavemeter W. Coil L, of course, is coupled to

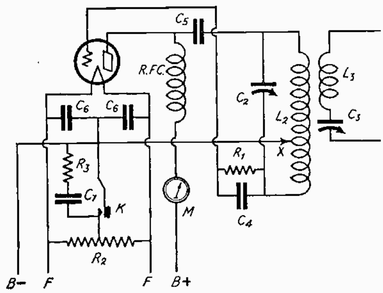

Fig. 20

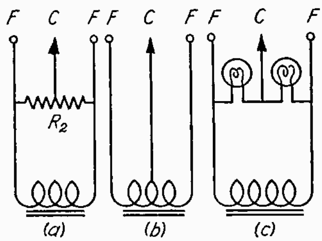

Fig. 21

coil L_2 so that transfer of energy can take place from the latter to the former.

The wavemeter should be placed at the plate end of the coil L_2 as indicated in the diagram and coupled at least three or four inches from the coil L_2. Adjust the values of C_1 and C_2 until the flashlight lamp B lights the brightest. At this setting of C_1 and C_2 the meter M should read about half normal plate current flow and it should read as low a minimum as possible with correct plate voltage. Now connect the antenna and adjust capacity C_3 until ammeter A reads maximum. This will make meter M read a greater value which is desirable. Readjustment of C_2 and in turn C_1 will have to be made because the antenna circuit will have thrown the transmitter off frequency.

If the needle of the meter M suddenly jumps to a high value or if the lamp B on the wavemeter goes out, coil L_3 is coupled too close to L_2 and coupling should be reduced. Coil L_3 should be spaced 3 or 4 inches from the plate end of the oscillator coil L_2.

Adjustment of the TNT circuit, as in Fig. 18, is much simpler because there is no capacity C_1. The same instructions can be used in adjusting this circuit.

Remember that when the meter M reads its lowest value, the oscillator is functioning most easily and the greatest amount of power can be drawn from it. When the antenna is coupled to the oscillator the meter M should read as high as it is possible to make it read.

In the adjustment of the Hartley circuit, the same wavemeter may be used. With reference to Fig. 19, capacity C_2 should be adjusted for maximum brilliancy of the wavemeter lamp and minimum reading of the meter M. The wavemeter, of course, is drawing some power from the transmitter which

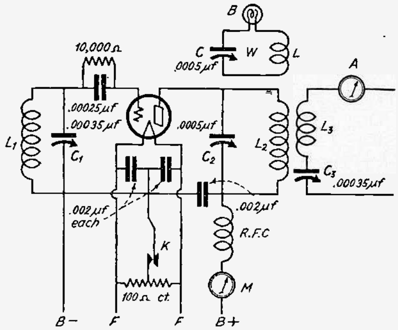

Fig. 22

will tend to make the meter M read slightly lower, just as the antenna will. The wavemeter should, therefore, be coupled sufficiently loose so that the light in the wavemeter lamp is just visible.

The clip making the tap on the coil at X should be moved as close to the grid end or as far down the coil L_2 as possible for highest circuit efficiency. Move this clip down the coil one turn at a time until the oscillator will not function and then move it back one turn. The clip can be brought closer to the grid end of the coil by sliding it around one turn on the coil towards the grid end.

As usual, when the antenna is coupled to this circuit and tuned to resonance, the reading of meter M will increase and power will be radiated. Readjustment of C_2 will again be necessary so that the oscillator will be functioning at the right frequency.

TEST QUESTIONS

Be sure to number your Answer Sheet No. 32FR-1.
Place your Student Number on Every Answer Sheet.

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson.

In that way we will be able to work together much more closely, you'll get more out of your course, and better lesson service.

1. What are the advantages of short wave communications?

2. Is there any difference between regeneration and oscillation in a receiving detector?

3. Draw a diagram of a short wave regenerative detector circuit using a good method of throttle control.

4. At what frequencies must the detector circuit be made capable of oscillating in short wave work?

5. What would you say was the two most desirable methods for shifting from one band to another in the same circuit of a short wave receiver at the same time covering a wide frequency range?

6. Draw a diagram showing how you would couple a radio frequency stage to a short wave detector circuit.

7. Explain what is meant by a "dead spot" on a tuning dial of a short wave detector circuit, and how this condition can be avoided.

8. Name three types of vacuum tube oscillator circuits used at the present time for both amateur and commercial Radio transmitters.

9. Draw a diagram of a Hartley transmitting circuit.

10. What instrument would you use for adjusting the wavelength or frequency of a transmitter circuit?

TRANSMITTING ANTENNAS AND THEIR RADIATION CHARACTERISTICS

33FR-1

PIONEER HOME STUDY RADIO SCHOOL

NRI

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

BE CHEERFUL ALWAYS

Can you lose at sports or games, or make some little mistake in repairing a set that makes it necessary for you to put extra time on the job, and yet be cheerful?

Can you stand just criticism without resentment?

Are you cheerful no matter what the state of the weather?

Are you as cheerful at 6 o'clock in the evening as in the morning?

If you can answer "yes" to these questions you are indeed fortunate, for you have the habit of cheerfulness. You find it easy to make and keep friends. And everyone you talk to during the day feels better—more cheerful, for having come within the range of your influence.

On the other hand, if you must in honesty to yourself, answer "no" to any of these questions, now is the time to begin to develop the habit of cheerfulness. Make up your mind that you are not going to allow anything to get under your skin and that you are going to try to appear cheerful all the time, no matter how you feel.

It may be hard at the start—some of your attempts at appearing cheerful may be rather painful, but don't give up. Each day it will be easier to appear cheerful and if you keep on trying long enough and hard enough, you will find that it isn't so hard after all. And then the great time will come when you won't have to force yourself to be cheerful—you will have learned the habit of cheerfulness.

You will begin to radiate good cheer instead of gloom. Your friends will find an increased pleasure in your company. The place you work will be brighter for your presence. And you yourself will be happier.

It's worth the effort, isn't it?

J. E. SMITH.

NATIONAL RADIO INSTITUTE

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Transmitting Antennas and Their Radiation Characteristics

THE TRANSMITTING ANTENNA

The antenna is the direct means of contact between transmitting and receiving stations, through that intangible medium, which we call ether, that pervades all space. The transmitting antenna excites the medium on the one hand, and the receiving antenna on the other hand absorbs energy from it. The whole art of radiotelegraphy and radiotelephony is founded upon the skillful application of energy to this "link" provided by nature. A knowledge of the properties and characteristics of various types of antennas is consequently of great importance in the study of radio communication.

1 It may be said in general, that for a given frequency the effectiveness of a transmitting antenna depends on two factors, the height of the antenna, and the amount of current which flows in the antenna. As the frequency is fixed for any given station, the quantity "height x current" in meters and amperes, is a direct measure of the effectiveness of the transmitting antenna. Under normal circumstances, the greater the "meter-amperes" the more favorable are the transmitting conditions. More will be said later as to the significance and method of measurement of the "meter-amperes" of an antenna.

The amount of energy picked up at the receiving station is also dependent on the height of the receiving antenna and the frequency of transmission. The higher the antenna and the higher the frequency of transmission, the greater will be the amount of energy picked up. On the other hand, the picked up energy decreases as the distance between the transmitter and receiver increases, and in the same way the greater the resistance of the receiving antenna, the less energy will be picked up.

2 The practical measure of received signal strength is the "microvolt per meter." The microvolts per meter of a certain antenna $(\frac{mv}{m})$ are obtained by dividing the voltage induced in the receiving antenna by the antenna height in meters. Thus an antenna 15 meters high, approximately 45 ft., picking up 150 microvolts of energy, will be in a field having a useful signal strength of 10 microvolts per meter. From what has been said it will be clear that increasing the height of the

antenna will result in greater pickup. If the antenna resistance is reduced to a minimum the losses will be at a minimum and maximum signal will be available.

Antenna systems have been constructed in a great variety of forms. Essentially, however, they consist of a system of elevated wires and a ground system which may be a single wire or a network of ground wires.

A number of antenna types in common use are illustrated schematically in Fig. 1. It should be understood that although only single wire elements are shown, each line may consist of of a group of wires arranged symmetrically on a spreader, or in cage form, without changing the type of the system indicated.

The L type and the T type are in general use at both marine and land stations. The umbrella type requires much land and its use is ordinarily confined to large shore stations. The single wire vertical antenna is an effective radiator in all horizontal directions, and is very satisfactory for broadcast purposes. Transmitting loop antennas are commonly used in those services that require a certain degree of directive transmission, such as the radiobeacon service. They are also well adapted to submarine use. The marine loop is effective both for transmission and reception. A considerable effectiveness of reception is possible with the loop entirely submerged.

Later in this lesson we shall give some of these types of antennas more detailed consideration. However, before we can consider the characteristics of these antennas, we shall have to know more about electric and magnetic fields, as well as induction and radiation fields.

THE ELECTRIC AND MAGNETIC FIELDS

Properties of electric and magnetic fields are closely associated with the phenomenon of radiation from an antenna. An electric field consisting of electrostatic lines of force between a pair of metal plates is represented in Fig. 2(a). If the medium between the plates is air, the lines represent an electrical stress through the air.

This stress, or as we commonly refer to it, the number of electrostatic lines of force, will increase as the voltage applied to the plates is increased. It will decrease as the distance between the plates is increased—assuming a fixed applied voltage.

Now if our two plates were spaced quite far apart and a comparatively high voltage were applied to them, but not high enough to cause the dielectric to break down, a portion of the electric field would spread out beyond the area bounded by the plates. This portion is called the "leakage" field. It becomes greater as the distance between the plates is increased.

In connection with what has just been said and all throughout our study of antenna radiation, it must be borne in mind that the electric field is definitely associated with voltage—and as we shall soon see, the magnetic field is definitely associated with current.

If the plates in Fig. 2(a) were disconnected from their voltage source, and shorted by means of a wire across the two plates, a momentary current would flow through the short-

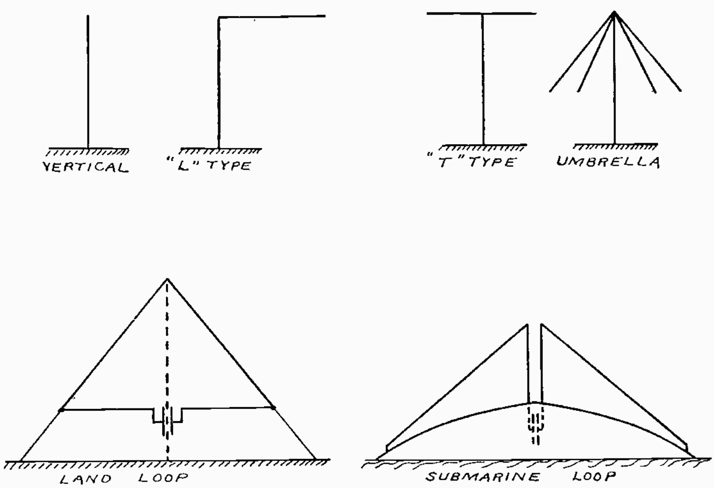

Fig. 1.—Schematic Diagram of Transmitting Antenna Types.

ing wire. This current would set up a momentary magnetic field around the wire as indicated in Fig. 2(b). Thus the energy in the electric field associated with the plates would be converted into an equivalent magnetic field associated with the wire. The intensity of the magnetic field is directly proportional to the current flow—when the current decreases, the magnetic field decreases.

A magnetic field is said to be concentrated when confined to a coil as shown in Fig. 2(c). The mmf. of the field in this case is proportional to the number of turns and to the current. The field being in air, the field intensity is measured in terms of "ampere-turns" of the coil. When the field is unconfined as in Fig. 2(b), it extends a great distance from the wire. When the current flowing in the wire is interrupted, the magnetic field immediately collapses. And just as the collapse of an electrostatic field caused by shorting two charged plates resulted in the formation of a magnetic field, so too the collapse of a magnetic field results in a momentary electric field.

From this we can see that the electric and magnetic fields are very closely associated. One type of field in motion sets up a field of the opposite type. When a simple antenna, such as that shown in Fig. 2(d), is energized from a source of high frequency current, a magnetic field will be established during the alternations of current, and an electric field during the intervals that the current passes through zero. Thus the energy of the antenna alternates between magnetic and electrostatic energy at twice the frequency fed to it.

Only part of the antenna energy is radiated, that part which corresponds roughly to the leakage field mentioned above. The rest of the energy is confined to the antenna system and may be considered as the local field. The higher the frequency of transmission the greater will be the proportion of energy in the radiation field.

THEORY OF RADIATION

The radiation field constitutes the signalling portion of the energy supplied to the antenna. The local, or more properly called, the *induction* field, remains quite close to the antenna system, and both the electric and magnetic fields constituting it expand from and collapse on the antenna. The radiation field on the other hand, which also consists of an electric and a magnetic component, once separated from the antenna, never returns to it, but moves on through space at the speed of light—300,000,000 meters per second. The two components of the radiation field are at right angles to each other and to the direction of motion as shown in Fig. 2(d).

The intensity of the radiation field decreases with the distance from the transmitting antenna. The induction field on the other hand is extremely intense near the antenna but negligible at any distance away from it. The intensity of these fields is measured in terms of meter-amperes. The two fields are of equal strength at a distance of approximately 1/6 of a wavelength from the antenna.

The meter-ampere rating of an antenna is the product of the current in the antenna in amperes at the point of maximum current and the effective height of the antenna in meters. It should be remembered that the effective height of an antenna is not the actual physical height. This is always less than the actual height and must be calculated, taking into consideration the current and voltage distribution in the vertical portion of the antenna system.

Imagine an antenna consisting of a single vertical wire. Let us say a signal current is fed into it from the ground end. As the current flows up, it will decrease in value. That is, the current falls off from a maximum at the ground end to a mini-

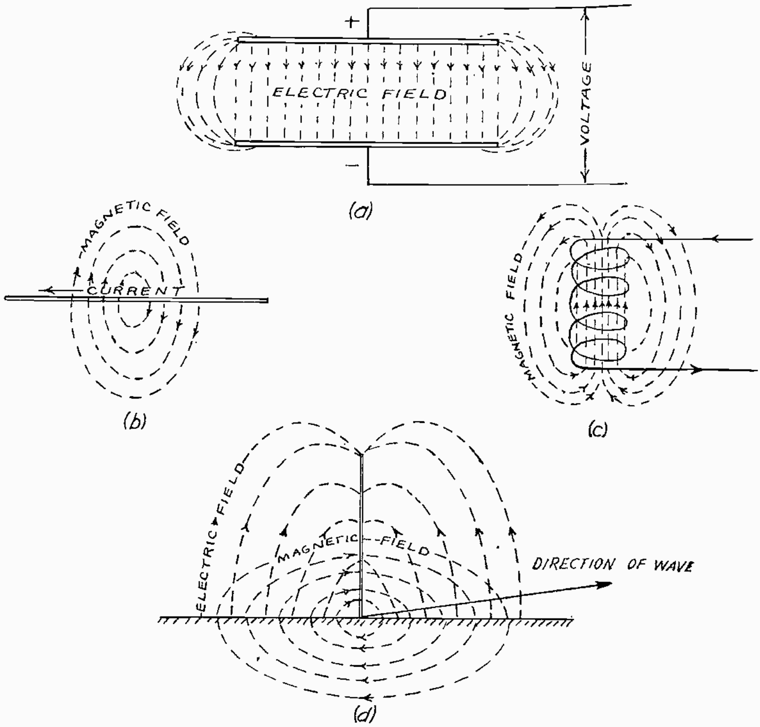

Fig. 2.

mum at the top in a sine wave manner, as illustrated in Fig. (3a). The average value of the antenna current divided by the current at the base gives us a factor which we use in determining the effective height of the antenna system.

The effective height varies widely with various kinds of antennas. A large, horizontal portion tends to make the current in the vertical portion more uniform, thus increasing the effective height of the antenna.

The actual distribution of current and voltage also varies in the different types of antennas. Figure 3 illustrates the current and voltage distribution for the T type, the L type (Marconi or grounded types), and the doublet or half-wave types (Hertzian). The currents in the top halves of the T type antenna flow in opposite directions, their fields cancel and there is no radiation of energy from the top. On the other hand, the top of the L type contributes slightly to the radiated field as indicated by the dotted extension above the horizontal portion in the drawing. The half-wave, or doublet antenna, has about double the radiation efficiency of the quarter wave (Marconi type) antenna, illustrated in Figs. 3(a), 3(b) and

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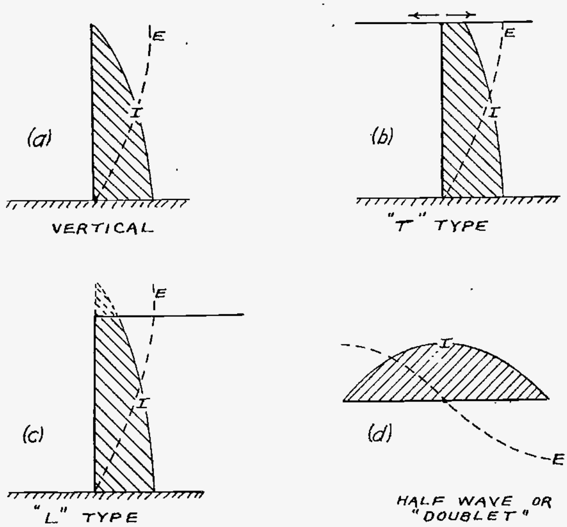


Fig. 3.—Current and Voltage Distributions of Various Antenna Types.

3(c). The doublet antenna, about which we shall learn more later, is adaptable only for use at short wavelengths due to physical limitations, for the characteristic of the doublet antenna requires that it be actually ½ wavelength long.

GROUND AND COUNTERPOISE SYSTEMS

Antennas of the quarter wave type, having an effective length equal to ¼ wavelength, more commonly referred to as Marconi type antennas, require a direct connection to an earth network, or a ground system. Nearly all long wave stations operating at high power, over great distances, as well as broadcasting stations, use antennas of this type. The efficiency of

5 an antenna system of the long wave type, depends to a very large degree upon the effectiveness of its ground system.

There are three general types of ground systems—the single wire buried in the ground, the star arrangement of wires buried in the ground, and the counterpoise. Each of these systems will be considered separately in the order named.

Extensive tests on buried ground wires at various frequencies have indicated that the useful length depends upon

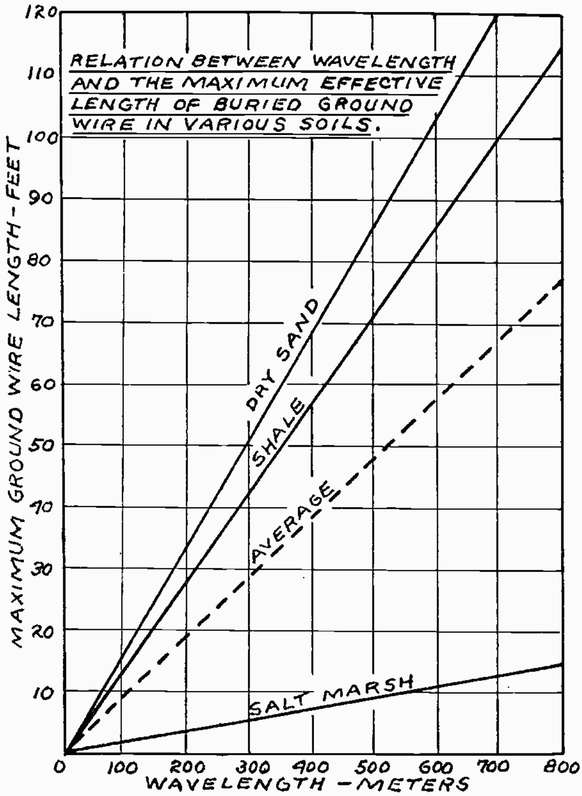


Fig. 4.

the nature of the soil and the frequency of the current. The effect of high conductivity soil is to slow down the rate of current travel, making only a short length of the wire effective. Beyond a critical length, the wire presents a reactance, and the current seeks the easier path through the soil to the antenna.

It should be noted here that soft marsh land is most conductive and loose sandy earth is least conductive. A soil having low conductivity has less slowing up effect on current and consequently permits the use of a longer ground wire.

The relation between wavelength and the maximum effective length of a ground wire, as determined by extensive tests in various soils, is shown in Fig. 4. From this it can be seen that nothing can be gained by using a ground wire longer than 5 per cent of a wavelength in low conductivity soil, and in highly conductive soil the effective length of the ground wire is approximately 1 per cent of a wavelength.

In the case of a ground system of the star type illustrated in Fig. 4(a), an increase in the number of radials is more effective in reducing the resistance of the system than an increase in the length of each radial. Increasing the length beyond the critical value will actually result in increased resistance.

Some long wave stations use several star grounds of relatively short radial lengths connected in parallel by means of wires supported above the ground. Another method that is often used to reduce the ground resistance is the multiple tuning of a large antenna. Here there is a ground system for each tuned path so that the single ground resistance is divided up into many smaller resistances.

A counterpoise system is a group of wires slightly elevated above and insulated from the ground to form the lower system of conductors of a quarter wave antenna. Since the wires are elevated, the speed of current flow in them will be higher than in buried wires, making the use of long counterpoise wires practicable with consequent greater antenna efficiency.

The current distribution in the wires should be as nearly uniform as possible. This may be accomplished by arranging the system in the form of an equiradial star or by using equalizing coils (reactances) so placed as to equalize the current distribution. An increase in the number of radials will result in decreased resistance, as in the case of the buried ground wires.

It should be noted here that even in the case of the counterpoise system, there is considerable ground loss due to its proximity to the soil. Even an *antenna* less than two wavelengths in height will be affected by ground losses. In short wave work it is possible to build an antenna at least two wavelengths high so that ground losses in it will be kept down to a minimum, but in the case of broadcast and longer wavelengths, it is obviously impracticable to build even the antenna two wavelengths high so that a counterpoise high enough to be unaffected by ground resistance is entirely out of the question.

From all this it can be seen that while a counterpoise might reduce ground resistance, it by no means eliminates it altogether and in spite of its advantage in this respect, the buried ground system is the more commonly used. It is obvious that a counterpoise consisting of low hanging wires is unsightly, it takes up a great deal of room and makes it difficult to service the antenna.

THE FREE WAVE IN SPACE

The radiation field, which becomes dissociated from a transmitting antenna and shoots out into space at the speed

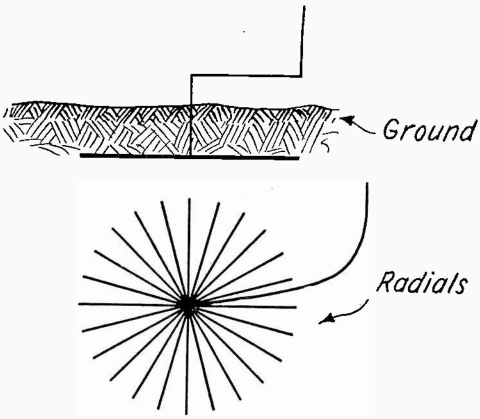


Fig. 4(a).

of light, consists of electromagnetic waves which alternate at the frequency of transmission. In other words, there are two motions involved, the outward motion of the radiation field as a whole, and the alternating motion of the individual free wave which moves to a maximum in one direction, reverses, moves to a maximum in the opposite direction, etc.—always at the frequency of the transmitted signals.

As the radiation field moves away from the antenna, its intensity decreases due to atmospheric absorption and the terrain over which it passes. The frequency of the free waves, however, remains the same always.

It has been mentioned that the terrain over which radio waves pass contributes largely to the attenuation of the radiation field. This is particularly true of long wave reception in which the waves are largely confined to regions close to the earth. Consequently the nature of the surface of the earth over which the waves pass affects the distance over which signalling is possible. Cities, woods, mountains and rivers, all absorb some of the radiated energy. The striking difference between signalling distances over land as compared to over water is illustrated in Fig. 5. Notice that a signal which will travel 800 miles over water will travel only 200 miles over land. This explains why marine shore stations are placed as close to the ocean as practicable.

In short wave (high frequency) systems between 12 and 100 meters, the energy is radiated both as ground waves and as sky waves. The attenuation of the ground waves is high and they can be picked up at most only 10 to 20 miles per kilowatt from the antenna. The sky waves on the other hand are radiated at an angle above the ground and take their paths in the rarefied upper atmosphere. Here the attenuation losses are low, making possible large signalling distances.

However, this high angle radiation encounters the ionized layer above the earth known as the "Heaviside layer." This layer is less dense than the atmosphere beneath it so that radio waves will be refracted (bent), when entering the Heaviside layer from the denser atmosphere. This action can very well be compared to the refraction of light as it passes from water to air. Imagine a flashlight held under water. Rays from the light, passing from the water to air will be refracted, and at a certain critical angle, all the rays will be refracted along the surface of the water and will not enter the air.

In the same way, if a radio wave strikes the Heaviside layer at a certain critical angle, the entire wave will be refracted along the plane between the atmosphere and the less dense layer. Likewise, if the radio waves strike at an angle less than this critical angle, usually somewhere between 10 and 45 degrees, depending on the time of year, the time of day, and the wavelength, they will enter the layer. And if the incident angle is greater than the critical angle, the radio waves will be reflected back to the earth again.

Then too, the density of the Heaviside layer is not the same throughout, so that there may be a steady refraction and it can easily be seen that a refracted wave might strike a particularly rarefied portion of the Heaviside layer at such an angle that it will be reflected back to the earth.

For the present, however, let us forget about refraction and consider only reflection as illustrated in Fig. 6. The light portion at the left of the illustration represents the transmitted wave, and the light portion at the right of the picture represents the reflected wave.

From this figure it will be clear that a receiver located somewhere in the dark portion, if out of the range of the

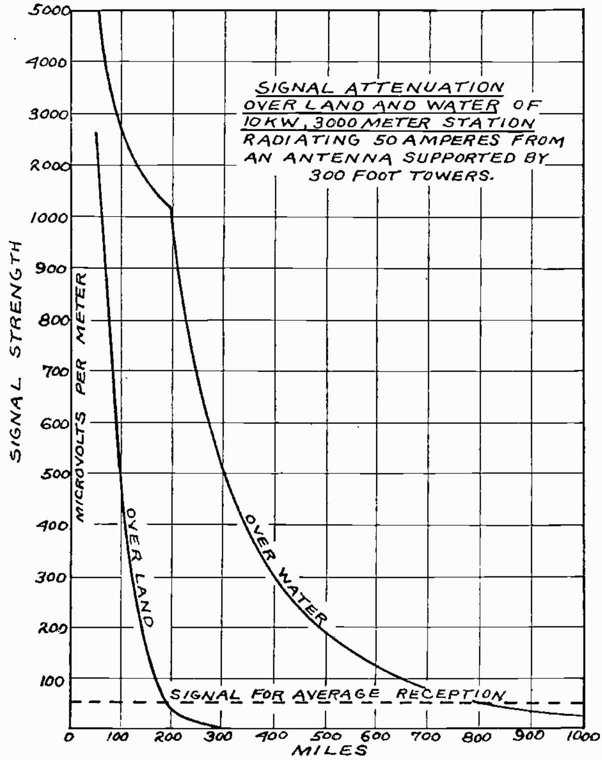


Fig. 5.

ground signal, will not be able to pick up any signals at all. This space is called the "skip distance" for obvious reasons. Thus the fact that a receiver only a few hundred miles away from a short wave transmitter will not be able to pick up signals, while a receiver a thousand miles or more away will be able to, is accounted for.

The height of the Heaviside layer varies between wide limits. In the daytime it may be at a height of 100 miles, while at night-time it may rise to 500 miles or more. Figure 7 illustrates the effect the height of the layer has on reception.

Besides the phenomenon of skip distance, there is another

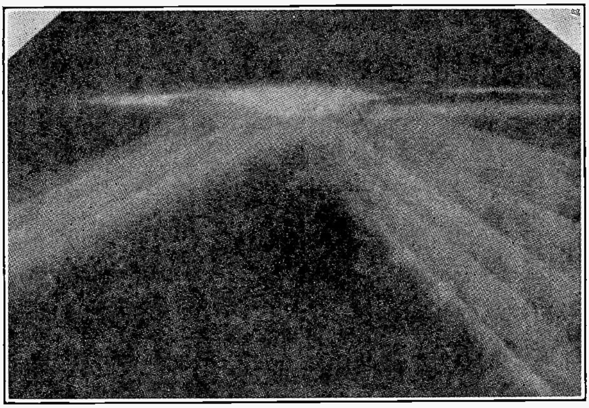


Fig. 6.—Ground Reflected Rays.

effect, also directly traceable to the Heaviside layer, which is particularly noticeable in short wave work and that is fading. It has been mentioned that the height of the layer varies from 500 miles at night-time to 100 miles or so in the daytime. How-

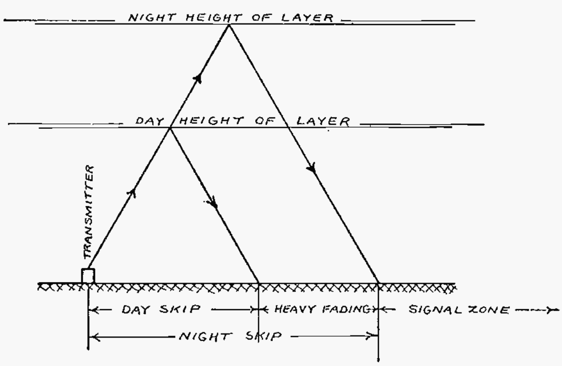


Fig. 7.—Action of the Heaviside Layer in Producing Skip Zones.

ever, the movement of the layer is by no means regular, consequently there will be irregular reflections of the signal from the layer, resulting in unequal signal intensity at the receiver.

Then too, it often happens that the same wave will reach a receiving station over two or more paths. If it takes one wave a trifle longer to get to the receiving antenna, it may be out of phase with the first with the result that the two waves balance and wipe each other out. On the other hand, should they be in phase, the signal heard will be louder than normal.

Fading in the broadcast band is usually the result of interference between the sky waves and the ground waves. While it is true as previously stated that at the longer wavelengths the ground wave is of chief importance, the fact remains that under certain conditions the sky wave will extend as far as the Heaviside layer and be reflected. When the reflected wave reaches the receiving antenna in phase with the ground

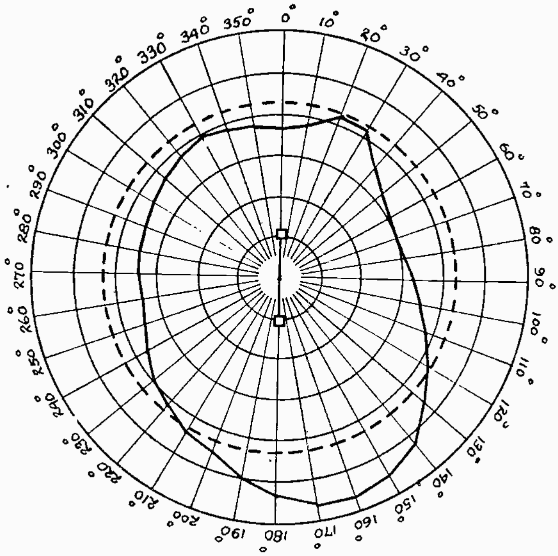


Fig. 8.—Actual and Ideal Field Patterns of a Broadcasting Station.
————Actual ----------Ideal.

wave, the one will reinforce the other and the signals picked up will appear extremely strong. On the other hand, if they are out of phase the one will wipe out the other to a greater or less degree, resulting in fading.

DISTRIBUTION OF RADIATED ENERGY

In broadcast transmission an equal radiation of energy in all directions is desirable. In other words, a receiver 100 miles to the east of a transmitter should receive its signals with the same intensity as receivers 100 miles to the north, west or south. This is very seldom the case, however, even though absolutely nondirectional antennas are used, for variations in the terrain surrounding the transmitter result in varying signal attenuations.

If we were to plot the relative intensity of the radiation field at the same distance from the transmitting antenna in all directions, we would obtain what is called the field pattern of the antenna. This is actually done when broadcasting stations are being built to determine to what extent its transmission will be directive. It is to be noted that even such an apparently small factor as re-radiation from the supporting towers of the antenna may result in a considerable directional effect.

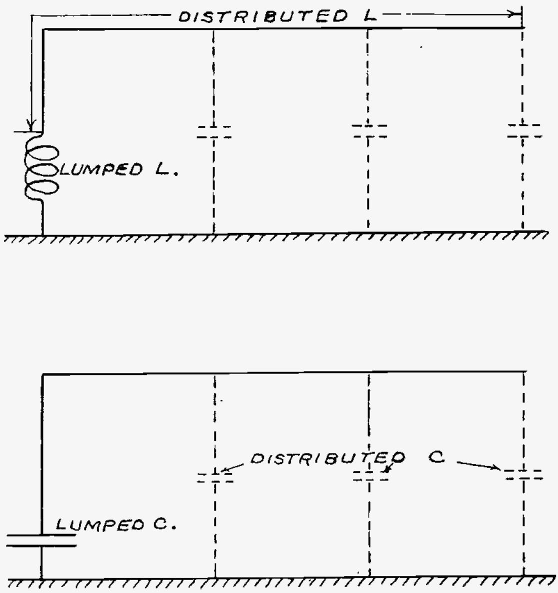


Fig. 9.—"L" Type Antenna Systems Showing Lumped and Distributed Constants.

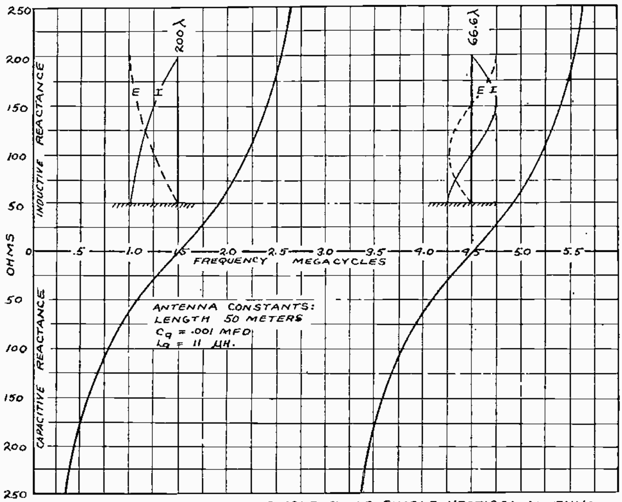
Figure 8 illustrates this very nicely. Notice the difference between the ideal field pattern shown in dotted lines and the actual field pattern.

ANTENNA CONSTANTS

Every antenna has a certain amount of distributed capacity and distributed inductance. We say that these electrical properties are distributed because they are spread out over large distances, and not *lumped* as is the inductance of a coil or the capacity of a condenser.

An antenna system may have both lumped and distributed capacity and inductance—in fact, a quarter wave antenna is possible because a certain amount of lumped inductance can be put into it. The distinction between distributed and lumped constants of an antenna system is illustrated in Fig. 9. Ordinarily, lumped constants are inserted for purposes of tuning the antenna. On the other hand the distributed constants are the natural constants of the system.

When the total capacitive reactance of an antenna is equal to the total inductive reactance at a certain frequency, the antenna is tuned to that frequency and the antenna current is equal to the driving voltage divided by the total antenna resistance.



REACTANCE VARIATION WITH FREQUENCY OF SIMPLE VERTICAL ANTENNA SHOWING MODES OF OPERATION.

Fig. 10.

The reactance variation of a simple 50 meter long vertical antenna at various frequencies is indicated in Fig. 10. It will be noted that at low frequencies the reactance is capactive and that above a frequency of 1.5 megacycles the reactance is inductive. Exactly at 1.5 megacycles the reactance is zero. In other words, the antenna is tuned to 1.5 megacycles (200 meters). If the antenna is operated at 1.5 megacycles we say that it is operated as a quarter wave antenna.

Note that this same antenna will also resonate to 4.5 megacycles, in which case the antenna acts as a three-quarter wave antenna, or third harmonic antenna. In the same way the antenna would resonate to the 5th, 7th, 9th—any odd harmonic. Any grounded antenna system may be tuned to its fundamental, or to any odd harmonic mode of operation.

Having considered inductance and capacity, there still remains the antenna resistance to be considered. The total antenna resistance is made up of three major parts: Wire and ground resistance, radiation resistance, and dielectric absorption, which in effect is equivalent to a resistance.

The wire resistance increases with frequency and the ground losses usually decrease with an increase of frequency. Thus this component of the total resistance tends to remain

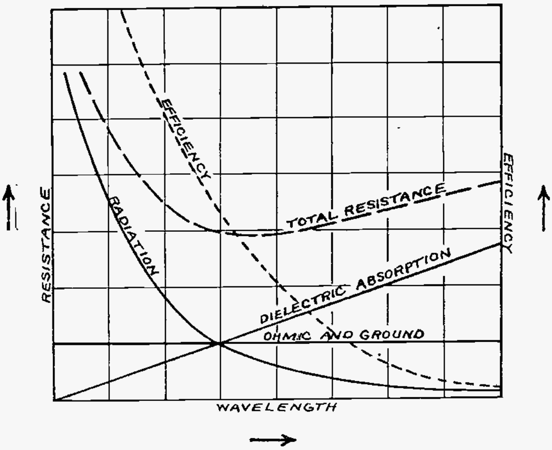


Fig. 11.—Composition of the Total Antenna Resistance at Various Wavelengths and Relative Efficiency.

constant throughout the wave band as shown in Fig. 11. Dielectric absorption due to trees, houses and other obstructions in the electric field of the antenna, increases directly with wavelength due to the decrease of voltage with wavelength. The radiation resistance* of the antenna increases inversely as the square of the wavelength—it is high at short wavelengths. Ordinarily, the largest losses are the ground and dielectric losses.

3

Now consider the "total resistance" curve in Fig. 11. There is a point of minimum total resistance which one would think would be the point of most efficient operation. However, this is not the case. It must be remembered that what we are chiefly interested in is radiation efficiency. Therefore, the

*The antenna radiation resistance is an apparent resistance equal to the ratio of the total power radiated by an antenna to the square of the current (r, m, s) measured in the antenna at the point of maximum current.

efficiency of an antenna is measured in terms of the ratio between radiation resistance and total resistance:

$$\textit{Percentage of efficiency} = \frac{\textit{radiation resistance}}{\textit{total resistance}} X\ 100$$

The relative efficiency of the antenna whose resistance components are shown in Fig. 11, as indicated by the dotted curve. Notice that the antenna is much more efficient at low wavelengths than at high wavelengths.

Where it is desired to calculate the efficiency of an antenna in terms of power, that is, power in the antenna and power radiated, we use the formula:

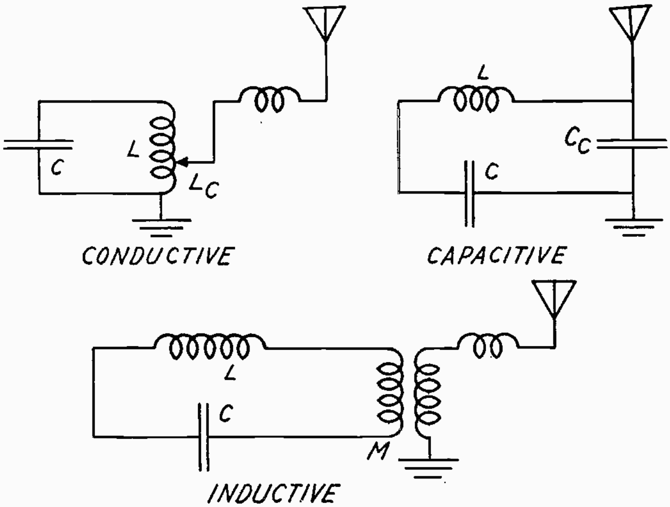


Fig. 12.—Types of Couplings.

$$P\ \textit{efficiency} = \frac{I^2R_r}{I^2R_t} X\ 100$$

where I is the current in amperes.
R_r is the radiation resistance in ohms.
R_t is the total resistance in ohms.

INDIRECT ANTENNA COUPLING

As you are already familiar with the various types of direct coupling between the transmitter and the antenna, which as you know, may be conductive, inductive or capacitive (see Fig. 12), these need not be explained here in detail. In this chapter we shall consider indirect coupling of the type that is used where the antenna and transmitter are widely separated, the connecting link being a transmission line. This is necessary where a directive antenna system is used or where the transmitter is one of high power, possibly above 5,000 watts, to avoid the necessity of shielding the transmitter against the strong fields of the antenna which would result in considerable feed-back, were the antenna close to the transmitter and if the latter were unshielded.

Transmission lines connecting the transmitter to the antenna, which serve to convey the energy from the transmitter to the antenna, are of two general types—the double wire type and the single wire type. Double wire transmission lines consist essentially of two parallel feed wires equally distant from the ground and ranging in length up to 1,000 feet or more. Here, the wires cannot be considered, as in the case of D.C. and low frequency A.C., as two simple conductors having only resistance. There is distributed capacity between the wires themselves and between the wires and ground. The wires also have distributed inductance. These electrical constants of a transmission line give it a characteristic impedance which is ordinarily referred to as the "surge" impedance of the line.

In order that transmission loss may be kept at a minimum, it is essential that the antenna resistance be matched to the surge impedance of the line, and that the resistance at the source be made to match the surge impedance of the line. This may be accomplished by using R. F. coupling coils at both the transmitter and antenna ends of the line, in much the same way as a loudspeaker is matched to a power tube.

Of course it is also essential that radiation from the transmission line be kept at a minimum. In a double transmission line this is not difficult as the fields about the two wires cancel each other.

The single wire transmission line may be considered as a double wire line in which the ground is the return conductor. A system of this kind is much more likely to radiate energy than the two wire system.

A typical arrangement of an antenna system energized by a two wire transmission line is shown in Fig. 13. The counterweight at the bottom of the vertical portion of the line is merely for the purpose of taking up any sag in the aerial which may appear with varying weather conditions. In this case the antenna is of the doublet or Hertzian type, the impedance of which is matched to the impedance of the transmission line by the proper spacing of the feeder wires where they connect to the horizontal portion of the antenna, the horizontal portion between the feeders acting as a high impedance. In an antenna system of this type it is unnecessary to use R. F. coupling coils for impedance matching purposes.

THE HERTZIAN ANTENNA

The name "Hertzian" is applied to all types of antennas that function without a ground connection. The antennas of the type we have been considering that require a ground connection are called "Marconi" antennas.

There are several features in the construction and operation of each type of antenna which enable us to distinguish between them definitely. These features are:

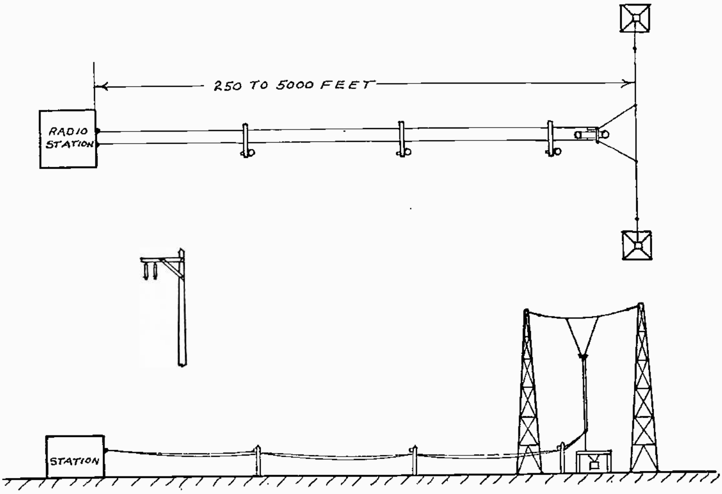


Fig. 13.—Typical Arrangement of Radio Station With Antenna Energized by a Transmission Line.

1. The Marconi type of antenna makes use of a ground or counterpoise system and the Hertzian types have neither.

2. The length and shape of the Marconi antennas are not necessarily determined by the frequency of transmission, but the length and shape of the Hertzian antennas are definitely fixed by the frequency (or wavelength).

3. The elevation of the Marconi antenna controls its electrical constants, but the elevation of the Hertzian antenna does not in general affect its electrical constants.

4. The radiating system of the Marconi antenna includes the entire antenna circuit but the Hertzian radiating system is a separate unit usually fed with a transmission line.

5. The Hertzian antenna supports a "standing wave," but the Marconi antenna does not.

6. In general the Marconi antenna is adaptable to long wave transmission whereas the Hertzian types are practical only for short waves.

This classification includes every type of antenna—under the Marconi classification we have the inverted L, T, fan, cage, umbrella and numerous others, while in the Hertzian classification the commonest are the doublet, the zeppelin, the loop and the beam antennas.

It has been calculated that the velocity of an electric current in a conductor or a system of conductors is approximately 5 per cent less than the velocity of a wave. Thus, while it is customary to consider a Hertzian antenna as being of the same length as the radiated wave, in practice, when an antenna is built, it is made 5 per cent shorter than the wavelength, and a "40 meter antenna" will be only 38 meters long.

Figure 14(a) shows an antenna 38 meters long holding a single *40 meter wave.* Several things are to be noticed in particular: The voltage E and current I are exactly 90° out of phase. The current in the left half of the antenna, which is simply a straight length of wire, is flowing toward the center and that in the right half is flowing toward the center also, showing that they are flowing in the opposite direction at the same instant. During the next half cycle the current in each half flows toward their respective ends and *no current ever flows through the exact center of the antenna.* A very sensitive R.F. ammeter could be placed at (3) and it would never show any deflection regardless of the power fed to the antenna. Since this point is a point in the antenna of no current it is called the "current node" of the antenna. As no current could possibly flow out either end of the antenna, the two ends (1) and (5) are also current nodes. At the ¼ and ¾ lengths, i. e. at points (2) and (4) the R.F. current is always maximum. To distinguish these points from nodes they are called the "current antinodes" (opposed to nodes).

Similarly, no voltage ever exists at points (2) and (4) as long as the antenna is excited with the same frequency (7500 kc. for 40 meters) regardless of the power used. The voltage will be maximum at either end and at the exact center. Therefore points (1), (3), and (5) are called "voltage antinodes" of the antenna and points (2) and (4), "voltage nodes." This current and voltage distribution can easily be proved. An ammeter placed anywhere in the antenna will deflect according to the current at that particular point and can be used to prove the existence of current nodes and antinodes. A neon lamp indicator will glow the brightest at points of highest voltage (voltage antinodes) and will not glow at all at the voltage nodes (2) and (4).*

A little consideration of this antenna, which by the way is a "full wave" Hertzian antenna because it holds one complete "standing wave" will show that the wave radiated by one-half will be out of phase with the wave radiated by the other half, and the two will tend to neutralize or cancel each other. We therefore use only one-half of this full length for

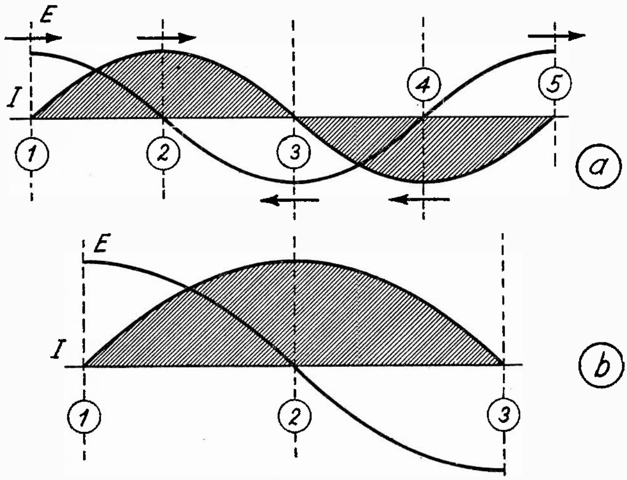


Fig. 14.

transmission. Suppose we cut the antenna in Fig. 14(a) in half, and use only the length between (1) and (3) as in Fig. 14(b). All of the current in this half is flowing in the same direction at any given instant and the magnetic field forming the radiated wave can meet with no interference or cancellation. The antenna thus becomes a half-wave antenna which is the fundamental length of all Hertzian antennas. Thus an antenna 19 meters long (38 ÷ 2) is a fundamental half-wave Hertzian antenna for 40 meters. By cutting the

*Either contact of the neon lamp is simply touched to the wire at various points to check the voltage distribution.

full wave antenna in half we do not affect the wavelength of transmission.

Nineteen meters is equal to 62.3 feet because 1 meter is equal to 3.28 feet ($19 \times 3.28 = 62.3$). Now from the ratio of the antenna length in feet to the wavelength of the transmitter we obtain $62.3 \div 40 = 1.56$ which is a factor that can be used in calculating the length of a Hertzian antenna for any wavelength. Simply multiply the wavelength of the transmitter by 1.56 to obtain the proper length of the antenna in feet. This, of course, will give the length of a fundamental half-wave Hertzian antenna.

FEEDING THE HERTZIAN ANTENNA

The current curve in Fig. 14(b) tells us something definite about the impedance of the antenna at any point throughout its entire length. It shows that since no current flows at either end the impedance of the antenna is infinite at these points. We know that if no current can flow under any conditions that the impedance must be high. In the center, however, the current is very heavy showing that the impedance here is quite low (it happens to be practically zero because the current flow through the center is limited only by the metallic resistance of the wire). Now we have learned something very interesting; namely, that the impedance varies from infinity at either end to zero at the center of the antenna.

Since no current can flow in or out either end (at the frequency of the antenna), it is necessary to feed the antenna with voltage at one end or the other (when fed at both ends it becomes a loop antenna). If a high alternating voltage is impressed on one end of the antenna, current will flow in it as shown in Fig. 15. The feed system in this case is called a voltage feed system and the antenna becomes a "voltage fed" antenna.

Figure 15 shows a two wire transmission line feeding the Hertzian antenna. A transmission line of one type or another is essential because it is impracticable to attach one end of a Hertzian antenna directly to the transmitter coil. You can see that this would be a very awkward arrangement as the Hertzian antenna must be as straight as possible. The transmission line or feed system need not be straight and thus provides a highly efficient coupling between transmitter and antenna.

For maximum efficiency the feeders should measure ¼ wavelength from the antenna to the transmitter. They may also be ¾ wavelength or in fact any odd quarter wavelength in length. The important consideration is that maximum voltage and no current exist at the ends of the feeders. One feeder attaches to the antenna, and the other is open. They are both exactly the same length and are spaced from 8 to 12 inches throughout their length. The open end feeder is for the purpose of carrying equal and opposite current in every portion to that of the attached feeder, thus cancelling its field and preventing feeder radiation entirely. The feeders may be run parallel to the antenna or at any angle desired.

This voltage fed Hertzian antenna was first used on zeppelins because it allowed the antenna to be separated from the body of the ship in addition to requiring no ground connection. Any other type of antenna would constitute a hazard when so closely associated with a large body of inflammable gas. Because of this first use of the antenna it is called the "zeppelin antenna."

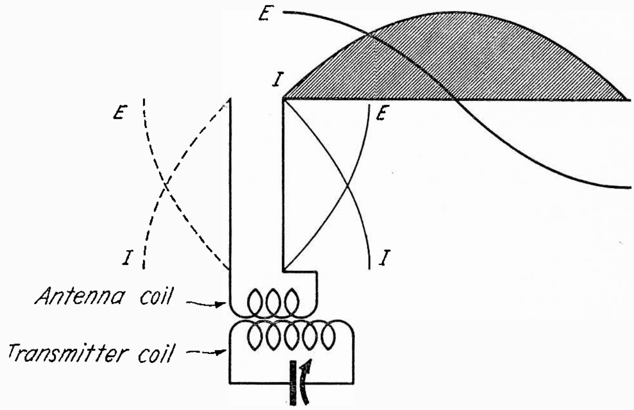


Fig. 15.

Now suppose we feed the antenna at the middle. To do this the antenna must be cut at the exact center and a feeder applied to each half as in Fig. 16. The impedance of the antenna at this point is practically zero and maximum current flows. This antenna is known as a "current fed doublet." The transmission line consisting of two parallel wires making any convenient angle with the antenna, are spaced from 8 to 12 inches and may be 1/2, 2/2, 3/2 or 4/2 wavelengths long.

The Zeppelin type of antenna can be used for harmonic frequencies; for example, an 80 meter antenna can be used for 40 meter transmission in which case it becomes a full wave 2nd harmonic 40 meter antenna. For 20 meters it is a double wave 4th harmonic antenna. However, no Hertzian antenna can be used for a longer wavelength than that for which it is designed.

In addition to these two types of feed we have several types of "power feed" using double or single transmission lines. One type is shown in Fig. 17 where the two feeders diverge and connect to two points on the antenna at some predetermined distance from the center. It looks as though the feeders were simply shorted but they are not because of the impedance of the antenna between the feeder terminals. The feeder wires are accurately spaced equidistant from the center of the antenna so that the terminal impedance at the antenna is equal to the surge impedance of the transmission line.

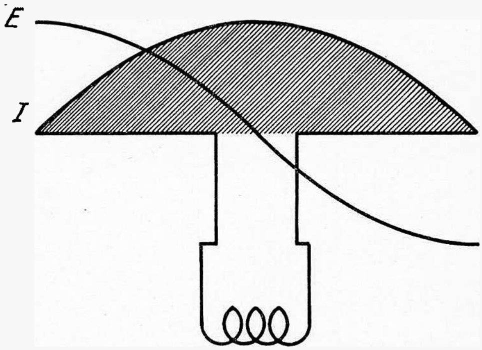


Fig. 16.

9 The single wire type of power feed is used to some extent because of its high efficiency and simplicity. It is connected to the antenna as in Fig. 18 at a point where the antenna impedance is equal to the impedance of the feeder. For an 80 meter half-wave antenna 133 feet long, it would be about 49 feet from one end. The single wire transmission line is untuned, does not support standing waves* at the antenna and is not at all critical in length. To make it work best, lengths equal to the antenna should be avoided to prevent the line from radiating energy.

THE WAVE ANTENNA FOR LONG WAVE RECEPTION

The wave antenna or full-wave antenna came into being with transatlantic commercial long wave service. It was

*Standing waves are waves which have points of maximum and minimum voltage and current that remain fixed in position along the length of a conductor.

found that for the reception of long wave signals an antenna exactly one wavelength long was the most efficient. It can be seen that for long wave commercial work, the antenna would have to be extremely long. For example, if the wavelength is 12,000 meters, which is of the order of wavelengths used for long wave transatlantic commercial service, an antenna 7½ miles long is needed.

In the simplest form, the wave antenna is a single wire antenna, carefully placed in the direction of communication. At the end nearest the distant transmitting station the antenna is connected to ground through a resistor. This resistance is made equal to the characteristic or surge impedance of the antenna and is called the "surge resistor." The receiver is at the other end of the antenna which is grounded in the usual manner. The arrangement is shown schematically in Fig. 19(b).

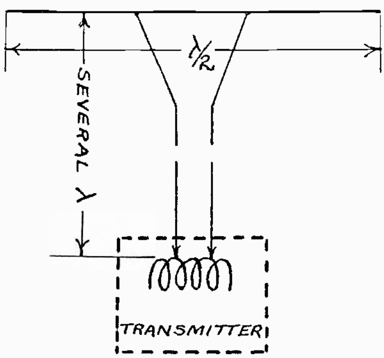


Fig. 17.—Doublet With Voltage Feed.

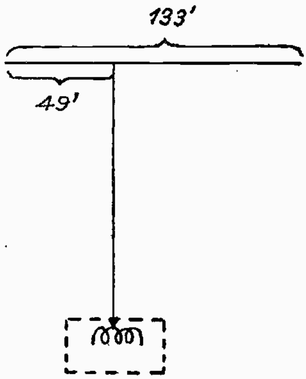


Fig. 18.—Single Wire Feeder.

The explanation of the high efficiency of an antenna of this type is interesting. When a signal wave reaches the antenna it induces a voltage in it at the end away from the receiver. But the signal wave doesn't stop there—it continues to move along the antenna inducing a voltage along its entire length. These various voltages all pile up as illustrated in Figs. 19(b), (c) and (d), until by the time the signal reaches the receiver, the total voltage is quite large.

Now suppose the signal arrived from the opposite direction. Striking the antenna at the receiver, a small voltage will be induced and this small voltage will be built up as the wave passes along the antenna. Thus the voltage will be largest at the end closed by the surge resistor which will completely absorb it, preventing the voltage wave from being reflected back to the receiver. This briefly explains the unidirectional characteristic of an antenna of this type.

In actual practice, however, for transatlantic commercial use, the rear of the antenna is pointed toward the southwest. The result is that the pick-up of atmospheric disturbances which are particularly strong from this direction, especially in the summer, is kept down while the desired signal from the northeast is amplified. Therefore the signal-to-noise ratio is high.

In commercial operation the position of the surge resistor

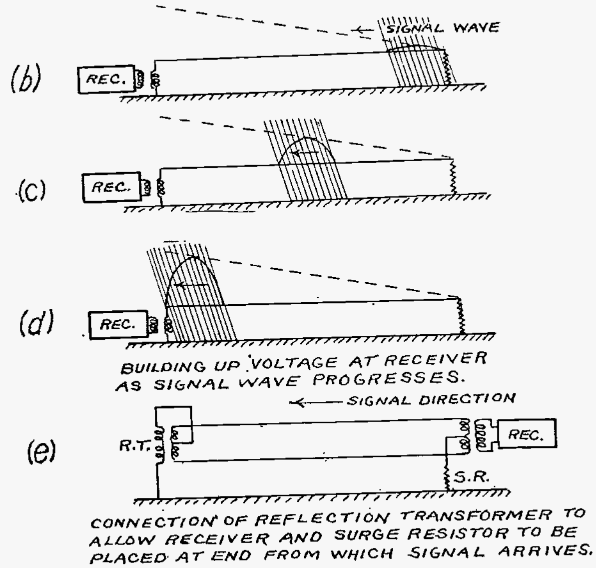


Fig. 19.

at the far end of the antenna is a disadvantage due to its absorption of energy. To overcome this a "reflection" transformer is often placed at the far end of the antenna. In this case a two wire antenna system is used and the surge resistor is placed at the receiving end of the line as shown in Fig. 19(e).

The reflection transformer changes the phase of signals coming from the desired direction and sends them back to the receiver, whereas the undesired signals and noise are balanced out of the receiver and absorbed by the surge resistor. With this type of antenna it is possible to receive as many as six signals simultaneously without interference.

BEAM ANTENNAS

By means of a special type of antenna it has been found possible to concentrate the radiated energy of a transmitter in one direction and greatly reduce the energy in all other directions.

One type of antenna accomplishes this by reflecting the energy radiated by an ordinary vertical antenna (usually of the Hertzian type) in much the same manner as a parabolic silvered reflector reflects light. An ordinary automobile headlight would be practically useless without the parabolic reflector used to concentrate all of the light rays in one direction. The same principles are used for radio waves and the reflector is made with vertical wires in the shape of a parabolic screen with the radiating antenna at its focal point as shown in Fig.

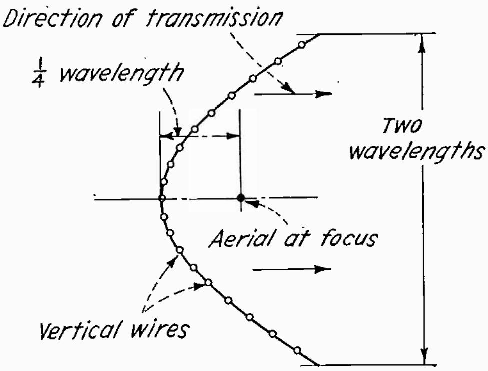


Fig. 20.—View of Parabolic Screen With Radiating Antenna.

20. This type of antenna is adaptable to short waves only, because of the limited size of the reflecting apparatus.

Other types of directional antennas sometimes called beam antennas serve to concentrate the energy of radio waves along a single path. The principles of their operation are based on the phase relations of waves leaving the antenna in various directions. For example, one arrangement sends two waves out in such a way that in one direction they are aiding each other and in the opposite direction they are opposing each other.

Beam radiation increases greatly the effective power in one direction, theoretically allows more stations to operate on the same or adjacent channels without heterodyne interference, and allows for some degree of secrecy of messages because only the stations in line with the beam can receive satisfactory signals.

Up to the present time such antennas are used only for high frequency point to point communication and usually for very long distances using high power. They have been successfully used for ultra short wave broadcasting known as

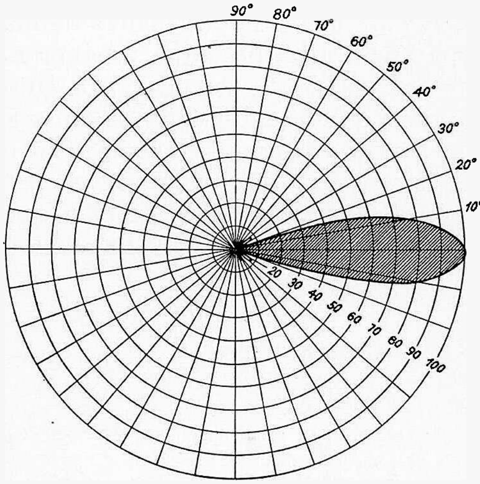


Fig. 21.—Field Patten of Beam Radiation.

"micro-ray" broadcasting for very short distances because ultra short waves are only adaptable to short distances.

The principles can be used for reception as well as transmission enabling the receiving station to concentrate the received energy and thus increase the effective power of the wave at the receiver.

TEST QUESTIONS

Be sure to number your Answer Sheet No. 33FR-1.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson.

In that way, we shall be able to work together much more closely, you'll get more out of your Course, and the best possible lesson service.

1. Upon what two factors does the effectiveness of a transmitting antenna depend?
2. How is the signal strength in microvolts per meter of any receiving antenna found?
3. (a) What 3 major factors make up the total antenna resistance? (b) Which two of these factors are undesirable?
4. Draw a diagram illustrating the current and voltage distributions for a "T" type antenna.
5. Name the three general types of ground systems.
6. What does the Heaviside layer do to radio waves coming in contact with it?
7. Does a Hertzian antenna system require a ground or counterpoise?
8. What is the difference between a Zeppelin and a Doublet antenna?
9. Describe a double wire transmission line and explain why transmission lines are used.
10. State the advantages of beam radiation.

MODERN AUTOMATIC VOLUME CONTROLS

OPERATION AND REPAIR

33X

REFERENCE BOOK

PIONEER HOME STUDY RADIO SCHOOL

NRI

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Modern Automatic Volume Controls

Silent A.V.C.; Tuning Indicators, Off-Resonance Muters, Direct and Amplified A.V.C. Delay, Diode Detectors; Servicing Notes.

AUTOMATIC VOLUME CONTROLS

Tuning a sensitive receiver having the usual manual volume control is often a rather unpleasant job for the layman. If the volume is set at a normal level for weak signals, local stations and the more powerful distant stations will "blast in" when tuning them. Such receivers must be tuned with one hand on the station selector and the other on the manual volume control. Automatic volume control (A.V.C.) simplifies tuning, making station selection simple and convenient. With perfect automatic volume control built into a receiver, and with the manual control set to give a definite sound output level, all stations far or near should come in with the same intensity.

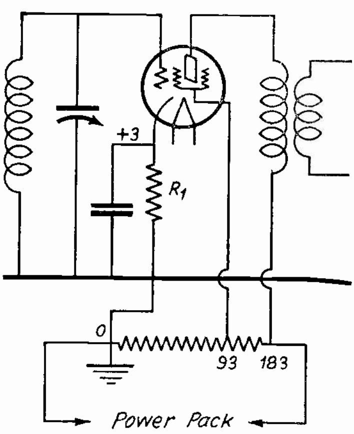

FIG. 1

In the development of automatic volume control new difficulties appeared requiring special solution. For example, in tuning the first sets equipped with A.V.C., between stations the noise was sometimes almost unbearable—this led to the development of off-resonance noise suppression. A combined automatic volume control and noise suppressor is referred to as a silent automatic volume control (S.A.V.C.).

Then, too, A.V.C. results in apparent broad tuning, making it difficult to tune a station to the center of its carrier. This difficulty is largely overcome by the use of meter, shadow, reactance, or neon light tuning indicators—and quite recently, by the use of the off-resonance muter circuit with which it is impossible to get signals unless the set is tuned to the exact center of the carrier. We will consider all phases of silent automatic volume control in detail.

Let us start with A.V.C. Most modern superheterodyne receivers* use variable mu tubes ('35, '51 and 58) in the R.F. and I.F. stages, the volume being controlled by varying their C bias. If you study the E_g-I_p curves of these tubes, you find that they have a long curved characteristic and the plate current does not cut off until about —50 volts are applied to the grid. The slope (incline) of this curve at every value of E_g is a measure of the mutual conductance of the tube. As you increase the negative bias, you automatically decrease the mutual conductance of the tube. Decreasing the mutual conductance of a tetrode tube directly decreases the gain of the stage. This is the nature of the tetrode tube in the circuits used. For automatic volume control then, all we need is a C bias supply whose negative will be large for strong carrier signals and small for weak carrier signals. Before we consider what means are taken to accomplish this automatically, let us study closely how a variable C bias may be inserted into a tube circuit.

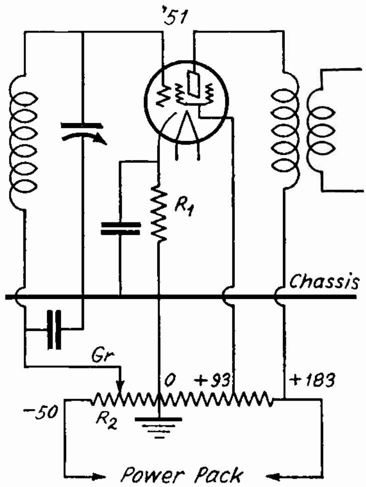

FIG. 2

A.V.C. Using C Bias Rectifiers: Consider an R.F. stage using a '51 variable mu tube with its ganged condenser grounded to the chassis and the tube operated at normal voltages – C bias – 3 volts, screen grid 90 volts, and plate at 180 volts, as shown in Fig. 1. If normal C bias is obtained by the plate and screen grid currents flowing through R_1, then the over-all voltage supply must be 183 volts. If we wish to introduce a further control on the bias (down to —50 volts), then the power pack must supply 183 + 50 or 233 volts, and the grid return circuit should be as shown in Fig. 2. Potentiometer R_2 through which the voltage divider bleeder current flows has a voltage drop of 50 volts across it, the variable contact feeding a changeable voltage to the grid of the tube through the inductance of the tuned circuit. Note that the tuning inductance does not connect to the chassis.† As the negative bias on the grid is

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* We will limit our discussions in this text essentially to superheterodyne receivers. In order to get ideal A.V.C., an extremely sensitive set is required.

† The R.F. signal is by-passed to the chassis.

increased, the plate current through R_1 decreases, thus decreasing the normal 3 volt bias it contributes.

Refer now to Fig. 3 which is essentially the same as Fig. 2 with the 0 to —50 terminals shunted by resistances R_2 and R_3 in series. With this connection, the voltage drop between terminals 1 and 3 will be 50 volts. Note that the grid of the tube is connected to terminal 2, thus placing a negative bias on the grid of the tube, the value of which depends on the relative values of R_2 and R_3. When R_3 (indicated as variable) is made large, then the drop across R_2—which determines the negative bias on the tube—will be small. Likewise, a small ohmic value of resistance R_3 will cause a large negative bias.

On the other hand, suppose R_2 were made variable and R_3 were fixed. Then a small value of R_2 would supply the tube with a low negative grid bias, while a large value of R_2 would supply the tube with a high negative bias. The action is the reverse of the condition in which R_3 is varied. Either action can be made use of in the application of A.V.C.

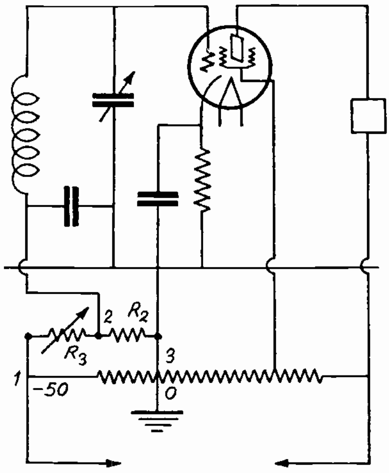

Fig. 3

If we can find an electric device whose resistance will vary with the strength of the received radio carrier, we can substitute this device for either R_2 or R_3 and thus have A.V.C. A little thought on your part will show you that the D. C. plate resistance of either the C bias or the grid leak-grid condenser vacuum tube detector will vary with grid (carrier) excitation.

Now we know that the D. C. plate resistance of any tube is its applied plate-to-cathode voltage divided by the plate current. In grid bias detectors we know that with no R.F. carrier applied to the grid, the plate current will be low. Assuming a normal plate voltage, we can immediately infer that the D.C. plate resistance is very high. When an R.F. carrier voltage is applied to the grid, the average plate current goes up and with approximately the same applied plate voltage it must follow that the D.C. plate resistance is reduced. Therefore, if we remove R_3 in Fig. 3 and insert a grid bias detector tube, its plate connected to terminal 2 and its cathode to terminal 1, and the grid input to any point in the R.F. or I.F. system of a receiver where a substantial R.F.

carrier voltage is available, we will have our automatic volume control. The tube supplying this varying resistance is referred to as the A.V.C. or controlling tube. Its grid input is usually fed through a coupling condenser connected to the plate of the last I.F. tube.

A practical circuit showing the control tube (A.V.C.) and the controlled tubes (the R.F. and I.F. tubes) is given in Fig. 4. The output of the last I.F. tube feeding the second detector in the superheterodyne receiver connects through C_L to the grid of the A.V.C. tube. This tube obtains its cut-off bias (making it act as a detector) from the IR drop in resistor R_4 applied to the grid through a high resistance leak R_L. The plate-cathode connection simulates R_3 in Fig. 3 while R_2 simulates R_2 of the same figure. The plate current I_p of the A.V.C. tube flows through R_2. The IR drop in R_2 is now the controlling bias for the R.F. and I.F. tubes. Note that R_2 is shunted by C_2. This is necessary as the plate current of the A.V.C. tube is varying at A.F. and R.F. or I.F. frequencies. A large filter condenser C_2 is necessary if the variations are to be smoothed out.

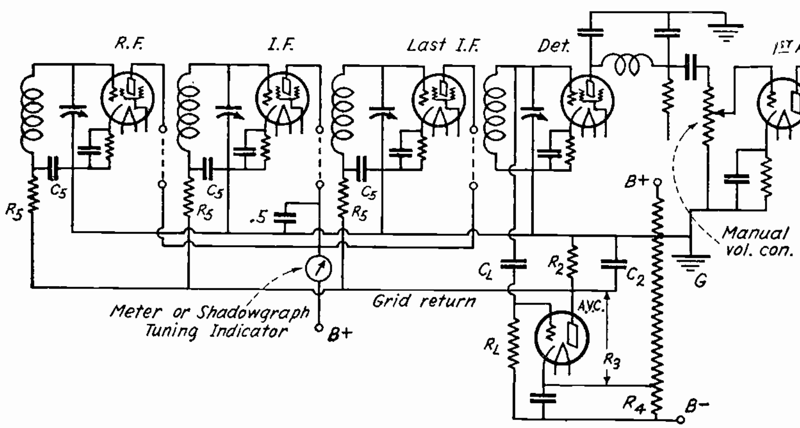

Fig. 4

Furthermore, the condenser prevents sudden changes in carrier intensity from showing up instantly. This is referred to as the time delay. The time delay in seconds is the product of R_2 in ohms, and C_2 in farads. The plate of the A.V.C. tube connects to the grids of the R.F. and I.F. tubes through resistive filters R_5-C_5 which prevent coupling between R.F. and I.F. stages. If the time delay of R_5-C_5 is large enough, condenser C_2 may be omitted. In some cases, it is desired to have different controls on one or more tubes, in which case R_2 is tapped in one or more places and the grid returns brought to these taps.

Resistor R_2 may be a potentiometer with the grid return of the controlled tubes connecting to the variable contact. In this way, modified A.V.C. is obtained and after a fashion the potentiometer acts as a manual volume control. The usual way of getting manual volume control in an A.V.C. receiver is to control the A.F. level in the audio system. It is worth remembering that under normal conditions current does not flow in resistors R_5.

Fig. 5 shows the alternative method, using a grid leak-grid condenser detector. In this circuit the plate-cathode of the A.V.C. tube simulates the resistor R_2 shown in Fig. 3. However, this method of A.V.C is not desirable, as the variation in plate resistance is small, the tube acts as a load on the receiver, draws grid current, and blocks on strong signals. A "C" bias detector is universally used in A.V.C. systems.

Although in Fig. 4, the A.V.C. tube is shown as a triode, four element or screen grid tubes are used extensively. The higher the active (with carrier input) plate resistance of the tube, the larger should be the fixed resistor R_2. The actual voltage between G and $-B$ in Fig. 4 may be as high as 100 volts.

Let us stop to see how an A.V.C. system "levels out" signals. When no signal is tuned in, the A.V.C. tube is unexcited (we will neglect noise in this discussion), the D.C. plate resistance of the A.V.C. tube is infinitely large, the drop across R_2 (Fig. 4) is negligible and the bias on the controlled tubes is

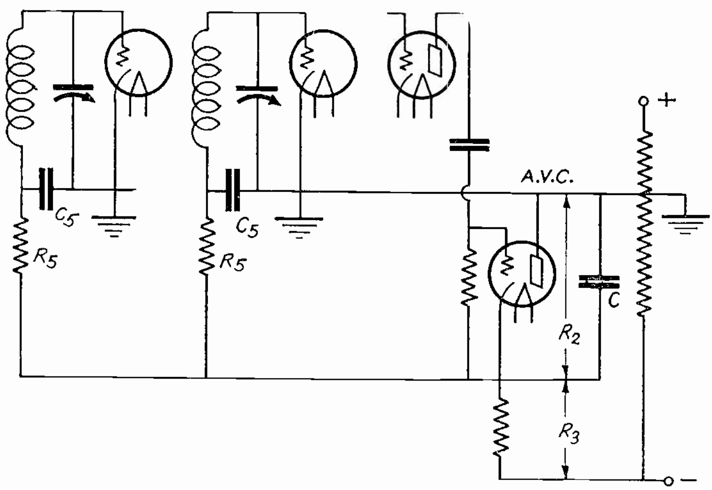

Fig. 5

normal. All tubes are working at their peak G_m (mutual conductance) and the set is in a supersensitive condition.

When a signal is tuned in, if the A.V.C. system is sluggish, it may at the start sound very loud and then reduce to normal level—that is, the normal output of the audio system, if the manual control in the A.F. system is wide open. If it were not for the A.V.C., the supersensitivity of the set would allow the signal to overload the detector. What happens? The carrier feeding the A.V.C. tube causes its plate current to go up, the drop across R_2 increases, thus placing a large negative bias on the controlled tubes, the G_m of each of the controlled tubes goes down, and as the over-all R.F. gain of the receiver depends on the product of their G_m's, the over-all gain of the receiver rapidly drops and so does the strength of the signal at the input of the A.V.C. and detector.

It might appear that this in turn would tend to increase the gain of the receiver. However, a balancing takes place—a decrease in R.F. gain balanced by a slight increase in A.F. output. Leveling off takes place to a marked degree when the signal is reasonably large.

Of course, it is unreasonable to expect the R.F. system of any receiver to deliver the full detector signal with a weak signal input. From 5 to 30 microvolts input, let us say, the detector input voltage will increase, and it will not be until a signal of 30 microvolts is supplied that normal A.V.C. action takes place and reasonable constant output is obtained. Yet even in this range, the A.V.C. of the system is influencing sensitivity, causing the over-all gain of the receiver to be reduced. If it were possible, it should do the reverse—tend to make the receiver more sensitive than the no-signal condition. But, of course, this is impossible. The least that can be done is to delay the controlling action of the A.V.C. tube until the detector is fed with normal input (threshold input).

The C bias A.V.C. tube lends itself to this delay. An over-bias will delay rectification and when plate current flows, the rise in current will be great for further increases in grid excitation. Furthermore, with the use of variable mu tubes (35, '51 and 58), the over-all variation in G_m is small for low negative

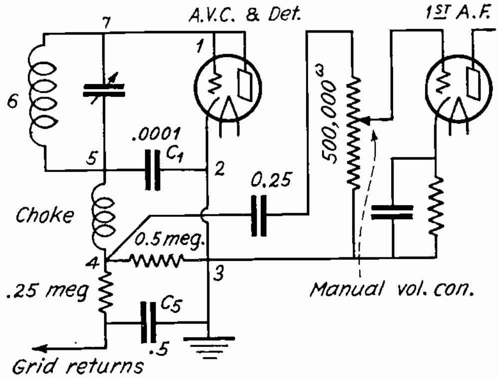

Fig. 6

biases, thus tending to delay the A.V.C. action. In the ideal A.V.C. system, once the detector tube is supplied with an R.F. voltage capable of giving normal audio output, further small increases in carrier signal will cause a rapid increase in the plate current of the A.V.C. tube.

We should not expect perfect leveling of signals. Most A.V.C. systems are controlled by the strength of the signal carrier, but the A.F. level is also controlled by the percentage of modulation. Thus, with two signals of equal carrier intensity, the one having the greater percentage of the modulation will give the greater sound level, in spite of the A.V.C. We would hardly expect the A.V.C. tube to act if its input were not increased. This in turn indicates that strong signals will always be louder than weak signals, the amount depending on the sensitivity of the A.V.C. tube. For low signal inputs, assuming perfect A.V.C. delay, the signal level will depend on the signal as in the ordinary set. Signals worth listening to with a given receiver are above this minimum. It is not to be expected that fading will be leveled out in this weak signal region—this may only be accomplished by further raising the sensitivity of the receiver. Fortunately, at threshold conditions the ear will only observe wide changes in power level and the imperfect A.V.C. system appears to be a perfect sound leveler.

A.V.C. with Diode Detectors: For a long time it has been known that the two element tube—the diode—is an excellent detector. But it requires a large R.F. input. Furthermore, it decreases the selectivity of the stage in which it is used. But because the modern superheterodyne is so extremely sensitive and selective, a diode second detector is practicable and we now find its use growing. A '27 or 56 triode with its plate connected to the grid or to the cathode may be used as a diode.* When used as a detector, the tube rectifies the signal and its output is a pulsating current containing I.F. or R.F., A.F. and D.C. components. By allowing the current to flow through a suitable resistor and by-passing it to filter out the I.F. or R.F. ripples, the D.C. potential modulated by the A.F. signal remains, the latter component being fed to the audio system. If the same potential is filtered further to wipe out the A.F. variations, we may obtain a negative potential to control the I.F. or R.F. tubes. As the signal increases, the resistor current increases, increasing the negative bias on the controlled tubes and thus decreasing their amplification.

For a diode, the A.V.C. potential increases uniformly for increases in

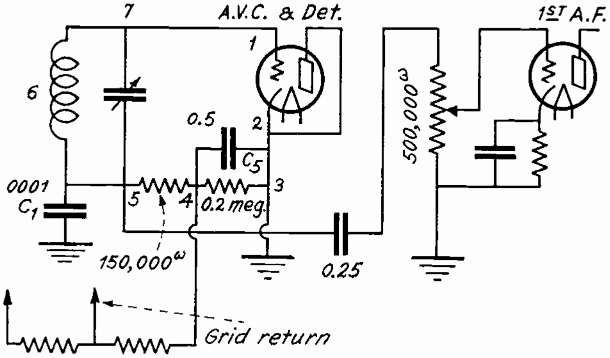

FIG. 7

signal strength although with an A.V.C. using a C biased tube, the increase may be uniform, it also will be very rapid. Perfect A.V.C. control must therefore depend on the criticalness of the G_m of each stage. A.V.C. delay is not inherent in diode detectors so that it is proposed to introduce a fictitious delay in the A.V.C. tube by introducing a positive potential in the A.V.C. system which must first be overcome before a net negative bias is fed to the controlled tubes. Essentially, this is a bias on the bias.

A typical diode second detector-A.V.C. circuit is shown in Fig. 6. The modulated I.F. signal is fed to points 1 and 2, and rectified current flows from 1 to 2, to 3, 4, 5, 6, 7 and to 1 (electrons flow in the opposite direction). A drop is created in the resistor between 4 and 3, terminal 4 being negative with respect to terminal 3. (Current flowing from a high to low potential.) The I.F. signal is by-passed by the condenser between 5 and 2 and prevented from entering the resistor by the I.F. choke between 5 and 4. The voltage between 4 and 3 is a pulsating signal, varying at A.F. frequency—the sound signal.

* In some circuits the serviceman may find a '27 or 56 tube used as a double diode. The cathode (at R.F. potential) and the grid act as one diode, while the cathode and plate act as the second diode. Resistors in series with the plate and grid to ground develop the A.V.C. and A.F. signal potentials.

A 500,000 ohm potentiometer across 4 and 3, blocking out the D.C. component with a .25 mfd. series condenser, feeds the A.F. signal to the first A.F. amplifier. The D.C. voltage component of the potential across 4 and 3 is fed to the grid returns of the controlled tubes through the resistive filter (.25 meg. resistor and .5 mfd. condenser), the filter removing the A.F. variations and introducing time delay.

A slightly different circuit is shown in Fig. 7. In this case the plate is connected to the cathode. The plate acts as an electron deflector. Electrons which pass the grid are repelled to the grid by the plate which is at a negative potential with respect to the grid. Connecting the plate to the cathode reduces the input capacity of the diode rectifier; a valuable asset for a high quality receiver. Rectified pulsating current flows over the path 1, 2, 3, 4, 5, 6, 7 to 1. Terminal 3 is at zero D.C. potential with points 4 and 5 relatively more negative. The resistor between 3 and 4 is by-passed by a large condenser, thus smoothing out both R.F. and A.F. components. The negative bias between 4 and 3 is therefore used for A.V.C. The voltage drop in resistor 5 to 4 is by-passed to ground with the .0001 mfd. condenser and only the

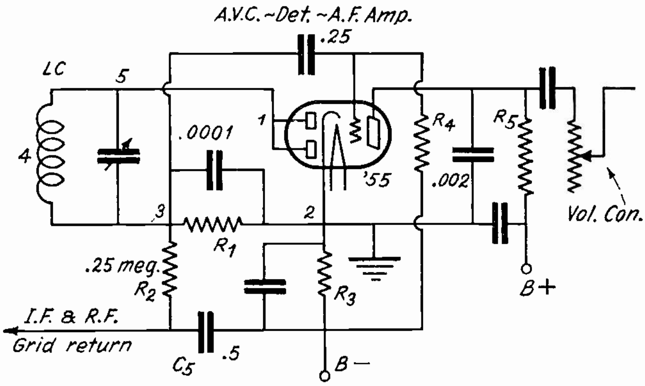

FIG. 8

A.F. component exists in it. The drop is thrown across a 500,000 ohm potentiometer and the D.C. component wiped out by the .25 mfd. blocking condenser. The potentiometer provides a variable A.F. input to the first A.F. amplifier tube. Observe in the circuits shown in Figs. 6 and 7 that the diode is not operated by a voltage from the power supply. It may be considered, as far as the A.V.C. negative potential is concerned, as a power supply, deriving A.C. power from the amplified signal.

By providing for sufficient R.F. gain ahead of the diode second detector and following it by an intermediate A.F. amplifier, the shortcomings of the diode detector are overcome. This required at least one additional tube, which prompted tube makers to design a combination diode-triode in a single envelope. To make the tube of universal use, a double diode is built in. Tubes type 55 (A.C. set) and 85 (automobile set) are the so-called duo-diode-triode tubes. Physically, these tubes contain a single long cathode (electron emitter) having two small plates around the lower end. Above this assembly and separated from it by a shield is the triode section containing a grid and plate. By connecting the diode plates together we can duplicate the entire circuit including the first A.F. shown in Fig. 7 as in Fig. 8.

A modulated R.F. voltage appears across the LC tuned circuit shown in Fig. 8 and the diode rectifies the signal, causing a rectified current to flow in the direction 1, 2, 3, 4, 5 to 1. Resistor R_1 between 3 and 2 has across it a pulsating voltage consisting of the D.C. and the modulating sound signal components. The R.F. component is wiped out by the small .0001 mfd. condenser shunting R_1.

Point 3, from a D.C. point of view, is more negative than point 2, and a tap from point 3 to the grid returns of the controlled tubes will give us the necessary controlling bias for A.V.C. Resistor R_2 shunted to ground by a .5 mfd. condenser will further wipe out the A.F. signal component. As resistor R_1 carries the A.F. signal component, it serves to excite the triode section of the duo-diode-triode. Note the .25 mfd. coupling condenser connecting point 3 with the grid. Naturally, the condenser prevents the D.C. component from reaching the grid by blocking it.

In order for the triode to work as an amplifier, the grid of the triode must have a fixed C bias, furnished by the drop in resistor R_3. R_4 connects the

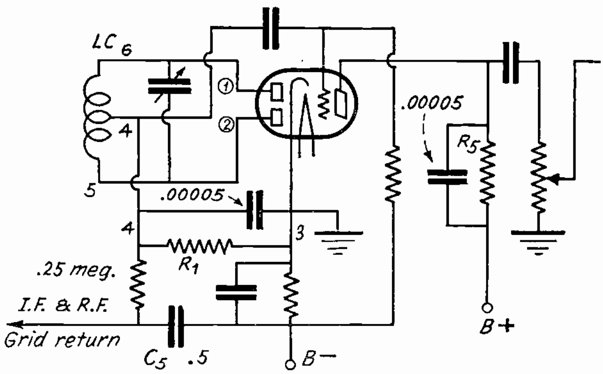

FIG. 9

grid to the normal C bias potential. R_3 must be shunted by a large condenser (.25 to 1.0 mfd.). The plate of the triode may now feed into any of the conventional A.F. couplers—a resistance coupler is shown in Fig. 8. Where several negative potentials for the controlled tubes are desired, R_1 may be tapped, each tap, however, feeding through its own resistive filter to isolate the detector from the I.F. and R.F. systems, and from each other, and at the same time wipe out the A.F. signal component. Cathodes of all controlled tubes should be connected through their cathode bias resistors to point 2 indicated as at ground or chassis potential.

The diode detector is capable of rectifying signals modulated with high audio frequencies with minimum distortion. To get the maximum high A.F. response, the condensers shunting R_1 and by-passing R_5 in the circuit shown in Fig. 8 should be as small as possible. These condensers could be made very small if the diode were fed directly from the R.F. system as in a tuned R.F. receiver. This should be clear when we realize that carriers of 550 to 1500 kc. are to be filtered. The value of the condensers must be increased when the I.F. section of a super feeds a single diode detector. In this case, we must filter out a 175 to 460 kc. signal. It takes a larger condenser to filter out lower frequencies and when this is done we also filter out the higher A.F. frequencies. In the case of the duo-diode second detector, the problem is simpler for the carrier in the common lead of two diodes in a balanced input arrangement can be easily filtered.

Referring to Fig. 9, we find a duo-diode-triode connected for full-wave rectification.* The total modulated R.F. signal appears across terminals 5 and 6—half appearing between 4 to 6 and 4 to 5. If we consider 4 as the reference terminal, point 6 is positive when point 5 is negative. Note that the load on the diode resistor R_1 is between 4 and the cathode of the diode. Let us say that 6 is positive; rectified current then will flow over the 1, 3, 4, 6 to 1 path. No current will flow through the 2, 3, etc., path. Under these conditions, the voltage across R_1 will follow the positive half cycle of the impressed R.F. signal. During the negative half cycle of the signal, rectified current will take the 2, 3, 4, 5 to 2 path and, of course, the voltage across R_1 will follow it.

Because successive alternations are rectified, the voltage across R_1 will be the result of both positive and negative alternations of the signal, and the R.F.

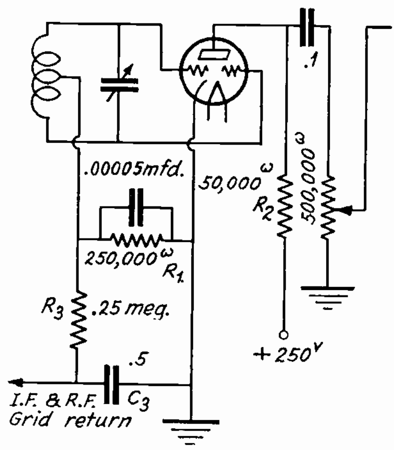

FIG. 10

signal will have a frequency of twice the R.F. input to the diode. Under these conditions, a very small filter condenser (.00005 mfd.) across R_1 will wipe out the R.F. or I.F. component of the pulsating voltage across R_1. In fact, half the capacity used in the circuit arrangement of Fig. 8 may be used in Fig. 9, as we have doubled the frequency of the rectified component. Likewise, the R.F. or I.F. shunt condenser across R_5 may be eliminated or a very small one used as indicated.

Special Detector and A.V.C. Circuits: The Wunderlich (a trade name) tube is now available for use as a combined full-wave rectifying detector, A.V.C. and audio amplifier. This tube is like a '27 or 56 tube but with two identical control grids, intermeshed and around the cathode. The tube acts as a power grid leak condenser detector tube, rectifying in its grid circuit and amplifying like a triode. A standard circuit is shown in Fig. 10.

* The duo diode pentode may be used in circuits similar to the duo diode triode with the addition of a screen grid supply connection. With the pentode output a higher resistance plate load is required.

As far as the grid circuit is concerned, the tube acts like the diode circuit shown in Fig. 9. Full-wave rectification takes place, creating across R_1 a full-wave rectified voltage consisting of the D.C., R.F. and A.F. components. As the R.F. frequency is double that of the signal supply, a .00005 mfd. filter condenser shunted across R_1 is sufficient to wipe out the R.F. component. The D.C. component acts as an automatic bias for the triode amplifier. The A.F. component across R_1 is fed to the respective grids in successive alternations and is amplified by the grid-plate as in an ordinary three element tube. No R.F. by-pass condenser is necessary across R_2 as the R.F. is substantially wiped out by the condenser across R_1. For A.V.C., the D.C. component across R_1 is fed through the resistive filter R_3-C_3 to the grid returns of the controlled tubes. It is claimed that this circuit is sensitive, will handle large R.F. signals, and the output is sufficient to feed directly into an ordinary power amplifier tube.

The Bureau of Standards in its development of aircraft receivers for beacon reception developed a form of A.V.C. which is readily adapted to existing airway beacon receivers. The system is not recommended for broadcast

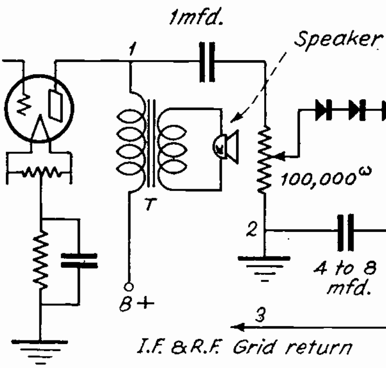

FIG. 11

receivers as it depends on the percentage or depth of modulation for its control. Where the modulated signal is of constant amplitude as in aircraft beacon transmission, the system works well. The method is introduced here for completeness in the presentation of A.V.C. It takes a part of the A.F. component from the power output tube, rectifies and filters it, and employs the resulting voltage as bias for controlling the I.F. and R.F. tubes. In this system, copper oxide rectifiers are used—the type used in changing D.C. milliammeters to A.C. milliammeters.

The output circuit is shown in Fig. 11. All apparatus to the right of points 1 and 2 is the A.F. to D.C. conversion system. As a large A.F. voltage is essential if we desire a large controlling negative bias, terminals 1 and 2 should be connected across the plate and ground, using the 1 mfd. blocking condenser to prevent any D.C. flow. You could, of course, use a 1 to 1 ratio transformer across the primary of transformer T with one side of its secondary grounded. In fact, with a push-pull output, such an arrangement would be necessary. Observe that at least three rectifiers in series are necessary, as each rectifier element will handle a limited D.C. voltage. The grid returns of the respective controlled tubes lead back to terminal 3, preferably through resistive filters. Once installed, the 100,000 ohm potentiometer may be used as a combined variable sound level and A.V.C. control.

In adapting such a system to beacon receivers, the ground ends of the coils in the grid circuit of the tubes to be controlled are disconnected from the ground. The free end is now by-passed to ground by a .25 mfd. condenser and the free end led to terminal 3 as shown in Fig. 11, through .1 megohm resistors. A small 1 to 1 audio transformer in the case of push-pull outputs should be used, eliminating the 1 mfd. blocking condenser. A midget 4 mfd. dry electrolytic filter condenser may be used. The entire A.V.C. system can be closely assembled and placed in any convenient place on the chassis. The A.V.C. action will depend on the percentage of modulation of the received signal and not on the strength of the carrier.

While we are on the subject of copper oxide rectifiers, we should mention a new detector—using this rectifier—which appears to have good possibility of adaptation in the future. It has been recognized that the copper oxide rectifier might be used in place of the vacuum tube detector if it were not for its high capacity which would by-pass the R.F. signal before it would be pos-

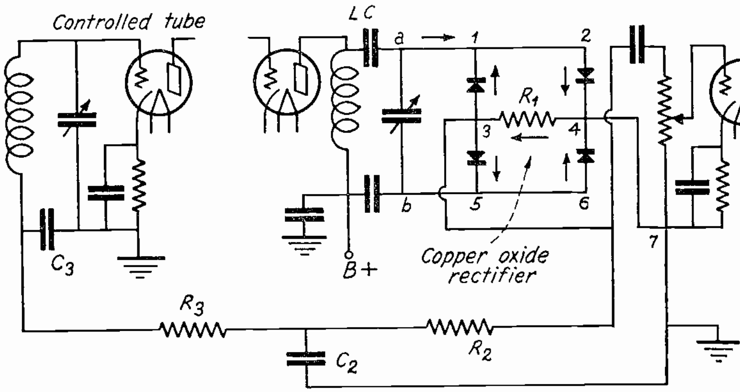

FIG. 12

sible to rectify it. The usual copper oxide rectifier elements used for meter work are about one-half inch in diameter, but by a special construction they have been reduced to one-sixteenth of an inch. When several are used in series, the net capacity per section is radically reduced, making it suitable for R.F. rectification. Four sections are needed to form a balanced bridge full-wave rectifier and the entire rectifier may be built into a small *UX* tube base.

Four such sections are shown in Fig. 12 in a balanced bridge circuit. Current may flow through the rectifiers in the direction of their arrows. When the tuned circuit *LC* is excited by a signal so that terminal *a* is positive, the current will flow over the a, 1, 2, 4, 3, 5 to b path creating a pulsating voltage across the rectifier load R_1. Terminal 3 will therefore be negative with respect to terminal 4. When *b* is positive the current will flow over the b, 6, 4, 3, 1 to a path. Also under this condition, terminal 3 will be negative with respect to terminal 4. The self-capacities of the rectifiers may be considered as a condenser in shunt with R_1 which is sufficient to wipe out the R.F. component of the voltage across R_1. The A.F. component across R_1 through a blocking condenser and controlled by the potentiometer, feeds the A.F. tube. Terminal

3 supplies the negative bias for the controlled tubes through the A.F. resistive filter R_2-C_2. Each controlled tube should have its own decoupling resistive filter as indicated by R_3-C_3. For linear detection R_1 should be large. A value of 250,000 ohms appears to be best in the tests made.

We have by no means exhausted the possible A.V.C. systems, but with basic systems given in this presentation you should have little difficulty in tracing the systems in general use. Radio receiver designers have their pet methods, each new set has peculiarities of its own and in that way there will be variations in A.V.C. systems in use. Figs. 13, 14 and 15 show typical commercial systems.

In Fig. 13 you will observe that the half-wave rectified current flows through R_1. Resistor R_2 in series with condenser C_2 shunts R_1 and absorbs the A.F. signal component as the R.F. component is by-passed by C_1. R_4 is the triode grid leak resistor and furnishes a path for the C bias created across the by-passed resistor R_3 and a path for feeding an A.F. voltage from R_2. The A.V.C. controlling potential across R_1 is fed to the controlled tubes through the A.F. resistive filter C_5 and R_5.

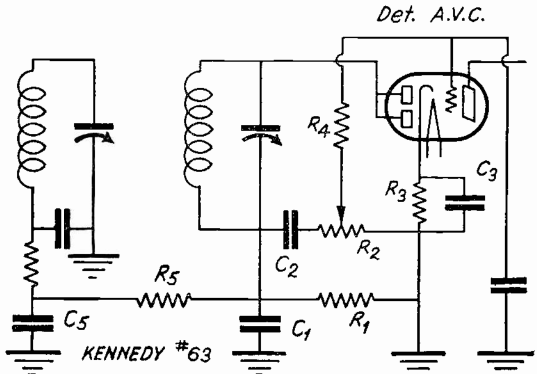

FIG. 13

Majestic radio receivers have used a double diode detector of their own make to furnish detection and A.V.C. One of these circuits is shown in Fig. 14. A full-wave rectifier circuit is used. Rectified current flows through R_1 and the R.F. choke. The R.F. choke together with condensers C forms a π (pi) filter, so that no R.F. signal can get through to the A.F. volume control P. Resistive filter R_2-C_2 is the only one used in their 210 receiver to introduce time delay and to filter the A.F. component from the controlling potential.

The A.V.C. used in the Kolster K-70, shown in Fig 15, employs a tetrode for the A.V.C. tube. It is arranged like the circuit shown in Fig. 4 except that it requires an operating potential for the screen grid which in this case is the drop in the field coil of the dynamic speaker. A variable bias is fed to the A.V.C. tube through the potentiometer P. When set near point 1, the A.V.C. tube plate current is high, causing a large negative voltage to feed to the controlled tubes. Very little controlling action takes place. When P is set at point 2, maximum A.V.C. takes place, the A.V.C. tube plate current is low, feeding a low negative bias to the control tubes and increasing the sound level for weak signals. In this way the volume of the set is controllable.

Direct and Amplified A.V.C. Delay: If a receiver is built without A.V.C.

and the R.F. system is operated without manual attenuation, then the audio voltage obtained from a linear detector will increase with increases in R.F. pickup. This may be represented by the solid line curves *A* and *B* in Fig. 16. Obviously curve A represents the input-output curve for a receiver which is more sensitive than the receiver represented by *B*. It would appear that the more R.F. input obtained the more A.F. output, but there is a point where the R.F. amplifier and detector will overload, the overloading detuning the R.F. stages, actually causing a decrease in A.F. output for increased R.F. input. This is represented by the continued dotted curve. Overloading is possible in receivers without A.V.C. if the manual volume is turned on to maximum output setting without retuning the receiver and a large signal is fed to it.

In A.V.C. operated receivers, this overloading is automatically avoided. Theoretically, an A.V.C. receiver should operate as shown by the solid curve

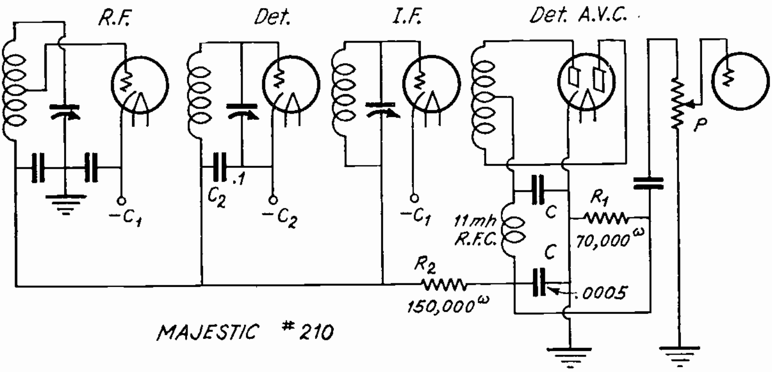

FIG. 14

Note that the I.F. grid tuning condenser is not isolated from the grid coil by a condenser as in the R.F. and first detector grid circuits. This is not necessary as the condenser in the I.F. system is not, for constructional reasons, grounded to the chassis as is the case where tuned ganged condensers are used. This I.F. transformer connection is universally employed in commercial receivers.

Circuit Fig. 14 serves to show how to tell, when reading a diagram, if A.V.C. is employed The ground end of the tuning coil if directly connected to the ground indicates no A.V.C.; if the coil leads through a resistive filter to a resistor to ground A.V.C. is employed.

in Fig. 17. For low R.F. input the A.F. output increases to point a—called the threshold point—and the A.V.C. from this point holds the A.F. output constant. This is the ideal sought for in all designs. Actually where the A.V.C. acts from the very start, the input-output curve is more like the dotted curve shown. Note the lowered sensitivity at low R.F. input, the absence of a definite threshold point, and the presence of overloading. The maximum output is determined by circuit conditions and is established by the condition where the product of the over-all R.F. gain and R.F. voltage input is constant. In other words, the reduction in gain so balances the increase in R.F. input that the detector is fed with constant R.F. voltage. When we stop to realize that the gain can only be reduced by an increased controlling negative bias and the latter can only increase with an increase in R.F. voltage at the input of the control tube, which is usually the same as the input to the detector, we see that a rise in A.F. output must exist when A.V.C. is in normal operation.

The rise in A.F. output may be greatly reduced by introducing an A.V.C. delay. Suppose that for threshold conditions an A.V.C. input of 5 volts is obtained and that overloading occurs when the input is raised 25 volts—a total input of 30 volts. Then the input to the detector will increase from 5 to 30 or the output will increase six times. Refer to the dotted curve in Fig. 17. Let us introduce a bias on the A.V.C. so that the threshold conditions do not appear until 20 volts are fed to it and again assume that overloading takes place with a 25 volt increase. The A.F. output will increase by a ratio of 20 + 25 to 20 or 2.25. Although this delay may reduce the threshold output, it will take place at a lower input, the threshold action will be sharper, the output after that point will vary to a lesser degree, and the overloading will take place at a greater input as shown by the dashed curve in Fig. 17. Where A.V.C. delay is introduced, to compensate for loss in sensitivity a more sensitive R.F. system is employed. It can be seen that the greater the A.V.C. delay, the flatter will the A.V.C. characteristic be but at a sacrifice of sensitivity unless more gain is built into the receiver.

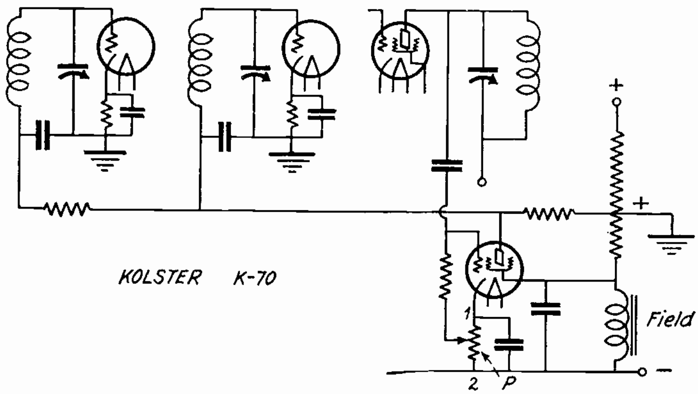

FIG. 15

Designers have figured that if the A.V.C. control voltage can be amplified before it is delayed and then fed to the controlled tube, the threshold input potential could be set at a lower value and the increase in delay voltage made such that a very flat A.V.C. characteristic would be obtained. Suppose that the threshold conditions are desired when the input to the detector and A.V.C. tube is again 5 volts and the A.V.C. amplifier increases it 8 times to 40 volts, and then a 40 volt delay is introduced. Assume as before that a 25 volt A.V.C. increase is sufficient to prevent overloading. To get this 25 volt increase, the input must increase 25 ÷ 8 or about 3 volts. Under these conditions the output after threshold conditions will be increased by the ratio of (5 + 3 ÷ 5) or 1.6 times—an improvement over direct delay. At the same time the threshold sensitivity is set at 5 volts. Because of the amplified delay it will take an extremely large signal to overload the receiver for after the initial delay is overcome, the controlling bias is increased 8 times.

An amplified delay circuit has been developed around the 55 tube and a fundamental circuit is shown in Fig. 18. The I.F. output is fed to one of the diodes of the 55 tube D_1, the rectified signal appearing across R_5. Condenser

C_1 wipes out the I.F. component, leaving only A.F. and D.C. across R_5. Resistor R_6 feeds the full D.C. potential across R_5 to the triode section of the 55 tube, while condenser C_2 feeds a variable A.F. component by means of the potentiometer control. This provides a manual A.F. output control. The plate of the triode is fed with a plate potential and the load R_4 is, contrary to conventional methods, placed in the cathode leg. This makes the cathode

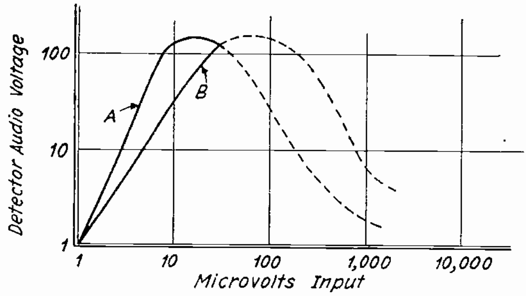

FIG. 16

positive with respect to $B—$. The amplified A.F. signal is tapped off R_4 through a blocking condenser. Diode D_2 is connected to R_1 through the second diode load resistor R_2. Note that the cathode connection of all controlled tubes is made directly to point 1. The voltage between 1 and 2 is the minimum bias of the controlled tubes and is fed to the grids of the controlled tubes through resistive filter R_3-C_3. With no signal picked up, the cathode

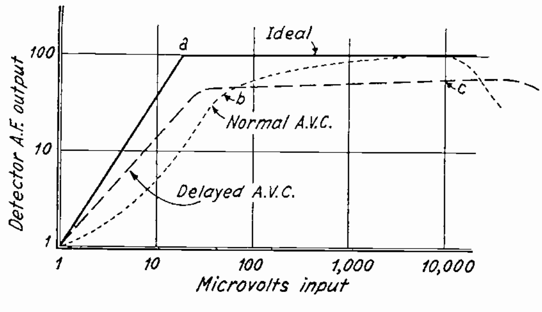

FIG. 17

of diode D_2 is quite positive with respect to point 3 and the potential between 2 and 3 is so set that although the plate of D_2 is positive with respect to 3, it is negative with respect to the cathode. The difference is the delay voltage. When a signal is tuned in, the negative bias on the triode of the 55 tube goes up, its space current drops, the D.C. potential across R_4 drops, and the plate of diode D_2 becomes less negative with respect to its cathode. When the delay voltage has been overcome, D_2 draws current increasing the negative bias across R_2 and thus feeds the controlled tubes with increased negative bias.

The triode section amplifies the D.C. and A.F. potential across resistor R_5 about 8 times, the amplified potential appearing across R_4. Condenser C_4 is large enough to bypass all A.F. modulation which might get into the A.V.C. system. Varying R_1 changes the minimum bias on the controlled tubes and changes the threshold sensitivity of the receiver by controlling the initial gain on the receiver.

Servicing the A.V.C. System: It should be clear after studying the circuits using A.V.C. that a set analyzer inserted in the A.V.C. tube socket, especially where diodes are used, will give little direct service information. The proper procedure is to get a service diagram with the values of the resistors

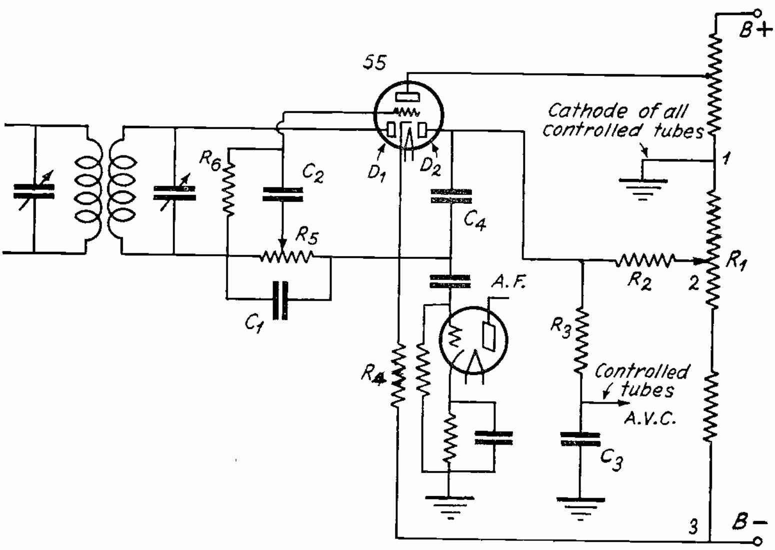

FIG. 18

noted and proceed to measure the values of the resistors from point to point and to prove conclusively that continuity exists. There are, however, certain symptoms and tests which may indicate the trouble.

Quite often an A.V.C. controlled receiver (basically like Fig. 4) will lack power or will not sufficiently cut down the signal on powerful stations. You may find that the grid bias on the controlled tubes is above normal when no radio signal is picked up. This may indicate a defective A.V.C. tube which should be replaced by a new one. If a good tube fails to remedy the situation, check the grid bias on the A.V.C. tube if one is used. If for some reason it is too low, the plate current in the A.V.C. tube will be high, cutting down its D.C. plate resistance and will thus throw an abnormally high negative bias on the controlled tubes. If this is the case, replace the defective C bias resistor on the A.V.C. tube or replace the low C bias resistor with one of higher value. A variable test resistor will be helpful in choosing a correct resistor.

In selecting a tube, the A.V.C. tube should be removed and a weak signal tuned in. A tube should be selected which will not cause the signal to fade out, and which will on the other hand give the desired control when a strong signal is tuned in.

Should resistor R_2, as indicated in Fig. 4, become shorted, it would be obvious that no A.V.C. control action can take place.

Note that the cathode of the A.V.C. tube shown in Fig. 4 is at a positive potential with respect to the maximum $-B$ terminal. Should the cathode by-pass condenser become shorted, the bias of the A.V.C. will be destroyed. In such an event, the receiver will be insensitive to all signals.

An old tube, one that has lost its emission, which can be tested to have a low mutual conductance, when used as the A.V.C. tube will naturally cause the tube to have a large D.C. space resistance (R_3 in Fig. 4), and make the set behave as if there were no A.V.C. When the A.V.C. tube is removed, the signal level will not materially change. Test the tube for normal mutual conductance.

A gassy A.V.C. tube will result in current flow in the grid circuit—from grid through R_L to $B-$ in Fig. 4, thus making the grid less negative. The A.V.C. tube will then have abnormally low bias, the effective D.C. plate resistance (R_3) will go down and the set will behave as if the bias resistor were shorted—reducing the sensitivity of the receiver. On the other hand, if a gassy tube is used in the controlled R.F. or I.F. sections, grid current will flow through R_5 (see Fig. 4). The flow of current through R_5 makes the grid positive with respect to the grid return. Realizing that the grid return with respect to the cathode of the controlled tube is made negative by the A.V.C., we should see that the net negative bias is reduced by a gassy tube. The action results in the creeping up of the sound level with the sound gradually increasing in strength.*

When in doubt, it is advisable to test for gas content. The ordinary tube tester may be modified for this test. In the usual tube tester, the grid of the tube to be tested is connected to $B-$. If a 1 megohm resistor is inserted in series with the grid lead and the resistor is shunted by a shorting switch, a simple gas tester is obtained. Test the tube with normal bias, with the shorting switch mentioned closed. Open switch. If plate current creeps up (caused by grid becoming less negative), a gassy tube is indicated. The amount of plate current rise is an indication of the amount of gas, and by comparison with tubes with allowable gas content you can determine if the tube under test is acceptable. All reliable tubes are tested for gas content before leaving the tube manufacturer.

Should condenser C_L in Fig. 4 short or leak, a positive potential will be applied to the control tube. The effective D. C. plate resistance of the A.V.C. tube will go down, the negative bias on the controlled tubes will increase and weak reception will be indicated by this defect.

In circuits like those shown in Figs. 6 and 7, an open plate connection will result in poor rectification and thus destroy the controlling action and detection of the tube. This will manifest itself in general weak signal reception. Should condenser C_1 be shorted, signals will stop. A leaky C_1 condenser will reduce the signal intensity. An open in any of the resistors will destroy the operation of the set.

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* Electrons streaming from cathode to plate bombarded the gas molecules in the tube, creating positive ions. The latter are attracted by the negative grid creating a current away from the grid in the external tube socket.

Condensers C_5 in Figs. 4, 5, 6, 7, 8 and 9, and C_3 in Fig. 10 act to delay the change in negative bias due to the signal intensity change. Of course, they act to wipe out the A.F. component on the control bias voltage. The delay action is important. If the condenser is too small, a swinging or a fading signal will be noticed. It must not be too large as sharp interference signals may cause the desired signal to decrease in intensity and come back to normal in too long a time. If this condenser is shorted or leaks, the A.V.C. action will either be destroyed or modified in extent.

TUNING INDICATORS

In tuning a radio receiver, it is important that the station selector dial be so adjusted that the tuned circuits of the set are at the center of resonance. This is important if we wish to prevent distortion due to unequal or no amplification of some of the side-band frequencies. In the ordinary set, this may be accomplished by setting the selector dial to the maximum and clearest signal. In a very selective set there is no difficulty in this adjustment as distortion is readily noticed even by the novice. In broadly tuned sets, it makes little difference and the adjustment is not critical. Of course, a milliammeter could be placed in either the plate or grid bias circuit of the second detector

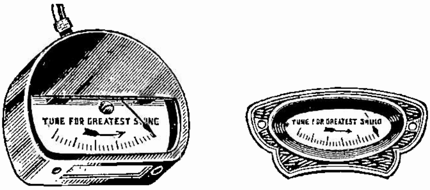

FIG. 19

of a super and the set selector adjusted so that for C bias detectors the meter will read to maximum, and for grid leak-grid condenser detectors it reads minimum. As this addition is of little advantage in the standard receiver, it is generally omitted.

When a set is equipped with A.V.C., the ear is a poor device to guide the set owner in tuning the set to the center of resonance. Usually tuning is set by the least background noise. A little reflection will convince you that as the set is tuned off-center, the decrease in signal input is automatically made up by increasing the sensitivity of the R.F. system. Distortion may or may not be noticeable but the volume is affected to a very small extent. A meter is then an important device and is universally used in all modern A.V.C. receivers with the exception of the very cheap ones. This meter should not be inserted in the plate circuit of the detector tube. Clearly the A.V.C. tends to keep the input to the detector constant, thus making any change in plate current small.

The meter should be placed in the common plate supply lead of all controlled tubes, or at least in the one whose C bias is controlled the most. As the carrier is tuned to resonance, the negative bias on the controlled tubes increases. This in turn reduces the plate current of the controlled tubes. With the meter in the plate circuit, a minimum reading will indicate that the set has been tuned to resonance. A simple milliammeter is used with the words

"Tune to greatest swing" * and an arrow showing the direction of swing (see Fig. 19 and Fig. 4).

Many set manufacturers prefer to use a neon lamp as a visual resonance indicator. The ordinary neon lamp consists of two electrodes in a glass envelope with the air removed and a small amount of neon gas introduced. Such a tube behaves in a peculiar manner. The more current that flows through the space between the electrodes, the brighter will be its characteristic red glow. It will be found that on applying an increasing D.C. voltage, the current will be substantially zero until a definite voltage (called the striking potential or ignition voltage) is applied (about 150 volts), then the current rises with any increase in applied voltage.

The so-called Tune-A-Light works on this principle but in this case, the electrodes are two round, stiff wires, one 3 inches and the other 0.5 inch long. The device is about 0.5 inch in diameter and cemented into a small automobile bulb base. At the striking potential, the lower portions of the parallel electrodes are illuminated. With an increase of voltage the current between the

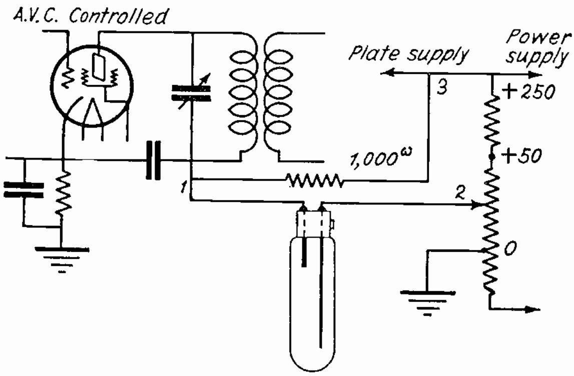

Fig. 20

electrodes increases, causing the lower half to become more brilliant and the arc to creep up towards the top of the long electrode.

To apply such a device for visual tuning, we must find two terminals in a radio set to which this device can be connected which will be slightly below the striking voltage when no signals are received, and which will rise 40 to 50 volts when the signal is tuned in. It is rather simple to locate two such points in an A.V.C. set. Consider the voltage supplied to one of the controlled I.F. or R.F. tubes and let us insert in series with the plate supply lead and the lead on the power supply a 1 to 5 thousand ohm resistor as shown in Fig. 20. Then let us connect the neon lamp between point 1 and a point 2 which may be varied above ground potential through a range of 50 volts. Suppose we adjust point 2 so that the neon lamp is operating just below the striking potential. With no signal fed to the A.V.C. controlled tube, the current from 1 to 3 will be normal. As the signal is tuned in, the negative bias on the controlled tube increases and the plate current decreases—that is, the current from 3 to 1 de-

* The meter is mounted upside-down so when it measures the least current, the pointer will be at the right-hand side of the scale.

creases. If the supply voltage between 2 and 3 is constant, and it should be in a well-designed radio receiver, a decrease in plate current will cause the voltage between 1 and 2 to increase (less IR drop). And in this way, the neon lamp gets a larger voltage, lighting and lengthening the light beam.

The simple neon light beam indicator shown in Fig. 20 is not as critical as could be desired. When tuning in a station, the beam is likely to glow over a long tuning range. For ultra selective receivers, the response so to speak of the beam should be as sharp as possible if good resonance indication is desired. For this purpose an anode controlled glow lamp is desired. Such a tube is nothing more than a regular glow lamp with its two electrodes and a short electrode near the anode placed at a negative bias. This third electrode influences the space charge to a very large extent until the critical striking potential (which will be higher) is reached. Once current flows between the anode and cathode of the glow lamp, this third electrode which we may call a grid, has no influence whatsoever. The action is sharp and the glow rises very rapidly with increased voltage.

A three element glow lamp is shown in Fig. 21. Note that anode *P*

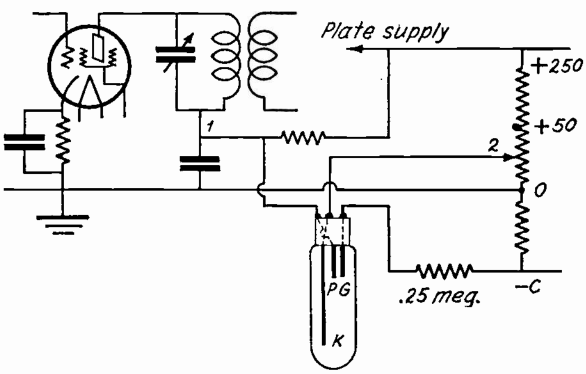

Fig. 21

through the base is connected to terminal 1, the cathode *K* to terminal 2 which is variable so that the desired striking potential may be selected, and the grid *G* is connected to a negative potential through a 250,000 ohm current limiting resistance. Such a device has been referred to as a Flash-o-graph and a Tonebeam (trade names).

Neon glow lamps may be used in a number of ways. They may be mounted on the front tuning panel of the set surrounded by a embossed escutcheon, and the height of the light column used as an indication of correct tuning to resonance. Or, they may be mounted behind the tuning dial so that the flash of light indicates the presence of a station, the brillancy of the light an indication of correct tuning. The first scheme seems to be universally used. All sets using the neon glow lamp have the variable control, terminal 2 in Figs. 20 and 21, built into the chassis. This is necessary to take care of the variation in striking potentials of various tubes.

A third type of tuning indicator referred to as the Shadowgraph is nothing more than the usual milliammeter indicator, but the indications are observed on a light scale. The milliammeter is connected in the common plate supply of the controlled tubes. The device consists of a small radio pilot lamp, its light thrown on a translucent window about 2 inches long and 3/8 inch high. Close to the lamp, pivoted on the moving coil of the meter, is a flat vane. See Fig. 22a. When the signal is at zero level, the vane turns to one side as indicated by Fig. 22b, thus throwing a large shadow on the window. As the set is tuned to resonance, the vane turns perpendicular to the window, casting a smaller and smaller shadow width, clearly evident in Figs. 22c and 22d. The tuning selector is then adjusted for maximum window light or least window shadow.

The Grisby-Grunow Company has introduced into some of the Majestic and Columbia chassis a novel reactance resonance indicator as shown in Fig. 23. A 3-legged iron core reactor is employed, the two outside coils being connected in series and to a secondary of the power transformer. A ½ ampere pilot lamp is also connected in series. The central coil is connected in series with the plate supply of the A.V.C. controlled tubes. When the receiver is tuned off resonance, the normal current flowing from the B+ supply through L_3 to the R.F. plates causes a flux to be created in the three legs as shown by the solid arrows. The cores are saturated, thus making the reactances of L_1 and L_2 essentially zero. The A.C. voltage supplied to the lamp circuit

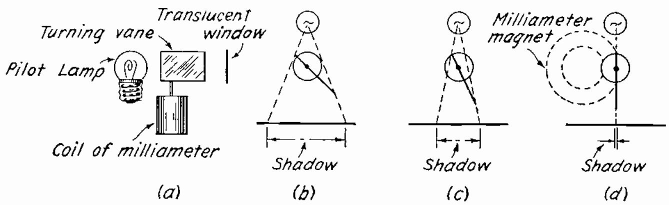

FIG. 22

is just enough to allow normal A.C. current to flow to the lamp which lights to normal brilliancy.

When the receiver is tuned to resonance, the plate current to the controlled tubes reduces. This in turn prevents core saturation in the special reactance discussed above, because this reduced current flows through L_3. Now the reactance of L_1 and L_2 increases, decreasing the A.C. current and dimming the pilot light. In actually tuning the set the pilot light will *blink* when the station is tuned quickly to resonance. Because coils L_1 and L_2 are so wound that they produce flux in L_3 in opposite directions, as shown by the dotted lines in Fig. 23, very little A.C. signal will be induced in the plate circuit of the R.F. tubes. As a further precaution, a 20 mfd. electrolytic condenser shorts the A.C. signal as L_3.

Value of Tuning Indicators in Servicing: At some time or other, it becomes necessary to align the condensers on receivers using A.V.C. When such receivers are equipped with a sensitive tuning indicator, the usual procedure is followed—the adjustments are made so the tuning meter reads the greatest swing, the longest light beam or the minimum shadow, depending, of course, on the tuning indicator used. The only time such a procedure fails is when an R.F. or I.F. stage is not A.V.C. controlled and this stage is the last in the R.F. or I.F. amplifier—that is, the stage just before the A.V.C. tube. To adjust this stage, use the regular output meter.

When an A.V.C. set is not equipped with a tuning indicator, a milliammeter may be inserted in the common plate supply lead or the plate circuit of that controlled tube whose tank circuit is being adjusted. Then, too, the filament prong of the A.V.C. tube may be insulated so as to destroy its control * but not to remove its circuit effects. In this case, an output indicator should be used in the audio system. The alignment is obtained as in regular sets without A.V.C.

MUTING SYSTEMS—SILENT A.V.C.

A set with A.V.C. and visual tuning is not enough to satisfy the present day set buyer. When an A.V.C. set is tuned, you will find that a considerable amount of noise is heard when tuned off a station. And when a weak station is tuned in, the background noise may make reception from that station annoying.

If it were possible to take a power curve, voltage input plotted against power output with no noise entering or created within the receiver, we would

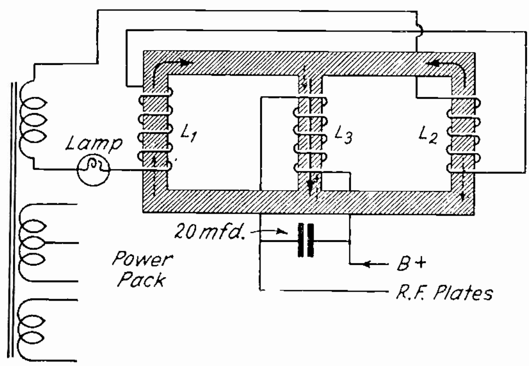

FIG. 23

get a curve similar to the curve *a, b, c* and *d* in Fig. 24. It will be observed that the threshold conditions take place at an input of about 20 microvolts. (All values are imaginary and used for purposes of illustration.) After this, if the manual control is turned on to capacity, the output is always 5 watts. The conditions represented may be considered good as we would rarely care to listen to stations whose input to the receiver was below this threshold value. Turning now to realities, if we were to introduce a varying R. F. input into a receiver connected to a normal antenna, we would find that the power curve would be as shown by curve *x, y, b, c* and *d*. It appears that with substantially no signal input, the output is nearly 100 milliwatts. This is the result of man-made, atmospheric, tube and circuit noises. The difference between that portion of the curve indicated by *x, y, b, c* and *a* to *b* is the noise component. At a signal input of 8 microvolts, the noise component is negligible—most of the output is contributed by the desired signal.

Obviously when this receiver is tuned to a station of substantial input,

* Study the A.V.C. circuit, there are exceptions. For example, the diode detector A.V.C. combination.

the ratio of signal-to-noise will be large. As soon as the receiver is tuned off-resonance, the entire output will be noise. Can this be overcome? Clearly if some device were built into the radio which would prevent any signal below 8 microvolts from coming through and all above 8 microvolts to be amplified, we may rid this set of noise when the set is tuned off a station. The power curve will be as represented by *Q, b, c* and *d* in Fig. 24.

This means that no signal below 8 microvolts will be received. In an ideal installation, the set should be installed for minimum man-made interference, using noise reducing antennas and destroying all interference at its source. This leaves atmospheric, tube and circuit noise. The noise level will vary with locations and the adjustment subject to variation. In any event, the minimum value should preferably be variable for in cities the noise level will be high and in country localities the noise level will be low, and the owner may choose to eliminate all stations except those which come in clear. Such controls are now built into radio receivers. They are called muters, automatic interchannel noise suppressors, automatic squelches, or inter-carrier noise suppressors, and A.V.C. sets so equipped are said to have silent A.V.C., abbreviated S.A.V.C., or noise suppression control, abbreviated N.S.C.

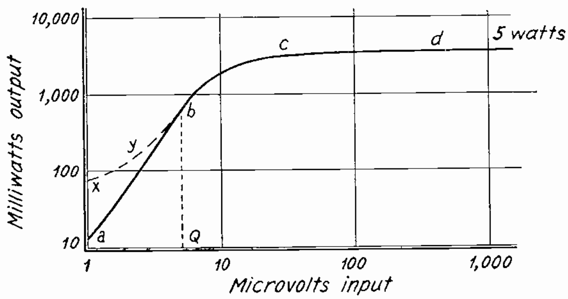

FIG. 24

These devices are basically simple. When the set is tuned off a station, the first A.F. tube is instantly fed with a large negative bias which destroys its amplifying properties. It takes the minimum level, 8 microvolts in the case we just considered, to restore the bias to normal. Such a device will not remove the background noise when a signal is tuned in. It is necessary to design the N.S.C. so that at this minimum level, the negative bias on the A.F. tube is rapidly reduced. One more fact. Sets equipped with N.S.C. will not pick up weak distant signals. In fact, maximum sensitivity is set by the noise level cut-off. To the average broadcast listener this is fine, but for the DX (long distance) listener this is a shortcoming. Some people want to hear stations 2,000 or 3,000 miles away even if the "crash-bangs" come in with it. Some manufacturers allow the removal of the N.S.C. by the flipping of a switch.

The muting system used in a Fada receiver, shown in Fig. 25, is typical. The final I.F. transformer feeds into a diode rectifier which serves the purpose of detection, supplying the A.V.C. potential and the control potential for the muting tube which blocks and unblocks the first A.F. tube. The rectified current flows from the cathode of the diode (ground) through points 1, 2, 3, 4, the latter being the most negative terminal. The varying A.F. voltage appearing between points 3 and 4 is used to supply the A.F. signal to the first A.F. tube. This A.F. potential is distributed between the series .25 and 1.0 megohm resistors, the latter a potentiometer providing a manual volume control in addition to the A.V.C. (simultaneously adjusted) manual control between points 2 and 3. The potential of 3 with respect to 1 being negative serves as the A.V.C. potential. This negative value increases, of course, with the intensity of the received carrier. A portion of this potential, namely, that between 1 and 2, serves as the control potential for the 57 muter tube.

The screen grid and the plate of the muter tube, and the entire voltage supply for the tube which the muter controls, are fed from a voltage divider which in turn receives its power from the power pack. The first audio has its cathode insulated, as far as D.C. is concerned, from the ground and is at a positive potential of 90 volts with respect to the ground. Its grid through

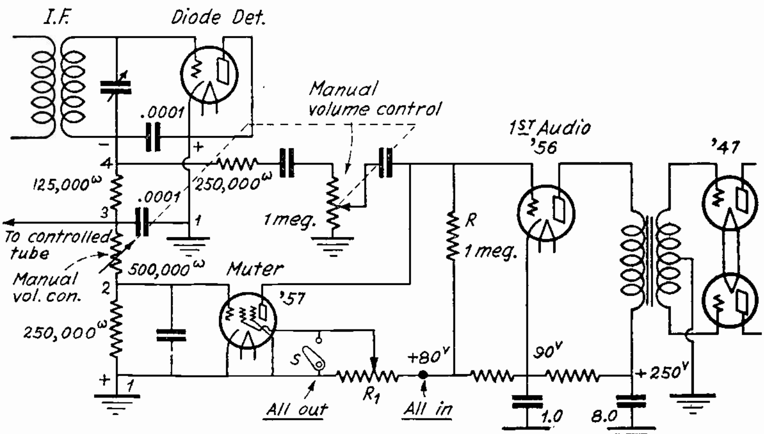

FIG. 25

a 1 megohm resistor is at 80 volts with respect to ground, whereas its plate is at 250 volts with respect to ground. As far as the tube is concerned, assuming for the moment that the muter dbes not exist, the voltage with respect to the cathode are grid —10 volts and plate +160 volts, correct for normal amplifier operation.

Turning now to the muter, we note that its grid control potential is obtained from terminals 1 and 2, no fixed bias being used. Its plate is supplied with a positive potential through the 1 megohm resistor R. We observe that the voltage drop existing across R increases the negative bias of the first A.F. tube above the normal —10 volts, and if the net bias is great enough, the A.F. tube becomes inoperative. Potentiometer R_1 supplies the screen grid with a varying positive potential. When placed in the *all out* position, it renders the muter tube inoperative. By varying the position of the potentiometer R_1, the cathode-plate current may be varied and in the *all in* position, maximum plate current exists. Naturally, the larger the plate current the greater the negative bias on the 56 tube.

When the receiver employing this system is tuned off-resonance, the negative bias between 1 and 2 reduces to zero and the plate current of the muter tube is at maximum. This in turn blocks the A.F. tube. The presence of noise signals tends to make the potential across points 1 and 2 slightly negative. Now by reducing R_1 so that the noise is just heard and then increasing R_1 slightly, the muter can be made to just cut off the noise. The higher the noise level, the greater must be the screen grid voltage. R_1 is usually set for the noise level of the locality and shorted out manually whenever DX signals are desired.

In the system to be described next, used by the Atwater-Kent Manufacturing Company, the A.F. tube is made inactive by reducing the plate voltage* of the first A.F. tube when the set is tuned off-resonance. The muting tube is adjusted so that the plate voltage will rise sharply when operated by a C bias just below the cut-off value. Referring to Fig. 26, you will observe that a 55 duo-diode-triode is used. The secondary of the I.F. transformer feeds the

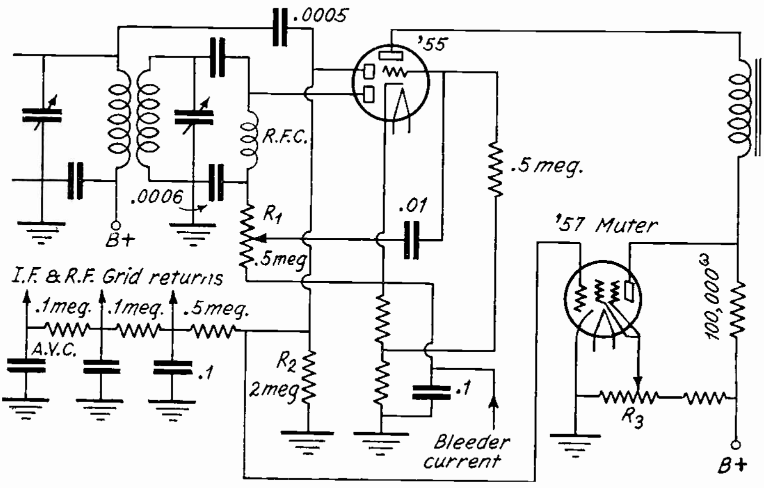

Fig. 26

detector diode and the A.F. voltage produced across R_1 is used to feed the triode system within the 55. The R.F. voltage across the primary of the I.F. transformer feeds the A.V.C. diode, and the D.C. potential across R_2 is the control voltage. The entire voltage across R_2 controls the 57 muter. Observe that the plate of the 55 and the plate of the 57 connect to the B+ supply through a 100,000 ohm resistor. When the muter tube is at a low negative or zero bias, it will draw a large plate current which must flow through this .1 megohm resistor. Thus, the voltage applied to the 55 plate is reduced sharply.

If the set is tuned off-resonance, the negative potential across R_2 is zero (assuming no noise signal). The plate current of the 57 muter is high and

* In some isolated cases where screen grid audio amplifiers are used the muter may control the screen voltage.

the B voltage to the 55 triode will be low, rendering the latter inactive. With the presence of a noise signal, the voltage across R_2 is of definite value. If this negative bias fed to the 57 tube is sufficient to cut off the plate current in the latter tube, noise will be heard. By varying R_3 (changing the E_g-I_p characteristic) so that the bias is below the cut-off value, the muter will draw current and thus make the set inoperative. The system is successful because E_g-I_p characteristic of a 57 tube is very steep once the grid excitation is less than the cut-off grid bias.

A very ingenious muting system has been introduced into Lyric sets, working on the assumption that even with a tuning meter the set owner rarely bothers to tune in correctly. With their system of off-resonance noise suppression, they also compel the operator to tune to within 2 kc. of the center of the carrier and thus automatically assure correct tuning. Briefly, they precede their muting tube with a tuned input detector loosely coupled to the last

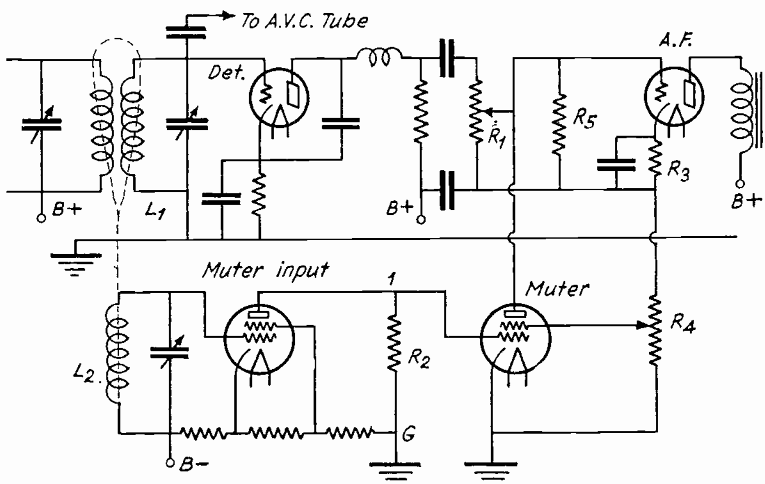

Fig. 27

I.F. coupler. When the set is off-resonance, the muter input receives no carrier and blocks the audio system. When the carrier is tuned in, it is not sufficient to tune roughly but to within at least 2 kc. and then the muter input feeds enough control potential to make the muter unlock the A.F. amplifier.

Referring to Fig. 27, note that the coil L_1 feeds the detector and the latter feeds an A.F. signal controlled by the potentiometer R_1 to the A.F. tube. L_2 is weakly coupled to the magnetic flux which couples L_1 to its primary. In this way, the muter input receives a carrier signal which is only appreciable in strength when the carrier is tuned by the preceding system exactly to resonance. The muter input tube plate is grounded through a high resistance R_2 and its grid is connected directly to the $-B$ voltage. Of course, the plate is at a positive potential with respect to the cathode and its potential is substantially that of the ground with no signal on the grid. The drop across R_2 is the negative bias for the muter and is nearly zero for off-resonance adjustment of the set, because the muter input is operated as a C bias detector and the plate current is then zero.

Now let us analyze the A.F. tube circuits. Trace from the $B+$ supply to the plate, through the bias resistor R_3, resistor R_4, to ground. Only a portion of the voltage between $B+$ and ground is intended for the A.F. tube. A portion of the voltage across R_4 supplies the screen grid voltage of the muter and the voltage across R_4 is the plate voltage of the same tube reduced by the drop in R_5. The drop in R_5 also increases the normal bias of the A.F. tube (drop across R_3), and if large enough will make the A.F. tube inactive.

The set is tuned to resonance and when within 2 kc., the input is sufficient to cause the plate current of the muter input to rise (C bias detection). The voltage drop across R_2 increases, making point 1 more negative with respect to ground. This in turn decreases the plate current in the muter. The current in R_5 reduces, cutting down the negative bias of the A.F. tube and thus unblocking the audio system. Fig. 27 does not show the A.V.C. tube and its associated circuits because it would complicate the explanation of this

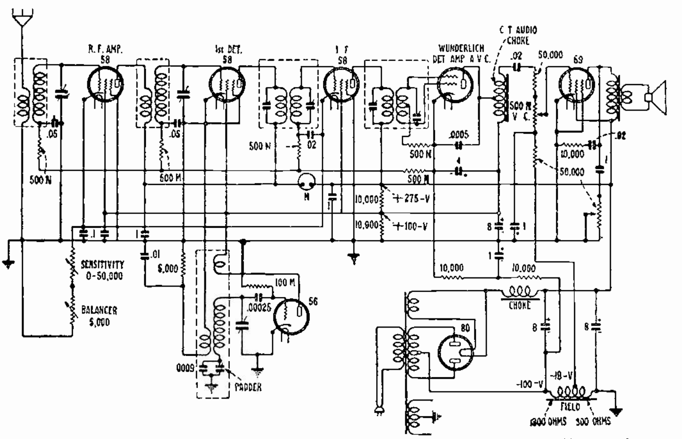

FIG. 28 *Courtesy Radio Engineering*

unique muter system. It is used, and is essential if the muter input is to feed the muter with substantially the same negative bias for all signals, weak and strong.

Simplified circuits with amplified A.V.C. and inter-carrier noise suppression: The circuit shown in Fig. 18 is unique in that the adjustment of potentiometer R_1 has the desirable effect of controlling the amount of signal input required to give rated threshold output. As contact *2* or R_1 is moved toward point 3 (increasing the initial negative bias), the initial input sensitivity of the receiver is reduced. Referring to Fig. 17, curve *a* (ideal A.V.C.), we are adjusting the receiver in such a way, that the power characteristic will be to the right of the curve shown and will produce a condition where the output of the receiver at low signal input will be very low. From a practical point of view we have introduced a simple inter-carrier noise suppressor, which some radio receiver designers prefer to the so-called tube "trigger" muters. When a receiver so designed is installed in the home, potentiometer R_1 is adjusted for minimum off resonance noise for that locality. The one disadvantage of this system is that the threshold output takes place at a higher signal input.

This principle of inter-carrier noise suppression is utilized in the circuit shown in Fig. 28, a simple 7-tube superheterodyne with unusual characteristics. The control consisting of a $50{,}000^{\omega}$ resistor (designated sensitivity) in series with a $5{,}000^{\omega}$ resistor (designated balancer) both variable, are shown below the antenna coupler. With no signal input, the initial C bias to the R.F. and I.F. tubes is adjusted for no noise output. The resistor referred to as the balancer is mounted on the chassis, so that the noise level of a given installation may be balanced out.

The circuit shown in Fig. 28, developed by Norman E. Wunderlich, employs a unique amplified A.V.C. and consequently gives a very flat power characteristic once the threshold conditions have been reached. The A.V.C. potential is obtained in the plate circuit of the Wunderlich detector tube. Observe that the cathode of this tube leads through two 10,000 ohm resistors to the highest negative point in the power supply, —100 volts. This voltage is produced across the field coil of the dynamic speaker. As a large current flows through the coil, any variation in the tube circuit currents will not materially affect this drop. Note that one end is grounded (placed at zero potential), thus making the other end —100 volts. A portion of this drops, —18 volts, serving as the C bias for the power output tube.

The plate of the Wunderlich tube is connected through the auto-transformer (C.T. audio choke) to a potential of +100 volts. Let us say that with zero bias applied to the tube, a current of 5 ma. will flow through the plate circuit. This current flows from the cathode through the two 10,000 ohm resistors, giving rise to a 100 volt drop. As the current flows from the cathode to the ground, the cathode will be at a potential of +100 volts with respect to the —100 volt terminal. The net voltage from the cathode to ground will be zero. (In practice, the cathode series resistor should be chosen to make the net cathode to ground voltage zero with no input signal.) This cathode to ground potential is the A.V.C. voltage applied to the controlled tubes, in this case through 500,000 ohm resistors, and as it is zero the initial bias on the controlled tubes will be furnished by the drop in the sensitivity and balancer resistors.

As a signal is tuned in, the usual full wave detector action takes place in the grid circuit and the A.F. signal appearing in the plate is stepped up by the auto-transformer feeding into the power output tube, through the manual sound level control. At the same time the D.C. plate current in the detector tube decreases, cutting down the IR drop in the two 10,000 ohm resistors. The net cathode-ground potential, therefore, approaches with increased signal input, a maximum of —100 volts. Because this A.V.C. potential is produced in the plate circuit, it is at least ten times as great as the usual D.C. potential in the grid circuit. This circuit is an improvement over the method shown in Fig. 10.

POWER AUDIO AMPLIFIERS
POWER LEVEL

34X

REFERENCE BOOK

PIONEER HOME STUDY RADIO SCHOOL

NRI

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

PUTTING YOUR IDEAS ACROSS

I cannot stress too greatly the importance of getting along with people. Your success depends to a great extent upon whether you can put your ideas across—whether you can sell yourself, your services and your products to others; in these things strategy will be one of your biggest aids. All successful executives use strategy, consciously or not, in putting their ideas across to their associates, employees, friends or even strangers.

You can win the good will of people and gain their attention by asking them to do a favor which they will enjoy granting—particularly favors touching on one of their hobbies or special interests. Get them to talk about their own affairs and opinions, encouraging them with questions which they will enjoy answering.

Oftentimes it is possible to put your idea across by merely suggesting it and letting others take the credit for originating the idea.

Take pains to show people that you consider them important—that you are genuinely interested in them—and you will have more influence than if you tried to impress them with your own importance.

Try to discover in advance the objections which people have to your proposals, and take these into account when presenting your ideas.

An argument is nearly always useless and often harmful. It is far better to get your ideas accepted in such a way that others do not have to admit they were wrong.

J. E. Smith.

NATIONAL RADIO INSTITUTE

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Power Audio Amplifiers

DISTORTION

Speech and music consist of many fundamental frequencies and with each are associated many harmonics and overtones. The intensities of the fundamental frequencies and their harmonics, and the distribution of harmonic and overtone energy differs widely for various persons and instruments, even though each may say the same word or sound the same note. It is this radical difference which makes possible identification of a voice or an instrument and determines the quality of the sound.

No matter how many frequencies are involved in a musical program, or in fact, any sound transmission, the electrical amplifying system must not alter a single one of these frequencies in the least. At any rate, this is the goal of all audio amplifier designers—amplification of the whole audible frequency range without altering the intensity of any frequency or frequencies with respect to the other frequencies and the original, both at low and high frequencies.

We have learned from previous study that a complex sound wave or its equivalent electrical current can be resolved into a number of sine waves* and a steady or D.C. component. It is important that the output signal of a transmission or amplification system have a wave form identical to the original input wave form, otherwise distortion exists. The three types of distortion, which may be present are:

1. Shift of phase of the components.
2. Unequal amplification of the frequencies which make up the characteristic sounds.
3. Introduction of frequency components in the output wave which did not exist in the input wave.

Phase shifting is by no means new, as we studied this subject in connection with impedances in A.C. circuits. We learned that a capacity in a series circuit tended to make the current lead the applied voltage while an inductance tended to make the current lag the applied voltage.

Fortunately the ear takes no note of phase shift, for it responds only to the intensity and frequency (pitch) of the sound components. In considering audio amplification we may dismiss the problem of phase shift. When dealing with currents which are to be converted into visual patterns, as in television or oscillograph systems, distortion due to phase shifting is important. In the latter case, the impedances of the involved circuits must be made negligible. As we are concerned only with audio amplification we will not discuss phase shift any further.

It has been proved theoretically as well as practically that unequal amplification of signals at various frequencies is not due to the speed of electrons in a vacuum tube or to the action of any of the electrodes (cathode, grids and plate) on the electron stream. The fact that a vacuum tube amplifier will amplify one frequency better than another, is, as you know, due to the characteristics of the input (grid) and output (plate) circuits of the amplifier. This phase of the subject is important. You may find this type of distortion referred to as "selective attenuation."

The third type of distortion, often called amplitude distortion, is generally due to the character of the vacuum tube. When the E_g-I_p characteristic is not linear (a straight line), the output wave form is not identical to the

*For any group of frequencies the components need not be in phase when compared to zero amplitude time of the fundamental.

input wave form. For this reason, frequencies appear in the output which are not present in the input. Amplitude distortion may be due to a non-linear output or input device, for example, a transformer or a choke with an iron core operated so distortion due to saturation or hysteresis is present. Again, if the grid circuit of a vacuum tube draws current in a non-linear manner, the input device contributes its share of amplitude distortion. Practical audio amplifiers must be designed so that these effects are negligible or partially balanced out so they become negligible.

PRELIMINARY CONCEPTS

In the discussion of practical amplifiers it is not feasible to consider all components in the wave form at one time. It is well established (proved mathematically) that in any linear electrical circuit (*one in which the current is always proportional to the voltage*) that the effect of each component in the original wave form may be considered separately and the output considered merely as the sum of the effects. This is often referred to as the principle of *Superposition*. For example, a complex voltage found to contain 10 volts D.C., 20 volts at 60 c.p.s. and 5 volts at 120 c.p.s. is connected to a 5 ohm resistor. If we were to analyze the current wave we would find that it contained 2 amperes of D.C., 4 amperes of 60 c.p.s. current and 1 ampere of 120 c.p.s. current. Note that we could derive the same fact if we considered that each voltage existed and acted alone in the circuit.

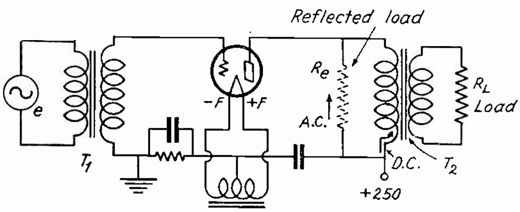

FIG. 1

This principle holds for circuits and transmission lines where the electrical values of inductance, capacity and resistance of the various parts of the circuit do not change regardless of the value of voltage, current or frequency. This ideal condition is nearly always assumed at the start, in considering radio and electrical circuits. The use of vacuum tubes, iron core chokes, transformers, and resistors which change their value as the current flowing changes, make a simple treatment of the circuit impossible. It is for this reason that a discussion of radio circuits using the principle of superposition will not bring out the effects which often appear in practice.

In dealing with actual vacuum tube amplifiers it is customary to consider a pure sine wave input of a single frequency and determine, usually graphically, the effect of the system on the output wave form. If a band of frequencies is involved, let us say 30 to 10,000 c.p.s., then the analysis should be repeated for a number of frequencies within the band, for example: 30, 100, 500, etc.

Many assumptions are made in radio to simplify the process of circuit analysis, but we should be aware of these assumptions. The assumption that the plate load of a vacuum tube is treated as a resistance, the μ of a tube is fixed, and that the dynamic plate resistance is a constant, are typical.

All simple formulas used in the design of vacuum tube amplifiers are based on the assumption that the principle of superposition holds true. This is a reasonable assumption with class A amplifiers (low distortion amplifiers), but not so safely applied in other types of amplifiers unless the distorting effects are balanced out or otherwise made negligible. Graphical analysis is generally used as it gives a true picture of the state of affairs. With these facts in mind we may proceed to analyze the usual power audio amplifiers.

SINGLE TRIODE AMPLIFIERS

Second harmonic distortion: An E_g-I_p curve is perhaps the most useful tube characteristic in determining graphically the output wave form for a given input wave form. Do not make the mistake of using the E_g-I_p curve of the tube for no plate load.

In another part of our course we learned how to obtain the dynamic E_g-I_p curves from a family of plate characteristics and an assumed resistance as the plate load. Such a treatment is possible with a circuit using a transformer feeding a resistance load, if we assume that the load in the secondary of T_2, Fig. 1, is reflected across the primary. It is assumed that the resistance

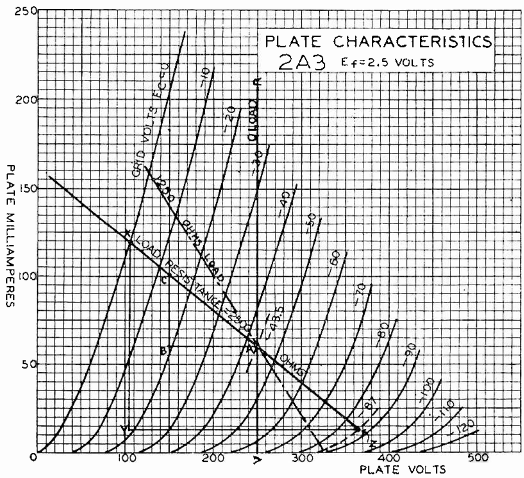

FIG. 2

of the primary and secondary is negligible and the inductance of the primary and secondary is large and there is no magnetic leakage. This is the condition for an ideal transformer which is assumed in practice as an initial start in analyzing a transformer circuit.

With no grid excitation the net plate-cathode voltage is equal to the supply voltage, there being no drop in the primary of the transformer. Referring to Fig. 1, the primary passes the D.C., but the plate circuit has as its load a reflected resistance R_e, shunted by the reactance of primary which is extremely high. Thus the load is essentially R_e. This is the usual assumption in dealing with transformer coupled outputs.

A family of plate characteristic curves for a 2A3 triode tube, is given in Fig. 2. This tube is intended to operate with a filament voltage of 2.5 volts A.C., a plate voltage of 250 volts, and a -45 volt C bias voltage measured from the center of the filament. The C bias with respect to the $-$ F terminal is approximately -43.5 volts. This sets the operating point at A. It is now possible to select a load which will give the least amplitude distortion. Several load lines should be drawn. Line XZ is the 2500 ohm load line. In this case the value of AB in volts divided by the value of BC in amperes is the A.C. load resistance, that is, 100 volts divided by .040 ampere equals 2500 ohms. The vertical line VR is the zero ohm load line. The dash dot load line is for a 1,250 ohm load.*

It is now possible to draw the corresponding dynamic and static E_g-I_p curves as in Fig. 3. It should be clear from Fig. 3 that as the load resistance is increased, the E_g-I_p mutual characteristic straightens out—becomes a linear characteristic. If you were to analyze Fig. 2 for large and small ohmic loads you would find that the voltage across the load varied to a larger degree for high ohmic loads than for low assumed loads. This is the reason for using high resistive loads in voltage amplifiers. As the load resistance is made lower, the current variation through the load resistance becomes larger. For power amplifiers the voltage and current variations must be such that the product (multiplication) of both is a maximum.

Power amplifiers are primarily intended to give the maximum power output with the least distortion. Both facts may be determined from Fig. 2. Assume a sine wave input voltage.

(1) $P = \frac{1}{8}(E_z - E_y)(I_x - I_y)\dagger$ (Power output in milliwatts)

(2) $D_2 = \frac{\frac{1}{2}(I_x + I_z) - I_a}{I_x - I_y} \times 100$ (Percentage of second harmonic with respect to fundamental)

Formulas (1) and (2) are constantly used to determine the best load for any tube under a given operating condition. Of course, the best load is worked out by the tube manufacturer. We, of course, want to know how they made these calculations so that the operation of tubes will be clear. Both the 1250 and 2500 ohm cases for a grid variation equal to the C bias are worked out as follows.

1250 *Ohms*

$$P = \frac{1}{8}(324 - 126)(158 - 2)$$
$$= \frac{1}{8} \times 198 \times 156$$
$$= 3860 \text{ milliwatts}$$
$$D_2 = \frac{\frac{1}{2}(158 + 2) - 60}{158 - 2} \times 100$$
$$= \frac{80 - 60}{156} \times 100$$
$$= 12.8\%\ddagger$$

2500 *Ohms*

$$P = \frac{1}{8}(364 - 105)(120 - 13)$$
$$= \frac{1}{8} \times 259 \times 107$$
$$= 3460 \text{ milliwatts}$$
$$D_2 = \frac{\frac{1}{2}(120 + 13) - 60}{120 - 13} \times 100$$
$$= \frac{66.5 - 60}{107} \times 100$$
$$= 6.1\%\ddagger$$

These simple calculations show that although a 1,250 ohm load gives more power output than a 2,500 ohm load—about 11.5 per cent—the second

* For a given transformer the relation between R_e and R_L is that R_e = Turn ratio × Turn ratio × R_L. Call the step-down ratio T_R, then $T_R = \sqrt{\frac{R_e}{R_L}}$ This permits the selection of the correct transformer knowing R_e and R_L.

† In certain amplifiers, called drivers, the peak power is important. The peak power is merely $\frac{E_z - E_y}{2} \times \frac{I_x - I_y}{2}$ milliwatts. Subscripts x, y and z of the letters E and I refer to the voltage and current at points x, y and z in Fig. 2.

‡ All calculations in this text were made on a slide rule for practical answers.

harmonic distortion is more than twice as much. The maximum undistorted output is derived only by this trial method, using a large number of load lines having, in the case of triodes, values near that of the tube's A.C. plate resistance. Of course, the maximum output is obtained when the load resistance equals the tube dynamic plate resistance. Although we have considered only the second harmonic, the odd and the other even harmonics will be present but to a degree negligible in comparison to the second.

Grid swinging positive: In Fig. 2 the grid to (— F) voltage with no grid excitation is set by the operating point A, in this case — 43.5 volts. We assumed that a sine wave voltage applied to the input having a peak value of 43.5. Thus the grid varies from 0 to — 87 volts or we may say that the grid swing is 87 volts. Quite often one-half this variation is called the half grid swing. In the previous discussion the grid swing was limited to 87 volts

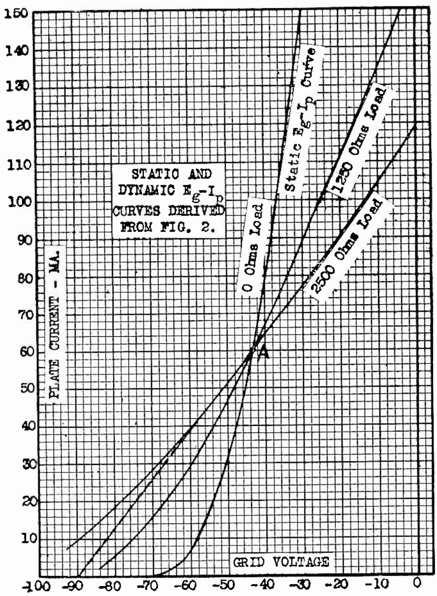

Fig. 3

to prevent the grid from being positively charged and to give the least distortion due to E_g-I_p curvature. Let us look at the problem graphically.

For a given plate load there is a definite dynamic E_g-I_p curve. The operating point is determined by the C bias and the grid swing determined by the grid excitation. These two factors have considerable bearing on the output wave form. Referring to a typical dynamic E_g-I_p curve as shown in Fig. 4, observe that point *1* is the operating point, line *02* is the zero bias line, and S is the grid swing. *S/2* is the half grid swing and is equal to the peak grid A.C. voltage. Of course, most A.C. voltages are measured in r.m.s. (root mean square) values. Therefore,

(3) $E_{\text{peak}} = 1.41 \times E_{\text{r.m.s.}}$ and

(4) $S = 2.82 \times E_{\text{r.m.s.}}$ grid swing

For all practical purposes the swing S should be restricted to the straight portion of the mutual (E_g-I_p) characteristic. If an A.C. voltage is applied so that the peak voltage is not greater than the value between points *1* and *2* as shown in Fig. 4, clearly the operation is confined solely to the linear portion of the mutual characteristic and the grid never becomes positively charged. But if the peak voltage is allowed to extend from *1* past *2*, we find that although the operation takes place over the linear portion of the mutual characteristic, the swing extends into the positive grid region. Of course, grid current will flow in the input circuit. Figure 5 shows how the grid current may vary for positive values of grid-cathode voltage.

Referring to Fig. 1, if e (r.m.s. value) is the original signal which is stepped up by the transformer T_1, the secondary voltage is the voltage applied to the grid. The grid swing as indicated by S in Fig. 4 will be 2.82 times greater than this secondary voltage. As long as the swing is confined to the linear portion of the mutual characteristic and no grid current flows, the wave form of the plate current is identical to that of e.

It is customary to consider this grid input as a supply having a voltage

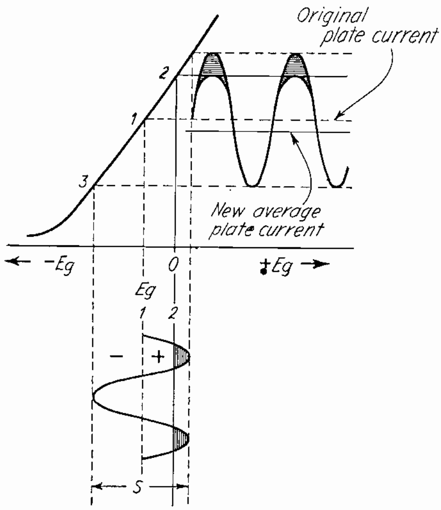

Fig. 4

fed through an impedance. Obviously, when no grid current flows, the voltage applied to the grid-cathode of the tube is not affected by the presence of the impedance. When current flows through the secondary, the net grid-cathode voltage is the induced secondary voltage less the drop in the impedance. The impressed grid voltage instead of following the original wave form is cut off when the grid draws current, as shown by the shaded area in the E_g curve in Fig. 4. This in turn reduces the plate current on positive excursions of the grid voltage as shown by the shaded area of the I_p curve. Here is a case of amplitude distortion, resulting in harmonics which did not exist in the original.

This type of distortion is easily detected by placing a D.C. milliammeter in the plate circuit. If the plate current decreases in value after the grid is excited, then it is generally accepted that grid current is distorting the wave form. The reason for the decrease in average plate current is obvious when we estimate in Fig. 4, the average D.C. current before and after grid excitation.

Tubes may operate with grid current and still have negligible distortion. It is customary to design transformer T_1, shown in Fig. 1, so that the equivalent secondary impedance is low and the consequent drop negligible. Knowing how this is done is important. Usually the plate circuit of a voltage amplifier feeds into T_1. Then the grid-cathode behaves as a load whose resistance R_g is $\Delta e_g / \Delta i_g$ that is, the reciprocal of the slope of the E_g-I_g curve.* Note that at any grid voltage the dynamic grid-cathode resistance is equal to a small change in grid voltage divided by the corresponding change in grid current. Obviously the dynamic grid resistance varies throughout the complete voltage range. From *0* to *a*, Fig. 5, the resistance is positive in value; at *a* the resistance is extremely large and from *a* to *b* the resistance has a negative value. In practice where the grid does not swing as far as point *a*, the smallest grid resistance is approximately equal to $E_g \div I_g$, considering E_g and I_g the maximum operating values.

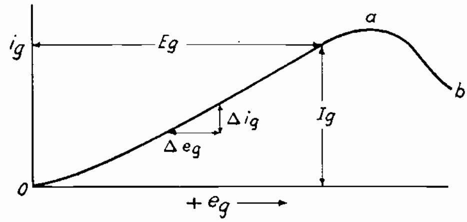

FIG. 5

Let us further say that the voltage in the plate of a voltage amplifier is μe_{g1}, where e_{g1} is the grid voltage applied to the voltage amplifier, μ its amplification factor; and r_p its plate resistance. We may replace the input circuit of Fig. 1 by the circuit shown in Fig. 6a. If T_1 is an ideal transformer, we may replace the circuit shown in Fig. 6a with its equivalent shown in Fig. 6b. T_R is the ratio between the secondary and primary turns.

This last transformation is worth remembering. A transformer produces a secondary voltage in proportion to its turn ratio, and reflects the source resistance into the secondary circuit by the square of the turn ratio

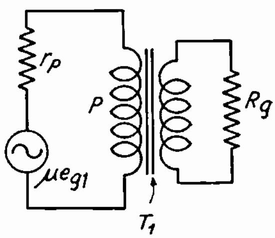

FIG. 6a

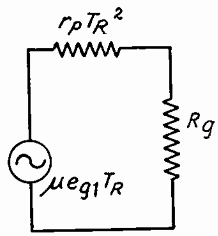

FIG. 6b

(T_R^2). When the grid current I_g flows in the circuit shown in Fig. 6b, the voltage $\mu e_{g1} T_R$ is reduced by the drop $I_g r_p T_R^2$.

If T_1 is a step-up transformer, that is, the secondary has more turns than the primary (plate coil of the voltage amplifier), the secondary voltage and equivalent resistance will be increased, the resistance, of course, much more than the voltage. On the other hand, should a step-down transformer be used, the voltage and equivalent resistance will be reduced, the latter much more than the voltage. Here we have an answer to reducing the wave form distortion due to a varying load R_g to negligible proportions. If a step-

* See Fig. 5. The symbol Δ is often used to denote a small change. Thus Δe_g means a small change in grid voltage.

down transformer is used we naturally reduce the voltage available to excite the output tube, but we cut down to a far greater extent the distortion due to the input voltage drop. We can compensate for the lowered voltage by using greater amplification ahead of the voltage amplifier.

We should not call the tube ahead of the output tube a voltage amplifier. It supplies power to the grid of the output tube and the peak power is equal to $E_g \times I_g$. This tube drives the grid of the power tube and for this reason is called a *driver* tube. The driver should be able to supply the peak power without introducing its own distortion. For example, in Fig. 5, if E_g is the maximum positive grid excursion and I_g is the resultant grid current, the driver must be able to supply a peak load of $E_g \times I_g$ with negligible distortion. Consider an imaginary case. Suppose the grid swings to +40 volts and the grid current is 5 milliamperes. Then the peak power required is 200 milliwatts, and a driver tube must be chosen to give this power with negligible distortion.

To eliminate the distortion due to the IR drop in the output of the coupling transformer, we would require an extremely high ratio step-down transformer. Of course, this is impracticable as the grid voltage would become extremely low. Suppose we say that we can tolerate a drop of 5 volts, that is, the grid swings to +35 while the source swings to +40 volts. The allowable reflected secondary resistance is thus 5/.005 or 1,000 ohms.

A driver stage is required which will supply at least 200 milliwatts and the coupling transformer must reduce the plate resistance of the driver to 1,000 ohms. Consider, for example, the drivers shown in the table on page 23. A single '27 tube operated at 200 volts and operating with a recommended peak plate load of 23,000 ohms will deliver 500 milliwatts and will more than suffice. The transformer should have the following step-down ratio.

$$T_R = \sqrt{\frac{23{,}000}{1{,}000}} = \sqrt{23} = 4.8$$

Grid swinging too far negative: If an amplifier tube is operated with a high negative bias, we obtain a condition as represented in Fig. 7. The bias is set by E_1 and *1* is the operating point. The grid swings from points *3* to *2* and even though confined to the negative portion of the mutual characteristic, distortion will appear due to the bend in the characteristic from *3* to *1*. Note that with a sine wave input voltage E_g, the wave form of the plate current is flattened at the low plate current values.

Distortion of this type has the effect of increasing the average D.C. plate current and a D.C. milliammeter placed in plate circuit will increase when the grid is excited. This effect may be removed by: using a lower C bias, if the excitation is not too great; increasing the plate voltage, if the tube will stand a greater plate loss; or by using a higher ohmic load, if reduced power will not be objectionable.

Quite often the practical man is confronted with replacing a bias resistor in a tube circuit when he does not know the bias resistor value or the bias voltage. From what has been discussed, he can adjust the bias to the value which gives the least distortion. This is naturally the best bias for the existing load conditions. A variable resistor is inserted in place of the defective bias resistor and a D.C. milliammeter is connected into the plate circuit. The tube is excited with a reasonably large value of grid voltage* and the resistor value is varied so that the plate current reading is as near the non-grid excited value as possible. The grid excitation should be reduced to see that the resistor setting is suitable for low excitation. Measure the resistor with an ohmmeter and substitute a fixed resistor of the measured value.

*A grid voltage having a root mean square value approximately equal to the plate voltage divided by 3 times the μ of the tube.

DEFINITION OF CLASS A, A′, B AND C AMPLIFIERS

Radio men must have a common understanding of tube operation and for reference purposes a given tube operation should be referred to in a simple conventional manner. Amplifiers are classified by the operating characteristics into class A, A′ (read A prime) B and C amplifiers. It is important that you understand what these classifications mean.

Class A amplifiers operate so that the plate current wave form is essentially that of the grid excitation wave shape. Our discussion so far has been confined to this type of operation. Remember that we considered the no-grid-current and the grid-current cases. By common practice it is agreed that class A operation is the one where the C bias, load resistance and grid excitation is so chosen that the grid never becomes positive and the tube operates over the linear portion of the mutual characteristic. The second harmonic distortion must not exceed 5 per cent. Class A amplifiers are extremely inefficient, rarely over 30 per cent in practice. The efficiency of a tube may be determined by dividing the maximum undistorted power as given by the manufacturer by the power input (normal D.C. plate voltage × normal D.C. plate current). To change to per cent efficiency, multiply by 100. Here are three commonly used class A operated tubes and their efficiencies.

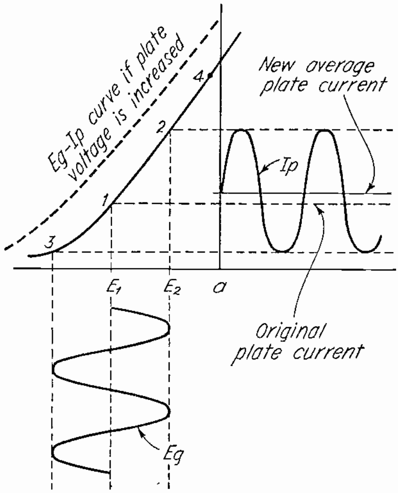

FIG. 7

'45	'47	2A3
$\text{Eff} = \dfrac{1600 \times 100}{250 \times 34}$	$= \dfrac{2500 \times 100}{250 \times 31}$	$= \dfrac{3500 \times 100}{250 \times 60}$
$= 18.8\%$	$= 32.3\%$	$= 23.3\%$

These examples indicate that the '47 pentode is the most efficient and triodes the least efficient. The 2A3 is a special multi-filament triode tube and its efficiency is unusually high when compared with regular triode power tubes.

Class A′ amplifiers differ from the class A type in that the grid is allowed to swing positive over its linear portion of the mutual characteristic. We have already learned how the distortion due to grid current is made negligible. It is interesting to note that class A′ operation has been referred to as class A″ (double prime), class A‴ (triple prime), class AA, class AAA, extended class A and modified class A. All the same for your information.

To operate in class A′ fashion, a low negative grid bias is used and the grid is fed with an excitation large enough to swing the grid positive, but not negative enough to include the lower bend of the E_g-I_p dynamic characteristic. In this way greater tube efficiency is obtained. Referring to Fig. 2, 2,500 ohm line, suppose the operating point is set by a bias of —30 volts and the grid swings 100 volts or from +20 to −80 volts. When the grid swings from −30 to −80 volts, the plate voltage varies from 206 to 352 and the plate current varies from 77 to 19 milliamperes. Assume the same plate change when the grid swings from −30 to +30 volts. The plate voltage variation is then 2(352 − 206) equal to 292 volts and the plate current variation is 2(77 − 19) equal to 116 milliamperes. The power output in milliwatts is ⅛ x plate voltage variation x plate current variation, and in this case equal to ⅛ x 292 x 116, equal to 4,230 milliwatts, the *apparent* efficiency is 100 × 4,230 ÷ 15,900 * equal to 26.6 per cent. We said apparent efficiency because the amplifier requires input power to operate it.

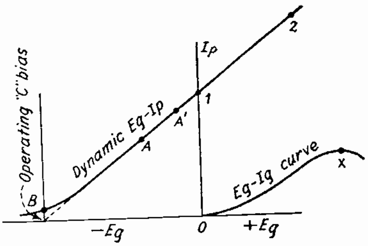

FIG. 8a

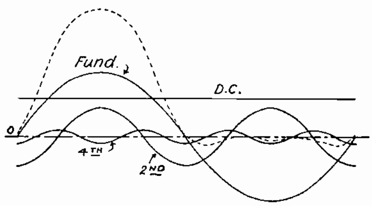

FIG. 8b

The ratio of the power output to the power input is called the power amplification. It is roughly proportional to the square of the amplification factor and inversely proportional to the tube plate resistance. That is, a tube with a high μ and a low plate resistance will have a high power amplification.

Class B amplifiers are defined as operating so the power output is proportional to the square of the grid excitation which is another way of saying that the plate current is proportional to the grid voltage. Class B amplifiers are, therefore, called *linear* amplifiers. If a grid swing of 50 volts gives, let us say, 4 watts output, a grid swing of 100 volts will give 4 × 4 or 16 watts output. Such operation is realized by operating the tube with a negative grid bias such that the plate current is almost zero with no excitation. This is best understood by referring to the dynamic E_g-I_p curve in Fig. 8a. *A* is the operating point for class A, *A′* the operating point for class A′, and *B* the apparent cut-off point and the C bias voltage for class B operation, (which is roughly the plate voltage divided by the μ of tube).

If a sine wave voltage is applied to a class B amplifier, positive grid excitation will produce a plate current having a wave form essentially identical to the input wave form. With negative grid excitation practically no

*Average plate input power for —30 volts *C* bias operation, which is 206 × 77 = 15,900 milliwatts.

plate current can flow as the operating point is practically at the cut-off point of the mutual characteristic. Obviously a single tube class B stage is of no value for audio amplification as one-half of the output wave form has been destroyed. The plate current has a wave shape similar to that obtained from a half wave rectifier. A half sine wave may be considered to have a D.C., fundamental (frequency equal to that of the grid input), a second, fourth and other even harmonics. Figure 8b shows graphically how a D.C., fundamental, second, fourth, sixth and other even harmonics which start out of phase with the fundamental add up to give a half sine wave (dotted curve).

A class B amplifier may be used in radio frequency amplifiers, especially transmitter circuits, if the plate load is a parallel resonant circuit tuned to the fundamental frequency. In this way the resonant circuit offers a high resistance to the fundamental frequency, producing a large fundamental frequency voltage, and very low impedance to all harmonics, producing low applied tank voltage. These amplifiers are of value in R.F. power amplification because of their high efficiency. This should be clear when we realize that the tube draws practically no plate current when there is no grid excitation. Input plate power is required only when output plate power is drawn.

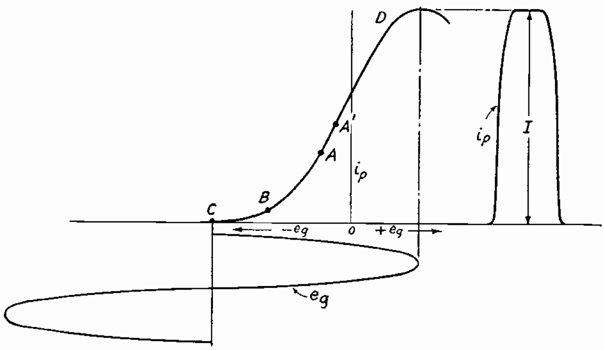

FIG. 9

Again referring to Fig. 8a, we see that as long as the grid swing is limited to the negative portion of the mutual characteristic, no grid current flows and therefore no input distortion can take place. When the grid swings positive as is usually the case, distortion takes place which, although removed by the resonant tank circuit, does cut down the efficiency of operation. It is important that the positive grid swing is limited to a value below which the grid current decreases (*X* in Fig. 8a). Operation beyond this point may start self-oscillation * in the amplifier even if it is neutralized.

Self or automatic bias cannot be used in class B amplifier. The plate current in varying from zero to maximum, with grid excitation (case where modulation exists) is not readily filtered to assume a fixed value. As it is important that the operating point remain fixed, it is customary to use C batteries, grid voltage generators, the output of an oscillator rectified and filtered, or a special power pack. The C bias supply is placed in the grid circuit. If the grid excitation is limited to the negative portion of the mutual characteristic, the C voltage supply may have any impedance. Should grid current

*Due to dynatron action.

flow, it is important that the supply have a low resistance, otherwise grid current will change the applied C bias.

Class B amplifiers are now used in audio signal amplifiers by the simple expedient of using two class B amplifiers, one operating only on the positive alternation of the grid voltage and the other tube operating only on the negative grid voltage alternation. Thus two half sine wave currents are formed in the common plate circuit to give a pure sine wave current. We will shortly discuss this circuit in greater detail.

Class C amplifier operation is obtained when the A.C. power output varies substantially as the square of the plate voltage. For example, if 40 watts output is obtained operating with 1,000 volts on the plate, the use of 2,000 volts on the plate raises the output to 160 watts. Although this amplifier is not used in audio signal amplifiers, we are including a discussion of it for completeness. Class C amplifiers may be used in power R.F. amplifiers where harmonics may be filtered out of the output by a tuned load circuit, in high efficiency oscillators and when harmonics are desirable, and in a tuned R.F. amplifier following a crystal oscillator where harmonics are desirable for

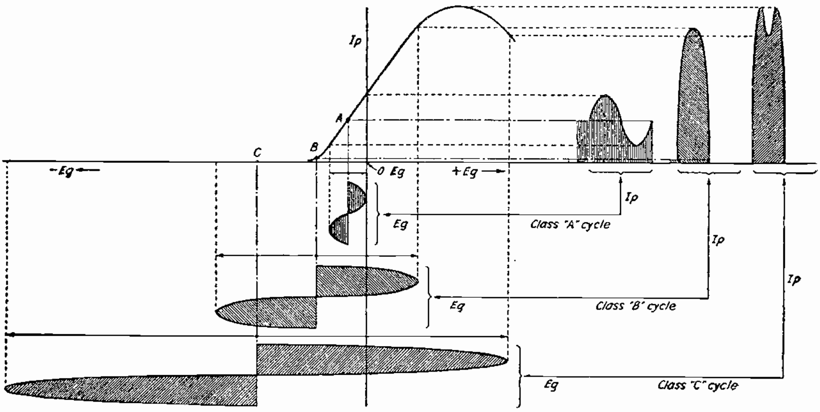

FIG. 10

frequency multiplying systems. It is especially valuable as the modulated amplifier in transmitters.

Figure 9 gives a graphical representation of such operation. The C bias is much greater than for class B and the grid excitation is extremely large. The result is that plate current flows for only a portion of the positive alternation, and has a substantially rectangular wave form. Two peaks may appear due to a downward curvature of the dynamic E_g-I_p characteristic after saturation is reached or due to grid current cutting off the sine wave input at peaks of grid excitation. Raising the plate voltage has the effect of making the slope *BD* more perpendicular (slope up) with the result that *I*, the peak plate current, increases. This increase is nearly proportional to the plate voltage. For a given load the power output is proportional to I^2 and hence the power output is proportional to the square of the plate voltage. Class C amplifiers are useful as they have high plate output-input efficiency, and they require relatively small grid input power.

By referring to Fig. 10 you will quickly observe the difference between class A. B and C operation of amplifier tubes.

PARALLEL TUBE OPERATION

When it is desired to get more output than possible from a single tube, it is often the practice to use two or more tubes of similar characteristics in parallel. As long as the tubes are operated in a class A manner, no change need be made in the input circuit. If the grids draw current, a driver stage capable of furnishing the peak power drawn by the grids in parallel must be used. The effective driver impedance must be made low enough so as not to distort the input wave form. It is to be remembered that all grids, plates, cathodes and filament leads direct from the tubes are connected together. Quite often a resistance is placed in each grid feed line to prevent interaction of tubes. In stubborn cases, a resistance is also placed in series with each plate lead and in both cases connected into the grid and plate electrode connections.

Care must be taken in choosing a correct output transformer. As the tubes are in parallel, the net recommended load resistance is reduced to ½, ⅓, ¼, etc., that of one tube, if 2, 3, 4, etc. tubes are used. In figuring the step-down ratio of the output matching transformer, the net recommended load resistance must be considered. Example: Suppose two type 2A3 tubes are connected in parallel to give 7 watts output. The manufacturer recommends a load of 2,500 for a single tube. If a dynamic speaker of 15 ohms, which will handle 7 watts, is used, the turn ratio should be $\sqrt{\frac{2500}{2 \times 15}} = \sqrt{83.3} = 9.1$. A step-down transformer of 9 to 1 or perhaps 10 to 1 will suffice.

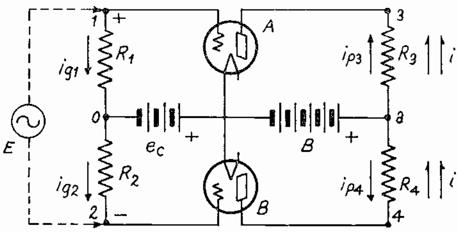

FIG. 11

Theoretically, the distortion is no more than what would be had with one tube. Practically a larger distortion will be obtained due to the inability to match tubes.

PUSH-PULL AMPLIFIERS

A push-pull amplifier as usually constructed for radio receivers consists of two tubes of the same static and dynamic characteristics, the grids being fed out of phase and the output change combining in phase. In this way the even harmonics due to tube distortion are eliminated. The odd harmonics including the fundamental remain. The third harmonic distortion must be limited to 5 per cent. It has been generally stated that a push-pull amplifier will deliver with equal distortion, as much output as 3 tubes in parallel. Two tubes in push-pull will deliver 1.5 times the amount of undistorted power as two tubes in parallel.

A resistance coupled push-pull circuit, as shown in Fig. 11, although not used for practical reasons, helps to explain the push-pull principle. When no grid excitation exists, the plate battery B sends a current i_{p3} through R_3 in the upward direction into tube A, making point *3* negative with respect to *a*.

Likewise, the current i_{p4} through R_4 to tube B makes point *4* negative with respect to *a*.* If tube A is identical to tube B, and R_3 equals R_4; then i_{p3} equals i_{p4} and the drops in R_3 and R_4 are the same. Therefore, the net voltage between *3* and *4* is zero.

Suppose a sine wave voltage E is applied to points *1* and *2* at such a time that a current flows from *1* to *0* to *2*. If R_1 is equal to R_2, the drop across R_1 will equal that across R_2. The sum of these two voltages is equal to E (the applied voltage). By convention current flows from + (point *1*) to − (point *2*). Due to these drops, *1* is positive with respect to *0*, and *2* is negative with respect to *0*. These drops must be added to the C bias e_c, to get the total grid voltage. Consider tube A. The net grid voltage is made less negative because the plus voltage across R_1 reduces the effect of the negative bias e_c. Thus the current i_{p3} is increased as shown by the double arrow. In the case of tube B, the negative drop from *0* to *2* adds to e_c which makes the plate current i_{p4} less than the static value, as shown by the adjacent double arrow. The currents i representing this increase and decrease are in the same direction,

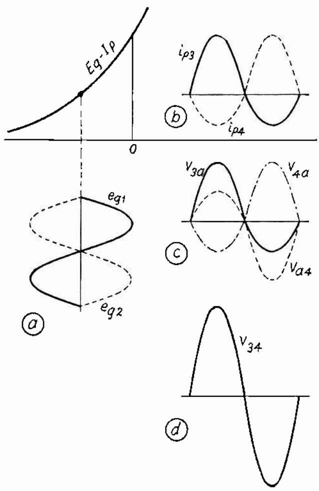

FIG. 12

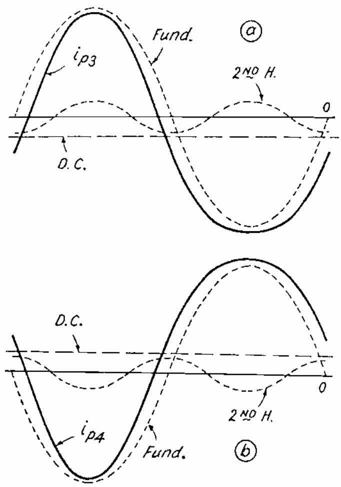

FIG. 13

so $i \times (R_3 + R_4)$ will be the net voltage measured between *3* and *4*. What we have shown is that although the respective applied grid-cathode voltage changes are out of phase, and the plate-cathode voltage variations are also out of phase; that for a given grid-to-grid input voltage a definite plate-to-plate output voltage is obtained.

Figure 12 shows the E_g-I_p curve for an assumed plate load (R_3 or R_4). For simplicity and as is usual, assume E in Fig. 11 to be a sine wave. Half this voltage e_{g1} appears across R_1, and the other half e_{g2} appears across R_2. Both are sine waves but 180 degrees out of phase as shown in Fig. 12a. The resultant plate current variations are given as i_{p3} and i_{p4}. Note that while i_{p3} is increasing, i_{p4} is decreasing and vice versa. The voltage variation between points *3* and *a* is represented in (c) as V_{3a} and the voltage variation between points *4* and *a* as V_{4a}. As we are interested in the voltage between *3* and *4*, we must add V_{3a} to V_{a4}, the latter 180 degrees out of phase with V_{4a}. Adding

*Current flows through a resistor from the + to − terminals.

V_{3a} *and* V_{a4}, we get V_{34}, as shown in (d), with the distortion observed in (b) and (c) cancelled out.

If you consider the distorted plate current waves as made up of a fundamental, a direct current component, and harmonics and then add them out of phase as we did for Fig. 12d, we would find that all the even harmonics and the D.C. component are eliminated. Graphically this may be shown as we have in Fig. 13. Note i_{p3} may be reproduced as a fundamental, a D.C. component and a second harmonic out of phase. The same is done for i_{p4}. Now when both waves are added 180 degrees out of phase, the fundamental wave doubles and the second harmonic and D.C. components are eliminated. In the same way we could show that all odd harmonics double and all even harmonics are wiped out.*

In place of resistors, chokes can be used. We can go a step farther and use transformer input and output as illustrated by Fig. 14. In the latter case the primary of transformer A induces a voltage E into the secondary. Half this voltage adds to the C bias, the other subtracts. We must fix in our mind the fact that the initial plate current flows through B and B' away from the B battery and to the plates of the two tubes. The primary turns, tracing them in the direction of current flow, are in the opposite direction, so no initial flux is produced in the core. Any simultaneous increase or decrease in the plate current has no effect on the flux, but an unbalance in one will create

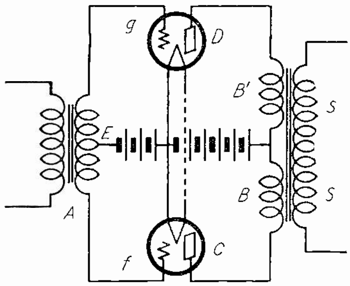

FIG. 14

flux. Now the current in B', let us say, increases and that in B decreases due to grid excitation. Thus, if one plate current increases and the other decreases, a flux variation exists which induces a voltage into the secondary S, which is twice that due to the current variation of one plate alone. Even harmonics are eliminated as we already have seen.

Push-pull amplifiers employing transformers are the most common in use, as any value of load coupled through S may be reflected into the plate circuits and may be made to match ideal tube conditions. Furthermore, the usual load, a speaker, cannot be conveniently divided in two equal parts replacing R_3 and R_4 as shown in Fig. 11, except by the use of a primary center tapped transformer. Of course, if the main object is to create a resistance loss or a voltage difference, two pure resistance loads may be employed. An output transformer provides a means of splitting a single load into two equal halves and so altering their values so that they are equal to the recommended load values for the tubes used. The input transformer provides a means of stepping up or down the initial signal voltage.

From the above discussion we deduce that a variation in plate voltage,

*If the plates of the output tubes are connected together and fed through a regular output transformer, the fundamental and odd harmonics cancel and the D.C. and even harmonics double.

due to improperly filtered rectified voltage will not induce hum because the plate currents through B and B' increase and decrease simultaneously. In a similar way a voltage variation in the C bias merely causes the plate current to increase and decrease in both sections of the output simultaneously and the effect is cancelled out. For this reason it is customary to omit the condenser across the bias resistor. Because a certain amount of ripple in the supply can be tolerated, the voltage supply connection is usually made to a point between the first and second chokes in the power pack filter system. Care must be taken that variation in the power supply due to the current swing is not introduced into the input or a previous circuit, otherwise distortion will appear.

The use of a transformer having a center tapped primary makes the load resistance appear in the entire primary as a reflected center tapped resistance. The total reflected resistance across the entire primary must be twice the value recommended for a single tube used as a class A amplifier.

It takes two tubes to make a push-pull amplifier. It is possible to use 4, 6, 8, etc., using 2, 3, 4, etc., tubes in parallel in each section. The power output is increased 2, 3, 4, etc., times with no change in percentage of distortion. More care is required in matching tubes. When figuring the turn ratio of the matching transformer, the recommended load value for 2, 3, 4, etc., tubes in parallel should be ½, ⅓, ¼, etc., that of a single tube section.

Inasmuch as the flux produced by each half of the primary of the output transformer cancels each other at zero grid excitation, producing zero core flux, it is possible to make small output transformers (small cores) and wind the primary and secondary close together, reducing substantially the leakage reactance.

A number of modified push-pull circuits have been used in practice, all of them it appears employing a special circuit to get two equal grid signals 180 degrees out of phase. Some of the schemes employed have little or no advantage over the usual method (Fig. 14) other than a designer's desire to have something different, and in other cases to use a practical method of resistance coupled input apparently for flatter audio response over the usual frequency range.

Figure 15a shows a combination transformer and resistance-capacity coupling. It is a fact that the primary input and secondary output voltages of a transformer are 180 degrees out of phase or exactly in phase, depending on the secondary connection. In this circuit, tube A is fed directly by the resistance-capacity coupling shunted across the primary and the secondary of the 1 to 1 ratio transformer is connected 180 degrees out of phase with the primary to tube B. The output transformer is of the usual type. Obviously the input signal voltage is not divided into two equal parts and, therefore, the circuit is equivalent to a 2 to 1 step-up transformer connected in the usual push-pull circuit. From a constructional point of view, low ratio transformers may be designed to give a flatter frequency characteristic than step-up transformers.

In an amplifier having a resistance load or reflected resistance load, as in a transformer, the grid excitation is 180 degrees out of phase with the A.C. voltage across the load. This is simple to see if you refer to Fig. 2. Starting with point A, as the grid signal swings positive from A to C, the plate voltage goes down. The push-pull circuit in Fig. 15b uses this principle. Points *1* and *2* are at the same A.F. potential. As the grid of tube A becomes more positive, the A.F. potential between points *2* and T decreases. By coupling T through the .06 mfd. condenser to the control grid of tube B, the latter is fed with a voltage 180 degrees out of phase with tube A. Tap T is chosen so that both input voltages are alike.

Figure 15c employs a phase shifting tube P_s. Tube A receives the same grid excitation as the input of the phase shifting tube P_s. The output of tube

P_s is so designed that no amplification exists. Only a 180 degree phase shift is obtained. This shifted excitation is fed to tube *B*, the second tube in the push-pull arrangement.

Figure 15d shows the push-pull principle applied to radio frequency circuits. Odd harmonics are usually eliminated by the resonant load and neutralization is effected by the cross connection of plates and grids through small trimmer type condensers. The real value of push-pull in tuned R.F. circuits is the simple neutralizing connection and the reduction of input and output tube capacity.

PUSH-PULL WITH CLASS A′ AMPLIFIERS

Radio receivers are now built with audio amplifiers which give as much as 10 to 20 watts output. Not because it is desired to operate at high level outputs but to obtain a variation in output level more in line with the original presentation. The strong passages of symphonic, band, and expressive vocal and instrumental music, are made more realistic if the output, normally set for 0.5 watts, can vary from inaudibility to 10 or 20 watts, than if it varies

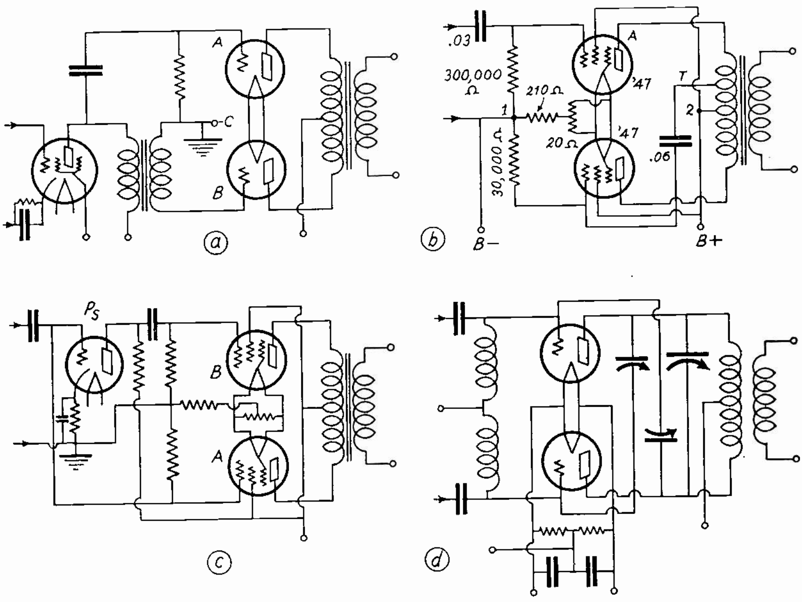

FIG. 15

only from inaudibility to 5 watts. Two and three speakers are often used in one receiver to handle without distortion these peak powers.

One way of getting this peak power is to use a push-pull amplifier, the tubes operating as class A′ amplifiers. The result is a more efficient amplifier and if the usual precautions are taken to keep the input impedance to each half of the system low, distortion due to the grids swinging positive is made negligible. It is to be remembered that each half of the input transformer alternates as a driver and when figuring the correct ratio for the step-down transformer, the primary of the transformer and only one-half the secondary should be considered. The average load resistance is still the peak grid-cathode voltage divided by the peak grid current of one tube.

Because a class A′ push-pull amplifier will draw large plate currents on peaks, it is important that the power supply have good regulation. Usually two full wave type ′80 rectifiers in parallel using a choke input, a mercury vapor type ′82 or ′83 rectifier or the new high vacuum rectifier type 5Z3 with choke input filters are used. All chokes and transformers must have low D.C. resistance.

PUSH-PUSH CLASS B AMPLIFIERS

In the design of battery and automobile receivers it is important to use a power output stage that will give a large output signal with the least power input. In both cases the B power supply is a battery which must be replaced or recharged at considerable expense and trouble. An efficient output amplifier reduces the number of replacements and recharges.

In A.C. receivers large peak powers are required if the strong passages in any reproduction are to be faithful. Amplifiers in public address systems must deliver large power outputs. For replacement purposes, the tubes used should be inexpensive and easily obtained.

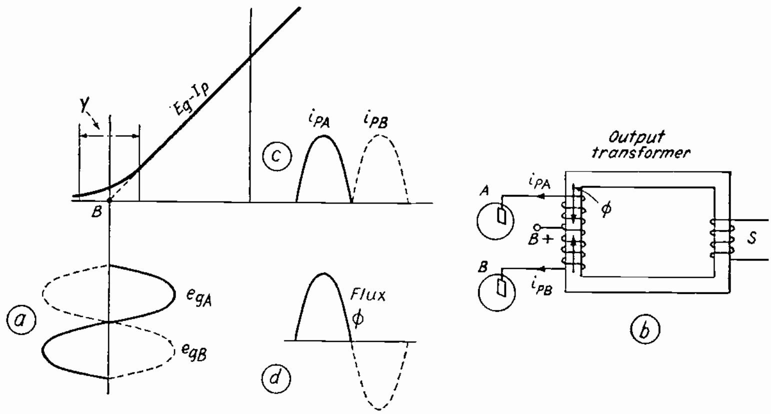

FIG. 16

These problems are met by using ordinary tubes in a class B push-push arrangement. The success of this system has prompted tube makers to provide special tubes which will eliminate or reduce troubles unique to this system.

If the C bias in a push-pull circuit is increased until both tubes operate as class B amplifiers, as shown in Fig. 8a, we find that a sine wave voltage from the secondary of each half of the input transformer is effective in producing plate current in the associated tube for only one-half a cycle. Refer to Fig. 16. The two grid voltages e_{gA} and e_{gB} are shown operating on the dynamic E_g-I_p curve at B, the cut-off point (point for class B operation). Obviously only one-half the grid swing is effective in producing a current flowing from the $B+$ supply to the plate, as indicated by the arrows in Fig. 16b. Naturally the half wave plate currents of tubes A and B are 180 degrees out of phase as shown in Fig. 16c. If we apply our right hand current-flux rule to the schematic primary winding in Fig. 16b, we observe that because of the direction of the coils, current i_{pA} produces a downward flux and current i_{pB} an upward flux. Clearly the flux due to i_{pA} is in the opposite direction to the flux due to i_{pB}, creating a complete sine wave flux as shown in Fig. 16d. This sine wave flux induces a sine wave voltage into the secondary S.

Note that the E_g-I_p curve does not cut off sharply at B. In fact, through the range Y, push-pull action takes place. While e_{gA} increases, causing a plate current i_{pA} to have a value greater than the linear value, voltage e_{gB} causes a current i_{pB} to flow which is not zero in value. The net result is that both deviations from the linear value cancel each other; actually second and even harmonics are cancelled by the push-pull action taking place in this region of operation.

In dealing with push-push class B amplifiers, it is customary to draw two E_g-I_p curves, one for each tube, as shown in Fig. 17; draw the grid voltage wave e_g, one-half the total across the secondary of the input transformer; and erect the equivalent A.C. plate current i_p. Usually a number of E_g-I_p curves are taken for various plate loads and the load which gives the maximum output and the least distortion (straightest E_g-I_p characteristic) is used. Two curves *1* and *2* are drawn and one inverted and so located that a straight line AB passes through the major portion of the two E_g-I_p characteristics. The intersection of this line with $O'O$ determines the correct bias for push-push action. In Fig. 17 the square of the value of the maximum current I is a measure of the output power.

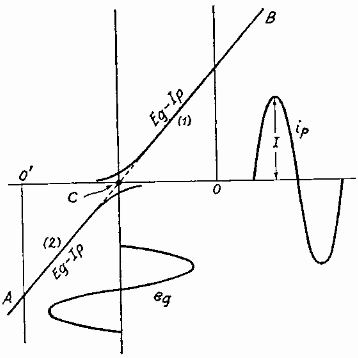

FIG. 17

A class B push-push amplifier may have the half grid swing limited to the C bias, thus preventing the grid from swinging positive; or as is usual, fed with a grid signal, whose peak value is much greater than the cut-off bias. In the latter case the grids will draw current during part of the operating cycle.

Automatic C bias (a cathode to $-$B resistor) cannot be used in push-push circuits. At the cut-off bias very little plate current flows. To get the cut-off bias, a resistor of large ohmic value will be needed. Increased excitation results in increased plate current and the C bias increases. Only C batteries or special C bias supplies can be used connected in the common grid circuit. The impedance of this supply must be low when the amplifier is operated into the positive grid region.

Class B Amplifier Tubes: In A.C. operated receiver it is an inconvenience to use batteries to get cut-off bias. It is not economical to build a special C supply. To overcome these objections there has been developed a number of class B amplifier tubes and a number of twin class B amplifier tubes, (two tubes in one glass envelope). These tubes, either by construction or by special connection of the grids (where several are provided), are made to have a large amplification factor. If you will recall, the cut-off bias is roughly E_B/μ.

Therefore, making μ large tends to make the cut-off bias near the zero value.* You will find with such tubes that the plate current is substantially zero with zero grid bias. This eliminates with one stroke the major problem of getting a suitable C bias.

The special class B amplifier tubes in general use are: type 49, 2 volt filament, 3.5 watt output; type 46, 2.5 volt filament, 16 and 20 watts output; type 59, 2.5 volt heater, 20 watts output; type 89, 6.3 volt heater, 3.5 watts output and the twin class B tubes (two tubes in one envelope); type 19, 2 volt filament, 2.1 watts output; type 53, 2.5 volt filament, 10 watts output; and the type 79, 6.3 volt heater, 5.5 watts output. Type 49 and 46 tubes have two grids and are connected together at the socket for class B operation. Type 59 and 89 are triple grid tubes and operate as class B amplifiers when the grid next to the plate and the plate are connected, and the two grids near the electron emitter are connected. All twin triode tubes (called duo-triodes and duplex-triodes) are two high mu power tubes in a single glass envelope with their filaments internally connected in parallel.

Figure 18 shows the connections of a push-push amplifier with a driver stage. Note the absence of a C bias resistor in the grid return of the 46 tubes, and observe that the two grids in each tube are connected together.

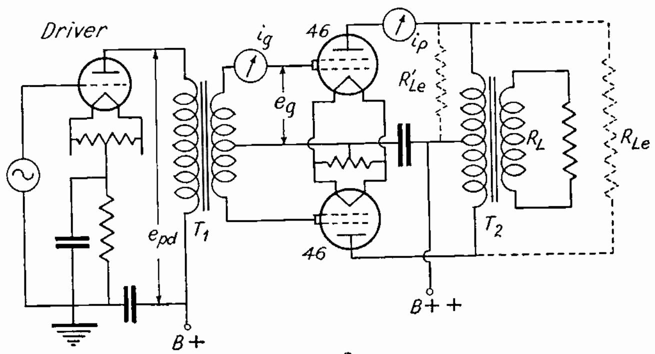

FIG. 18

R_L is the actual load, perhaps a speaker; R_{Le} the reflected load between plates of the two tubes; and R'_{Le} the reflected load for each half of the push-push amplifier. If dynamic E_g-I_p and E_g-I_g curves were taken for various R'_{Le} loads, they would be similar to one shown in Fig. 19. As R'_{Le} is made large, the curve takes on a shape indicated by the extended light dotted line. An E_g-I_p characteristic is selected which gives a large plate current and plate voltage variation, that is, a large power output. Naturally the characteristic chosen is the one that gives the maximum undistorted power—if it were not for grid current it would be the one with the straightest E_g-I_p curve. These curves may be determined graphically, using a family of E_p-I_p curves. Solid curves and dash-dot curves of Fig. 19 are typical.

If we assume for the moment that the effect of grid current is negligible, then we can see what the departure from a straight E_g-I_p curve has on the output wave. We already know that the distortion due to imperfect plate

*Regular power triodes having a large μ are suitable for class B operation using a battery to get cut-off bias. Type '30, '12A, '10, '11, 841, and 849 have been used successfully for low and high power outputs. It is interesting to know that a battery receiver with a push-push amplifier using '30 tubes gives 1 watt output whereas a '30 tube is only rated for .016 watt when used in class A fashion.

current cut-off, region $a'a$, results in low distortion due to the push-pull action at this low grid excitation. Only third and odd harmonic distortion will exist at low inputs. Distortion will exist at other grid values because of the upward bend, a to b; and the downward bend b to c. This will result in harmonics, but what harmonics? Let's go back to a few fundamental concepts.

Figure 20 shows at A a fundamental sine wave, at B a second harmonic, both starting in phase. Combining the two, C is obtained. A very striking fact is found in C. The vertical line V divides the first and second half period of the positive alternation. Note that the shaded half is not similar to the first half. If you repeated this graphical experiment using fourth, sixth, any or all even harmonics starting in phase or 180 degrees out of phase, with the fundamental you would find that this lack of symmetry exists. On the other hand, combining a fundamental with a third or odd harmonic gives a symmetrical resultant wave as shown in Fig. 21.*

If we assume that transformers T_1 and T_2 in Fig. 18 have negligible leakage and capacitive reactance and resistive loads are used, then we may assume no phase shifting. Assuming a sine wave input we get by the usual graphical process applied to the ideal E_g-I_p (- - - - - curve) of Fig. 19, a sine wave

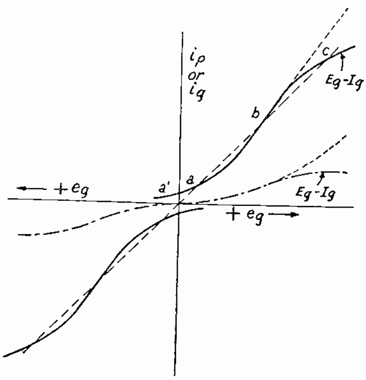

FIG. 19

output (- - - - - line in Fig. 22) and the solid line curve if the true E_g-I_p curve of Fig. 19 is used. Note that absolute symmetry is realized. This means that in an ideal push-push amplifier, only odd harmonic distortion takes place. The important harmonic distortion in push-push amplification is the third and the fifth harmonic. As some phase distortion takes place and tubes of similar characteristics cannot be obtained in practice, some second and even harmonics may exist, usually not over one per cent, a negligible value.

A part of the third harmonic distortion due to the curvature b to c (refer to Fig. 19), may be eliminated by introducing distortion into the grid input wave form. Theoretically, if the plate resistance of the driver is reflected into the secondary to a negligible value, then the wave form of e_g and e_{pd} (refer to Fig. 18) are alike. Actually, this reflected resistance must have some value. If the plate load of the output tubes is so chosen that the grid current characteristic is almost straight as in Fig. 19, the distortion due to grid current will be negligible. If the E_g-I_g curves upward as shown by the dash-dash line in Fig. 19,

*In both cases there must be a complete cycle, the positive and negative cycles being alike. A push-pull amplifier delivers a symmetrical output similar to Fig. 21, and for that reason has no even harmonics.

then the decrease in e_g input value at high grid excitation, due to the resistance drop, will, in effect, cancel the distortion due to the upward bend b to c. A plate load is chosen which gives an upward E_g-I_g characteristic. A step-down transformer T_1 is chosen, which will result in an effective secondary resistance that will give this necessary compensation. Usually the third harmonic distortion can be kept to about three per cent except at very low or very high grid excitations.

Tube makers specify the operating voltage and load resistance for the best operation of a given class B amplifier tube. The load resistance recommended may be R_{Le}, the resistance between plate to plate, or the resistance R'_{Le}, the load on one tube. It is worth knowing that R'_{Le} is equal to R_{Le} divided by *4*. The turn ratio of T_2 (entire primary to entire secondary) is found in the usual manner, that is:

$$\text{Turn ratio of } T_2 = \sqrt{R_{Le}/R_L} \text{ or } 2\sqrt{R'_{Le}/R_L}$$

The primary of T_2 is center tapped. As the core flux is not cancelled out, the transformer must be heavily built and have an air gap to prevent magnetic distortion.

The choice of T_1 depends entirely on the maximum power output desired, and the allowable distortion of the driver and push-push stage combined. If an over-all distortion of 5 per cent is to be tolerated in the combination, only

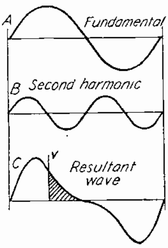

FIG. 20

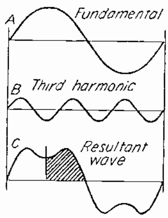

FIG. 21

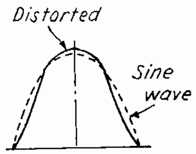

FIG. 22

2 per cent second harmonic distortion can be allowed in the driver stage. When single class A drivers are used, the plate load should be about 3 to 4 times the plate resistance. A lower load can be tolerated with push-pull drivers.

Tube makers usually give the following information which allows one to calculate the proper ratio of T_1, the input transformer. (1) The maximum peak power drawn by one class B operated tube at maximum grid excitation and (2) the best effective secondary resistance of the driver coupling transformer, usually expressed as the series resistance in series with the driver voltage. Item *1* permits us to select the correct driver, one capable of furnishing the peak power with minimum distortion, while item *2* determines the step-down ratio once the type of driver is selected. On the next page is a table of possible drivers as computed by the R.C.A. Radiotron Co., and the ones usually used with a 46 push-push amplifier. The second harmonic distortion of these drivers is less than 2 per cent.

Example: Consider a 46 push-push amplifier, operated at 400 volts on the plate with R'_{Le} equal to 1,450 ohms. Tube makers tell us that if the grids are supplied with a root mean square voltage of 41 volts, the output power is 20 watts. This is an input peak voltage of 41 × 1.41 or 58 volts. From an E_g-I_g curve we learn that the peak grid current is roughly 38 milliamperes. The peak grid power is 58 × .038 or 2.20 watts. An acceptable cancellation of third harmonics is obtained if the grid voltage is fed through a resistance of 250 ohms. Assume that the input transformer has an efficiency of 90 per cent. Then the driver must supply a peak power of 2.20 ÷ .9 or 2.44 watts Referring to the table of drivers, either a single type '45 tube or with a little more distortion a single type 46 tube in class A operation and operated at 250 volts may be used. Let us select the 46 type tube driver, so as to keep the number of different tubes in the amplifier down to a minimum.

The peak plate load is 8,000 ohms. If this is to be reflected as a resistance of 250 ohms, the turn ratio of the total primary to one-half the secondary of the input transformer is,

$$\text{Turn ratio} = \sqrt{\frac{8{,}000}{250}} = \sqrt{32} = 5.7$$

The turn ratio of T_1, Fig. 18, from total primary to total secondary would be one-half 5.7 or a step-down ratio of 2.8.

Assuming that two 15 ohm moving coil dynamic speakers are to be driven by the push-push amplifier in parallel, this is equivalent to a single 7.5 ohm load. The output transformer T_2 should have from half the primary to the entire secondary a step down

$$\text{Turn ratio} = \sqrt{\frac{1{,}450}{7.5}} = \sqrt{193} = 13.9$$

If we consider the entire primary, the step-down ratio is 13.9 × 2, equal to 27.8.

DISTORTION IN PUSH-PUSH AMPLIFIERS

In some cases, especially in regular triodes used in a push-pull arrangement, the grid is driven so far positive that the grid current actually decreases with increased grid voltage. Dynatron oscillations take place at a frequency determined by the secondary leakage inductance and distributed capacity of the driver transformer. These unwanted oscillations have the tendency of distorting the output, making it fuzzy and indistinct. A grid suppressor will usually eliminate this trouble. If the leakage reactance and distributed capacity in the primary of the output circuit has a resonant frequency in the audible range, the sharp cutting off and flow of current in the plate circuit may start oscillations with similar effects. This may be overcome by shunting each half of the primary with a high resistance in series with a small condenser.

It is important that the output transformer have a primary inductance of at least 30 henries, otherwise the shunt effect at low frequency may tend to lower the load impedance to such an extent that large plate currents will flow at low frequencies. This gives rise to a number of harmonics, identified as harsh grumbling hashy tones.

Optimum Driver Operating Conditions

Type	*Plate Voltage*	*Bias Voltage*	*Peak Plate Load† Ohms*	*Peak Power Output‡ Watts*
1–27	200	−15	23000	0.50
1–27	250	−21	21000	0.92
1–45	250	−50	8000	2.50
1–46	200	−24	9000	1.15
1–46	250	−33	8000	2.15
2–27*	250	−21	16000	2.00
2–45*	250	−50	16000	5.0
2–46*	250	−33	15000	4.5

* Push-pull.

† Maximum peak A.C. plate voltage divided by maximum peak A.C. plate current.

‡ Maximum peak A.C. plate voltage times maximum peak A.C. plate current.

MERIT OF PUSH-PUSH AMPLIFIERS

Insert of Fig. 23 shows two type 59 triple grid tubes, connected in push-push and driven by a single 59 as a class A amplifier. The circuit, if built as indicated, will give only 5 per cent harmonics for a maximum power output of 21 watts. To get this power the driver must have a grid excitation of 19.5 volts r.m.s., which is easily supplied in a modern superheterodyne receiver directly from the linear type second detector usually used. Curves in Fig. 23 show how a well designed push-push amplifier behaves at lower driver inputs. Particularly striking is the high harmonic content at low power output. This is typical for class B push-push amplifiers.

In Public Address Systems where the amplifier is nearly always run at maximum power output, the high distortion at low levels is relatively unimportant. With radio receivers it is usual to operate the receivers at a low level of 1 to 2 watts and allow the power to swing to higher levels on strong passages. Clearly the receiver is always operating at maximum distortion.

In contrast, the push-pull amplifier with normal output has negligible

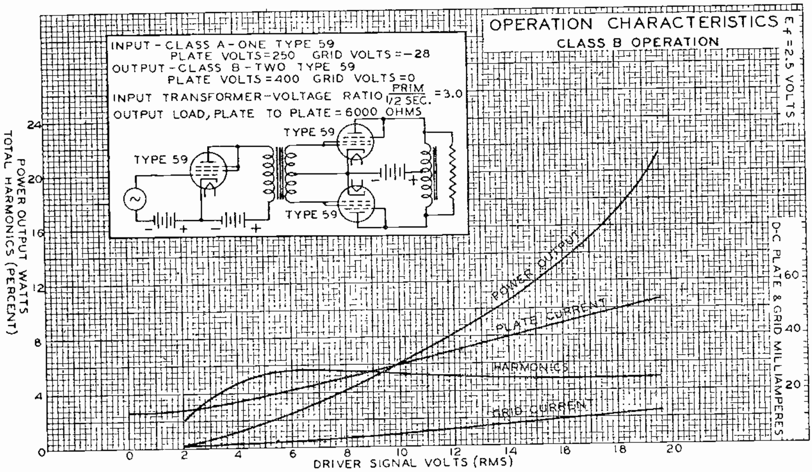

FIG. 23

distortion at low levels and maximum distortion at high levels. Amplitude distortion will take place on strong passages (large peak grid excitation) as the undistorted output is limited. Some designers, therefore, prefer to use the class A′ push-pull system.

The introduction of the multi-filamentary triode amplifier, type 2A3, gives the push-pull class A amplifier a better load characteristic. This tube requires a large negative bias for plate current cut-off. The high plate current, even with the grid negative, due to the large number of filaments in parallel, permits large changes in plate current for large grid swings. The fact that the grid is always negative eliminates the need for a driver. As the plate current swings over a wide range, the maximum undistorted power output is limited if self-biasing is employed. The maximum undistorted power output is increased 50 per cent by using an external bias, preferably a tap off the voltage divider fed by a power system having good regulation. The 5Z3 high vacuum full wave rectifier makes an ideal supply system for two 2A3 tubes in push-pull. Using a choke input filter and feeding 500 volts R.M.S. to each plate, the output voltage varies from 425 to 360 volts when the current drain varies from 40 to 250 milliamperes. This is equivalent to a 16.5 per cent regulation from average voltage output. Low resistance in the transformer and chokes and a high bleeder current in the voltage divider are required.

Power Level

In dealing with audio amplifiers it is inconvenient and unsatisfactory to say that the power output must vary a million fold, that the amplification is increased 58 per cent or that the loss in a transmission or coupling system is 15 milliwatts. It is inconvenient because in actual practices we are forced to use extremely large or decimal numbers; and unsatisfactory because, as an example, tripling the sound power output does not imply that the sound will be 3 times as loud.

The *decibel* measure or notation for *gain* and *loss* of power is widely used by radio men, as you probably know, and it is important that you should understand its meaning and use. It is customary to say that an increase in power is so many *db gain* (pronounced *dee bee*) and a decrease in power is so many *db loss, db down,* or *—db* (minus db). An increase of power from 5 to 15 watts is referred to as a 4.8 db gain. A reduction of power from 20 to 3 milliwatts is referred to as —8.2 db or a loss of 8.2 db. You will learn shortly how to express loss and gain in decibel units. Mathematics will be omitted from the main text, except for a few footnote references.

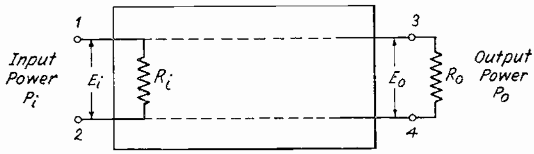

FIG. 24

The decibel is only a unique and convenient way of expressing the *ratio* of power output to the power input. After you compute the ratio of the power, a table and a chart will simplify converting the number you obtain into decibels.* If we deal with sound energy, the power output and power input must be in sound units; if we deal with electrical power the power input and power output must be in electrical units, as milliwatts, watts, kilowatts, etc. We must not compare sound and electrical power units, for example, so many watts fed to a loudspeaker which has an output of so many *ergs per second* † of power. If we convert the sound units into watt units, we may compare electrical watts input to sound watts output.

Figure 24 is a box which may represent an audio amplifier, a radio receiver,

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*The decibel value of the power output, P_o, to the power input, P_i, is:

$$(1)\quad db = 10 \log_{10} \frac{P_o}{P_i} \text{ or } \quad (2)\quad db = -10 \log_{10} \frac{P_i}{P_o}$$

where formula *1* is used for P_o greater than P_i and formula *2* for P_i greater than P_o.

†Ergs per second is a fundamental mechanical unit of power. It is the amount of work required to lift one gram of material one centimeter in a second. It is rarely used in practical sound work.

a transmission system, a coupler, in fact, any system which receives power at its INPUT and delivers power at its OUTPUT.*

Let us say that the input power is P_i and the output power is P_o. An input power may be more than, less than or equal to the output power.† The power input and power output may be said to be so many watts, milliwatts or other units We refer to this as their power level. Suppose the input power level is 7 milliwatts and the output 63 milliwatts. Unquestionably the device within the box has raised the power level to a value nine times the amount put into it. A radio receiver may derive energy from an antenna and deliver upwards of a million fold more power to the loudspeaker.

Knowing the input and output power, the ratio of power levels is obtained by division. Now we want to express the power ratio in terms of db. The simplest case is where the power ratio is between 1 and 10. In Fig. 25 we locate this power ratio along the horizontal or power ratio scale. Trace vertically upward until you strike the curve and read the db value to the left. Power ratios of 3; 5; 7; 8; 9 and 10 are equal to 4.8; 7.0; 8.4; 9.0; 9.5 and 10 db respectively.

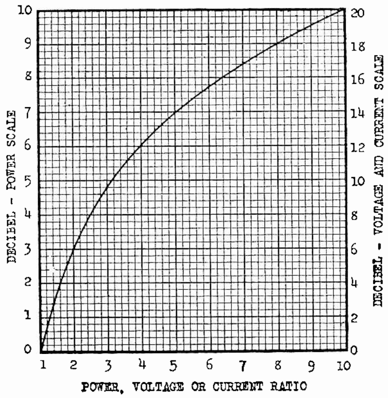

Fig. 25

If the power output is less than the power input, divide the power input by the power output and prefix to the db value the minus sign (—). By doing this the ratio you work with will always be greater in numerical value than one.

Should you know the voltage input E_i and the voltage output E_o, their

*The power delivered by the input device and the power absorbed by the input naturally are equal. The same is true for the output and the load powers.

†If the internal resistance of a source is equal to the resistance of its load, the power developed in the system is twice that consumed by the load. In some cases the resistance of the input device is matched to the input resistance R_i (see Fig. 24). In other cases an absolute match is not desirable. Quite often it is desired to compare the power developed by the input device to the power delivered by the system to the load. If the input device is matched to the input of the system to which it is connected, the power developed by the input device will be twice the input power. When the input device has a resistance R which is not equal to R_1, then the power developed by the device is P $\frac{R + R_i}{R_i}$ where P_r is the power input.

power ratio in decibels may be found.* Merely compute the voltage ratio by dividing the large voltage by the small voltage. Locate this numerical value in the voltage ratio scale (same as power ratio scale), follow up to the curve and then horizontally to the right and read the db value on the right hand scale. If the output voltage is less than the input voltage, the value is expressed as so many —db. Figure 25 can only be used if the input resistance R_i or impedance and the output resistance R_o or impedance are equal.†

It is also important to be able to interpret a power change in db units. Suppose the output of an amplifier increases from 2 to 15 watts when a 30 cycle note is replaced by a 1,000 cycle note. Obviously the power ratio is 7.5 and from Fig. 25 we find that it is an increase of 8.7 db. Outputs of various radio devices are constantly compared under various conditions. The outputs of two devices may be compared on a basis of voltage or current ratio in the above simple manner, only if the two devices have the same output impedance or resistance. No such equality is necessary for comparison of power values.

Now let us consider the case where the power ratio is other than a value between 1 and 10. If the voltage or power ratio is less than one, divide the large voltage, current or power by the small voltage, current or power and prefix the minus (—) sign before the db value you obtain, as explained previously. Now the ratio is always more than 1. Disregard the actual value of the number and "point off" the first digit. Consider the first figure as a number from 1 to 10. For example, if we have a power, current or voltage ratio of 9,730; 126; 184,000; 32; we would instantly consider the ratio as 9.730; 1.26; 1.84000 and 3.2. Using Fig. 25 we would find the db value according to whether it is a power or voltage ratio. If all four values mentioned are power ratios, we would find from Fig. 25, the values 9.9, 1.05, 2.7, and 5.1. Add 10 for each digit following the point you placed as explained above. Then for 9,730 add 30 to 9.9; for 126 add 20 to 1.05; for 184,000 add 50 to 2.7 and for 32 add 10 to 5.1. Therefore, the db values for power ratios of 9,730, 126, 184,000 and 32 are respectively 39.9; 21.05, 52.7 and 15.1. When a voltage or current ratio is involved, the number you add is always twice as much.

Examples involving db units:

(1) The power input to an amplifier is 50 milliwatts, the power output 22 watts, which is equivalent to 22,000 milliwatts. What is the *db* gain? Power ratio is $22{,}000 \div 50 = 440$; considering 4.40 and using Fig. 25 we get 6.5. As explained above we add 20 and get 26.5 db.

(2) An audio amplifier initially gave 20 watts output. When the input voltage is removed, the total output due to internal hum is measured to be 18 milliwatts. What is the db ratio of hum to power? Dividing 18 by 20,000 (20 watts = 20,000 milliwatts) will give a fraction so we divide 20,000 by 18 and get 1,110. Consider 1.110 we get from Fig. 25 the value 0.4. As the ratio has 3 digits following the point, we add three 10's or 30 to 0.4 and get 30.4. To this we must prefix the — sign. The hum is —30.4 db or, as it is usually expressed, down 30.4 db.

(3) An amplifier has an input and output resistance of 500 ohms. The input and output are matched to the source and load. If the input voltage

* The procedure followed when the input current I_i and the output current I_o is known is the same as the voltage procedure. Power depends on voltage and current which gives a means of comparing power in terms of decibels.

† Formula $\text{db} = 20 \log \frac{E_o}{E_i} \frac{\sqrt{R}}{\sqrt{R_o}}$ or $\text{db} = 20 \log \frac{I_o}{I_i} \frac{\sqrt{R_i}}{\sqrt{R_o}}$ must be used if R_i and R_o are not equal. When $R_i = R_o$ then $\text{db} = 20 \log \frac{E_o}{E} = 20 \log \frac{I_o}{I}$.

is 0.5 and the output voltage 137, what is the db *power* gain? The voltage ratio is 137 ÷ 0.5 or 274. Consider the number 2.74. From Fig. 25, using the db voltage scale, we get 8.8. The initial voltage ratio has 2 places following the point so we add *twice* 20 or 40 to 8.8. The input *power* has been raised 48.8 db.

Reference Levels: It will be frequently found that the power output of a given amplifier is stated to be so many db. From what has been said before, this has no meaning unless the power level is referred to some fixed value or standard power level. Two standard power and voltage levels are in general use.

1. For sound picture and public address systems and for radio receivers, a standard level of 6 milliwatts or a voltage of 1.9 volts across a 600 ohm resistor is standard.

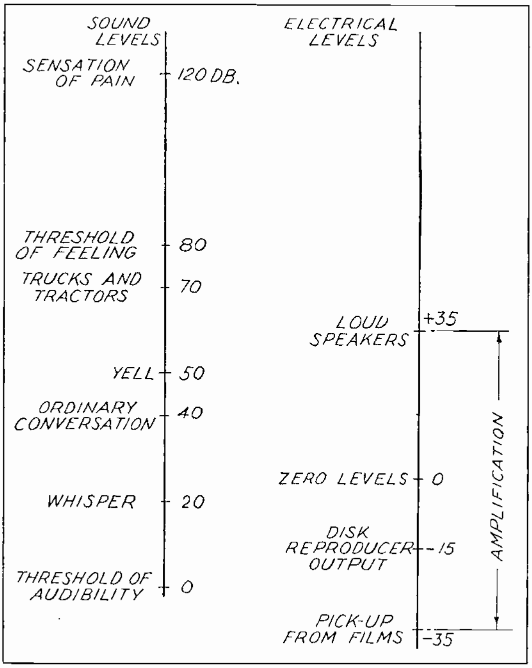

FIG. 26

2. For broadcasting systems use a level of 10 milliwatts or a voltage of 2.23 volts across a 500 ohm resistor.

Unless otherwise specified, a level of 6 milliwatts is implied in radio receiver and amplifier problems. It may be convenient at times to use the 10 milliwatt or other standards, but the reference level should be understood. To the right of Fig. 26 is a line chart showing the approximate db level for sound amplifier devices. Zero level or zero db is 6 milliwatts.

If you are anxious to master the use of the db, it is important that you work problems. Here are a few:

1. A photocell delivers — 40 db to the input of an amplifier which has a gain of 80 db. How much loss must be introduced to feed a loudspeaker at a

level of 35 db? Without the loss the output is $80 - 40 = 40$ db. Therefore, a loss of 5 db must be introduced, as $40 - 5 = 35$.

2. An amplifier at 1,000 c.p.s. delivers 26 db. At 4,000 c.p.s. the output is down 5 db. What is the latter output in watts? In terms of db level, at 4,000 c.p.s. the output is 21 db. Divide this number into two parts, 20 and 1 The number 20 indicates it is a value with two digits following the point. Turning to Fig. 25, locate on the vertical power scale the value 1, follow to the left to the intersection of the curve and locate the power ratio. Note that it is about 1.25. The point is moved 2 places to the right, giving a power ratio of 125. Assuming that the reference level is 6 milliwatts, the power output is 125×6 or 750 milliwatts or .75 watt.

3. A transmission line is fed with an input current of 43 milliamperes. The output current is .02 milliamperes. What is the db loss? The input and output systems are matched to the line impedance which means that the input and output resistance may be neglected. The current ratio is $\frac{.02}{43}$ so we will compute the value $\frac{43}{.02}$ which equals 2,150. Consider the number 2.150 and from Fig. 25 we get on the current scale a value 6.3. To this we must add the minus sign and twice 30 or 60, giving —66.3 db.

Sound Levels: The ear does not interpret the actual level of sound, but in terms of the surrounding sound or a previous sound. That is, a whisper would be heard in a quiet room but entirely inaudible in a noisy street. An increase in power of one watt from .5 watts would be evident, but an increase from 25 to 26 watts may be unnoticed. In terms of sound units, a change of a simple tone (output of a tuning fork) of 1 db is noticeable in a quiet surrounding, while a complex sound (speech and music) will be noticeable only if the db change is 3 db. The eye and ear respond in this manner and for this reason sound or visual outputs or electric power to be converted to sound and light are best expressed in db values. To get a true picture of amplifiers, it is best to express output and amplification in terms of db levels or variations.

The ear is affected by the change in pressure on the ear drums. The unit of pressure is one *bar*.* The atmospheric pressure on the ear drums is about 1,000,000 bars. Dr. Fletcher, an authority on the subject, states that from experience with a large number of people that a variation of about .0005 bars at 1,000 c.p.s. is just audible. Therefore, the threshold of audibility is .0005 bars or .5 millibars. It is interesting to note that at 60 c.p.s. a variation of 35 millibars, at 5,000 c.p.s. a variation of .4 millibars and at 15,000 c.p.s. a variation of 41 millibars is just audible.

With the frequency and pressure variation known, the db level for a given pressure may be computed. For complex sound a zero level of .5 millibars may be used. Figure 26 shows on the left the db level for a number of sounds which you have experienced. In figuring sound db level, remember that a sound pressure is similar to electrical voltage and in using Fig. 25, use the voltage decibel scale. Example: if a sound level of 116 db causes an ear sensation of pain, what is the pressure variation in millibars? Consider the number of 116 as divided into 2 times 50 and 16. From Fig. 25, 16 corresponds to a basic pressure ratio of 6.4. The actual power ratio must have 5 digits following the decimal point, which gives 640,000. If the reference level is .5 millibars, a pressure variation of $640{,}000 \times .5$ equal to 320,000 millibars or 320 bars will produce pain.

* A cubic centimeter of water would exert a downward pressure of 980.6 dynes, due to gravity. If a force of one dyne is exerted on a surface of one square centimeter, a pressure intensity of one bar exists.

POWER AUDIO AMPLIFIERS

34 FR

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

SOFT SPOTS

Just as a soft spot in an apple or a melon makes it unfit for sale, so a soft spot in a man's character makes it difficult for him to sell himself.

An employer, looking for men to promote, to take over his work when he is ready to retire, looks for sound men—men without any spots in their characters.

How about us—do we have any soft spots that might interfere with our success?

It is very hard for a man to admit he has any weakness that should be eradicated and so we might be tempted to answer "No." But if we examine ourselves carefully, we are almost sure to find a "soft spot" somewhere. And once we have located it we may realize that it has held us back and that unless it is "cut out" it may do us a great deal more harm.

This soft spot may be a streak of laziness, a tendency to shirk responsibility, to pass the buck, to pity ourselves, to put off until tomorrow what should be done today, to put pleasure before work, etc.

Yours may be one of these or it may be one of the hundreds I did not mention. Whatever it is, now is the time to cut it out. Get after it before it gets you.

Above all, be honest with yourself. Don't blind yourself to your "soft spot." It is no disgrace to have *had* a soft spot, the disgrace comes only when the soft spot is allowed to grow, only when you do not make any attempt to eradicate it.

J. E. Smith.

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Power Audio Amplifiers

INTRODUCTION

Not so many years ago a power audio amplifier was a rarity. Today, however, most full sized radio receivers have audio systems capable of delivering more than 3 watts of undistorted power. Occasionally radio sets are built for home use that are capable of delivering 10 to 12 watts of undistorted power output. However, this much power can only be used to advantage where a radio receiver is used in a large hall.

On the other hand, in the broadcasting end of Radio, power amplifiers must be capable of delivering an undistorted power output of from 10 to 30 kilowatts. In audio amplifiers used in sound recording, in sound projection (talking moving pictures), in public address systems, in hotel and apartment community radio systems, power outputs of from 25 to 100 watts or more are required.

In this lesson we are going to consider the problems that come up in the design and operation of various types and sizes of power amplifiers—not from the standpoint of design, however, but from a more general viewpoint so that you will obtain a thorough insight into the theory and practice of power amplification. We are going to learn how to calculate the amount of amplification needed to supply sufficient power for the operation of various loads and combinations of loads. We shall also consider over-all gain calculations, the effect of coupling, etc.

As was pointed out in earlier lessons, the audio system is made up of two parts, the voltage amplifier and the power amplifier, or we can consider them in this way—as gain level and power level amplification. The voltage amplifier boosts the original weak voltage to a point where it is capable of "swinging" the grid of a power amplifier tube or tubes.

The output e.m.f. of a grid leak detector is about .3 volt; that of a double carbon button microphone about .03 volt; of a magnetic phono-pickup, about 1 volt; of a short telephone transmission line, about .2 volt. Each of these voltage sources has its own internal impedance. To swing the grid of a single '50 tube for example, whose maximum allowable peak grid voltage is 84 volts (the C bias), it is necessary to have an audio system capable of raising the original voltage to $84 \div \sqrt{2}$ r.m.s.

(all the voltages measured are in root mean square values). Then, with a proper load impedance coupled to the '50 tube, maximum output power may be obtained.

These figures are used merely to give you an idea of the voltage amplification needed under various conditions. Later on we shall learn how to calculate the number of stages needed to provide the necessary voltage amplification.

It must be remembered that the maximum allowable peak signal voltage should not be exceeded, otherwise distortion will be introduced. In the same way, if the peak signal voltage falls below the maximum allowable peak voltage, the power output and the volume will be decreased noticeably. To calculate the actual allowable grid swing we must know the maximum undistorted power for the output tube or tubes. Manufacturers of power tubes will generally furnish this information on request.

The maximum undistorted power output is an extremely important consideration, for an amplifier must do more than amplify—it must deliver to the final load all the frequencies of the original signal, in exactly the same proportion, within a frequency range of 30 to 10,000 cycles per second. Furthermore, this must be true at both maximum and minimum powers, for in orchestral music there are wide variations in intensity. At times the music is barely audible; then when the musical score calls for full orchestra, we have the other extreme. The range of variation is about 60 db. (decibels).

Where raw and rectified A.C. are used for the power supply, an A.C. ripple in the output is inevitable. To keep hum down to 60 db. below the normal output so that it won't be heard above soft passages of music is by no means a simple matter.

And now that we have briefly considered the major problems in power audio amplification we are ready to go on to see how these problems can be solved.

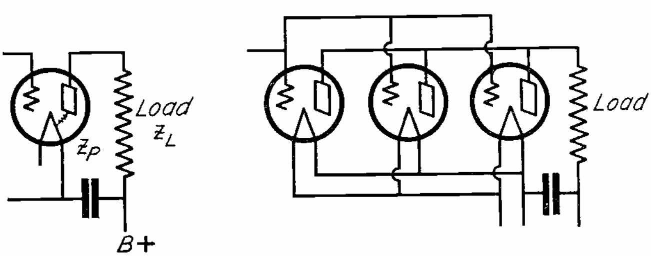
POWER OUTPUTS

In this lesson we are going to concentrate on the audio channels used in power radio receivers, in sound picture work, and in public address systems. Audio systems as used in radio broadcasting are taken up in a special lesson in the advanced course in Radio Operating. The channels we are going to consider may have as many as four audio stages capable of gains of 40 to 80 db., with power outputs from 4 to 100 watts.

It will help you through your study of this lesson to remember the general specifications of a well designed audio channel—its variation in fidelity should be only ½ db. over a range of 50 to 6000 c.p.s., and the hum output should be 60 db. below normal power output.

In determining the power output required of an amplifier for a certain purpose, both the output and input devices must be considered. Let us consider output devices first—the load on the audio channel. It may be one or more headphones, one or more magnetic speakers, dynamic speakers, or a combination of all three.

In hotels, hospitals, and more recently in special installations for the hard of hearing in S.P. theatres, phones are used in parallel. An average power of .005 watt (5 milliwatts) is sufficient for the operation of a headset. In a hospital installation where 400 headsets are used in parallel, two watts of power are needed just to supply the load. As line losses are usually considered as requiring 10 per cent of the total power, it would



(a) Fig. 1 (b)

be more accurate to say that the total power required would be 2.2 watts. A very small power output tube would be sufficient for an installation of this type.

The generally accepted practice is to install magnetic speakers in hotels and apartment houses (community radio systems). In the case of magnetic speakers, however, we must consider the size of the rooms in which they are to be used when estimating the power output required to operate them. For the sake of simplicity, let us say that 500 milliwatts (½ watt) of power per speaker is required. A small hotel installation might include 200 speakers, and if we assume that the peak load is 100 speakers on a channel, the required power would be 55 watts—50 watts for the speaker and 5 watts to take care of line losses.

In theatre and auditorium installations, and in P.A. systems for outdoor use, dynamic speakers are used. The speakers in a small theatre having a seating capacity of a thousand or so, may require 7 or 8 watts of power; in a large metropolitan theatre 30 to 40 watts may be required. Much also depends on the acoustics of the building. Outdoor systems may require 50 to 100 watts of undistorted output power.

While individual speakers are made that will handle as much as 30 watts of power, in general where considerable power must be handled, several dynamic cones, or exponential horns with dynamic units, are used as the sound projectors. The average dynamic unit requires about 2 or 2½ watts of power. Here, again, accurate figures on the power requirements must be obtained from the manufacturer of the speaker.

The method of connecting the loads (speakers), if more than one is used, is important. In community installations where sufficient power must be supplied to operate all speakers simultaneously, but where at some times only a few speakers might be in operation, parallel connections are quite essential.

When all loads are to be operated simultaneously, the arrangements may vary—they may be in series, in parallel or in series-parallel, whichever the designer finds best suited to his needs. In any case we must know the actual load impedance at a representative frequency in order to determine the maximum undistorted power output required. And maximum undistorted power output must be provided for by using a proper matching transformer so that the total impedance of the output is equal to twice the tube's impedance. Where maximum power output is required, the load impedance must be made equal to the tube impedance by means of the proper transformer.

In cases where the tube manufacturers recommend the best load impedance for maximum undistorted power output, his recommendation should always be followed.

As for the power tubes themselves, they may be used singly, there may be two or more in parallel, they may be in push-pull or parallel push-pull. The four possible connections are shown in Figs. 1, a, b, c and d. If we consider the plate impedance of a single tube as r_p, then for the various connections the total plate impedance will be:

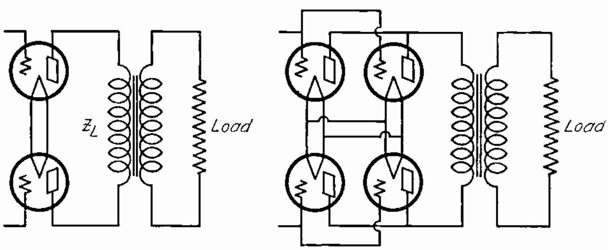
(a) r_p
(b) $r_p \div n$ (where n is the number of tubes in parallel)
(c) $2r_p$
(d) $4r_p \div n$ (where n is the number of tubes).

To determine the correct turns ratio for our impedance matching transformer, knowing the actual load impedance Z_L and the required impedance for purposes of matching (Z_N) we use the formula:

$$N = \sqrt{\frac{Z_L}{Z_N}}$$

Of course, if we want to obtain maximum *undistorted* output power, Z_N will be equal to the recommended load impedance or to twice the internal resistance of the output tube or tubes. If we are interested in obtaining maximum output power, Z_N will be equal to the internal impedance of the tube or tubes.

In an all-parallel connection of similar loads, the actual net load impedance will be the impedance of one load divided by the number of loads in parallel. You can easily calculate the net



(c) FIG. 1 (d)

impedance of a parallel series arrangement from your knowledge of impedances in series-parallel.

The maximum undistorted power output of a single tube is given by the tube manufacturer for all his types of tubes. Tubes usually encountered in P.A. systems are the '45, '50, 211 and 845 which have undistorted outputs of 1.6, 4.6, 10 and 20 watts respectively. In a parallel connection, the output is two or three times that of a single tube, depending on the number used.

There is considerable disagreement as to the undistorted power two tubes in push-pull can deliver. According to more conservative estimates, two tubes in push-pull will not deliver any more power than two tubes in parallel. On the other hand, one often hears claims that three times as much power can be obtained from two tubes in push-pull as from a single tube arrangement. The majority of designers assume a factor of 2.5 and count on obtaining 4 watts of power from push-pull '45's (2.5×1.6) and 11.5 watts for push-pull '50's (2.5×4.6).

Naturally two or three tubes in parallel in each half of a push-pull stage will deliver twice or three times that of a single push-pull stage.

Maximum power is always obtained when the grid swing is slightly less than twice the grid bias voltage. Under these conditions we can calculate the actual power delivered. Fig. 2 represents the equivalent plate circuit of a single tube or tubes in parallel. The tube amplification factor is μ; the A.C. voltage applied to the grid circuit is E_g (r.m.s.) which must always be less than the C bias voltage divided by 1.4; r_p is the net plate tube impedance in ohms and R is the equivalent load resistance. Because of the amplification of the power tubes, the A.C. signal voltage in the plate circuit will be μE_g. The current which will flow depends on the value of r_p and R in series. From Ohm's law:

$$I_p \text{ (plate A.C. current)} = \frac{\mu E_g}{r_p + R}$$

But it is not in the current that we are interested; what we are chiefly interested in is *power,* the power that is delivered to the load. Of course power is I^2R, and the complete formula for power, derived from the previous I_p formula, is:

$$P \text{ (load power)} = \frac{\mu^2 E_g{}^2 R}{(r_p + R)^2}$$

This formula is particularly important at the present time, as tube manufacturers are recommending plate load impedances other than twice the value of the tube plate impedance to obtain maximum undistorted power.

In cases where the load impedance is equal to or twice the tube plate impedance the formula can be simplified as follows:

$$\text{When } R = r_p; \quad P = \frac{\mu^2 E_g{}^2}{4r_p}$$

$$\text{When } R = 2r_p; \quad P = \frac{2\mu^2 E_g{}^2}{9r_p}$$

These formulas apply even though two or more tubes are used in parallel. The proper way of treating such a case is to consider all the tubes as a single tube, whose impedance is one-half, one-third or one-fourth, as the case may be, of the tube impedance of a single tube alone.

Of course it must be remembered that two tubes in parallel will not give twice the power output of a single tube unless the load impedance is changed. But with proper coupling transformers the maximum output can be obtained from parallel output tubes.

Before considering the power output obtainable from push-pull amplifiers, it will be wise to obtain a clear insight into the various factors which determine the power output. Fig. 3a is a schematic of a push-pull amplifier. Transformer *1* feeds to

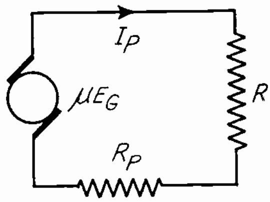
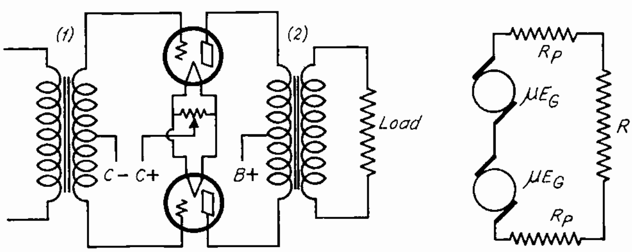


FIG. 2

each grid a voltage that is one-half the total voltage. E_g is this half voltage. It must never exceed the C bias divided by 1.41. Transformer *2* reflects the load into the plate circuit and we can say there is an equivalent load in series with the plates of the two tubes. Fig. 3b shows the equivalent circuit that must be considered in making calculations. Notice that there are two



(a) FIG. 3 (b)

e.m.f.'s in series, two tube resistances, and a single load resistance. In this case the power supplied to the load is:

$$P = \frac{4\mu^2 E_g{}^2 R}{(2r_p + R)^2}$$

If several sections of push-pull are used in parallel, the power output will be equal to the number of push-pull sections multiplied by the power output of a single section.

With the formulas given, you are able to calculate the power output when the tube arrangement, load resistance and the grid signal are known.

In the design of power amplifiers you are interested in the conditions which will give the maximum undistorted power. Table Fig. 4 gives the required grid signal input, load resistance, operating voltages, etc., for maximum undistorted power for various standard tubes.

OVER-ALL AMPLIFIER CALCULATIONS

In the previous chapter we learned about the powers required to operate the more common types of sound reproducing devices. We studied the formulas for determining the powers from various output tubes connected in four different ways, formulas from which estimates of actual output may be calculated. Now we are going to consider how much voltage amplification will be needed to raise the voltage generated in various standard pickup devices, to a level where it will operate a power tube. Of course we shall have to know the voltages generated by standard pickup devices and the voltage swing required to operate various types of power tubes.

We have already considered the average generated e.m.f. of standard sound pickup sources. You must remember, however, that these values ($.3^v$ for grid leak detector; $.03^v$ for microphone; 1^v for phono-pickup and $.2^v$ for the output of transmission lines) indicate only what may be expected. These values should be used only for purposes of rough calculations. If you were actually designing an amplifier, you should know the exact generated voltage of the pickup device to be used. You would have to determine this by experiment, by making exact calculations, or you would have to obtain the exact voltage output from the manufacturer of the device.

Furthermore, you would have to consider the internal impedance of the device used. Besides this, you would have to consider that the generated voltage would not be applied directly to the grid and cathode of the first tube but that a step-up transformer or some other coupling device would be used which also has a definite impedance, with or without a secondary load.

The amount of current that flows through the pickup unit will be equal to the generated e.m.f. divided by the impedance of the unit plus the impedance facing the pickup (in the case of transformer coupling with no secondary load this will be the primary impedance). All this is shown graphically in Fig. 5, where we have a simple series circuit containing a source of A.C. e.m.f. (a double button carbon microphone) and two impedances which would probably be an inductance and a resist-

TUBE	CONNECTION	R_P	PLATE VOLTAGE	C BIAS	PLATE CURRENT	AMPLIF. FACTOR	R_L FOR P MAX.	R_L FOR P MAX. UN.	MFGRS. R_L FOR P MAX. UN.	MAX. UN. POWER	$V_L=\sqrt{PR_L}$ *	Eg(r.m.s.) FOR P MAX. UN.
245	SINGLE	1,750	250	50.	34	3.5	1,750	3,500	3,900	1.6	79	34.
	PARALLEL	875			68		875	1,750	1,950	3.2	79	34.
	PUSH PULL	3,500			68		3,500	7,000	7,800	4.0	177	73.
	PAR.~P.P.	1,750			136		1,750	3,500	3,900	8.0	177	73.
210	SINGLE	5,000	425	39.	18	8.	5,000	10,000	10,000	1.6	127	24.
	PARALLEL	2,500			36		2,500	5,000	5,000	3.2	127	24.
	PUSH PULL	10,000			36		10,000	20,000	20,000	4.0	283	53.
	PAR.~P.P.	5,000			72		5,000	10,000	10,000	8.0	283	53.
247	SINGLE	60,000	250	16.5	32	150	-----	-----	7,000	2.5	132	9.
	PARALLEL	30,000			64		-----	-----	3,500	5.0	132	9.
	PUSH PULL	120,000			64		-----	-----	14,000	6.25	296	21.
	PAR.~P.P.	60,000			128		-----	-----	7,000	12.50	296	21.
250	SINGLE	1,800	450	84.	55	3.8	1,800	3,600	4,350	4.6	141	53.
	PARALLEL	900			110		900	1,800	2,175	9.2	141	53.
	PUSH PULL	3,600			110		3,600	7,200	8,700	11.5	316	118.
	PAR.~P.P.	1,800			220		1,800	3,600	4,350	23.0	316	118.
211E	SINGLE	3,500	750	30.	65	12.	3,500	7,000	-----	10.	264	33.
	PARALLEL	1,750			130		1,750	3,500	-----	20.	264	33.
	PUSH PULL	7,000			130		7,000	14,000	-----	25.	591	74.
	PAR.~P.P.	3,500			260		3,500	7,000	-----	50.	591	74.
845	SINGLE	2,100	1,000	150.	75	5.	2,100	4,200	8,000	20.	400	101.
	PARALLEL	1,050			150		1,050	2,100	4,000	40.	400	101.
	PUSH PULL	4,200			150		4,200	8,400	16,000	50.	894	223.
	PAR.~P.P.	2,100			300		2,100	4,200	8 000	100.	894	223.

* WHERE "P" IS THE MAXIMUM UNDISTORTED POWER USING THE "R_L" RECOMMENDED BY THE MANUFACTURER

FIG. 4

ance. Knowing the value of each reactance, the total impedance could be found by vector methods. Then the current could be determined from Ohm's law for A.C. circuits.

The simplest case is when Z_{pu} and Z_L are both resistances, in which case the current will be the induced A.C. voltage divided by the sum of the two resistances.

This would be true in the case of a microphone coupled to a tube by a transformer with a resistance load on the secondary (for example, a volume control). This resistance is reflected back into the primary circuit as a small parallel resistance so that the high transformer primary impedance can be neglected. However, we must not assume without reasonable assurance that the actual transformer impedance can be neglected.

Suppose we have a double button carbon microphone having a resistance of 200 ohms per button, or 400 ohms for the two in series, coupled to a tube through an ideal impedance matching transformer. The ideal coupling transformer, with the grid resistance as the secondary load, can now be considered as a 400 ohm resistor connected in series with a microphone. In this case the total resistance in series will be 800 ohms. If the microphone generates .03 volt, the current flowing will be $.03 \div 800$ or approximately .000038 ampere or 38 microamperes. Terminals *A* and *B*, in Fig. 5, are the input of the amplifier, and it is in the voltage across these terminals that we are chiefly interested. Naturally it will be the generated voltage, less the voltage lost in the resistance of the microphone; that is, $.03 - (.000038 \times 400)$ or $.03 - .015$, or .015 volt. This, of course, is half the generated voltage, from which we can see that, if the load resistance is equal to the generator resistance, the voltage across the load will be one-half the generated e.m.f.

Maximum transfer of energy is usually obtained when the load and supply impedance are equal. This explains why we used an ideal coupling transformer in our example.

We have already considered the amount of power needed at the output to operate the sound reproducing devices. It will be interesting to know how much *power* we start out with. Again let us consider the input circuit shown in Fig. 5. The power developed by the microphone will be the generated voltage multiplied by the current, in this case $.03 \times .000038$ or .00000114 (1.14 microwatt). Then for an ordinary public address system requiring 30 watts output, the power increase is $30 \div .00000114$, or a power amplification of 26,300,000. Converted to decibels, the amount of amplification needed would be 74.2 decibels.

While it is interesting to compare the input power and the output power and to calculate the power amplification needed, in practice we need consider only the voltage amplification up to the grid of the power tube. That is, our problem is to amplify the .015 volt supplied to the *input of the amplifier* to such an extent that it will swing the grid of the power tube so that the latter can provide the desired power for the load.

Let us say that the power amplifier, which is to deliver 30 watts of undistorted power, employs two 845 output tubes in parallel. From the chart in Fig. 4, the plate resistance of the 845 is 2,100 ohms, and for two in parallel the net plate resistance will be one-half, or 1050 ohms. When the load resistance is twice that of the tube resistance, maximum undistorted power can theoretically be expected. Therefore, our load resistance should be 2100 ohms.

We have said that the load on our power amplifier will

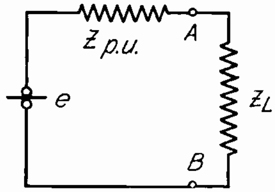


FIG. 5

absorb 30 watts. What will be the load voltage? Substituting in the formula $V_L = \sqrt{P \times R}$ we get:

$$
\begin{aligned}
V_L &= \sqrt{30 \times 2100} \\
&= \sqrt{63{,}000} \\
&= 251^{v} \text{ (r.m.s.)}
\end{aligned}
$$

Now what is the voltage required on the grids to obtain this load voltage and how much will its peak value be below the maximum permissible half grid swing? If the net tube plate resistance is one-half that of the load—that is, 1050 ohms—we should expect a voltage drop there equal to one-half the voltage drop across the load. As 251 ÷ 2 or 126 volts are lost in the plate resistance, the required grid A.C. voltage will then be the sum of the plate and load drops (126 + 251 = 377) divided by the amplification factor (5). Then the voltage required will be 377 ÷ 5 or 75.5 volts (r.m.s.). Quite obviously, 75.5 volts applied to the grid would hardly cause the tubes to go positive, as the bias of 150^{v} allows us to apply a voltage of $150 \div \sqrt{2}$ or 106^{v} r.m.s. In other words, there is a margin of 30.5^{v}.

To raise our sound power 74.2 db., or from 1.14 microwatts, it is necessary to raise the applied voltage of $.015^{v}$ at the input of the amplifier system to 75.5^{v} at the grid input of the last tube. The problem resolves itself down to the design of intermediate stages of audio amplification capable of a gain of $75.5 \div .015$ or a net voltage gain of 5030. This voltage gain would supply an undistorted output of 30 watts.

However, the tube manufacturer advises that a single 845 tube will deliver 20 watts of undistorted power, and two in parallel will deliver 40 watts. From a practical viewpoint it would be best to have sufficient voltage gain to obtain maximum undistorted power and then reduce the output to the necessary level by means of an attenuator.

Now let us see what the required grid voltage would be for an amplifier designed for 40 watts output and what voltage gain would be needed. Again from the formula $V_L = \sqrt{P \times R}$ we get

$$\begin{aligned} V_L &= \sqrt{40 \times 2100} \\ &= \sqrt{84{,}000} \\ &= 290^{V} \text{ r.m.s.} \end{aligned}$$

The voltage drop in the tube plates will be $290 \div 2$ or 145. The total voltage lost in the plate circuit will be $290 + 145$ or 435. The grid must then supply $435 \div 5$ or 87 volts r.m.s., which is equivalent to 87×1.41 or 123^{v} peak.* And the required overall gain will be $87 \div .015$ or 5800.

Summarizing all these facts, we find that, for 40 watts output, the amplifier must raise the applied voltage 5800 times. The grid voltage will then be 87^{v} r.m.s., and if the recommended C bias of 150^{v} is used, the grid will not swing positive as the half swing will be only 123^{v}, or the total swing will be 246. With a 150^{v} bias, the grid could swing a total of 300 volts without becoming positive. However, it would not be safe to allow a larger grid swing than 246^{v}, as the tube would operate beyond the straight portion of its E_g-I_p characteristic.

The intermediate A.F. amplifier, then, to provide 40 watts output, must be designed to permit an undistorted voltage amplification of 5800. Selecting suitable intermediate A.F. coupling

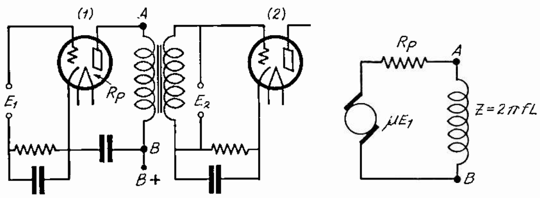
* This value differs from that given in Fig. 4, for in this case the load resistance was taken as twice the plate resistance. Figures given in Fig. 4 are recommended load values.

is a job requiring experience and expert knowledge, and the cost of parts must always be taken into consideration. While voltage gain results primarily from the μ of the tubes in cascade, when transformers and auto-transformers are used as coupling devices, an additional voltage gain is obtained which is roughly equal to the step-up ratio. The total gain is the product of each step.

There are any number of audio couplings, but in this lesson we are going to consider only those methods that are used in standard practice; that is, transformer, resistance, and impedance coupling.

A stage of transformer coupling will contribute a voltage amplification of μ times the turn ratio of secondary to primary. For example, if a '27 tube having a μ of 9 is followed by a 3 to 1 audio transformer, the total voltage gain will be 3×9 or 27.

On the other hand, resistance coupling reduces the gain



(a) Fig. 6 (b)

provided by a tube—a stage of resistance coupling will, on an average, reduce the gain to three-fourths the μ of the tube. For example, a '40 tube having a μ of 30 is followed with a stage of resistance coupling and the approximate voltage gain will be $30 \times 3/4$ or 22.5.

Where impedance coupling is used, it will be well enough for purposes of rough calculation to assume a gain equivalent to the μ of the tube used.

Suppose we are going to use transformer coupling throughout in the design of our power amplifier which is going to supply 40 watts of undistorted power output. Let us say these transformers will have a ratio of 3 to 1 and that we are going to use '27 type tubes. In each stage we would obtain a gain of 27 (3×9) or 20 log 27.0, which is 28.6 db. A total voltage gain of 5800 is needed. In terms of db. this is 20 log 5800 or 75.3 db. The number of stages needed will roughly be $75.3 \div 28.6$ or 2.6 stages. Now what are we going to do? Shall we use three stages or two stages? It must be remembered that the input to the first tube will be through a step-up transformer which will contribute some voltage gain in addition to the vacuum tube stages. Even though this first transformer has a low voltage gain (a small step-up ratio), it will provide the additional gain necessary and, theoretically at least, two stages would be sufficient. It must not be forgotten that we are only dealing with approximations and that if we were designing an actual audio system we should have to calculate the gain per stage very accurately.

TRANSFORMER INTERMEDIATE COUPLING

In the preceding chapter we assume that the voltage gain of a transformer coupled stage was equal to the μ of the tube multiplied by the turns ratio (N) of the step-up transformer. However, this was a purely theoretical assumption, made to simplify our study of voltage amplification stages needed. In practice, a transformer, even an ideal one, will not always contribute a gain equivalent to its turn ratio.

Fig. 6a shows two tubes coupled by means of a transformer having a turns ratio of N, which may be 1, 3, 5, 6, or any value you wish to assume. E_1 is the input voltage and E_2 is the amplified voltage. Of course, $E_2 \div E_1$ is the voltage gain.

Here again we must make an assumption—that the grid is properly biased so that no secondary current will flow. Then the audio transformer will have no secondary load and the impedance in the primary consists merely of the reactance due chiefly to the primary inductance. While the primary will also have resistance, in fairly good transformers this resistance will be quite small in comparison with the inductive reactance and so it can generally be disregarded. Therefore, as far as the plate circuit is concerned, we can consider Fig. 6b as a representation of the true state of affairs; a tube amplified voltage of $\mu \times E_1$, a resistance R_p equal to the plate resistance, and a reactance due to the inductance of the primary, equal to $2\pi fL$.

The amplified voltage μE_1 will now divide between R_p and Z, and the voltage across A-B, the primary of the transformer, is the only voltage that will be increased by the turns ratio of the transformer. The rest is an old story to us; if a source of e.m.f. is in series with two impedances, the voltage will be dropped in both of them—the greater amount in the larger impedance, and a smaller amount in the smaller impedance. This is exactly what we have here except that one impedance is a resistance and the other is a reactance. Obviously, if we want a large voltage across A-B, the reactance of Z in ohms must be high in comparison with the resistance of R.

When this is true, the amplification of a transformer stage will be $\mu \times N$, or 9×3 as in our previous example. However, as you know, the primary impedance is affected by frequency. In a good grade of audio transformer, the primary impedance may be very high even when the audio signal is as low as 60 cycles per second. In lower grade transformers, this might not be the case below 800 cycles, in which case the amplification will be considerably less than $\mu \times N$ below 800 cycles.

$$G \text{ (voltage gain)} = \frac{\mu \times N \times 2\pi f L}{\sqrt{R_p^2 + (2\pi f L)^2}}$$

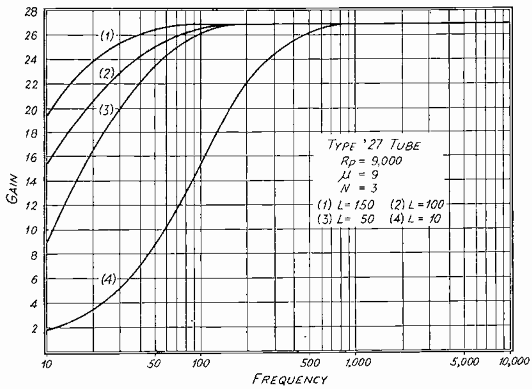


FIG. 7

The formula for gain which takes these factors into consideration (for the conditions illustrated in Fig. 6a) is:

The practical application of this formula can be shown by an example. Suppose we have a '27 tube and a 3 to 1 step-up audio transformer. If the tube is operated at a plate voltage of 180 and the C bias is 13.5 volts, R_p will be 9000 ohms. (This information is given in tube charts issued by the manufacturer.) Suppose then that our transformer has a primary inductance of 20 henries—although high grade transformers may have primary inductance values as high as 175 henries. Now, we want to see what amplification would be obtained at 30 cycles and 1000 cycles. Then μ will be 9, N will be 3, L will be 20, R_p will be 9000 and f will be 30 in the first case and 1000 in the second. By making substitutions in the voltage gain formula, we get:

G for 30 c.p.s . =

$$\frac{9 \times 3 \times 2 \times 3.14 \times 30 \times 20}{\sqrt{9000 \times 9000 + (2 \times 3.14 \times 30 \times 20) \times (2 \times 3.14 \times 30 \times 20)}}$$

$$= \frac{102{,}000}{\sqrt{81{,}000{,}000 + 14{,}200{,}000}} = \frac{102{,}000}{\sqrt{95{,}200{,}000}} = \frac{102{,}000}{9{,}760} = 10.5$$

G for 1000 c.p.s. =

$$\frac{9 \times 3 \times 2 \times 3.14 \times 1000 \times 20}{\sqrt{9000 \times 9000 + (2 \times 3.14 \times 1000 \times 20) \times (2 \times 3.14 \times 1000 \times 20)}}$$

$$= \frac{3{,}390{,}000}{\sqrt{81{,}000{,}000 + 15{,}800{,}000{,}000}}$$

$$= \frac{3{,}390{,}000}{\sqrt{15{,}881{,}000{,}000}} = \frac{3{,}390{,}000}{126{,}019} = 26.3$$

You will notice that, in working out these examples, we have only considered three significant figures. Thus, in the first example, 102,000 is used instead of 101,736. This is standard engineering practice, in cases where any of the factors can only be approximations. In this case an amplification of 9 is only approximate. In actual cases it might be 8.9 or 9.1, or there may be a larger discrepancy.

Now let us see what these examples can tell us. Of course, if conditions were ideal, we would obtain a total amplification of 27. However, our calculations show us that a transformer stage, in which the transformer has a primary inductance of 20 henries, provides a voltage gain equal to 10.5 when amplifying a 30 cycle signal. But, when amplifying a 1000 cycle signal, the gain is 26.9, which is very close to ideal.

It is evident from this that a transformer having a primary inductance of 20 henries will not respond well to low frequencies, so that the loudspeaker reproduction will be lacking in depth and fullness. On the other hand, if a high grade transformer is used, with primary inductance of let us say 150 henries, uniform amplification down to 30 cycles per second is quite possible.

Fig. 7 shows graphically the variation in gain for various primary inductances.

However, we run into difficulty when we start building transformers having high primary inductances. To obtain a high inductance, we must use a large number of turns. Then, of course, the secondary must have 2, 3 or 4 times as many turns as the primary, depending on the turns ratio. A large turns ratio would mean a tremendous number of secondary turns. Manufacture of transformers of this kind is costly and involves difficult constructional problems, particularly as distributed capacity must be kept down to a minimum. In large sound installations, where uniform response down to 30 cycles is required, the audio transformers used are costly.

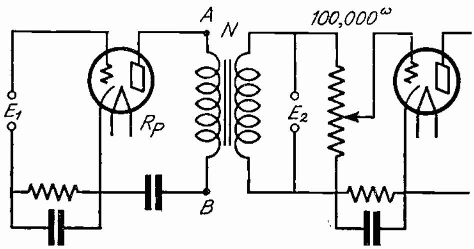
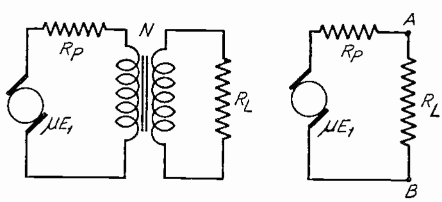


FIG. 8a

Now, before we go on to study resistance coupling, we have one more thing to consider. The secondary of the transformer may actually have a current passing through it; that is, the grid-cathode resistance may be appreciable or, as is often the case, a resistance or a volume control resistor may be shunted across the secondary.

To study the effect of this resistance, let us again consider the '27 tube operated on 180 volts plate and -13.5 grid. Refer



(b) FIG. 8 (c)

to Fig. 8a where R_p equals 9000 ohms and a 100,000 ohm volume control is placed across the secondary. Fig. 8b shows this same circuit in simplified form.

We have already learned that when a transformer is used to couple a source and a load, both having different resistances, the maximum power and the maximum voltage on the secondary load would be obtained when the turns ratio squared equals the ratio of the resistances. That is, in Fig. 8a, E_2 will be greatest when

$$N^2 = \frac{R_L}{R_p} \qquad \text{or} \qquad N = \sqrt{\frac{R_L}{R_p}}.$$

If R_L is 100,000 ohms and R_p is 9000 ohms, the proper turn ratio for maximum voltage will be:

$$N = \sqrt{\frac{100{,}000}{9000}} = \sqrt{11.1} = 3.33 \text{ approx.}$$

In this case it is very likely that a designer would specify a 3½ to 1 transformer.

What we are really doing in this case is matching the load to the source; that is, a 100,000 ohm secondary load can be represented as a 9000 ohm load in the plate circuit, as shown in Fig. 8c. Therefore, across the terminals A and B in Figs. 8a and 8b, the voltage will be one-half of $\mu \times E_1$. This voltage is increased by the turns ratio of the transformer, and the gain is $\mu N \div 2$.

A potentiometer is often connected across the secondary of a transformer and functions as a volume control. The higher the resistance of the potentiometer the higher will be the stage gain.

Once the value of potentiometer is chosen the highest gain is realized when the transformer matches the impedance of the load to the source. The gain is then one half that would exist if the load were removed.

Looking at the problem in another way. If a transformer gives a definite gain and its secondary is shunted by a potentiometer so that it is matched to the source, the stage gain will be cut in half.

RESISTANCE COUPLED INTERMEDIATE AMPLIFIERS

The advantages of resistance coupling between voltage amplifier tubes have long been known, but, until recently, the use of resistance coupling was somewhat limited because sufficiently high resistance and absolutely noiseless resistors were not commercially available. Now that resistance manufacturers are turning out resistors that meet the requirements, resistance coupling is gaining in favor.

Of course, resistance coupling does not contribute any voltage gain and, for this reason, high μ tubes are generally used.

What we are interested in now is in learning what are the actual gains possible when resistance coupling is used.

Fig. 9a shows the schematic diagram of a stage of resistance coupling as we are accustomed to see it in actual circuit diagrams. E_1 is the voltage applied to the grid of tube *1*; R_1 is the plate resistor; R_2 the grid resistor; C the coupling condenser between the grid and the plate—through which only audio signals can pass. R_p, Fig. 9 (b), of course, is the plate resistance of the amplifying tube and E_2 is the amplified voltage. We are assuming that the tube is supplied with the correct A, B and C voltages.

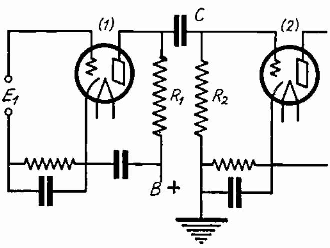
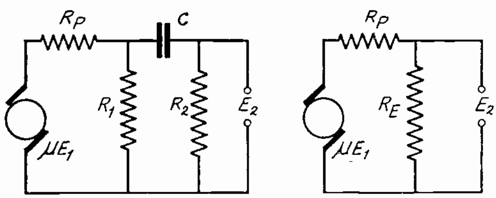


FIG. 9a

For purposes of calculation, it is best to represent the plate circuit of tube *1* as in Fig. 9b. The voltage amplified by the tube is now μE_1 in the plate circuit. R_p is in series with a parallel arrangement of R_1, R_2 and C. We are chiefly concerned with the voltage across R_2, as it feeds the following tube.

Let us say that the value of C is large and its reactance in ohms as compared with the resistance of R_2 is negligible. This



(b) FIG. 9 (c)

is not far from the actual state of affairs as R_2 is generally about 250,000 ohms and the reactance of C, when a .1 mfd. condenser is used, is about 1500 ohms at 1000 cycles. The plate load resistance now consists of R_1 in parallel with R_2 and from the formula for two resistors in parallel, the effective load resistance becomes:

$$R_{\text{eff.}} = \frac{R_1 \times R_2}{R_1 + R_2}$$

In the case of a '27 tube, R_1 would be 100,000 and R_2 would be 250,000 ohms. Then:

$$R_{\text{eff.}} = \frac{100{,}000 \times 250{,}000}{100{,}000 + 250{,}000} = \frac{25{,}000{,}000{,}000}{350{,}000} = 71{,}500^{\omega}$$

This can be represented as in Fig. 9c with the plate voltage in series with the tube resistance and the effective plate load resistance. E_2 is now the voltage across the effective plate load resistance and can be calculated from the formula:

$$E_2 = \frac{\mu E_1 \times R_{\text{eff.}}}{R_{\text{eff.}} + R_p}$$

The amplification per stage of resistance coupling can be calculated from the formula:

$$G = \frac{R_{\text{eff.}}}{R_{\text{eff.}} + R_p} \times \mu$$

In the case of a '27 tube, R_p is 9000 ohms, μ is 9, and $R_{\text{eff.}}$ as just calculated is 71,500 ohms. Then, the total gain for a stage of resistance coupled amplification using a '27 tube would be:

$$G_v = \frac{71{,}500}{71{,}500 + 9000} \times 9$$

$$= \frac{71{,}500}{80{,}500} \times 9$$

$$= .888 \times 9 = 7.99$$

From this we can see that the total amplification is about 90 per cent that of the μ of the tube.

You will remember that we assumed the condenser reactance to be negligible. The fact of the matter is that this assumption is perfectly true for frequencies above 1000 cycles—and the higher the frequency is above 1000 cycles, the truer the assumption is. But when the bass notes come through—that is, at audio frequencies of 60 cycles or less—the capacitive reactance becomes $20{,}000^{\omega}$. In comparison with 250,000 ohms in series, this can hardly be neglected. The result is a reduction in the actual gain of about 8 per cent at 80 cycles per second. And the lower the frequency, the greater will be the reduction in gain. In spite of this, however, a well designed resistance coupler provides almost equal gain over a wide band of audio frequencies.

A serious disadvantage in resistance coupling is the voltage plate supply drop in the plate resistor. If there are 180 volts on the plate of a '27 tube and the plate current is 6 ma., the voltage drop in the plate resistor will be .006 × 100,000 or 600 volts. Thus, the power supply will be required to furnish 600 + 180 volts or a total of 780 volts, most of which is wasted. In radio receivers, however, where the detector is followed by resistance coupling and the required plate voltage is between 45 and 90 volts, and the plate current is between ½ and 2 ma., sufficient voltage is easily obtained. In the case of P.A. amplifiers a high plate load resistance would necessitate the use of extremely high plate voltages; therefore this resistance is kept relatively small even at the loss of considerable gain.

To compensate for the reduction in gain when resistance coupling is used, a type '40 tube having a μ of 30 may be used. Then even though a rather high plate load resistor is used, about 70 per cent of the 30 can be obtained. Some designers have used

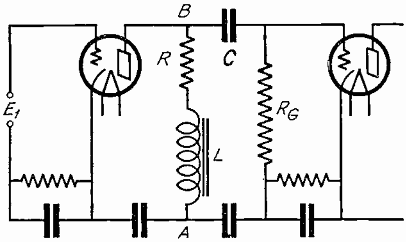


FIG. 10

screen grid tubes as intermediate audio amplifiers and have obtained a voltage gain per stage of 60.

While gain in a stage of resistance coupled amplification is comparatively constant over a wide band of audio frequencies, there is a dropping off in the amplification of higher frequencies due to the effective grid cathode and plate cathode capacity which shunts the plate load. This capacity in a triode circuit might be so high at frequencies between 9000 and 15,000 cycles that this capacity reduces the effective plate load and the amplification of the stage.

IMPEDANCE COUPLING

Impedance coupling offers many of the advantages of resistance coupling and has one big advantage over resistance coupling, that is, the voltage drop across the impedance is not nearly as great as that across a high resistance, and plate voltages need not be higher than the rated plate voltages.

A typical impedance coupling is shown in Fig. 10. You will notice that it is essentially the same as resistance coupling except that the first resistance is replaced by an iron core choke having an inductance of 30 to 200 henries and with a D.C. resistance between 1000 and 1500 ohms.

Even at low frequencies the impedance of the choke ($Z_L = \sqrt{R^2 + (2\pi f L)^2}$) is considerably higher than the tube plate impedance. Thus 90 to 95 per cent of the amplification of the tube can be obtained.

If the choke has a D.C. resistance of 1000 ohms, the voltage drop per milliampere of current will be $1000 \times .001$ or 1 volt. Therefore, for a '27 tube which requires 180 volts on the plate at 6 ma., only 186 volts are required as the total B supply.

However, unless the iron choke coil has a very high inductance value, and is free from distributed capacity, the fidelity will not be as good as when resistance coupling is used. Distributed capacity nullifies the inductance at high audio frequencies and at the lower frequencies the net impedance of the choke will be decreased, resulting in a decrease in fidelity.

Often a high impedance choke is used in place of R_g in Fig. 10. Then condenser C is in series with a grid inductance, and both are in series with the source of A.C. e.m.f., in this case L. It is obvious that this is a series resonant circuit. By choosing the proper values of L and C, resonance can be secured within the audio frequency range.

As you know, the voltage across the capacity or inductance in a series resonant circuit will be large. In this particular circuit, a large resonant voltage will be impressed across the grid and cathode of the following tube and amplification will be accentuated. By having this circuit resonate at a low frequency, a peak response can be obtained. And if the chokes are constructed with a minimum of distributed capacity, flat amplification can be secured up to 10,000 c.p.s.

A well designed stage of double choke coil coupling will provide an amplification almost equal to that of the tube.

PUSH-PULL INTERMEDIATE STAGES

In power audio amplifiers it is not uncommon to find push-pull stages before the output. Fig. 11 shows a typical push-pull intermediate stage preceded by a straight transformer coupled single tube stage. E_1 is the input voltage while E_2 is the voltage across the primary of transformer T_1. The voltage at this point is $\mu_1 E_1$. In going through the transformer the voltage is raised N times. This makes the voltage $\mu_1 \times N \times E_1$.

You will notice that the secondary of T_1 is split, and the center connects to the cathodes of the two tubes in push-pull. The audio signal voltage supplied to each tube is ½ of $\mu_1 \times N \times E_1$. Each tube amplifies this voltage μ times and in the primary of T_2, the outputs of the two tubes add and we have a final voltage of $\mu_1 \times \mu_2 \times N \times E_1$. This is the same signal output that would be obtained if a single tube transformer coupled stage were used. However, a greater effective amplification can be obtained as the tubes in push-pull can be considerably overloaded without distorting the signal.

A stage of intermediate push-pull amplification may be considered as a straight single tube audio stage in every respect if we remember that the plate resistance will be twice that of a single tube and the grid swing may be allowed to be twice the grid swing of a single tube. For this reason the primary of

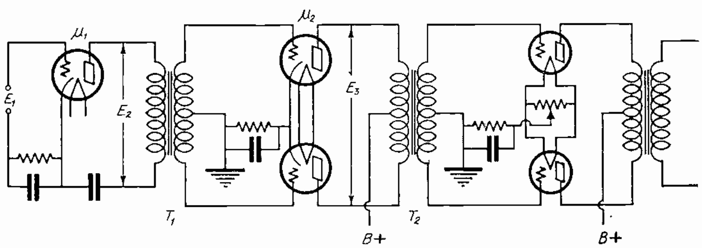


FIG. 11

transformer T_2 must have twice the impedance value of an ordinary transformer.

Reviewing the advantages of intermediate push-pull amplifiers—hum originating in the push-pull stage is greatly reduced due to the balancing out of the second harmonic; distortion due to non-linear tube characteristics would be considerably reduced; and the stage can handle a voltage swing at least twice that of a single tube, without distortion and without the grid swinging positive.

CALCULATION OF INTERMEDIATE AMPLIFIERS

Now let us go back to our original problem which was to raise a .03 volt r.m.s. signal produced by a double button carbon microphone to a power output equal to 40 watts. We have already determined that this amount of undistorted power output can be obtained from two 845 tubes if we fed the grid with 87 volts r.m.s., which was equivalent to a half grid swing of 123 volts. The total voltage gain from the *source* to the power tube grid is 87 ÷ .03 or 2900. In decibel units this would be 20 log 2900 or 69.3 db.

The microphone has a resistance of 200 ohms per button, or a total resistance of 400 ohms. It is to be coupled to the grid of a tube whose grid-cathode resistance may be as high as 1 megohm. It is customary to connect a fixed resistor across the microphone coupling transformer, but in this case let us use a potentiometer volume control. The resistance this potentiometer must have depends on the turns ratio of the coupling transformers that are available. A 20 to 1 step-up ratio is common. The resistance the volume control should have for a perfect source to load impedance matching is calculated from the formula:

$$N^2 = \frac{R_L}{R_S}$$

$$R_L = N^2 \times R_S$$

$$= 20^2 \times 400$$

$$= 160{,}000 \text{ ohms}$$

As standard 150,000 ohm potentiometers are available, we could possibly use one of this size and the 10,000 ohm difference would not be sufficient to affect the match noticeably.

We have already learned that, when a transformer matches a load to a source, the amplification is one-half of the turn ratio. In this case it would be 20 ÷ 2, a voltage gain of 10. In decibels this would be 20 log 10 = 20 db. gain.

Thus we have taken care of 20 db. gain out of the required 69.3 db. gain and it remains for the intermediate audio stages to furnish 69.3 − 20 or 49.3 db. As audio transformers having a ratio of 2 to 1 are standard, let us assume that our next stage will be a '27 tube stage with 2 to 1 transformer coupling. This stage will provide a voltage gain of $\mu \times N$, that is, 9×2 or 18 times. In decibels this will be 20 log 18 or 25.1 db. This leaves 49.3 − 25.1 or 24.2 db. gain for the last stage to handle.

It is clear that another '27 tube with a 2 to 1 ratio transformer will do for the last voltage amplifier stage. While there would be a little more voltage amplification than is absolutely necessary, and while there is some possibility of overloading the 845 tubes at large signal voltages, we can assume with considerable safety that the voltage generated in the microphone may be slightly less than .03 volt, and the slight additional gain can be put to good use.

Of course, if we wanted to, we could calculate the exact transformer turns ratio for 24.2 db. With no load across the secondary the turn ratio will be found as follows: Find the number whose log is the required db. gain divided by 20, divide this number by the amplification factor of the tube and the result will be the turns ratio. This procedure may be followed in calculating any audio transformer or coupling device. In our present case the db. gain divided by 20 is 24.2 ÷ 20 or 1.21. The number whose log is 1.21 is found from a log table to be 16.2. This number divided by the μ of the tube used (9.0 for a '27) is 16.2 ÷ 9 or 1.8, the turns ratio.

PERMISSIBLE GRID SWING

The complete amplifier we have just designed is shown schematically in Fig. 12. Now we want to find out whether there is any possibility of large signal voltages causing the tube grids to swing positive with resulting distortion.

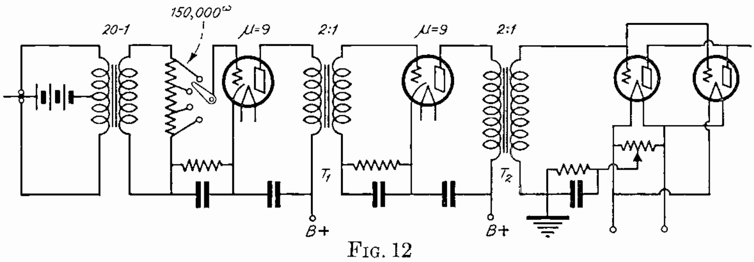


FIG. 12

The r.m.s. voltage applied to the grid and cathode of the first intermediate tube will be .03 × 20/2 or .3 volt r.m.s. This is the same as .3 × 1.41 or .423, the peak voltage. For a '27 tube having 180 volts applied to the plate and a bias voltage of 13.5, a peak voltage of .423 will certainly not cause the grid to become positive.

This peak voltage is amplified by the '27 tube and the 2 to 1 audio transformer 18 times (9 × 2). Then the peak voltage fed to the grid of the following tube will be 18 × .423 or 7.61 volts. This second '27 tube, with a proper C bias of 13.5 volts, will handle this half swing without distortion.

In going through the last transformer audio stage, the voltage is amplified to 9 × 2 × 7.61 or 137 volts (peak).

You remember that 123 volts must be applied to the grids of the 845 tubes to obtain an output of 40 watts.* But the 845

* We still are considering the case where the load resistance is twice the plate resistance.

tubes operate with a grid bias of 150 volts, and so, while our grid swing of 137 volts is slightly more than is needed to supply a 40 watt output, yet the grids will never swing positive and very little distortion will be introduced because of tube overloading.

In the amplifier we designed, we used 2 to 1 ratio transformers in the voltage amplifier stages. It should be mentioned here that we might have used a 4 to 1 ratio transformer in the first stage and a 1 to 1 ratio in the second stage without altering the db. voltage gain. But what about the grid swing in this case? The half grid swing of the second tube would be $9 \times 4 \times .423$ or 15.2 volts. This is above the C bias of 13.5 volts so that the grid would swing positive at times and distortion would be introduced.

We could get around this by using two '27 tubes in push-pull. This would reduce the grid swing on each tube to one-half of 15.2 or 7.6 volts. However, the new plate resistance would be 2×9000 or 18,000 ohms, and a 1 to 1 ratio transformer of sufficiently high primary impedance might be costly. If we could find a tube to be used in a push-pull arrangement which had a low plate impedance and a μ close to 9, our problem would be most likely solved. Referring to a tube chart we find that the '12A tube would meet the requirements very closely. Its μ is 8.5, its plate resistance is 5000 ohms, its grid bias is 13.5 volts with 180 volts on the plate.

It is common practice to use larger power tubes than the '12A in the last intermediate audio stage, especially when there are large power tubes like the 845 and 211 in the output stage. Suppose, as is customary, push-pull 45's are used in the last intermediate stage. From the tube chart we find that when 180 volts are used on the plates, the required C bias is 34.5 volts, the plate impedance of a single tube is 1900 ohms, and the μ is 3.5.

Thus the use of two '45's in push-pull would permit an input peak voltage of 34.5×2 or 69 volts. The combined plate resistance would be 1900×2 or 3800 ohms. While the high permissible grid swing and the low plate resistance are advantages, we have lost a gain of 14.8 db. [$20 \log (9 — 3.5) = 20 \log 5.5 =$ 14.8 db.] which must be made up in the amplifier. Obviously larger ratio transformers must be used. The additional turn ratio required to make up for this loss of gain is $9 \div 3.5$ or 2.57. According to our original estimate we needed a 2 to 1 transformer, a 1.8 to 1 transformer, and now to these we have to add a ratio of 2.57 to 1, and the total turn ratio for the first and second stage transformers will be $2 \times 1.80 \times 2.57$ or 9.25. For practical purposes we can say that a total turns ratio of 10 to 1 is required. We might possibly increase the turns ratio in the first stage transformer to 5 to 1, and use a ratio of 2 to 1 in the second audio stage. Let us see if we would be exceeding the permissible half grid swings of 13.5 and 34.5 volts.

Starting from the source, the first grid peak voltage is $.03 \times 20 \times \frac{1}{2} \times 1.41$ or .423, which is satisfactory, as it will not cause the grid to swing positive. Across the secondary of the push-pull input transformer we will have $.423 \times 5 \times 9$ or 19 volts peak. But as only half of this is impressed on the grid of each tube in push-pull, the half grid swing will be 9.5 volts, which is far below the permissible half swing of 34.5 volts. Then the peak voltage across the grid and cathode of the 845 tube is $9.5 \times 2 \times 3.5 \times 2$ or 133 volts. This is more than the required 123 volts peak but well below the permissible grid swing. We

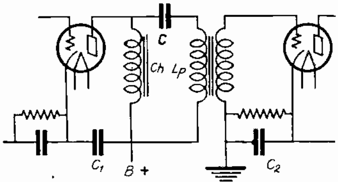


FIG. 13

can assume that our design is satisfactory because all through we have assumed ideal conditions and have not taken into account practical losses.

RESPONSE EQUALIZATION

No amplifier is considered complete until the over-all gain is measured over a wide range of audio frequencies and a complete response curve obtained.

Suppose the response curve showed that the output was more than the designer wanted. Rather than change any component, he might insert a resistance in series with the volume control, or insert an attenuating pad to prevent ordinary input levels from distorting the final output power. These pads must be selected so that the impedances will still be properly matched. No losser method is employed that will affect the over-all fidelity.

Then suppose the response curve shows poor bass response. The designer might attempt to increase the low frequency response by resonant methods. We have already seen how this can be done by using a double impedance coupling. The same scheme can be used for transformer coupling. A condenser C is placed in series with the primary inductance L_p as in Fig. 13. The plate of the tube is then parallel fed through an iron core choke (*Ch*) which must be extremely large, at least 500 henries,
9 to prevent even the lowest audio frequencies from passing directly back to the tube cathode.

The inductance L_p and the capacity C form a resonant circuit. We can make this circuit resonate to the desired frequency by using a capacity determined from the formula:

$$C = \frac{1}{39.4 f^2 L_p}$$

As you know, at resonance a large voltage will be placed across L_p, which will be further raised by the transformer turns ratio. Note, however, that the primary no longer carries a magnetizing current, with the result that its inductance is higher.
10 In calculating the value of C for a definite resonance peak, the inductance is measured at that frequency with no D.C. current flowing through it.

Suppose a peak were desired at 30 cycles and the primary inductance measured 50 henries. The capacity in microfarads required will be:

$$C = \frac{1{,}000{,}000}{39.4 \times 30^2 \times 50}$$

$$= \frac{1{,}000{,}000}{1{,}773{,}000}$$

$$= .564 \text{ mfd.}$$

Sometimes a peak response at a low frequency is made to compensate for poor speaker response at low frequencies. In any case, it must be remembered that altering the response characteristics reduces the gain per stage at other frequencies. For example, in Fig. 13, the voltage across L_p would be reduced by the presence of the reactance C.

Condensers C_1 and C_2 are by-pass condensers which play an important part in determining the response characteristic. For good bass reproduction they should be as large as possible.

TEST QUESTIONS

Be sure to number your Answer Sheet 34FR.

Place your student number on every Answer Sheet.

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson.

In that way, we shall be able to work together much more closely, you'll get more out of your Course, and the best possible lesson service.

1. What two types of amplification must be provided for in an audio amplifier?
2. Where a number of speaker loads are to be operated simultaneously but where at some times only a few speakers might be in operation, how should they be connected?
3. How many 2 watt dynamic speakers can be continuously operated on an apartment house receiver having an output of 100 watts, assuming that 10 per cent of the power output is lost in the transmission system?
4. How much maximum undistorted output power can be obtained from four 250 tubes connected in parallel push-pull? (See Table, Fig. 4.)
5. Show by schematic drawings: (*a*) 3 filament type output tubes in parallel, (*b*) 4 filament type output tubes in parallel push-pull.
6. What are the advantages of intermediate push-pull arrangements?
7. Why should hi-mu tubes be used in resistance coupled stages?
8. If you were to install a volume control in an audio amplifier by shunting the secondary of an audio transformer with a potentiometer matched to the source, what reduction in gain would you expect?
9. What is the function of condenser *C* in Fig. 13?
10. Would you expect to get good low frequency response if you used an intermediate coupling transformer having a low inductance primary?

A MODERN TRANSMITTING INSTALLATION

35 FR

PIONEER HOME STUDY RADIO SCHOOL

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WASHINGTON, D.C.

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I have always felt that no one can get too much training in the fundamentals of Radio if he wishes to master the practical aspects of sound, picture and code signal transmission and reception, or the unique problems of television, electronic control and public address systems, and I therefore strongly recommend that as you proceed with your Advanced Course, you systematically review the fundamental lessons and the fundamental reference books. Re-read each of these books at least once, and keep them handy for instant reference.

J. E. SMITH.

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A Modern Transmitting Installation

A TYPICAL BROADCAST STATION

Radio broadcasting, as we know it today, is only about ten years old, although the first experiments in radiotelephony were carried out early in the history of Radio. It was not until the development of practical vacuum tubes, however, that real progress was made. The enormous income from radio advertising has made it possible to spend large sums of money on improvements in broadcasting, and this is perhaps the main reason that the country is covered with transmitters today, many of them connected together by telephone lines to form networks.

Although we usually think of broadcasting as a purely radio science, in the case of network (chain) programs the entertainment which we hear travels actually a far greater distance over telephone lines than through the "ether." It is therefore important that we thoroughly understand the transmission of voice and music over wires. Even when the program originates at a local station, it must still pass through amplifiers and other equipment belonging to the domain of wire-telephony before reaching the radio transmitter.

Before we begin our study of the details of broadcasting, let us rapidly trace out the paths traversed by the program, starting with the sound waves produced by the artist in the studio and finishing with the radio waves which carry the entertainment to the listeners. In this way we can form a picture of the whole process that will be helpful when analyzing the separate parts.

As was pointed out, the longest circuit in broadcasting starts at the central network studio, located in a large city where it is close to important affairs and readily accessible to artists, speakers and entertainers. Actually there are a number of studios at the central point to provide for several programs at the same time and to allow space for rehearsals.

Condenser microphones are used to pick up the sound produced by the voice or instruments in the studio. The current variations in the microphone circuit are so minute that they must be immediately amplified before they can be passed on along the circuit, and a vacuum tube amplifier is always an integral part of the condenser microphone assembly.

Several microphones may be in service, particularly if a large orchestra or band is broadcasting. The various microphone output circuits are run individually to a monitoring control room where an operator controls and mixes them, keeping the total "volume" of the program within definite limits. We should remember that we are now dealing with electric currents of audio frequencies (approximately 30 to 10,000 cycles per second) and that both the frequency and intensity or amplitude are continually undergoing changes which correspond to the sound variations in the studio.

Before the program is sent to the member stations of the network, it is again amplified by what are known as line amplifiers. This is done regardless of the length of the lines so that the signals may be large in comparison with any noises which may be picked up on the line. An additional difficulty, due to the fact that telephone lines do not transmit the higher audio frequencies as readily as the low frequencies, is overcome by placing audio frequency resonant circuits, known as equalizers, across the line at a number of points. The need for this correction will be apparent if we recall the "thinness" of the voices heard in ordinary telephone conversations. Programs are transmitted over special high quality cable and open-wire circuits which, like other long distance telephone facilities, are owned and operated by the American Telephone and Telegraph Company and its subsidiaries. Repeaters on line amplifiers are also included in the telephone circuits to keep up the line level. Telegraph circuits also run between the network studios and the various outlet stations for message traffic relating to the handling of network programs.

After the program reaches the local broadcast studio, over wires leased from the local telephone office, it is monitored and controlled in volume by an operator, passed again through a line amplifier, and then is sent to the transmitter. In modern practice, the high powered transmitter is often located many miles from the studio in a spot which is favorable for radio transmission, and is connected with the local studio by means of carefully equalized telephone lines.

The local station also broadcasts programs originating in its own studios and programs which are picked up in local hotels, theatres, churches and the like; these last named are known as remote pick-ups. The local studios are similar to the network studios and the program is handled in much the same way. For phonograph records and recorded programs (electrical transcriptions), an electromagnetic phonograph pick-up, operating on a special constant-speed turntable, is substituted for the condenser microphone and its amplifier.

A double button carbon microphone is frequently used for pick-up of remote programs, although the modern tendency is toward the use of condenser microphones throughout, due to their superior characteristics. Since the remote pick-up is usually temporary, the microphone amplifier is constructed with portability in mind and is complete with input volume controls and other necessary features. The output of the amplifier is connected to a telephone line which runs to the local studio, where the program is further amplified and controlled before being sent to the transmitter. In addition to the program-carrying line between the remote point and the studio, there is an additional circuit, known as an order-wire circuit, which is used for communication between the studio and remote control operators.

It will be helpful to retrace these program routes now, referring to the block diagram in Fig. 1, before considering what happens at the transmitter.

At the transmitter end of the line from the local studio, there is located still another line amplifier, which in turn excites a high-power speech amplifier. The speech amplifier, which may be likened to the power output stage of a receiver or public address amplifier, is connected to the modulator. The modulator is the final unit in the long chain of audio frequency apparatus which begins at the microphone, and it performs the important function of imparting the signal variations to the radio frequency carrier that make possible the transmission of broadcast programs.

We have yet to consider the steps in generating, amplifying and modu-

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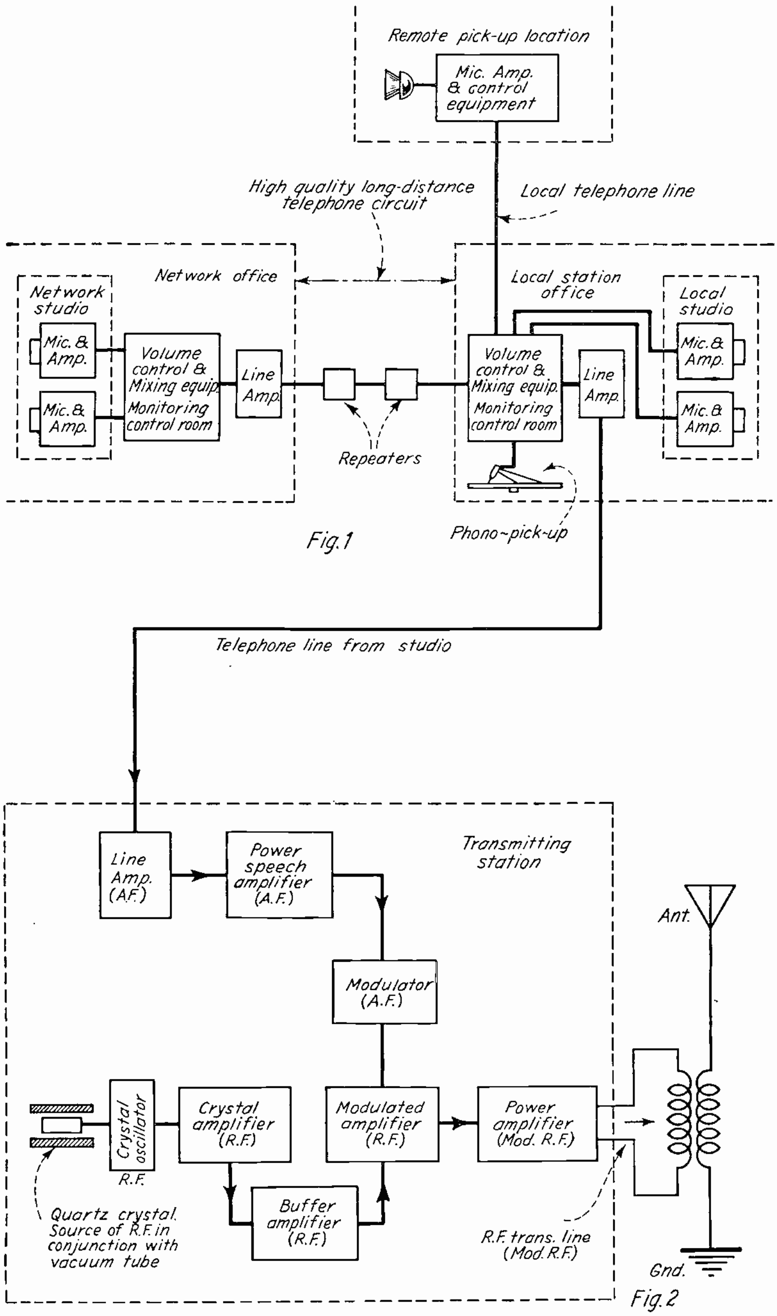


FIGS. 1 and 2. Block Diagrams of Program and Transmitting Circuits for a Typical Broadcast Station.

lating the radio frequency carrier which is responsible for the radiated broadcast signals. As we know, these signals have an enormously higher frequency than those encountered in speech and music. In the American broadcast band they lie between 550 and 1,500 kilocycles per second. As will be described later, quartz crystals connected in oscillatory circuits, can be made to produce these high frequency oscillations at an almost exactly constant rate, and they are now used almost universally for this purpose by broadcast stations.

The crystal and its associated vacuum tube produce only a few watts of high frequency power and hence further amplification is required. We shall see later that at times, a high powered transmitter may deliver as much as 200,000 watts (200 kw.) of power to the antenna. Several low power stages of R.F. amplification are connected after the crystal stage, followed by a buffer stage and then the modulated-amplifier stage. A block diagram of the transmitting circuits is given in Fig. 2. As will be explained further on, the modulator, when excited at audio frequency by signals from the studio, acts upon the modulated-amplifier (R.F.) and rapidly varies the ability of

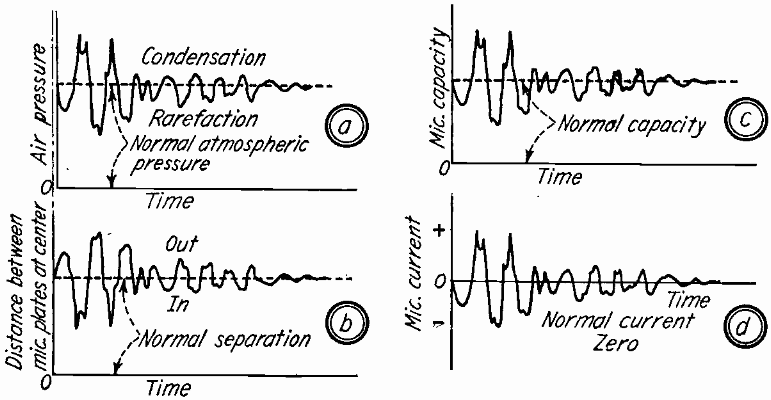


FIG. 3. Sound "AH" as in Father.

the modulated-amplifier to amplify the steady stream of R.F. power available from the oscillator. These variations in amplification follow all the variations of the original audio frequency signal, both in intensity and rapidity. The output of the modulated-amplifier therefore consists of R.F. oscillations whose amplitude or intensity depends on, and varies with the voice or music of the program. These oscillations are said to be modulated. Usually one or more stages of amplification follow the modulated-amplifier.

Radio frequency energy is transferred from the output stage to the antenna by means of a transmission line. Large modulated R.F. currents are caused to flow in the antenna-ground circuit and this results in a distribution of electric charges and magnetic lines around the antenna which travel away in all directions at a speed of approximately 186,000 miles per second. These traveling groups of charges and lines known as wave trains, are the radio waves with which we are so familiar.

It is a good idea to close your book now, and try to draw the circuits from the various pick-up points to the antenna. Use blocks as was done in Figs. 1 and 2, marking the function of each unit.

THE STUDIOS

Although the network studios are more elaborate than the studios of the local station, the principles are naturally the same in both cases. The following discussion of the local studio will therefore give us a good idea of what happens at the network studios.

Within the walls of the studio, we have to deal with the sound waves which have been studied in a previous lesson. As we learned there, sound waves, whether set up by the vibrations of human vocal cords, strings of instruments or resonant bodies of air in horns, are really variations in air pressure which travel outward from the source in all directions. Thus if a special air-pressure gauge, capable of following rapid changes, were located at a point in the studio, a record of its readings would provide a picture of the sound wave. If a speaker pronounced the sound "ah" as in "father," a plot of the gauge readings would appear like (*a*) of Fig. 3. A similar effect would be noted at other points in the studio, but the pressure varia-

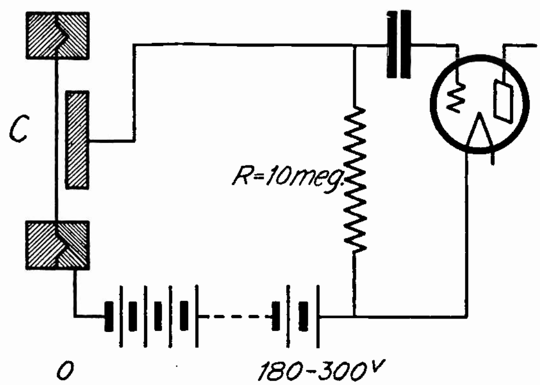


Fig. 4. Schematic Circuit of Condenser Microphone and First Stage.

tions would be greater or smaller, depending on whether the gauge was closer or farther away from the speaker. The shape of the wave remains the same whether the sound is faint or loud, but we would find the peaks of (*a*) lower or higher, accordingly.

Fig. 4 shows the circuit of the condenser microphone used to translate the sound waves into electric currents. As the air pressure in front of the microphone increases and decreases, its diaphragm moves back and forth, decreasing and increasing the distance between two conducting surfaces which are separated by air to form a small condenser. This is shown in Fig. 3b. Corresponding changes in capacity, as in Fig. 3c, result, forcing a fluctuating current as indicated in Fig. 3d, to flow through the grid resistor *R* of the microphone amplifier. As we can see by comparing *a* and *d*, this fluctuating current is a faithful electrical translation of the original sound wave which strikes the diaphragm. Fig. 4 shows how the voltage drops across a high resistance (R), which exists when microphone current flows through the resistor, is impressed on the grid of the first tube of the microphone amplifier.

Since all vibrations reaching the microphone diaphragm are transmitted as part of the program, a number of precautions are necessary in the studio. Mechanical vibrations, originating in the street or building, are eliminated by constructing the studio as a unit, supported on shock-absorbing cushions or cradles, and spaced from the building walls by a layer of air. Sound itself is prevented from entering or leaving the studio by the use of sound-absorbing and insulating materials on the walls, ceiling and floor. In addition, this reduces the amount of reflected sound likely to produce the unpleasant reverberations and echoes which you have observed in many large halls and auditoriums. So successful are these measures in the most modern studios, that only one ten-millionth part of any sound can penetrate through the studio walls. As a result, only the desired sounds, produced under suitable acoustic conditions, are transmitted.

A number of microphones are often used at the same time, especially when a large orchestra is broadcasting and it is desired to produce the proper balance between bass and treble sections. The announcer usually

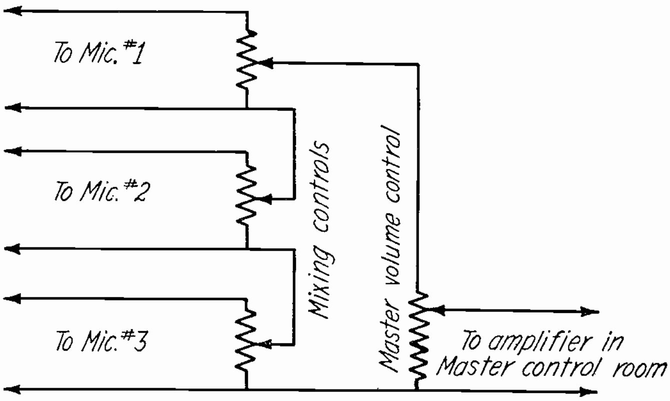


FIG. 5. Schematic Circuit of Mixing and Volume Controls in Monitoring Control Room.

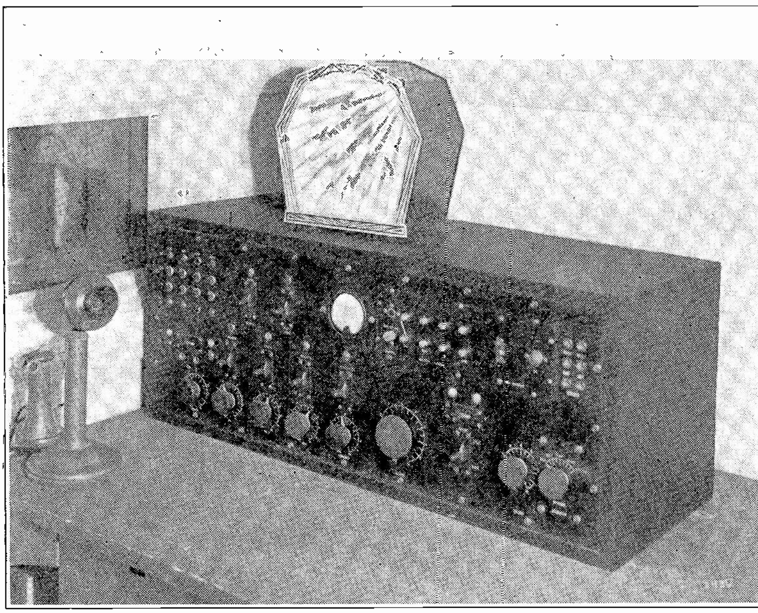
has his own microphone and, in most cases, some signalling devices connecting to the monitor control room. It is very necessary to proportion the outputs of the various microphones properly. This is not done in the studio but in the monitoring control room.

THE MONITORING CONTROL ROOM

Each studio has its own monitoring control room where actual control of the program is centered. The output of all the microphones within the studio are connected to volume controls or mixers in the monitoring control room. These are mounted on a control panel which also contains a master volume control, a volume indicator extension meter, switches for shifting from one line to another and pilot lights which indicate the lines in use. and a set of fuses for the microphone battery circuits.

Fig. 5 is a schematic diagram of a mixing circuit as used in the monitoring control panel. The individual mixing controls are adjusted by the control operator to give the desired output from each microphone circuit. The total volume is kept within certain limits during the course of the program by adjustment of the master volume control. The operator is aided in making these adjustments by a monitoring loudspeaker, whereby he can listen to the outgoing program, and by the calibrated volume indicator extension meter which actually measures the level of the program at the output of the line amplifier. We will refer to the monitor amplifier and volume indicator again later on. It is also of assistance to the control operator for him to be able to see the action within the studio, and for this reason, the monitoring control room is placed next to the studio with a double-glass sound-proof window between.

Network and remote pick-ups are passed through the monitoring control room for volume control and switching. The control operator has tele-



Studio Monitoring Control Box. Note Window at the Left through Which Studio Is Visible.

phone and telegraph facilities available so that he can communicate with remote points, the transmitter or with the master control room at any time.

THE MASTER CONTROL ROOM

The master control room is the supervision point and ultimate terminus of all studio and line circuits. Studio and line amplifiers, monitor amplifiers, volume indicators, amplifier plate supply rectifiers, battery panels, telephone line terminal switchboards and telegraph facilities are located here. We should bear in mind, however, that the monitoring control room is the point of volume control and switching *during* and *between* programs. The master control room may be thought of as the place where the main amplifying and auxiliary equipment is located, and where all circuit connections involving telephone lines are made *prior* to the actual broadcasting of the program. We can best show the part played by the master control room by tracing the routing of studio, network and remote programs through the master and monitoring control rooms, reserving detailed description of the equipment for later.

Fig. 6 is a block diagram of the master and monitoring control rooms as connected for a local studio program. The sections marked "local line termination" and "remote line termination" are telephone switchboards where the various studio lines and lines from the local telephone offices are connected to jacks. This allows the master control operator to arrange these circuits for any kind of program, or to shift to other lines in case of line trouble. Connections from one circuit to another are made by means of patch cords, or short lengths of double-circuit cord with telephone plugs on both ends. When a studio program is in progress, the electrical output of the microphones passes through the mixers and master volume control in the monitoring control room and then goes to the master control room as indicated in Fig. 6. Here the program passes through the studio and line amplifiers, which are set for the required amount of amplification or gain. The connection between the line amplifier and the line to the transmitter is through a patch cord as shown, and thus the program passes on to the transmitter, of course going through the local telephone office on the way.

Connected to the output of the line amplifier—that is, across the line—are two units marked "volume indicator" and "monitor amplifier," which we spoke of when discussing the monitoring control room equipment. The volume indicator, by means of the volume indicator meter, measures the level of "volume" of the program as it is sent out over the line to the transmitter. The volume indicator meter in the master control room is connected in series with the extension volume indicator meter in the monitoring control room, thus making possible simultaneous readings in both places. The monitor amplifier takes only a very small amount of energy from the line and amplifies this sufficiently to operate loudspeakers in the control rooms.

Network programs come to the master control room from the local telephone office and are patched to the monitoring control room for volume control as shown in Fig. 7. The program returns from the monitoring control room and is amplified, measured and monitored as before, passing then to the transmitter. Local announcements are made by the announcer, who can switch in his microphone when he hears the chimes or cue words on the network program. A headset or loudspeaker in the studio, fed from the monitor amplifier, enables the announcer to listen-in.

Remote programs from hotels, theatres and the like are handled in much the same way as the network programs, as in Fig. 7 shows. The program originates at the remote microphone, is amplified by the portable speech amplifier, and reaches the master control room through a telephone line. Next, the program is sent through the monitoring control room and then back through the equipment in the master control room and on to the transmitter.

Many precautions are taken to prevent interruption of the program. The master control operator often is provided with a radio receiver with which he listens to the transmitted program at all times. He can thus check over his equipment at once the instant that the program stops, and determine whether the break-down is at the studios, the transmitter, or elsewhere. Spare amplifiers are provided to replace those which may possibly fail during a broadcast. Important circuits are protected by relays so that mistakes in switching are not likely to prove disastrous.

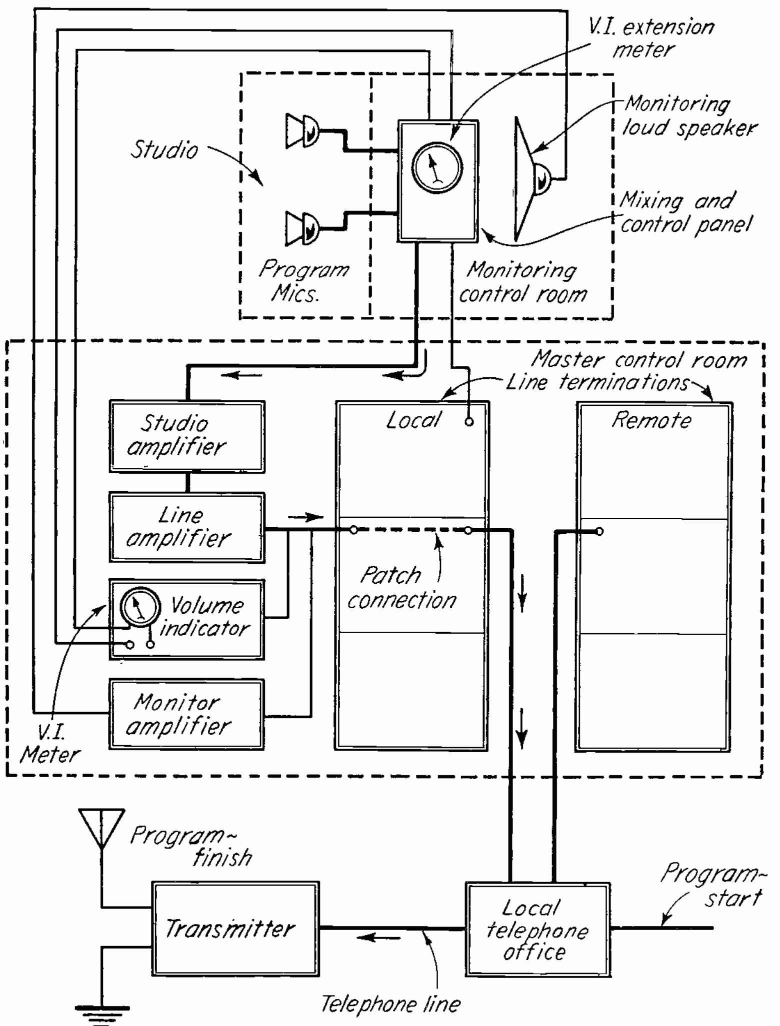


FIG. 6. Setup for Local Studio Program.

AMPLIFIERS AND AUXILIARY EQUIPMENT

Since we have traced the program through the audio frequency apparatus of the local studio and are acquainted with the functions of the equipment, we are ready to examine the various units in more detail.

The condenser microphone amplifier, sometimes called a condenser trans-

Studio A. The organ loft is concealed by the ornamental latticework above the platform. Note the ceiling mike just above the edge of the platform. Another ceiling mike hangs in the rear of the studio and is not visible.

mitter amplifier, is built into the condenser microphone assembly and is hence an integral part of each microphone wherever it may be located. Three stages is the usual number due to the extremely low electrical output of the condenser element itself. Resistance coupling is employed, except for an

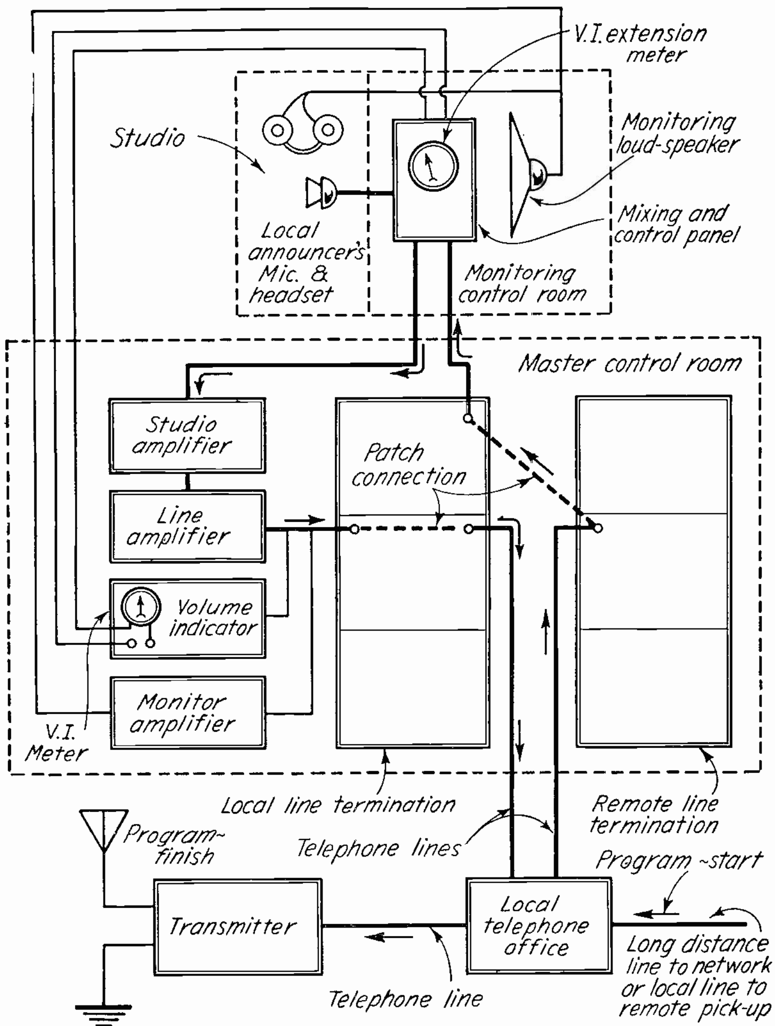


FIG. 7. Setup for Network or Remote Program.

output transformer. The filament, plate and microphone voltages are obtained through a flexible cord and plug connection. Storage batteries, located in a central battery room, are used exclusively for this purpose, for even the slightest amount of hum (if rectified A.C. were used) would drown out the faint signals at this point.

A portable speech amplifier, known also as a remote control amplifier, is used as a combined microphone and line amplifier for temporary remote pick-ups. It is adapted for use with either carbon or condenser microphones. A typical amplifier is composed of three transformer coupled stages and uses dry cell tubes, the batteries being either self-contained or carried in a small battery box. An additional tube is used in a volume indicator circuit so that the remote control operator can observe the level of the signals sent out on the line to the studio. Mixing controls for one to three microphones and means for controlling and measuring the battery currents, are also supplied.

The studio and line amplifiers are used chiefly for the sake of flexibility. The studio amplifier is always associated with a definite studio, and when both types of amplifiers are used, it may consist of two stages similar to the line amplifier described below. Both are located in the master control room.

Fig. 8 shows the connections of a line amplifier which consists of three stages of combined resistance and impedance or choke coupling with input and output transformers. The amount of amplification or gain is controlled

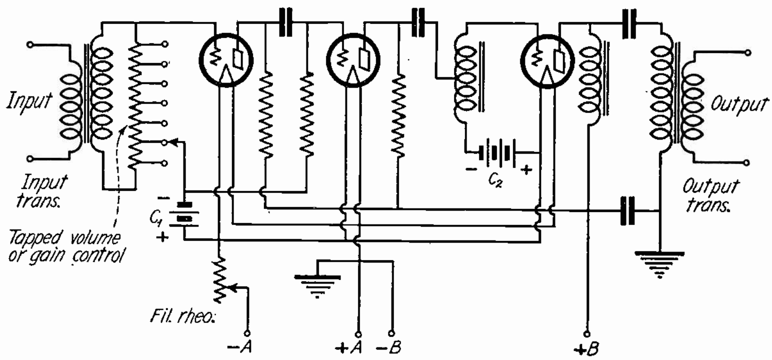


FIG. 8. Wiring Diagram of Line Amplifier.

in large steps by the tapped potentiometer or gain control as shown. There is nothing unusual about the line amplifier, and it is quite similar in principle and operation to the audio amplifiers in radio receivers and public address systems, except possibly, that its amplification may be more uniform over the entire range of audio frequencies. Filament current is obtained from the central storage battery bank and the plate supply may come from storage batteries also, or often from a rectifier unit which may supply the volume indicator and monitor amplifier plates as well.

A volume indicator, or level indicator, is an instrument which measures the audio frequency power flowing past a point in a circuit. It makes use of the vacuum tube voltmeter principle with which you are familiar. Fig. 9 shows the main connections of this instrument. When an audio frequency voltage is present across the input terminals, rectification takes place in the vacuum tube and the plate current therefore consists of direct current which fluctuates from instant to instant in accordance with the signal voltage. The scale of the plate current meter, spoken of as the volume indicator meter, is calibrated in decibels.

The apparent fluctuations of current through the meter are smoothed out somewhat by the combined action of the choke-condenser filter in the plate circuit and the inertia of the moving parts of the meter. The pointer therefore indicates an average level at any instant, the average of course increasing or decreasing with the loudness of the sounds which reach the microphone. Secondary taps on the input transformer extend the range of the meter from —10 to +30 decibels.

The volume indicator extension meter on the monitoring control room panel is connected in series with the main meter in the plate circuit as Fig. 9 shows. The control operator can thus watch the level of the program and keep it within the proper limits. If the level should exceed a certain maximum, overload of amplifiers farther along the circuit and of the transmitter itself will take place and a badly distorted radio signal will be heard by the listener.

The Monitor Amplifier. It is not desirable to connect loudspeakers directly across a broadcast line, since sufficiently loud reproduction would

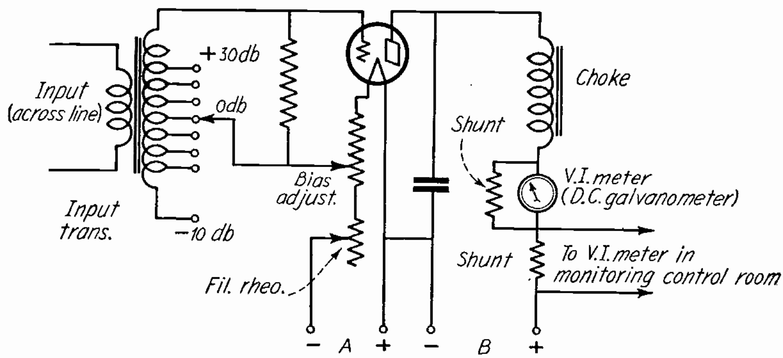


FIG. 9. Schematic Circuit of Volume Indicator.

not be obtained and the transmission characteristic of the line would be impaired. Monitoring loudspeakers are therefore supplied from an auxiliary amplifier, as shown in Figs. 6 and 7, which is designed so that it can be connected across the line without harmful results. This amplifier is known as the monitor amplifier. The control operators can thus check the quality and mixing, using speakers which afford accurate reproduction of the program. The announcer's headset or speaker is also supplied from the monitor amplifier, enabling him to listen-in on the preceding program and switch in his studio at the proper instant. The monitor amplifier is a conventional single-stage power amplifier.

The Rectifier Unit. While it is impossible to use rectified A.C. for the microphone amplifier, a rectifier unit is very often used for common plate supply on the line and studio amplifiers, monitor amplifier and volume indicator. The transformer-rectifier-filter circuit used is essentially the same as that employed in connection with the receivers and amplifiers with which we are very familiar. Much more elaborate filtering is necessary, however, so that no hum will be produced and transmitted along with the program.

LOCATION OF THE TRANSMITTER

The program is carried from the studio to the transmitter over a telephone line. Here the problem becomes one of generating radio frequency oscillations and producing a variation in amplitude of these oscillations which is exactly similar in form to the audio frequency signals arriving from the studios. Every precaution has been taken in the design and operation of the equipment at the studios to make the audio signals which reach the transmitter a faithful translation of the original sound waves. All controlling of the program during a broadcast is done at the studios, usually, and the chief concern of the transmitter operators is, therefore, to keep the station operating efficiently and on its assigned frequency at all times.

We mentioned before that the transmitter may be located many miles from the local studios, which are generally in the heart of the city. There are many reasons for this. It is difficult to find room enough for an efficient antenna close to the studios and the ground there is seldom sufficiently conductive to provide a good ground system. Nearby receivers would be subjected to excessively strong signals, while the presence of numerous buildings close to the antenna would result in greatly weakened signals at distant points. As we shall discuss later, a location away from that city in the open country makes possible the construction of the most efficient radiating system and will enable the greatest number of people to receive satisfactory radio programs.

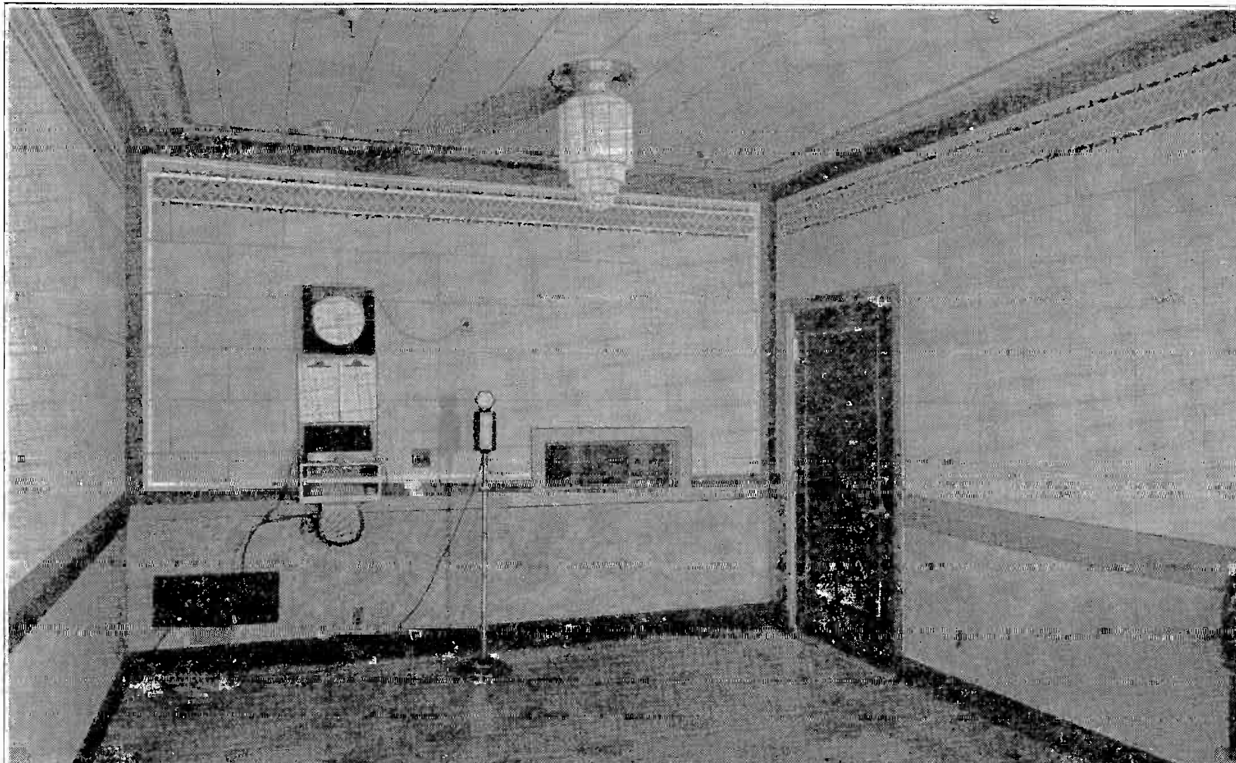
The functions and general arrangement of the apparatus were briefly described earlier in the book and it will be best to turn back to Fig. 2 and make certain that these facts are firmly fixed in mind before studying the details of the equipment.

POWER SPEECH AMPLIFIER

A line amplifier, which is entirely similar to the main amplifiers in the studio, is connected to the telephone line which brings the programs to the transmitter. The signals are then again amplified by the power speech
3 amplifier. The circuit arrangement of the power speech amplifier is conventional, but it differs from the more common audio power amplifiers in that resistance coupling is employed for the purpose of securing a uniform amplifier of all the useful audio frequencies of speech and music. The vacuum tubes are much higher powered than those used in the line amplifiers. The purpose of the power speech amplifier stage is to build up a powerful audio frequency signal to be fed to the modulator.

MODULATION AND THE MODULATOR

The oscillations produced by a vacuum tube, or other high frequency continuous wave source, have a constant amplitude or intensity. In order to transmit speech or music, or for that matter, any kind of signals, on an R.F. carrier the amplitude must be caused to vary in accordance with the signals. When the microphone of a broadcast station is idle, the transmitted wave is only noticed as a "swish" or "hiss" as the receiver tuning is varied. Such waves are *unmodulated,* and can be represented as in Fig. 10a. Now let us examine the wave when the sound "ah," which we studied in Fig. 3,



Interior of Studio E

is spoken into the microphone. Through the action of the modulator, the amplified audio signal causes exactly variations in the amplitude of the radio frequency oscillations, which are shown in Fig. 10b. This wave is said to be

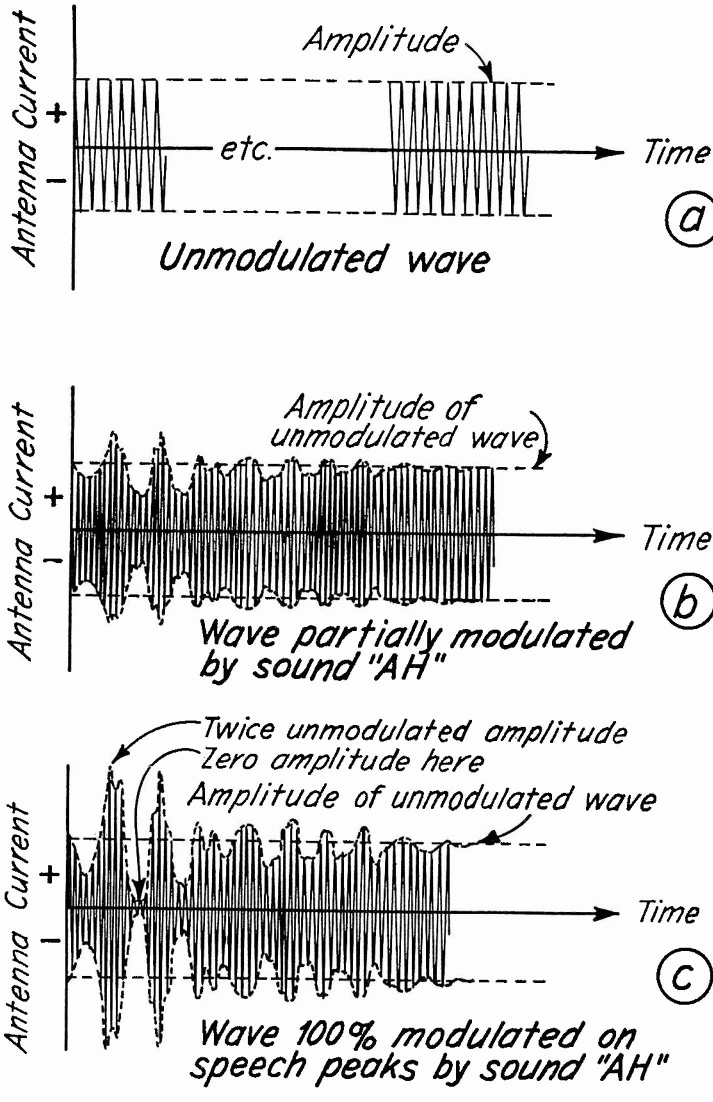


Fig. 10

modulated. The character of the sounds which we hear eventually from a receiver, depends only on the shape of these amplitude variations. The apparent strength of the received signal, however, depends on the amount of the amplitude variation or modulation, which is commonly expressed as a percentage of the unmodulated amplitude. It is therefore desirable to modulate the maximum possible amount without distorting the wave. Fig. 10c shows such a wave, which is said to be 100 per cent modulated. Notice, in contrast to Fig. 10b, that the amplitude falls at times to zero and at other times rises to a value twice that of the unmodulated carrier. We know from our elementary studies, that the power developed is proportional to the square of the amplitude. Thus a 50 kw. transmitter, capable of 100 per cent modulation, would at times deliver a maximum of four times this amount of power, or 200 kw.

There are a great many ways of producing modulation of radio frequency oscillations. The fundamental method which underlies modern broadcast practice, was devised by Raymond A. Heising, of the Bell Telephone Laboratories, many years ago, and is referred to as Heising or constant current modulation. Fig. 11a is the circuit of an R.F. tube and a modulator tube connected according to this method. The R.F. tube may be gen-

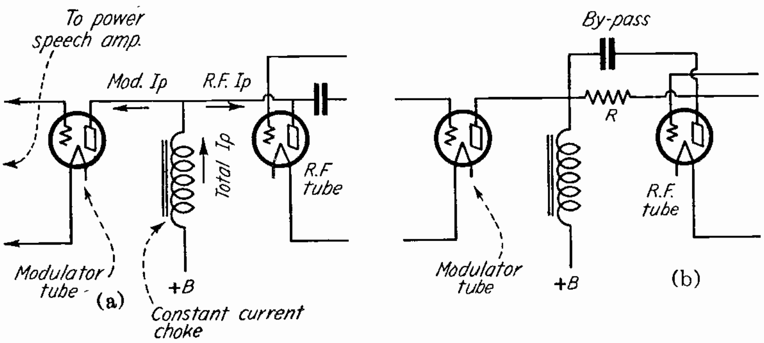


FIG. 11. Heising Modulation. Note: The filaments of the R. F. and Modulator tubes are fed from the same secondary supply.

erating the radio frequency oscillations itself or, as is universal practice in high powered broadcasting, it may represent an amplifier stage between the crystal oscillator and the antenna circuit.

The principle governing the action of the modulator is the same in either case. The plate current of the modulator is caused to vary in accordance with the audio signal voltage applied to its grid. The plates of both tubes, as may be seen from Fig. 11a, are supplied with plate voltage through a common choke, called a constant current choke or reactor. The high inductance of this choke opposes any variations in the *total* plate current of the modulator and R.F. tube. Thus, if the speech voltage on the modulator grid causes an increase in its plate current at a given instant, this must be accompanied by an equal decrease in the R.F. tube plate current, for the sum of these two currents tends to remain constant.

These plate current variations result in a varying voltage drop across the choke, which adds to or subtracts from the D.C. value of plate voltage at any given instant. The R.F. tube is arranged to operate so that the radio frequency current is proportional to the plate voltage. This is known as class C amplifier* operation. It will thus be seen that the radio frequency current will vary in amplitude in accordance with the instantaneous plate voltage on the R.F. tube. The total plate voltage undergoes changes which we have traced to the speech voltage variations at the modulator grid. For a number of reasons, however, the simple circuit of Fig. 11a is limited to about 50 per cent modulation without distortion. One method of extending the modulation capability to 100 per cent, is by use of a lower plate voltage on the R.F. tube than on the modulator, the voltage reduction being obtained through the resistor R in Fig. 11b, which must be by-passed for audio frequency currents.

The modulator is frequently composed of two power tubes in parallel, modulating a single R.F. amplifier tube of the same type. This is due to the fact that, for 100 per cent modulation, the modulator stage must have a power rating approximately twice that of the modulated amplifier. The modulator is the last unit directly concerned with audio speech signals, and we may now turn our attention to the radio frequency portion of the transmitter.

CRYSTAL OSCILLATOR

The radio frequency oscillations are originally generated in a low powered vacuum tube oscillator, later being amplified to the required amount. In all of the high powered stations, and indeed in many of the smaller ones, the frequency of this preliminary or master oscillator is controlled by the use of a quartz (piezo-electric) crystal, connected as shown in Fig. 12. The
5 condenser-inductance combination in the plate circuit is tuned to the natural frequency of the crystal, which depends mainly on its thickness and the axis along which it has been cut. Due to the fact that the crystal dimensions and properties change slightly with the temperature of the surroundings, for utmost constancy of frequency, the crystal must be maintained at the temperature at which it was calibrated.

6 The crystal is mounted between two metal plates, as shown in the diagram, and its action may be explained briefly as follows. When a voltage is applied across the metal plates, the crystal is compressed slightly in thickness and its length and width are increased a corresponding amount. If the voltage is removed, the crystal will return to approximately its original dimensions, but, due to its elasticity, it will swing past this condition in much the same way that a steel rod clamped at one end, behaves when the free end is pushed down and then released; in other words, there will be a number of mechanical oscillations which gradually die out.

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* Amplifiers are of three types—class A, class B, and class C. In class A amplifiers the plate current variation is identical with the grid input voltage wave form. This is accomplished by operating a tube on the straight portion of its E_g-I_p characteristic (linear amplification).

In class B amplifiers the power output varies as the square of the grid voltage. This is accomplished by operating a tube on the lower knee of its E_g-I_p characteristic.

A class C amplifier is one which operates so as to provide maximum power output without regard to the wave form of the output. This is accomplished by operating the tube with a C bias which makes the plate current nearly zero when no signal is impressed on the grid. Thus only the positive half of the signal is amplified.

The original voltage impulse which starts the crystal to vibrating mechanically at radio frequency may be produced by any electrical disturbance of the circuit whatever—for instance, that which occurs when the filament of the tube is turned on. Vibration of the crystal is accompanied by changes in voltage on the grid of the tube, which are therefore amplified. The amplified voltage changes in the tuned plate circuit are, however, fed back to the grid circuit, which contains the crystal, through the tube capacity. The crystal is thus continually supplied with the high frequency voltage necessary to sustain its mechanical vibration, and electric oscillations of constant amplitude are set up in the plate circuit at a frequency determined by the crystal.

The most successful results with crystal-control are obtained when the crystal oscillator supplies only a small amount of power. This power is immediately increased by one or more stages of low power tuned radio frequency amplification which are often made an integral part of the crystal control unit. Screen grid, or neutralized three electrode tubes are used in the crystal amplifier stages to eliminate any tendency to troublesome self-oscillation.

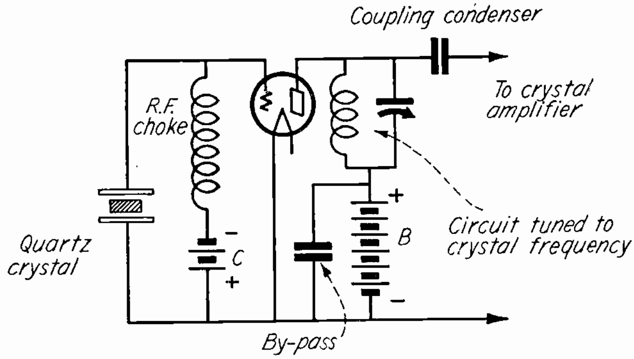


FIG. 12. Crystal Oscillator Circuit.

The crystal and its holder are mounted in an oven or box which is heat-insulated and kept at constant temperature by means of an internal heating element controlled with a thermostat. Under such conditions, it is possible to produce radio frequency oscillations which are of constant frequency to within 20 to 100 cycles per second at all times.

BUFFER AMPLIFIER

We have learned that modulation, and especially 100 per cent modulation, is always accompanied by violent changes in the currents and voltages in the circuit where modulation is taking place. There is always the danger that these changes may react on and adversely affect the stability of operation of the tube circuit just ahead of the modulated amplifier stage. For this reason, it is common practice to insert a buffer amplifier stage (so called because of its cushioning or shock absorbing effect) between the modulated amplifier and the crystal amplifier. The buffer stage thus acts as a one-way isolating device, passing on and amplifying R.F. oscillations from the crystal amplifier, but protecting the crystal amplifier from any

7

possible reaction from the modulated amplifier. The power rating of the buffer stage is of course intermediate to the ratings of the crystal amplifier and modulated-amplifier.

THE MODULATED AMPLIFIER

The action of the modulated amplifier has already been considered in connection with the operation of the modulator. Fig. 13, however, illustrates graphically the process of modulation and shows at a glance as well, the functions of the other units at the transmitting station, indicating the steps by which power is successively built up. It should be realized that when the microphone is idle, speech or audio signals are not present on the line and are of course not amplified by the line amplifier, power speech amplifier and modulator. However, this in no way affects the operation of the crystal amplifier and buffer amplifier, and while introducing no modulation, the modulated amplifier continues its amplifying function. The amplitude of the unmodulated oscillations from the modulated amplifier and power stages, is given by the dotted lines indicated in Fig. 13.

It was mentioned previously that the modulated amplifier is operated as a class C amplifier. This is accomplished by using a very high grid bias so that plate current only flows over a portion of the positive R.F. grid voltage swing. The maximum efficiency is obtained from the tubes in this way. While the plate current consists of radio frequency impulses instead of complete cycles, the tank circuit or tuned circuit associated with the output of the stage, takes these impulses and converts them into complete oscillations. As will be seen by examining the details of Fig. 13, each R.F. cycle has a double hump, indicating the presence of second harmonics. However, this has no effect on the general envelope of the modulated wave and the radio listener would therefore be unaware of it. These second harmonic humps would have the effect of producing faint radio signals at twice the operating frequency of the transmitter, so it is necessary to remove them from the final output by means which we shall consider below.

POWER STAGES

Modulation in fairly large broadcasting stations is carried out at powers which are low compared with the final output of the transmitter. One or two power stages follow the modulated amplifier to provide this power increase. Steps are also taken in the power stages to remove the undesired second harmonics of the high frequency oscillations which are the result of the high efficiency class C operation of the modulated amplifier section. Push-pull amplification with special filters is commonly employed in the power stages. The push-pull principle, whereby the second harmonics generated in the push-pull tubes operated as class B amplifiers are cancelled out in the output circuit, is already familiar to you from your study of power audio amplification. The action is of course the same in a radio frequency amplifier.

The R.F. power stages, in push-pull, are operated as we have just stated as class B amplifiers. Relatively less grid bias is used than in the case of class C amplifier, but quite high efficiency is still obtained. As before, the plate current delivers high frequency impulses to the tank* circuit,

* An oscillatory circuit excited by the output of the R.F. amplifier.

but these impulses are very closely halves of sine waves, and the resulting oscillations, supplemented by the push-pull effect, are practically free from tube harmonics. Slight traces of second harmonics which originated before

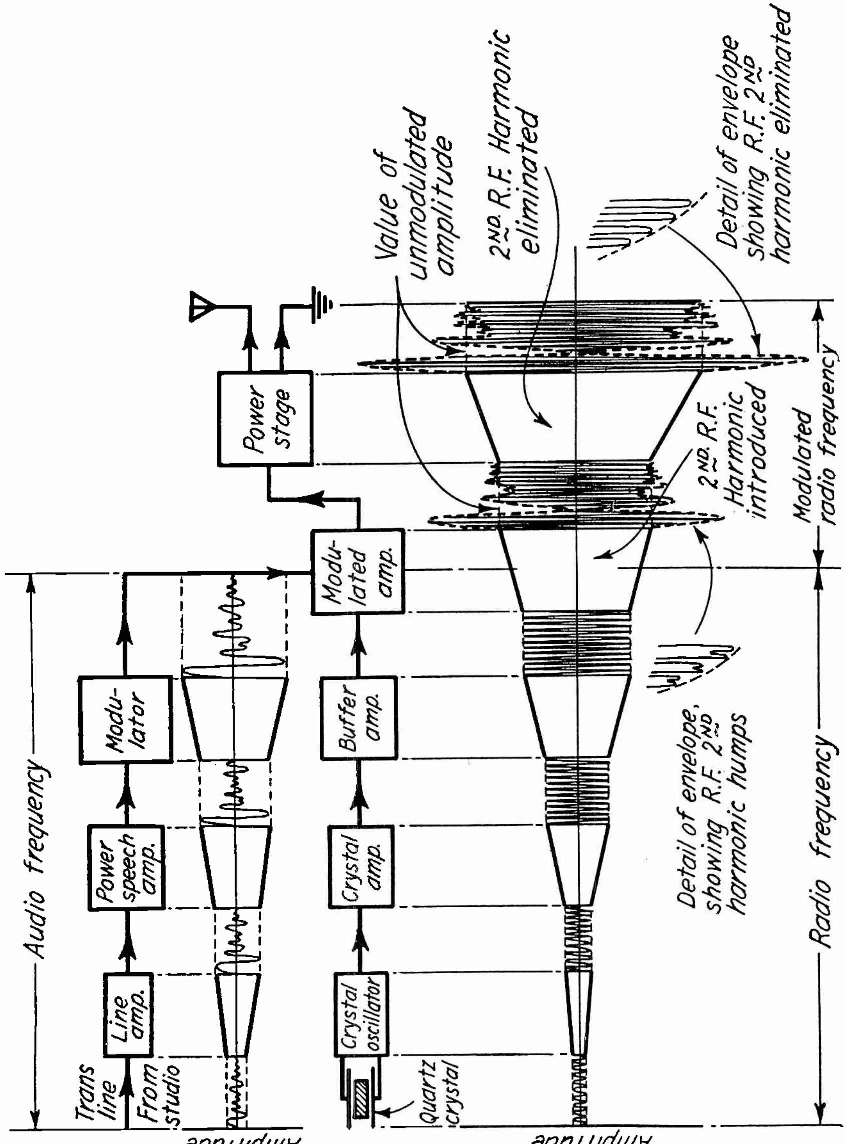


Fig. 13. Functions of Units in a Modern Broadcast Transmitter.

the push-pull stage and which come through the power stages are removed by tuned circuits which are shunted across the output as in Fig. 14. These circuits are resonant to the second harmonic, which is double the operating frequency of the station. It should be mentioned that the power stages often have a number of tubes in parallel on both halves of the push-pull circuit.

AMPLIFIER DETAILS

Many rather special features of construction are employed in high powered broadcast transmitters, some of which will be briefly mentioned. Many of the transmitting tubes, particularly in the power stages, generate so much heat that they would burn up almost immediately if water-cooling was not resorted to in these cases. A steady supply of cool water is so important that relays and valves are provided which shut down the transmitter at once if the water temperature rises above normal or the circulation is in any way impaired.

The problem of making tuning adjustments in circuits which carry many

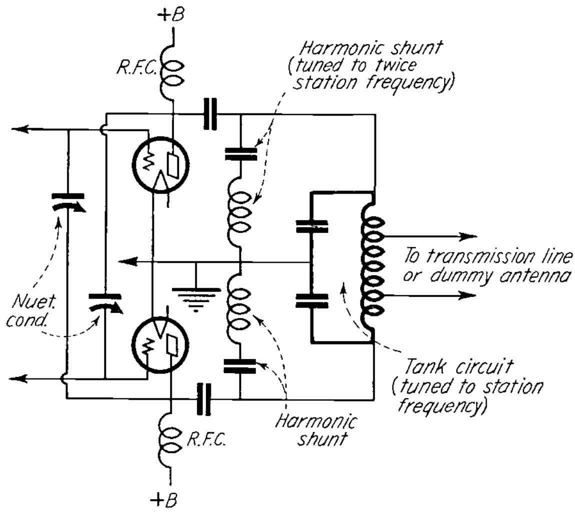


FIG. 14. Schematic of Last Power Stage.

amperes of R.F. current is likewise a serious one. Variable contacts, such as in variable condenser bearings, and sliding clips on tank circuit inductors, would cause power losses and reduce efficiency, and they are thus used in the low powered stages only. The high powered tank circuits make use of large, fixed air condensers, a number of sections being connected in series to withstand the enormous voltages. The inductors are adjusted to approximately the correct value when the station is constructed and all connections are made permanent. Some means must be provided, however, for slight readjustments of tuning from time to time so that the maximum output will always be radiated. This is done by changing the position of a closed metal ring which can be rotated within the field of the coil, thereby producing slight changes in the inductance. The arrangement is shown in Fig. 15.

It should be remembered that the frequency of a broadcast transmitter is not altered by the tuning of the amplifier circuits, but is solely determined by the crystal oscillator. The amplifier tuning is for maximum output and the resonant frequency of the various coil-condenser combinations is closely but seldom exactly the same as the crystal frequency. If any of the ampli-

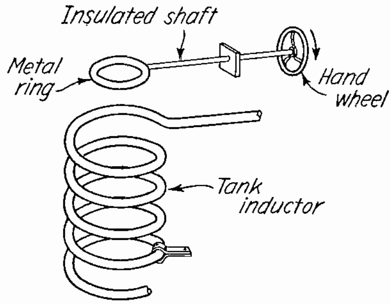


FIG. 15. Method of Tuning Power Tank Circuit.

fiers should start to oscillate, beats would be produced and the quality of the program would be impaired or ruined. This is prevented by careful neutralization similar in principle to the methods used in receiver amplifiers. Fig. 14 illustrates how push-pull stages are usually neutralized.

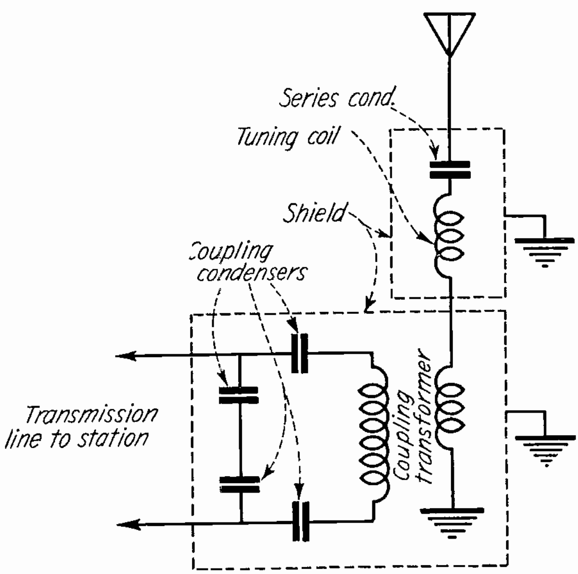


FIG. 16. Schematic of Coupling House Circuits.

R.F. TRANSMISSION LINE

9 The building which houses the transmitting equipment is located quite a distance from the antenna so as not to interfere with efficient radiation, and means must be taken to deliver power from the output power stage to the antenna system. A transmission line is used for this purpose, and it con-

sists merely of two well insulated conductors, supported on poles, running between the station building and a small coupling house directly below the antenna downlead. This coupling house contains coupling coils and condensers, by adjustment of which the maximum power can be transferred from the line to the antenna system itself. The station end of the line is connected to the final power stage in such a way that maximum power is fed to the line. The coupling house also houses a fixed series antenna condenser and a tuning coil, which are used to adjust the antenna to resonance at the transmitter frequency. Fig. 16 gives the connections for the coupling house equipment. The transmission line is designed so that it does not radiate appreciable R.F. energy and therefore does not interfere with the wave distribution about the antenna to any great extent.

DUMMY ANTENNA

In order that the station can be started up and adjusted prior to a broadcast without transmitting the signals, a dummy antenna is used. Fig. 17 shows the dummy antenna circuit. The power which would normally be radiated from the antenna is dissipated in a resistance bank, constructed to allow the large amount of heat energy to be carried off by air-cooling. The

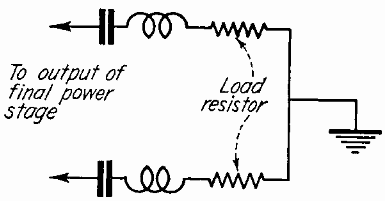


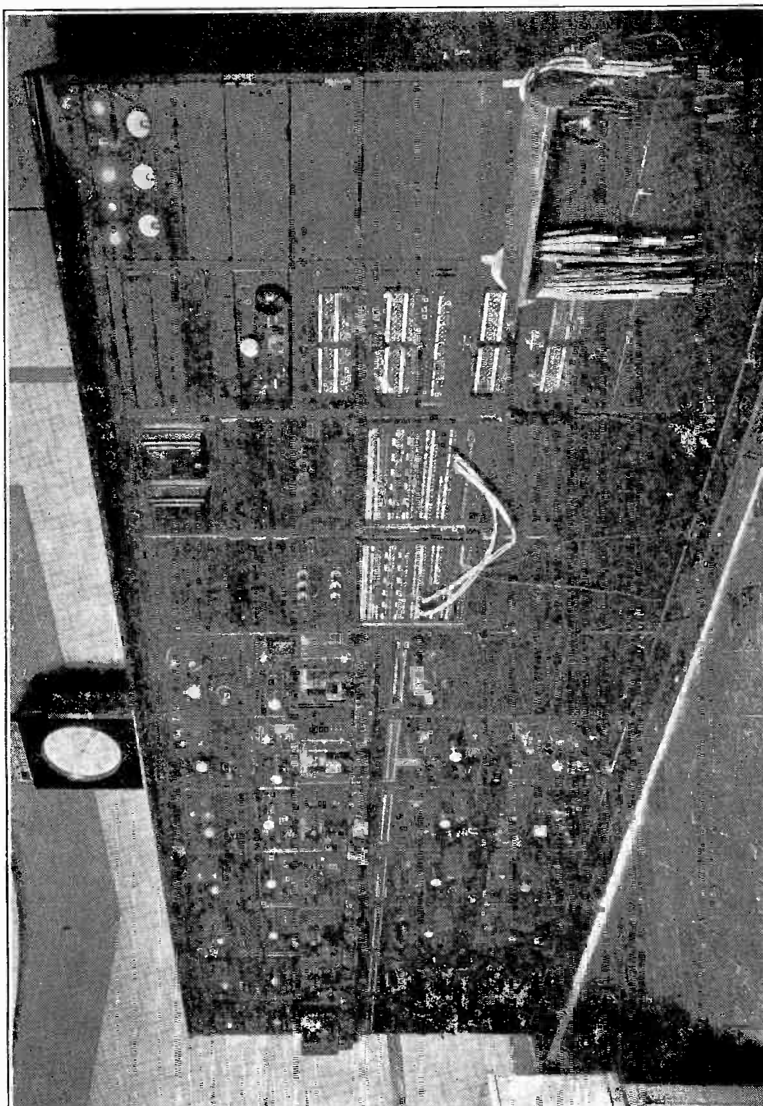
FIG. 17. Dummy Antenna Circuit.

value of the resistor bank is approximately equal to the characteristic impedance of the transmission line. The coils and condensers shown are used to adjust the dummy antenna circuit so that it produces the same electrical effect on the transmitter as the transmission line which it replaces. Switches are provided so that the transmitter output can be sent to the transmission line or to the dummy antenna, which is located in a protective cage within the station building.

THE RADIATING SYSTEM

All other things being equal, the strength of the signals at a point distant from the broadcast transmitter depends entirely on the design of the radiating system. Since the signals are unavoidably subject to diminution or attenuation as they travel away from the antenna-ground system, these signals should be as intense as possible and radiation should take place uniformly in all directions. In order to secure these results, the first requirement is a high antenna, clear of all surrounding objects, and built over highly conductive ground. These conditions are met by a location in the open country, well outside the city.

The towers which support the antenna are constructed of steel and are unguyed, often reaching a height of 300 feet. In order to keep the towers away from the antenna, and thereby minimize the shielding effects of the masses of metal, the distance between towers is usually not less than twice the tower height, the antenna being located in the center of this span. Towers are often insulated from the ground, and occasionally in very tall towers, the total height must be broken up into a number of electrically



THE EQUIPMENT RACK IN THE MASTER CONTROL ROOM

Seven complete studio amplifiers and accessories at upper left. Line amplifiers, lower left. Two studio line terminations, standard AT&T line termination, and studio battery panel, constitute the four bays on the right end (left to right).

isolated sections. This sectionalizing moves the natural resonance of the towers to a frequency considerably above that of the station. When towers happen to be resonant to the station frequency, the radiation is concentrated along the line connecting towers, and considerably reduced in other directions. This is very undesirable in most cases.

It is standard practice to make the antenna itself a single wire "T." Good radiation may be obtained, and the single wire is not likely to be damaged by wind or sleet. The ground system is composed of buried wires extending radially outward from the coupling house, located directly under the antenna downlead.

POWER SUPPLY

A large broadcast transmitter has a power demand equal to that of a small town. Commercial frequency, three-phase power is secured from the power company and, wherever possible, two independent power feeders are run to the station to provide an emergency source in case of trouble on one system or the other.

The filaments of the tubes in the various stages are heated in different manners. The crystal oscillator amplifier filaments may be heated with low voltage A.C., for these tubes are about the size of receiver output tubes. The modulator, buffer and modulated amplifier tubes are also heated by A.C., but at higher voltage. Due to the hum modulation effect which would be produced by intense alternating currents in the larger tubes, direct current is used to heat the tubes in power stages. This current is obtained from low voltage, high current capacity motor generators. The filaments of all rectifier tubes are A.C. heated.

The plate voltage supply is obtained from a number of transformer banks, rectifiers and filters. The final power stage requires considerable current at very high voltage and this is secured from half-wave mercury vapor or filament type rectifier tubes, fed from two three-phase transformer banks as shown in Fig. 18. Similar lower voltage rectifiers, making use of a single transformer bank, provide plate voltage for the low powered stages.

A number of motor-generators supply grid bias voltage for all stages except the crystal oscillator and its amplifier. The crystal units may use self-bias or the grid-leak method.

The whole power supply system is remote controlled from the chief transmitter operator's desk. Upon pushing the proper button, the transmitter starts up automatically. Filament voltage is turned on first, and after the tubes are warm, the plate voltage is applied. Time delay relays automatically connect the power supply system to the tubes in the correct sequence. All control handles and panels are grounded, and an operator cannot come in contact with a high voltage circuit, without first opening a door containing a safety switch, thereby shutting off all power.

RADIO FREQUENCY MONITORING

Besides maintaining the tubes and circuits in efficient operating condition, the transmitter attendants keep a close check on the station frequency and frequently examine the modulation. Trouble is rarely experienced with the crystal oscillator, but a spare unit is usually at hand to be switched-in in case of trouble, for the successful operation of the station is dependent on this vital unit. The steadiness of the transmitter frequency is usually checked with the aid of an additional crystal oscillator, or sometimes by means of a special wavemeter. The auxiliary crystal oscillator has a frequency within a few cycles of the station control crystal. This oscillator is coupled to a receiver, which also picks up the carrier frequency of the transmitter. A note will thus be heard, due to the beat between the two frequencies, and as long as the pitch of the note remains constant, it is probable that the main crystal

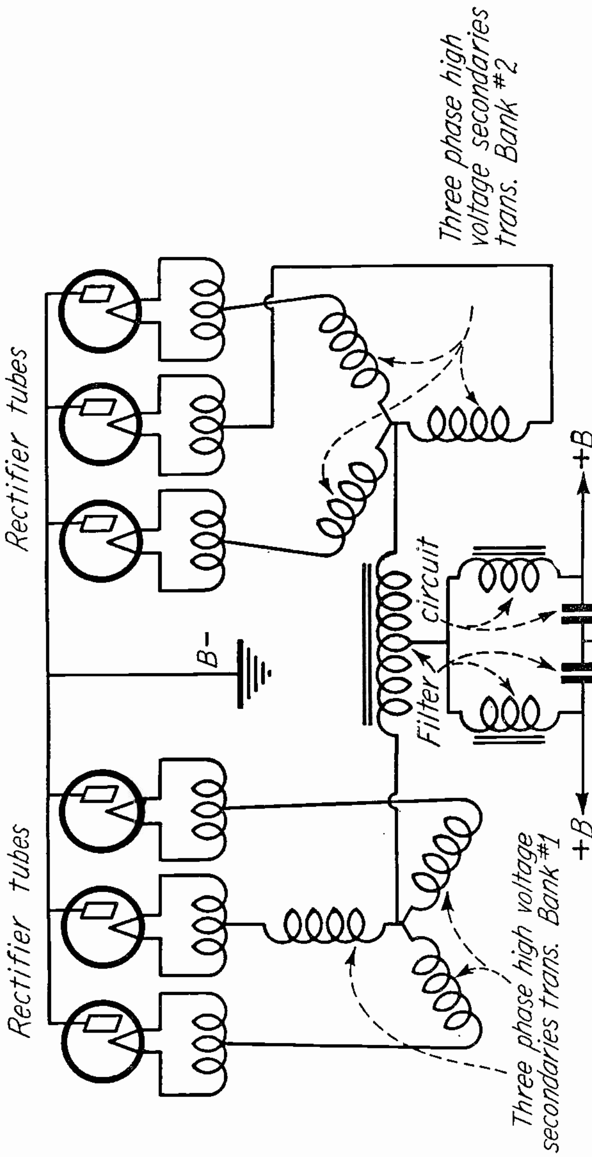
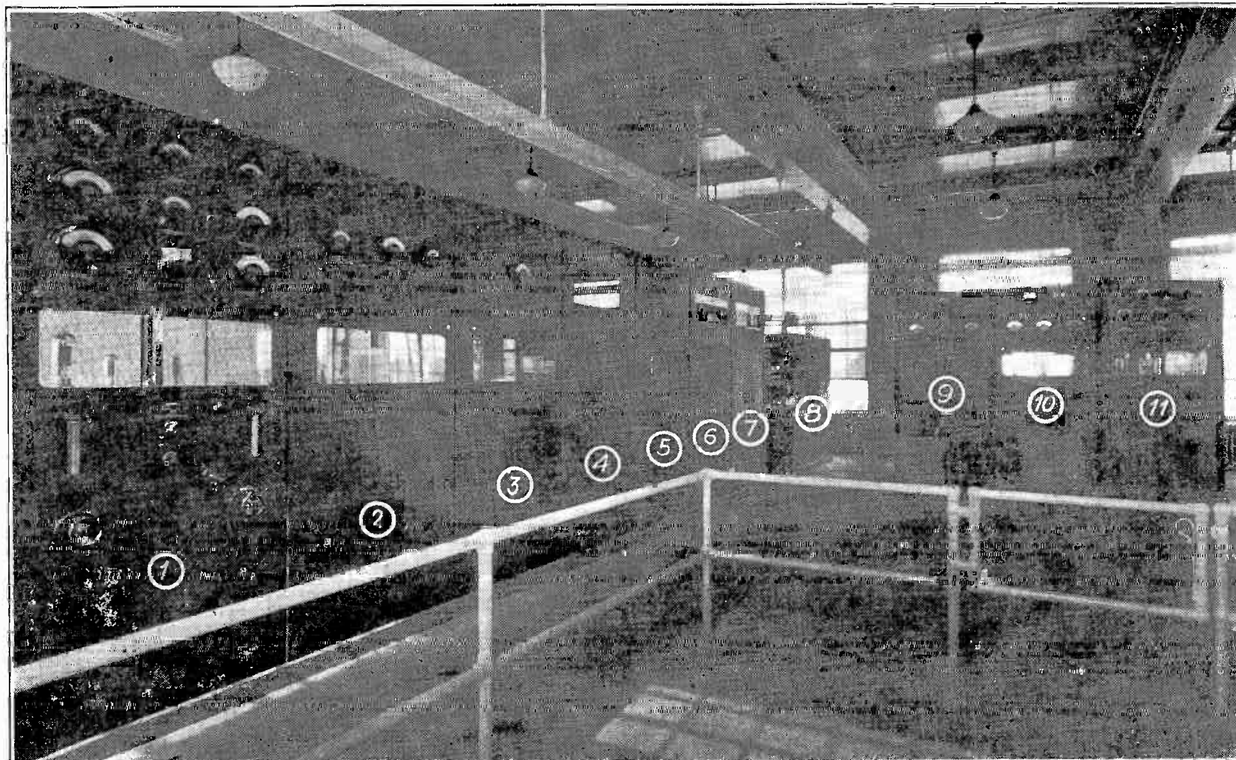


FIG. 18. High Voltage Plate Supply for Final Push-Pull Power Stage.

The primaries which connect to the three phase line are omitted for simplicity. In the actual power system they couple the Y connected secondaries to the power supply. Each tube in, let us say Bank No. 1, rectifies the current fed from its respective secondary 120 electrical degrees out of phase with the one next to it. Each tube gives rise to a half-wave current, 120 degrees apart. Corresponding positioned tubes in Bank No. 2 rectify the other half of the current. Both banks together give rise to a pulsating current consisting of six half-wave currents in a period equal to one cycle, which is easily filtered by the chokes and condensers. The center tap choke feeding the filter serves the purpose of equalizing the current supplied by each bank.

is maintaining constant frequency. This method is far more accurate than ordinary tuned circuit wavemeters.

If the transmitter modulation percentage is low, the station is not being



Western Electric 7-A 50 KW Transmitter. Units, left to right. (1) Crystal oscillator, crystal amplifier, buffer amplifier, modulated amplifier and modulator. (2) First power stage. (3) (4) Second power stage. (5) Final power stage. (6) (7) Tank circuit for final power stage. (8) Dummy antenna. (9) (10) (11) High voltage plate supply rectifier.

operated with the greatest effectiveness. If the transmitter is over-modulated, the result is distortion. It is desirable to operate with modulation close to the permissible upper limit, making some allowance for the possibility of occasional high peaks of speech voltage which always tend to cause over-modulation. The actual envelope of the modulated wave is often examined with an oscilloscope, giving a picture of the amount of modulation. This instrument is actuated by rectified currents which are picked up at the output of the final power stage. The rectification is accomplished by a low powered vacuum tube, thus leaving an audio frequency trace which is projected on a ground-glass screen in front of the oscilloscope. The height of this trace is proportional to the wave envelope and thus provides a clue to the degree of modulation. The modulation may be changed in intensity by adjustment of the gain control of any one of the numerous audio frequency amplifiers in the circuit.

TEST QUESTIONS

Be sure to number your Answer Sheet 35FR.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and the best possible lesson service.

1. What precautions are taken to prevent reverberation and external noises in broadcasting studios?

2. What radio apparatus is used in the broadcasting studio?

3. Explain the purpose of the power speech amplifier?

4. Draw a diagram illustrating the Heising system of 100 per cent modulation.

5. Why are crystal oscillators used in all modern broadcasting stations?

6. Why must the crystal be mounted in a thermostat-controlled constant-temperature box?

7. Why is a buffer amplifier placed between the crystal oscillator and the point of modulation?

8. Explain why tuned circuits (resonant filters) are shunted across the output of push-pull amplifiers in the R.F. power stages of a transmitter.

9. When are R.F. transmission lines used?

10. What would happen if the audio signal fed to the modulator tube were larger than the R.F. carrier (over-modulation)?

14 CIRCUIT DIAGRAMS EACH WITH TESTING INFORMATION

35 SS

SERVICE MANUAL

PIONEER HOME STUDY RADIO SCHOOL

NRI

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

FOREWORD

This booklet is one of a series of service manuals which contain service sheets giving typical information on radio receivers. Each service sheet shows the circuit diagram in the usual symbolic form for that radio receiver. Many of the service sheets will contain such special service information as space will permit.

By studying each service sheet, you will gradually develop the ability to read any diagram or manufacturer's service manual and learn the usual methods of set adjustment. Enough typical receivers have been selected to give you quickly a good insight to the entire radio problem.

In reading a circuit diagram, learn to trace independently the power supply and the signal circuits. Then locate the special control circuits, such as the automatic volume controls, tuning indicators, manual volume controls, etc. Detailed information on power, supply, signal and control circuits, as well as set servicing, is given in the course, to which reference should be made.

J. E. SMITH.

WPC3M10536

Printed in U.S.A.

RADIO-TRICIAN
REG. U.S. PAT. OFF.
Service Sheet
Compiled Solely for Students and Graduates
NATIONAL RADIO INSTITUTE, WASHINGTON, D.C.

STROMBERG-CARLSON MODELS 10 AND 11 RECEIVERS

Oscillation

TUBES. Tubes which cause instability (oscillation) are generally at great variance with standard characteristics. Tubes other than those specified for the receiver quite frequently cause such trouble. Check by the substitution of standard tubes in the R.F. section.

GROUND. Make certain that the ground is of the right type, and that the circuit is clean and firm in its contacts.

LOOSE TUBE COVER. Make sure that the tube section cover is in place and firmly screwed down.

DEFECTIVE BY-PASS CIRCUITS AND APPARATUS. Carefully check all by-pass condensers and the connections thereto. Check the wiring for breaks. Check also the Resistor R_2, which, in addition to being a hum control, is also a radio frequency by-pass for the UY-224 heater circuits.

By-pass capacities are most easily checked for loss of capacity (open) by shunting them with a like capacity. On capacitors having but one apparent terminal, the shell or case is the other terminal.

POOR GROUND CONTACT TO ROTOR PLATE BEARINGS. Grounding of the rotor plates, aside from the end bearings, is accomplished through the clip springs which slide down over the rotor shaft in each compartment. Make sure that these springs are in place and are firm and clean in their contacts.

INCORRECT PLATE OR SHIELD VOLTAGES. Check these voltages against the voltages furnished in the table.

Special Cases of Faulty Operation

RANGE CONTROL SWITCH INEFFECTIVE. Occasionally it will be found that setting this switch to the "Local" position does not have the desired effect. Check the 1st R.F. tube by replacing it, the ground (external), the switch contact, and the associated condenser.

RANGE CONTROL SWITCH TOO EFFECTIVE. This condition ordinarily would be due to a short in the associated condenser so as to completely short circuit, or ground, the incoming signal. It may also be due to the fact that the incoming signal is relatively weak, under which circumstances there is no point to using the "Local" setting.

Removal of Chassis and Loudspeaker

After the Radio-Trician has assured himself that the cause of faulty operation lies in the chassis, the chassis and loudspeaker should be removed from the cabinet for further inspection and test.

NOTE: Do not test the chassis without the speaker properly connected to it. Either the speaker should be removed with the chassis or the Radio-Trician should provide himself with a four conductor extension cord which will connect the speaker connector plug to the connector socket in the rear of the chassis. If such a cord is made up, proper insulation should be provided for the high voltage present in the field supply conductors.

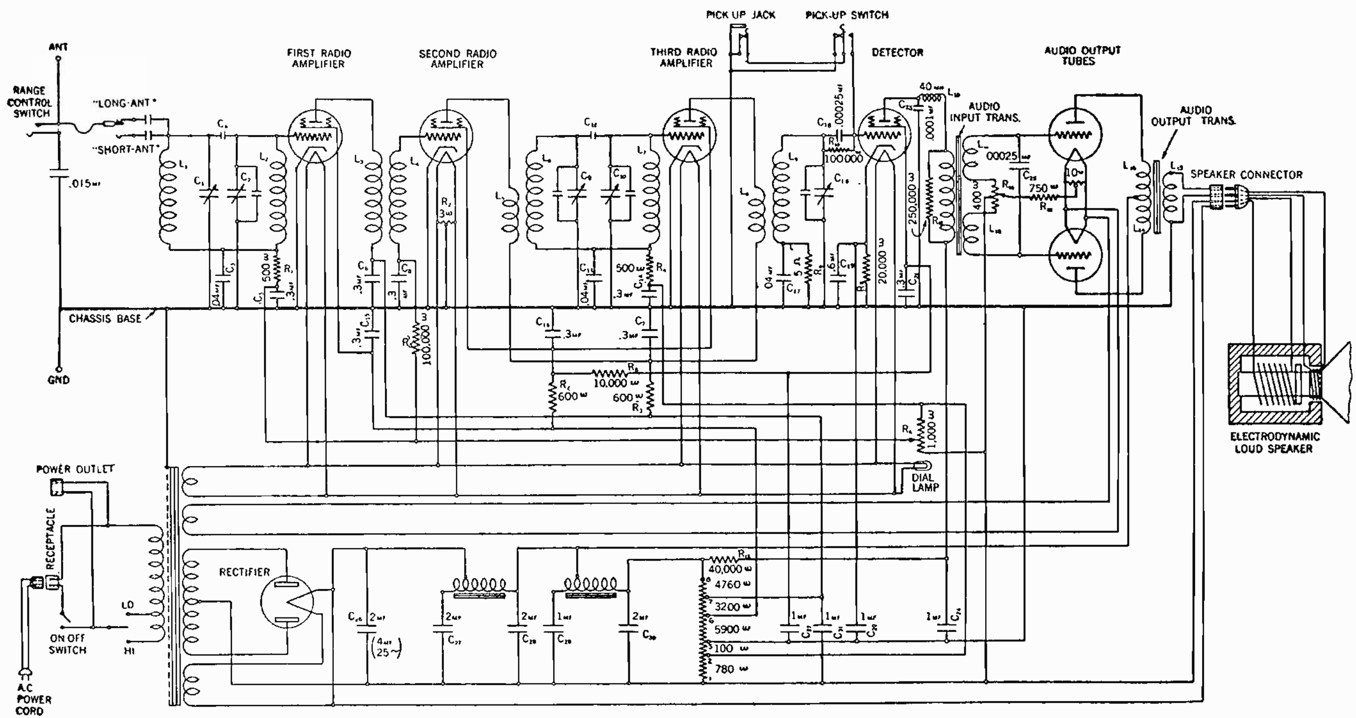
Removal of Chassis

Disconnect antenna and ground leads.
Remove speaker cord plug from its socket at the right rear of the chassis.
Remove A.C. supply cord plug from its socket at the left rear of the chassis.
Remove three control knobs from front of receiver by a steady outward pull.
Unscrew the three large machine screws from each end of the under side of the shelf which supports the chassis in the cabinet.
Slide chassis from cabinet.

TABLE OF VOLTAGES

Line Voltage 120—Voltage Tap High

Type of Tube	Position of Tube in Set	Filament or Heater	Plate or Anode	Control Grid-Space GD+	Normal Grid-Screen GD+
224	1 R.F.	2.4	135	2.5	80
224	2 R.F.	2.4	135	2.5	80
224	3 R.F.	2.4	135	2.5	80
224	Det.	2.4	200	—	75
245	PP-AF	2.4	235	—	45
245	PP-AF	2.4	235	—	45
280	Rect.	4.8	—	—	—



Schematic diagram—Stromberg-Carlson Models 10 and 11.

RADIO-TRICIAN
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PHILCO RECEIVER MODEL 45 (also 29)

ADJUSTING COMPENSATING CONDENSERS

For adjustment of compensating (padding) condensers an accurately calibrated signal generator and a special insulated padding wrench are needed. Adjustments are made in the following order—

ADJUSTMENT OF THE INTERMEDIATE FREQUENCY — Remove the grid clip from the type 6A7 tube and connect the "ANT" output terminal of the signal generator to the grid cap of the tube. Connect the "GND" terminal of the signal generator to the "GND" terminal of the receiver chassis.

Connect the output meter to the primary terminals of the output transformer. Set the signal generator at 460 K.C. (the intermediate frequency) and with the receiver and signal generator turned on, the wave band switch at left and dial at 600 K.C., adjust each of the I.F. compensating condensers in turn, to give maximum response in the output of the receiver. The three pairs of I.F. compensating condensers are located one pair at the top of each of the three I.F. transformer shields. These are the three metal "cans" near the rear of the chassis. Each of the transformers has a dual compensating condenser mounted at its top, and accessible thru a hole in the top of the coil shield. In the dual compensators, the Primary circuit is adjusted by turning the screw; the Secondary circuit is adjusted by turning the hex-head nut.

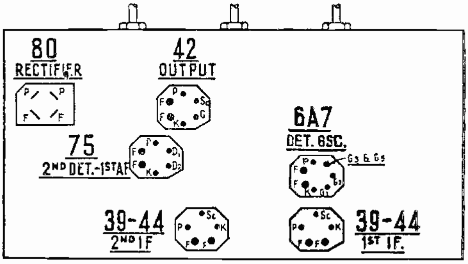
ADJUSTMENT OF THE WAVE TRAP —Replace the grid clip upon the Detector-Oscillator tube (Type 6A7). Connect the output leads from the signal generator directly to the antenna and ground terminals of the receiver. Set the Wave-Band Switch of the receiver to the standard broadcast band (left hand position) and the Station Selector at the low frequency (540 K.C.) end. Adjust the Wave Trap condenser to give MINIMUM response to a 460 K.C. signal from the signal generator. The Wave Trap is located at rear and underneath the chassis. It is reached from the rear of the chassis, by inserting the fibre wrench thru the hole near right-hand rear corner of chassis.

DETECTOR, AND OSCILLATOR "HIGH" AND "LOW" FREQUENCY ADJUSTMENTS—The "antenna" and "oscillator H.F." compensators are located on top of the tuning condenser assembly, reached from above.

Set the signal generator at 1500 K.C., tune in this signal on the set and adjust the antenna compensator (nearest tuning control) to give maximum reading in the output meter.

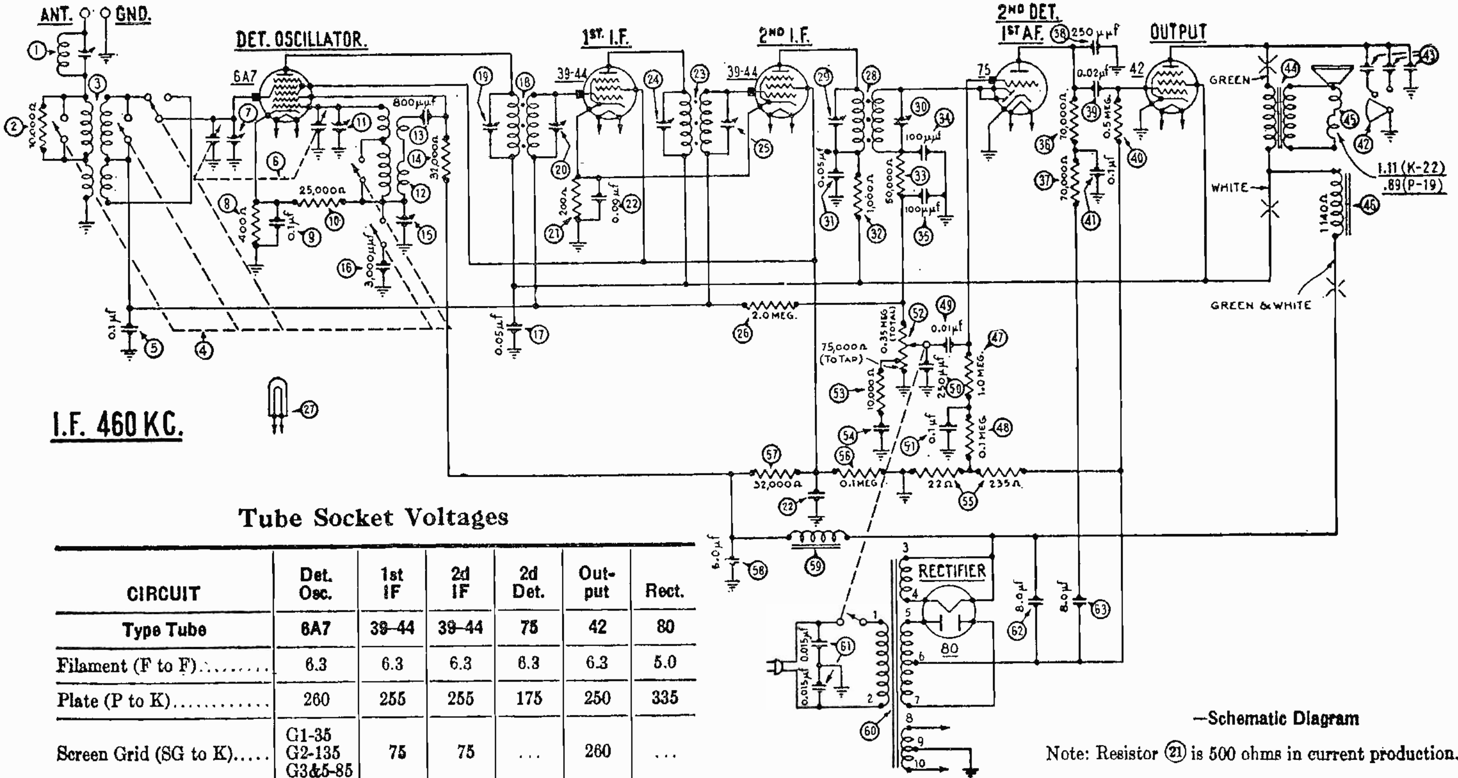
Next adjust the oscillator H.F. condenser (located on the other section of tuning condenser) to maximum reading.

Finally set the signal generator at 600, tune in this signal and adjust the oscillator "L.F. condenser," located underneath chassis to maximum reading. This adjustment is reached thru the hole in top of chassis, between the two electrolytic condensers (left hand end of chassis when facing rear).



Tube layout (underside)

PHILCO MODEL 45



Tube Socket Voltages

CIRCUIT	Det. Osc.	1st IF	2d IF	2d Det.	Out-put	Rect.
Type Tube	**6A7**	**39-44**	**39-44**	**75**	**42**	**80**
Filament (F to F).........	6.3	6.3	6.3	6.3	6.3	5.0
Plate (P to K)............	260	255	255	175	250	335
Screen Grid (SG to K).....	G1-35 G2-135 G3&5-85	75	75	...	260	...
Cathode (K to F).........	4.2	3.8	3.8	0	0	...

The above tests were made with an AC voltmeter for filament voltages and a high resistance DC voltmeter for all others. Dial at 550 KC, volume control at maximum. Test made with test prods applied to socket terminals underneath chassis. Line voltage 115.

—Schematic Diagram

Note: Resistor (21) is 500 ohms in current production.

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PHILCO MODEL 118

ADJUSTING COMPENSATING CONDENSERS

For adjusting compensating or padding condensers in Model 118, an accurately calibrated signal generator covering the broadcast range of frequencies is required and also a crystal controlled signal generator for the high frequency adjustments. For the former we suggest the Philco Model 024 Signal Generator and for the latter the Model 091, Crystal Controlled high frequency signal generator. The actual adjusting calls for a special insulated hex wrench and insulated screwdriver. Philco Part No. 3164 Fibre Wrench and No. 27-1159 Screwdriver are recommended. An output meter is also required, for connection to the receiver.

I.F. ADJUSTMENT—The I.F. (intermediate frequency) of Model 118 is 260 K.C.

Remove the grid clip from the top of the 6A7 tube and connect the shielded antenna lead from the Signal Generator to the cap of this tube. Connect the ground lead of the Signal Generator to the ground post of receiver. Connect the output meter to the primary terminals of the output transformer of receiver. Set the wave-band switch at the left position (standard broadcast).

Set the wave switch on the Signal Generator at 260 K.C., and the dial of the receiver at 550. Turn on the set (volume full on), and the Signal Generator. Now adjust the 1st I.F. Primary and Secondary condensers Nos (30) and (32) and the 2d I.F. primary and secondary condensers (37) and (75) to give maximum reading on the output meter. The I.F. primary condenser is adjusted by turning the screw on top of the I.F. transformer and the secondary is adjusted by turning the nut. The I.F. transformers are in the smaller metal "cans." The screw and nut are reached through the hole in top. If the needle on the output meter goes off the scale, turn down the "attenuator" on the Signal Generator until a lower reading is obtained.

Note: In early production the 1st I.F. compensating condensers only are adjusted as described above. Part (75) is not used. The 2d I.F. primary (37) is an 04000A condenser reached and adjusted through hole in top of chassis near the 42 driver tube.

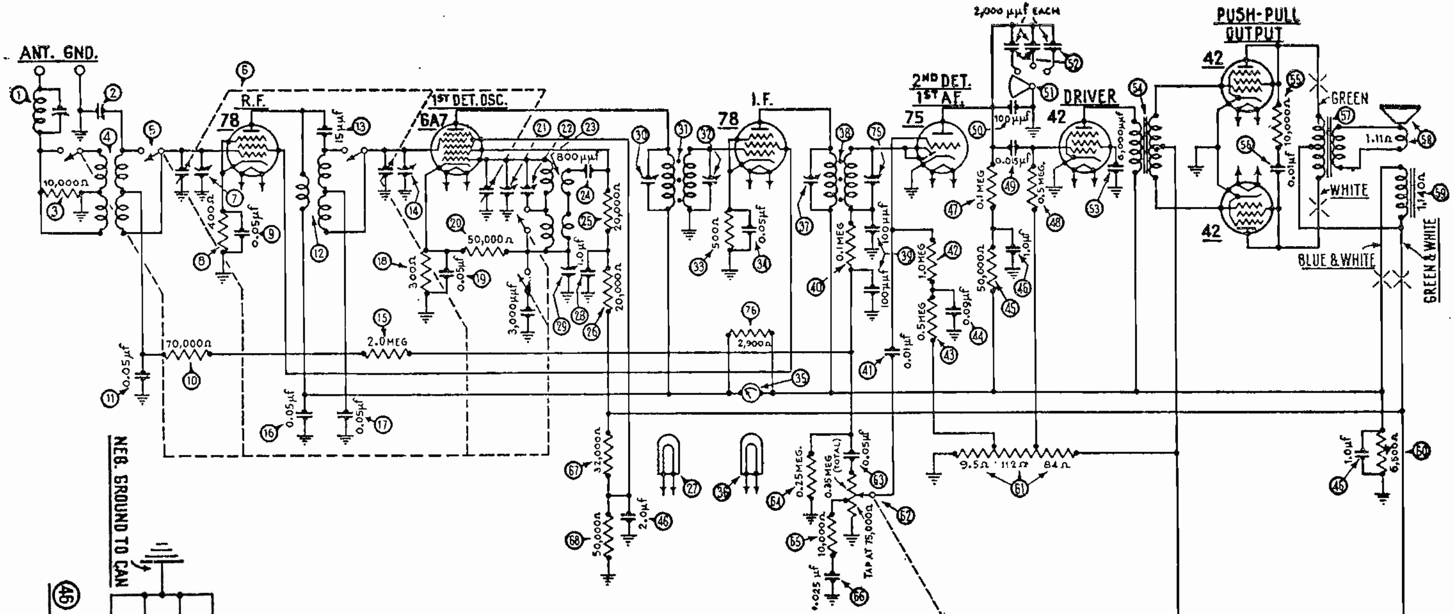
WAVE TRAP—Remove antenna lead from grip cap of 6A7 tube and attach it to antenna post on set. Replace cap on 6A7 tube. With Signal Generator still operating at 260 K.C., adjust wave-trap condenser (1) so as to get MINIMUM reading in output meter. This adjustment is made from underneath the chassis.

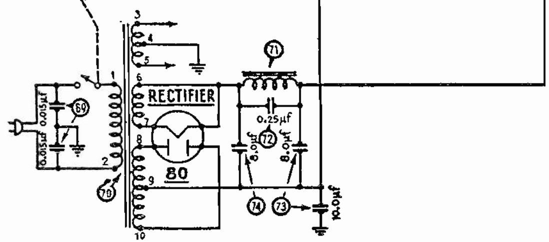
ANTENNA, DETECTOR AND OSCILLATOR H. F. (Broadcast)—These condensers Nos. (7), (14), and (21), are located on top of the tuning condenser gang, adjustment made by means of the fibre wrench. Set the signal generator at 1500 K.C., tune in the signal at 1500 on dial and adjust these condensers in the order given, to give maximum output reading. (7) is located on the section nearest the front and (14) on the center section.

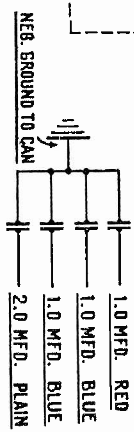
OSCILLATOR—LOW FREQUENCY—This is condenser (28) located underneath chassis and accessible from underneath. Use the fibre wrench. Set signal generator switch at 600, tune in the signal at 600 on the dial and adjust condenser to maximum.

ANT. AND OSC. H. F.—SHORTWAVE—The crystal controlled signal generator is used for these adjustments. These are condensers (2) (Ant. H.F.) and (22) (Osc. H. F.) located underneath chassis, and adjusted from underneath. The fundamental frequency of the Philco Model 091 crystal controlled signal generator is 3600 K. C. or 3.6 megacycles. The third harmonic of this is 10.8 M.C. Turn the waveband switch of the set to the right and the dial to just below 11 M.C. The 10.8 harmonic should be picked up here and the two condensers should be adjusted to give maximum reading on the output meter, on this signal.

PHILCO MODEL 118







46 BY-PASS CONDENSER CONNECTIONS

Tube Socket Voltages—Line Voltage 115

Function	R.F.	Det.-Osc.	I.F.	A.F.	Driver	Output		Rect.
Type	78	6A7	78	75	42	42	42	80
Filament (F-F)......	6.3	6.3	6.3	6.3	6.3	6.3	6.3	5.0
Plate (P-K).........	180	180	200	125	195	280	280	315
Screen (SG-K).......	80	175	80	...	195	290	290	...
Cathode (K to F)...	2.5	2.6	3.2	0	0	0	0	.
6A7· G¹ to K........	26							
6A7· G² to K........	150							

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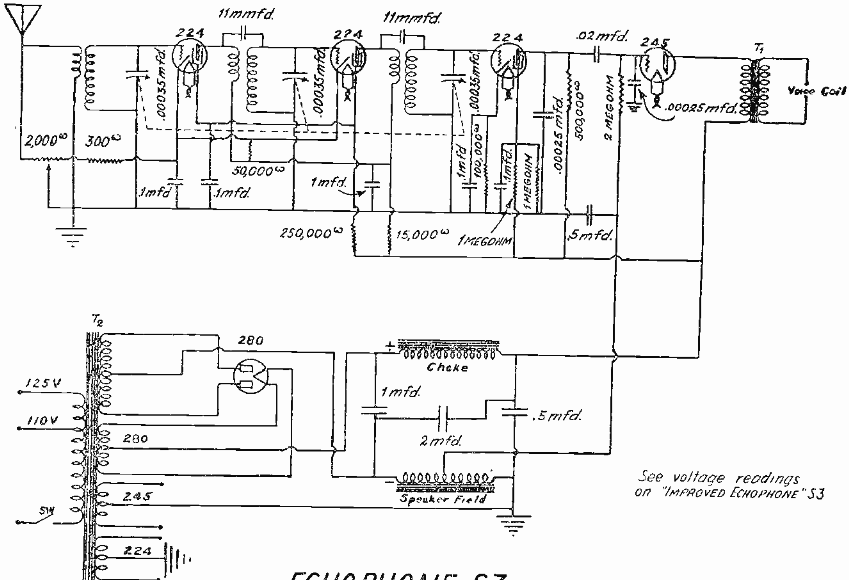
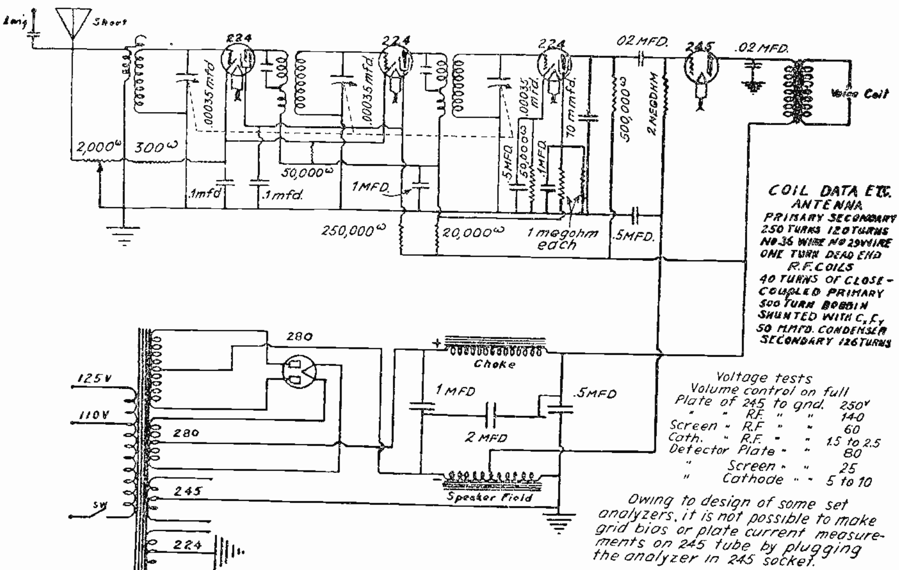


See voltage readings on "IMPROVED ECHOPHONE" S3

ECHOPHONE S3



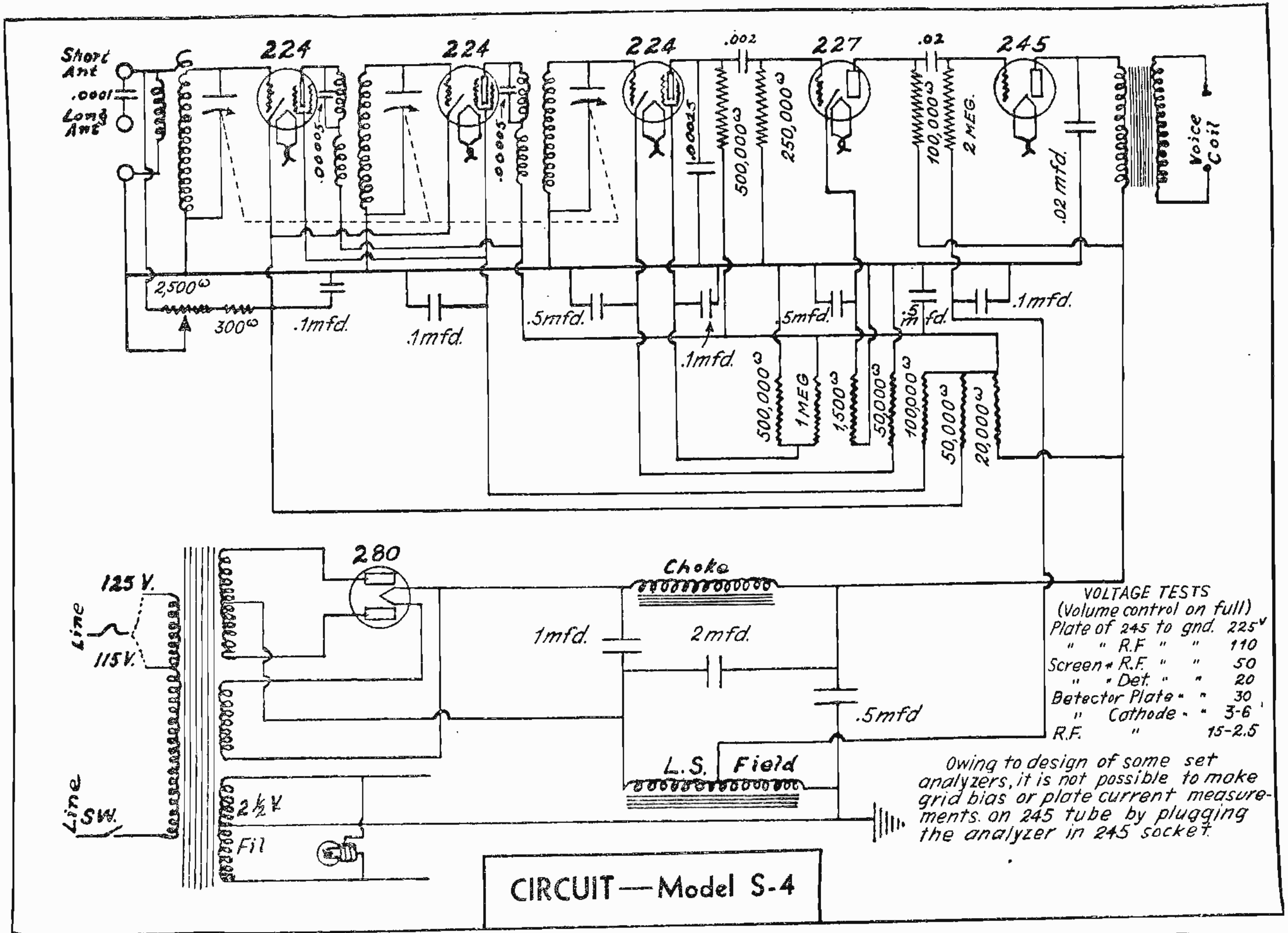
COIL DATA ETC.
ANTENNA
PRIMARY SECONDARY
250 TURNS 120 TURNS
No 36 WIRE No 29 WIRE
ONE TURN DEAD END
R.F. COILS
40 TURNS OF CLOSE-COUPLED PRIMARY
500 TURN BOBBIN
SHUNTED WITH $C_1 F_Y$
50 MMFD. CONDENSER
SECONDARY 126 TURNS

Voltage tests
Volume control on full

Plate of 245	to gnd.	250V
" " R.F.	" "	140
Screen " R.F.	" "	60
Cath. " R.F.	" "	1.5 to 2.5
Detector Plate	" "	80
" Screen	" "	25
" Cathode	" "	5 to 10

Owing to design of some set analyzers, it is not possible to make grid bias or plate current measurements on 245 tube by plugging the analyzer in 245 socket.

IMPROVED ECHOPHONE S3



CIRCUIT—Model S-4

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MAJESTIC SERIES 60—MODELS 61, 62 AND 163

COLOR CODE

Power Transformer

Primary: Start of Winding—Red; 105 volts—Red and White; 115 volts—Yellow; 125 volts—Green
Filament, Filament: 45 Blue
Heater, Heater, Heater: White—(135 v. above ground)

Heater—Red—(2nd Det. A.V.C. and Osc.)
Center Tap—45 Red
Anode—Green
C. T. Anode—Bare
Anode—Green
Filament, Filament: 80 Brown

FILTER UNIT

2 microfarad condenser—Green
2 microfarad condenser—Red
2 microfarad condenser—Blue

1 microfarad condenser—Yellow
.07 microfarad condenser—White
Condenser common—Black

CHOKE

Filter Output—Red
Detector Choke Low Side—Green

Junction of Chokes—Blue

Voltage Table of Majestic Series 60

Position	Tube	Fil. Volts	Plate Volts	Grid Volts	Screen Grid Volts	Cathode Volts	Normal Plate M. A.
1st R. F.	G-51	2.35	285	----	215	3	4.5
Oscillator	G-27	2.35	135	----	------	..	4.0
1st Det.	G-51	2.35	285	----	215	8	4.5
I. F.	G-51	2.35	285	----	215	3	4.5
2nd Det.	G-24	2.35	275	----	135	12	.25
1st A. F.	G-45	2.4	300	50	------	----	32.5
2nd A. F.	G-45	2.4	300	50	------	----	32.5
Automatic Volume Control Tube	G-24	2.35	*	----	45	11	.0
Rect.	G-80	4.88	490	----	----	----	.90 Per Plate

Note: All plate, screen grid, control, and cathode voltages are measured from Ground (Chassis) with a standard 1,000 ohm per volt voltmeter.
Voltages shown in above table with volume control at maximum position.
*Voltmeter: Readings of the automatic volume control tube plate terminal will be erratic because of the 700,000 ohm resistor which is in series with the plate supply lead.

TECHNICAL DATA FOR MODEL 160 MAJESTIC RADIO PHONOGRAPH CHASSIS

The radio circuit and performance of the Model 163 Radio-Phonograph Combination is identical with that of the Model 60 chassis.

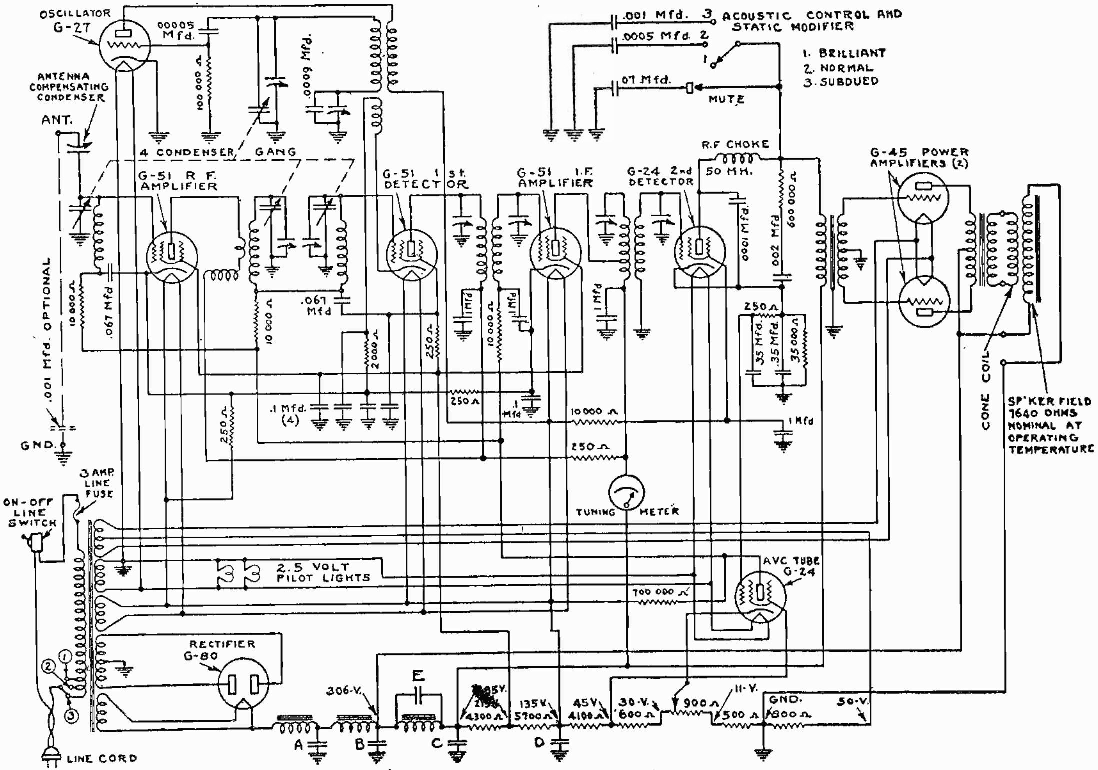
The front panel controls of the Model 163 combination are radio controls only, and are the same as that of the Model 61 and 62 radio receivers.

The phonograph side of the Model 163 combination consists of a pick-up, pick-up transformer, phonograph volume control, phono-radio switch and motor board assembly.

The second detector tube grid comprises the audio frequency input circuit when the phono-radio switch is in the phonograph position. The second detector tube becomes an audio frequency amplifier when the receiver is switched to the phonograph position, the grid bias and input circuit of this tube being changed accordingly.

The phonograph volume control is separate from the radio volume control and is located alongside the turntable on the motor board as is the phono-radio switch.

SCHEMATIC DIAGRAM OF MAJESTIC SCREEN GRID SUPERHETERODYNE AUTOMATIC VOLUME CONTROL RECEIVER - MODEL 60 CHASSIS 115 AND 220 VOLTS, 25-40 AND 50-60 CYCLES



NOMINAL - VOLTAGE - ACTUAL	①	②	③
(115)	105	115	125
(220)	200	220	240

WATTS	CYCLES	MFDS A	B	C	D	E
110	50-60	2	2	2	1	.07
125	25-40	4	3	3	1	.25

GRIGSBY-GRUNOW CO.
CHICAGO U.S.A.

If set stops playing suddenly, tuning meter pointer swings clear over to stop. Cause is shorting of by-pass condenser in plate circuit of i.f. tube. Unsolder leads from i.f. transformer, remove it from chassis and heat to melt wax. Remove can and melt wax from red lead to condenser with iron. Cut this lead, re-assemble the transformer with it projecting from case and mount replacement by-pass unit externally.

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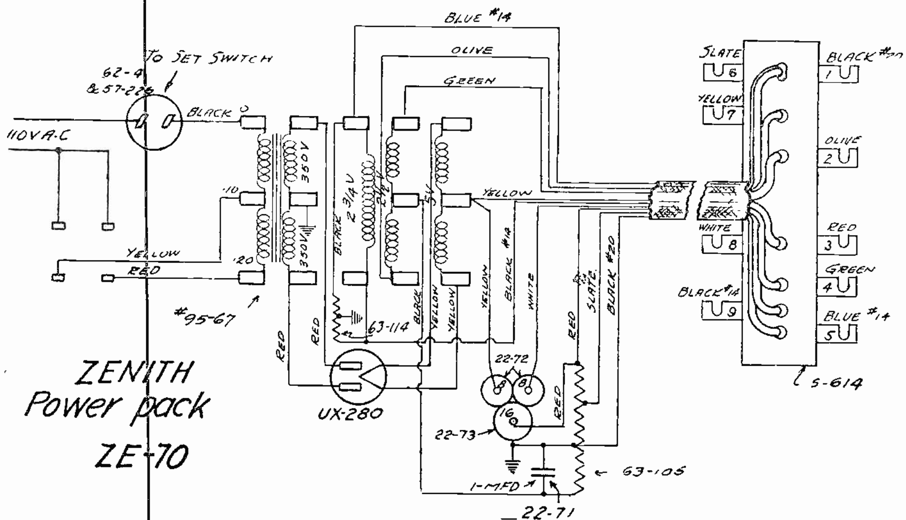
ZENITH MODELS 71, 72, 73, 77, 712, 722, 732 and 772

Balancing Set

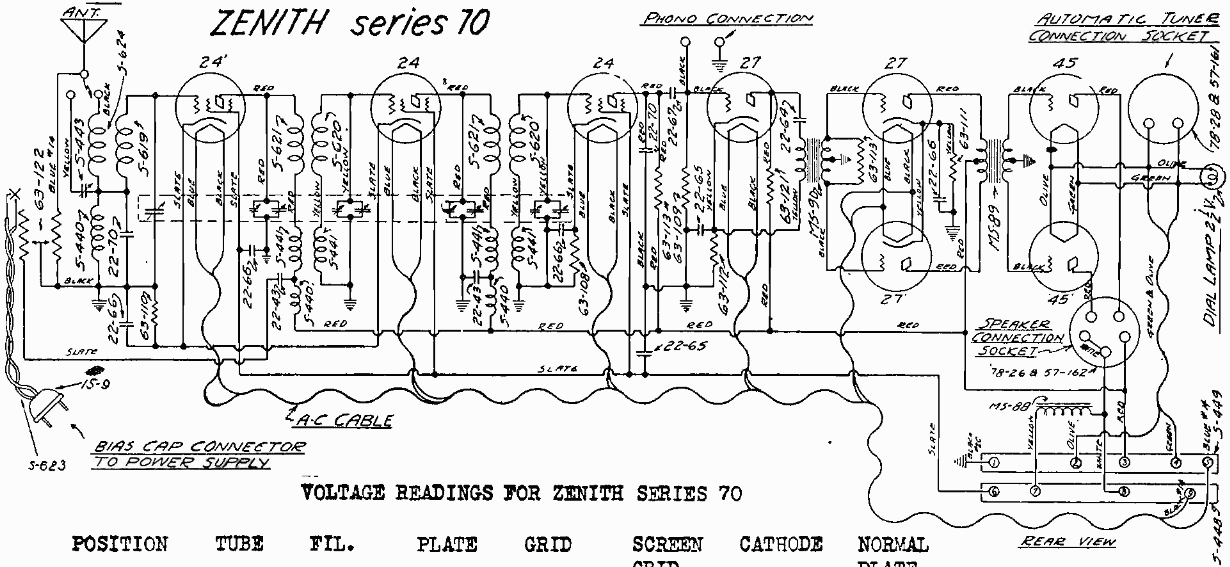
Referring to the instruction card supplied with the receiver, the Radio-Trician will find a layout diagram showing the rear of the set and will note from the diagram, four holes in the rear of the condenser shield and just above the shield grid cans. In these holes can be seen a hexagonal nut; it is the correct adjustment of the nut that brings the set to balance. A number 5 Spintite wrench can be used on this. For convenience we will number the holes from left to right: Nos. 1, 2, 3 and 4.

A broadcast oscillator adjusted at 14 hundred kilocycles should then be connected on the receiver. In the absence of an oscillator a broadcasting station cf this frequency can be used. After the set is tuned to resonance then slip the balancing wrench through hole number 4 and carefully turn the hexagonal nut slowly back and forth until the loudest signal is received. It should not be necessary to turn the balancing wrench more than one-half turn; then do the same with No. 2. These two, No. 2 and No. 4, being grid circuit adjustments, will be the most critical. Then adjust No. 3 and last No. 1. These two are less critical but a setting will be found for maximum volume. A final and further peaking of No. 4 and No. 2 may be still obtained after adjustment of No. 1 and No. 3. The set should then be retuned to exact resonance with the signal and if necessary the above adjustments repeated. It is not necessary to use a signal of exactly 14 hundred kilocycles, any signal between 12 hundred and 15 hundred kilocycles will be suitable.



ZENITH Power pack ZE-70

ZENITH series 70



VOLTAGE READINGS FOR ZENITH SERIES 70

POSITION	TUBE	FIL. VOLTS	PLATE VOLTS	GRID VOLTS	SCREEN GRID VOLTS	CATHODE VOLTS	NORMAL PLATE M.A.
1 RF	'24	2.5	180	2	60	2.	2.5
2 RF	'24	2.5	175	2.5	60	2.5	2.5
DET.	'24	2.5	90	4.4	*	2.5	.2
1 AF	'27	2.5	65	2	-	5.	1.3
2 AF	'27	2.5	160	13	-	13	3.
2 AF	'27	2.5	160	13	-	13	3.
PWR.	'45	2.4	260	55	-	-	43.
PWR.	'45	2.4	260	55	-	-	43.

Fuse in 110 Volt Clips - Line Volts 110

*Actual voltage same as on RF screen grids but can only be obtained by using Electrostatic Volt Meter.

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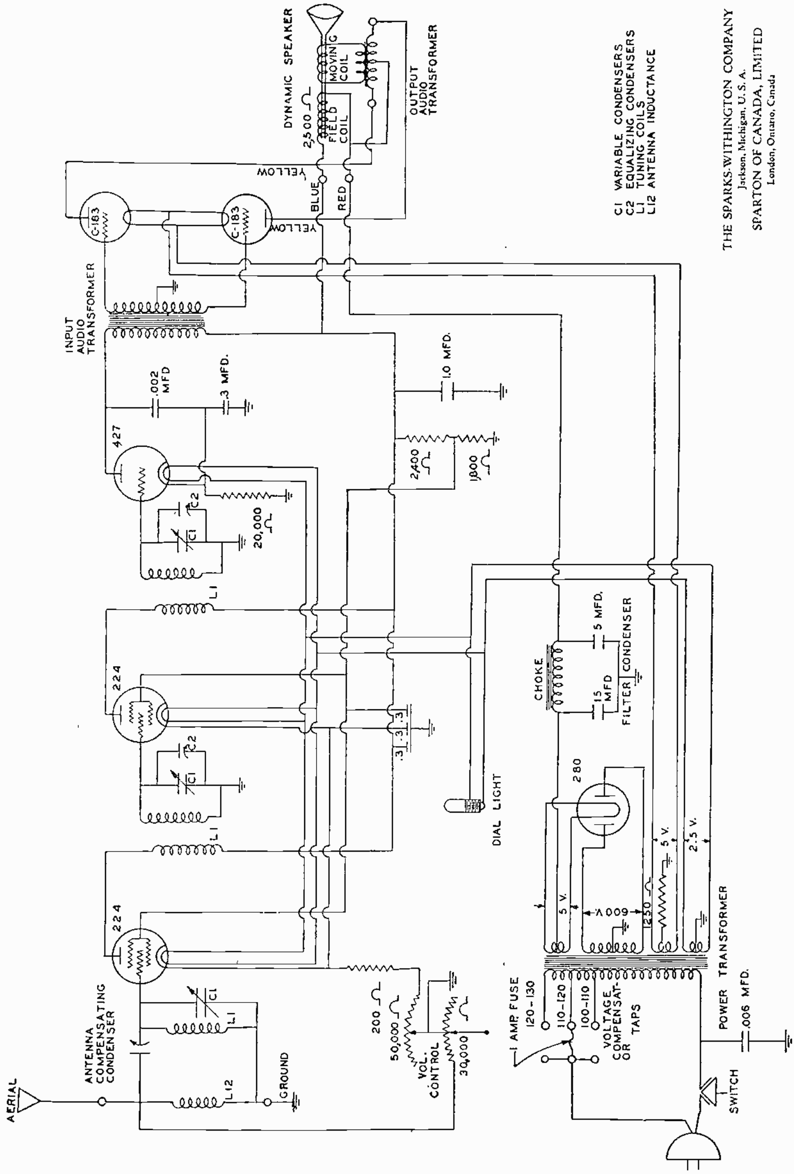
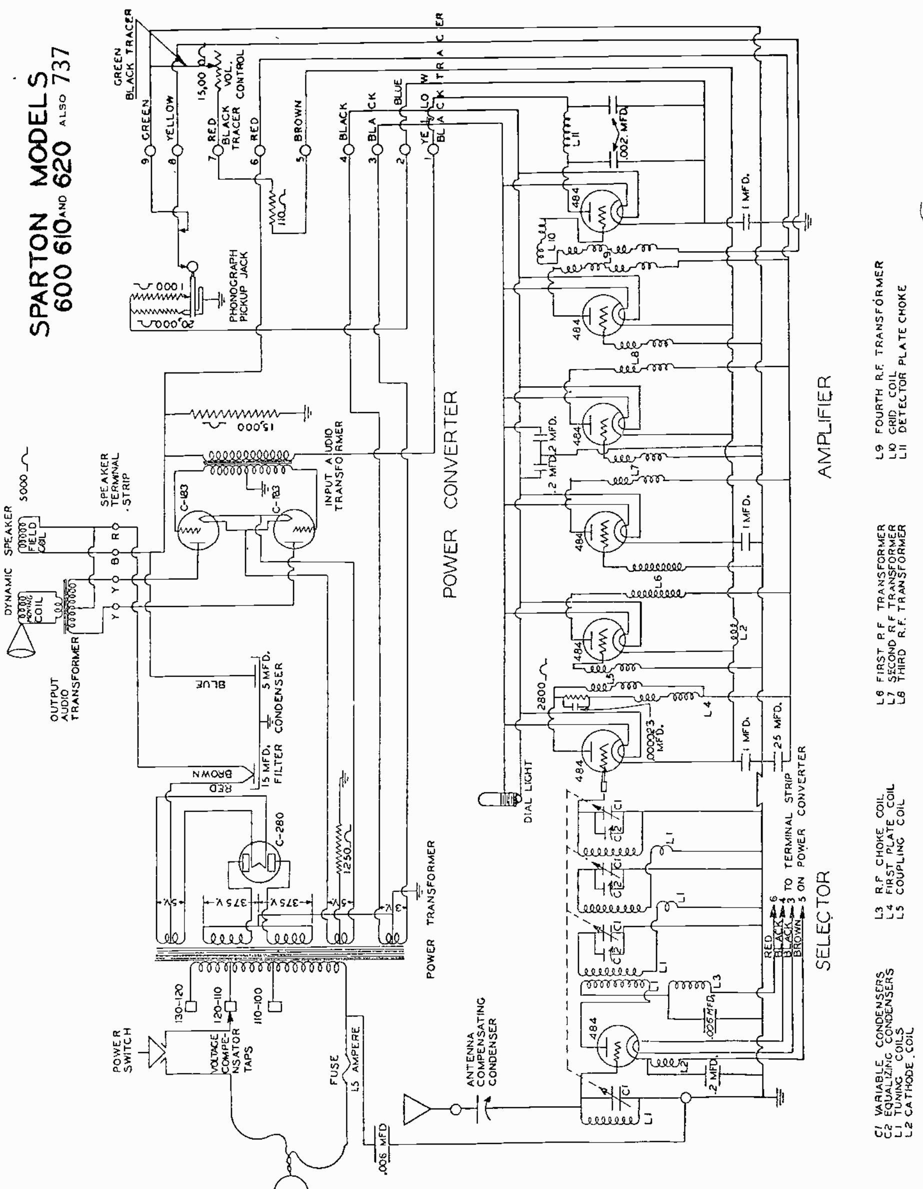
SPARTON MODELS 410, 420, 600, 610, 620 and 737

SPARTON MODEL 410 AND 420 A.C. RECEIVER



Sp-600



VOLTAGE READINGS AT SOCKETS

POSITION	TUBE	FIL. VOLTS	PLATE VOLTS	GRID VOLTS	SCREEN GRID VOLTS	CATHODE VOLTS	NORMAL PLATE M. A.
1 RF	484	2.9	120	4.5	-	-	7.5
2 RF	484	2.9	120	4.5	-	-	7.5
3 RF	484	2.9	120	4.5	-	-	7.5
4 RF	484	2.9	120	4.5	-	-	7.5
5 RF	484	2.9	120	4.5	-	-	7.5
6 RF	484	2.9	120	4.5	-	-	7.5
DET.	484	2.9	110	10	-	-	1
P.P.	C-183	4.9	270	35	-	-	20
P.P.	C-183	4.9	270	35	-	-	20

Line Voltage 120 Set on 120 - 130 Volt Tap Volume Control Position Max.

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CROSLEY MODEL 122

ALIGNMENT OF TUNING CONDENSERS

(Also for Chassis 123 and 124)

The alignment of the tuning condensers is a process requiring considerable skill, and should only be undertaken when absolutely necessary, and only by those who have had extensive servicing experience. While station signals can be used for aligning, it is advised that a local modulated oscillator be employed. The procedure for aligning the tuning condensers is as follows:

1. Tune to a signal between 1300 and 1400 kilocycles.
2. Turn the volume control all of the way on. If all signals within the required range are too loud, connect a 0.00025 m.f. fixed condenser between the "A" and "G" terminals, and then couple the antenna very loosely to a wire connected to the "A" terminal.
3. If, when carefully tuned to the middle of the band, the dial reading does not correspond to the frequency of the signal, but is not more than two channels off, set the dial at the correct frequency, and adjust the padding condenser on the oscillator tuning condenser (the tuning condenser nearest the front of the chassis) until the signal is loudest. Check the tuning by re-adjusting the station selector. It may not be possible to regulate the oscillator padding condenser so that the oscillator condenser is properly aligned with the exact dial setting, in which case align the padding condenser with a dial setting as close to the actual frequency as practicable.
4. After aligning the oscillator padding condenser, re-tune to a frequency between 1300 and 1400 kilocycles and carefully adjust the padding condensers on the other two tuning condensers until the signal is received with greatest volume.
5. If a screwdriver of insulating material is not available, adjustment may be made with an ordinary screwdriver by turning the screw slightly, removing the screwdriver, and re-tuning—repeating this process (being sure to turn the screw in such a direction that the tuning approaches more nearly the desired frequency, of course) until the dial setting agrees with, or approximates, the actual signal frequency.

ALIGNING INTERMEDIATE FREQUENCY STAGES

For Chassis Nos. 122, 123 and 124

The primary and secondary circuits of the intermediate amplifier transformer must be tuned accurately to 175 kilocycles. They are aligned carefully at the factory, and no change should be necessary. In order to align them, an accurately tuned local oscillator operating at 175 kilocycles is essential. The procedure is as follows:

1. A local oscillator tuned accurately to 175 kilocycles frequency is required.
2. Remove the oscillator tube from the chassis. Remove the clip wire from the first detector tube. Connect the test oscillator output from the first detector grid to ground, and adjust the two screws at either side of the front I. F. coil for maximum reading on the output meter. Always re-align the tuning condenser after aligning the I. F. amplifier.

CHANGES IN MODEL 122

The following changes as compared with the circuit diagram shown herein will be found in some chasses.

1. The pentode grid resistor is 300,000 ohms instead of 1 megohm as shown on the diagram.
2. The volume control resistor is 650 ohms instead of 2500 ohms, as shown.
3. The 3000 ohm resistor shown on the diagram just to the left and above the power transformer is changed to 1790 ohms.
4. The 1100 ohm resistor shunted across a portion of the volume control is deleted.
5. The 25,000 ohm resistor in the r. f. screen grid circuit is replaced by a 20,000 ohm resistor.

Diagrams for chassis 123 and 124 will be found on the following pages.

Voltage Limits

Filament Voltages

All tubes but rectifier	2.3 to 2.5
Rectifier tube	4.6 to 5.0

Plate Voltages

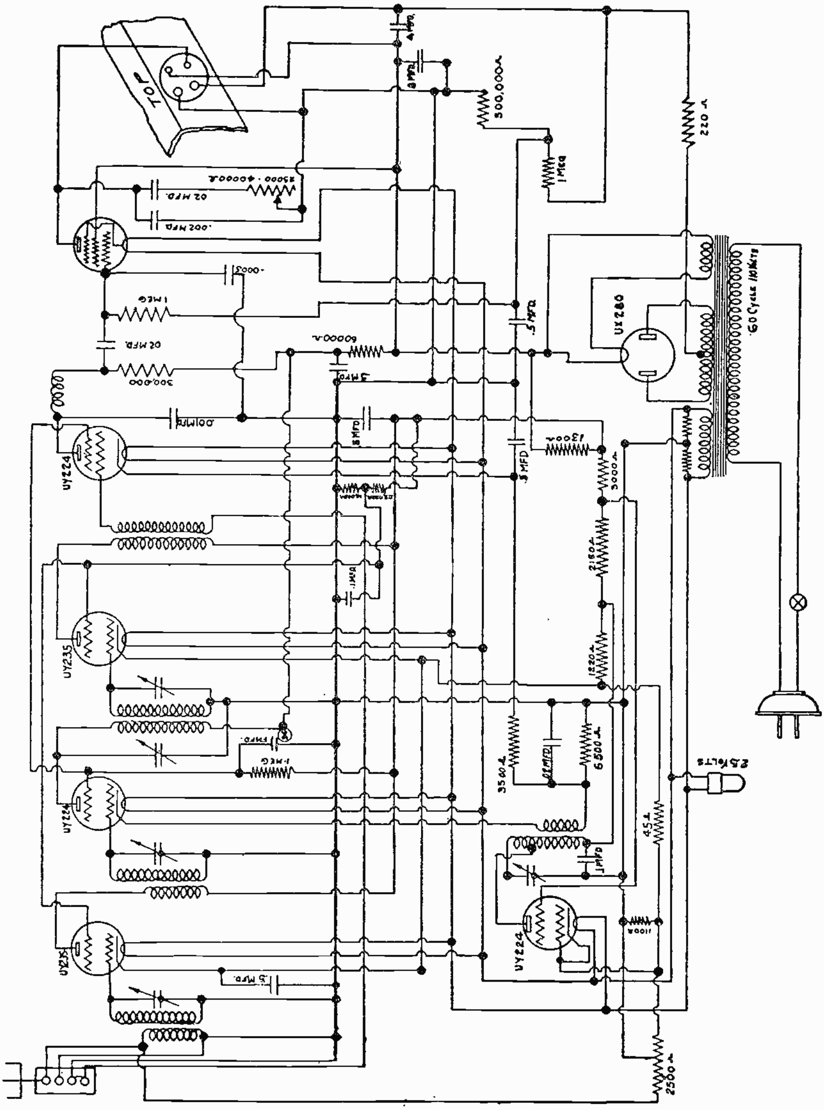
1st R. F. and Intermediate Amplifiers	170 to 200
Oscillator	28 to 38
1st Detector and 2nd Detector	185 to 215
Output	260 to 300
Rectifier (A. C. voltage)	280 to 320 each plate

Screen Grid Voltages

1st R. F. and Intermediate Amplifiers	45 to 55
1st Detector and 2nd Detector	60 to 80
Oscillator	80 to 100
Output	260 to 300

Control Grid Voltages

1st R. F. and Intermediate Amplifiers	1.5 to 2.5
1st Detector	6.0 to 8.0
2nd Detector	8.0 to 10.0
Output tube	18.0 to 22.0



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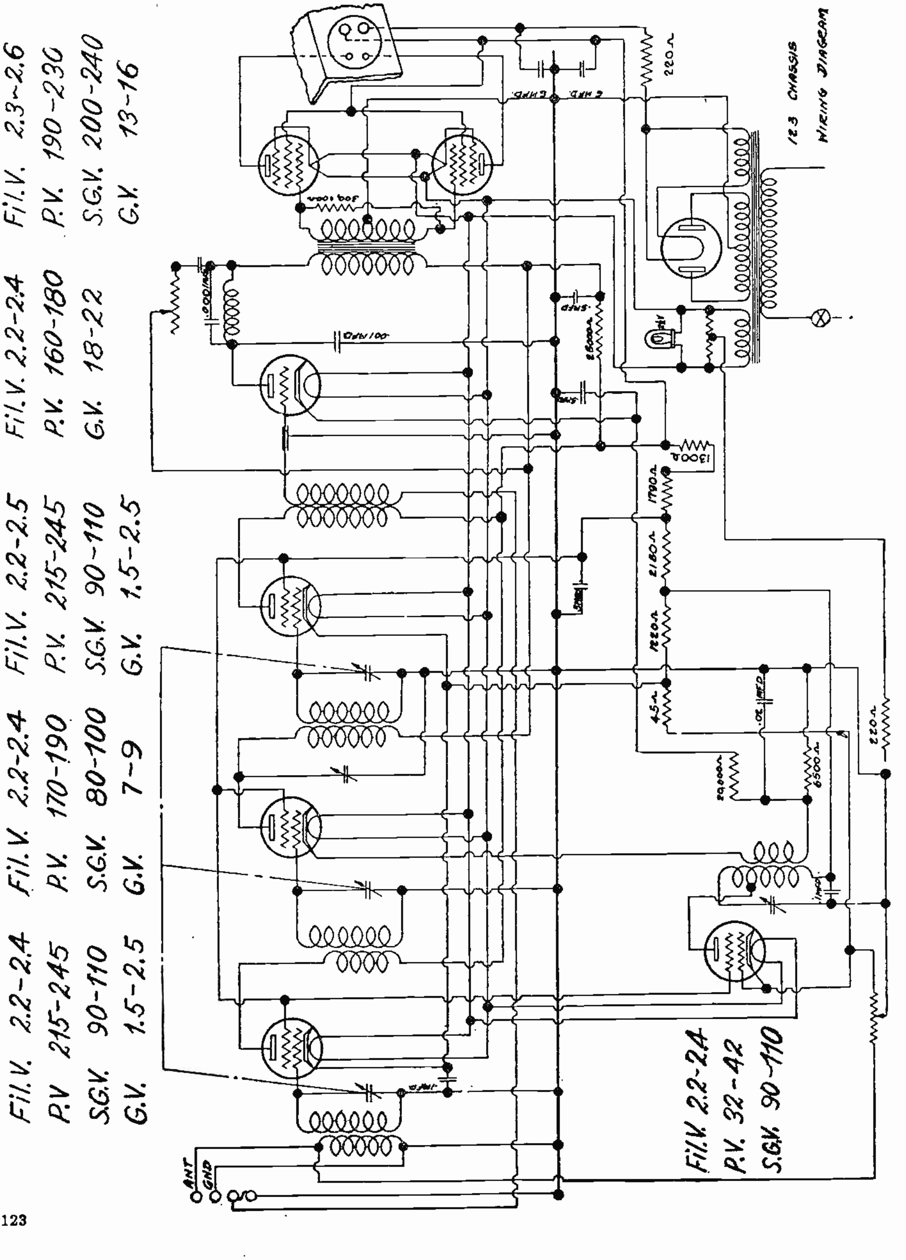
CROSLEY CHASSIS NO. 123



Voltage Limits

Filament Voltages	
All tubes but rectifier	2.3 to 2.5
Rectifier	4.6 to 5.0

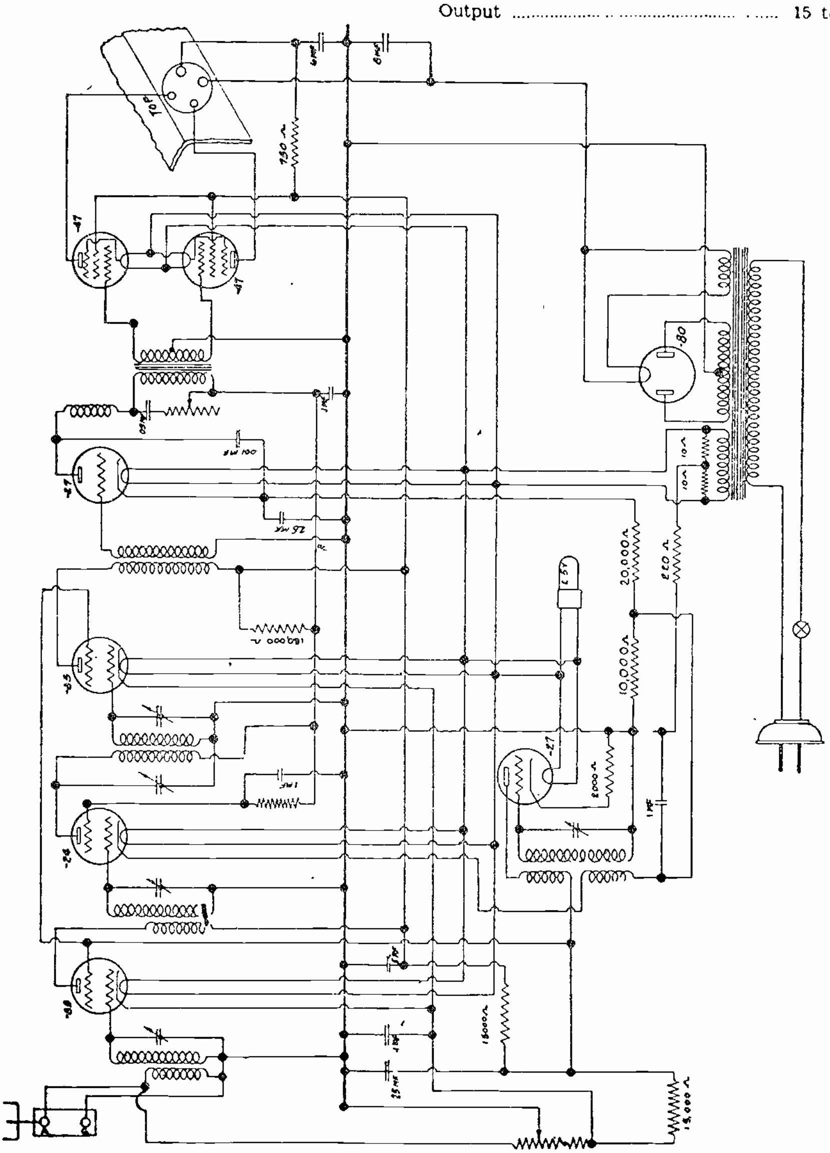
Plate Voltages	
R. F. and I. F. Amplifiers and Out-	235 to 265
put	170 to 190
First and Second Detectors	60 to 80
Rectifier, D. C. Voltage	300 to 340

Screen Grid Voltages	
R. F. and I. F. Amplifiers	80 to 100
First Detector	55 to 65
Output	230 to 270

Control Grid Voltages	
R. F. and I. F. Amplifiers	1.5 to [illegible]
First Detector and Oscillator	7 to 9
Second Detector	18 to 22
Output	15 to 18

CROSLEY

Model 124



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CLARION RECEIVERS, MODELS NOS. AC-51, AC-52 AND AC-55

These receivers use the same chassis, the only difference being in the cabinet design.

With reference to the diagram you will find that the circuit employs 3 screen grid 224 tubes, a 227 power detector and a 227 first audio resistance coupled, as well as two 245's in the push-pull amplifier. The conventional 280 tube is used as a rectifier.

When the receiver is first turned on the voltage regulator should be watched. If it becomes red hot a short circuited rectifier tube or a defect in the power pack causes it. The switch should be turned off and the short circuit or abnormal condition overcome. The speaker plug should be in place while the receiver is on. If the speaker plug is out of place, and the switch turned on the filter condensers will be overloaded. Three chokes are used in the filter circuit of the power pack including the field coil of the dynamic speaker. Ordinarily only two chokes are employed in A.C. receivers.

If oscillations occur look for an open screen grid by-pass condenser, an open plate by-pass condenser, an open grid bias resistor, poor contact between the variable condenser canopy and chassis, poor contact between Radio frequency unit chassis and the main chassis, open circuit of grounding strap between Radio frequency choke and main choke, poor contact between variable condenser frame and rotors through the tension spring clips or by open circuit of the ground strap between condenser frame and chassis. Chassis base plate loosely attached to chassis; poor ground connection, a high resistance connection in series with a by-pass condenser, tube shields not secure and high line voltage.

New receivers have the trimmer condensers on stages 1, 2 and 4 almost all the way in, that is, having almost maximum capacity. Trimmer condenser on stage No. 3 will be found adjusted about half way out. It is suggested that you leave the trimmers as found unless it is definitely ascertained that they are out of adjustment.

If it is found that the trimmer condensers must be reset, tune in a broadcast signal of about 1400 K.C. or use a modulated oscillator for a signal.

Starting with the detector stage (toward rear of chassis) turn the trimmer condenser in and out with an insulated wrench until maximum signal is heard. Be sure to have the tube shields and grid caps in place. Next adjust the trimmer condenser of the 3rd Radio frequency stage, repeating this operation through the 2nd and 1st Radio frequency stages successively. From here on do not touch the trimmers. Re-tune the receiver to 1000 kilocycles. Starting with the detector stage, bend the split rotor plate of the condenser in or out for maximum signal. Repeat this operation on the 3rd, 2nd and 1st Radio frequency stages in turn. Tune to 550 kilocycles, and reset the split rotor plate if necessary.

A table accompanies this article, giving the voltages which should be measured at the tube socket terminals with a line voltage of 105 and 60 cycle current.

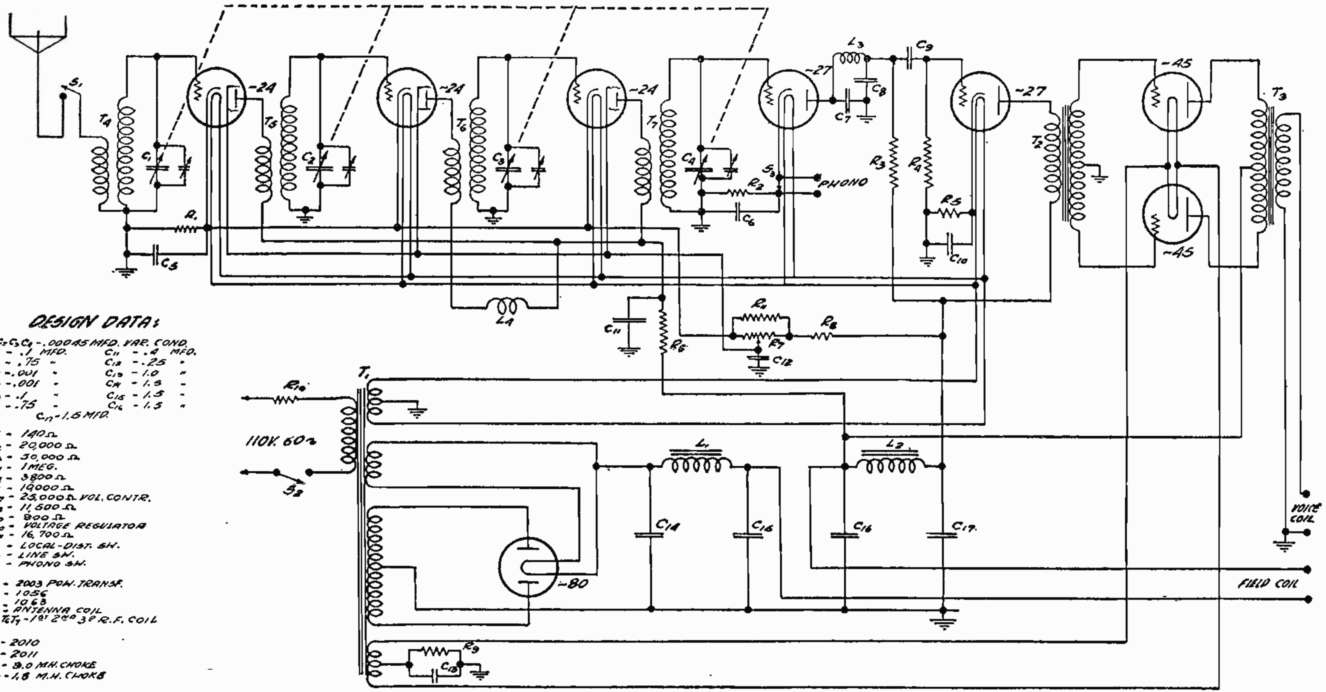
With this information as a guide and following standard practices on such receivers you will be able to correct any trouble that may develop in the Clarion receivers.

VOLTAGE TABLE

Tube Order	Tube Type	A Volts	B Volts	Cont. Grid Volts	Cathode Volts	Plate M.A.	Screen Volts
1	224	2.09	146	2.43	2.43	2.72	87.5
2	224	2.09	151	2.43	2.43	2.55	85.5
3	224	2.09	151	2 43	2 43	2.72	87.5
4	227	2.09	134	12 2	13 15	.58	—
5	227	2.14	170	1.22	13.6	3 31	—
6	245	2.14	195	37.5	—	20.4	—
7	245	2.14	195	37.5	—	23.4	—
8	280	4.51	—	—	—	35.	—

Line Voltage 105 60 cycle.

Volume Control Position Full



DESIGN DATA:

$C_1 C_2 C_3 C_4$ - .00045 MFD. VAR. COND.
C_5 - .1 MFD. C_{11} - .4 MFD.
C_6 - .75 " C_{12} - .25 "
C_7 - .001 " C_{13} - 1.0 "
C_8 - .001 " C_{14} - 1.5 "
C_9 - .1 " C_{15} - 1.5 "
C_{10} - .75 " C_{16} - 1.5 "
C_{17} - 1.5 MFD.

R_1 - 140 Ω
R_2 - 20,000 Ω
R_3 - 30,000 Ω
R_4 - 1 MEG.
R_5 - 3800 Ω
R_6 - 10,000 Ω
R_7 - 25,000 Ω VOL. CONTR.
R_8 - 11,500 Ω
R_9 - 800 Ω
R_{10} - VOLTAGE REGULATOR
R_{11} - 16,700 Ω
S_1 - LOCAL-DIST. SW.
S_2 - LINE SW.
S_3 - PHONO SW.

T_1 - 2003 POW. TRANSF.
T_2 - 1056
T_3 - 1068
T_4 - ANTENNA COIL
$T_5 T_6 T_7$ - 1ST 2ND 3D R.F. COIL

L_1 - 2010
L_2 - 2011
L_3 - 9.0 M.H. CHOKE
L_4 - 1.6 M.H. CHOKE

Wiring Diagram of Clarion Models AC 51-52-55.

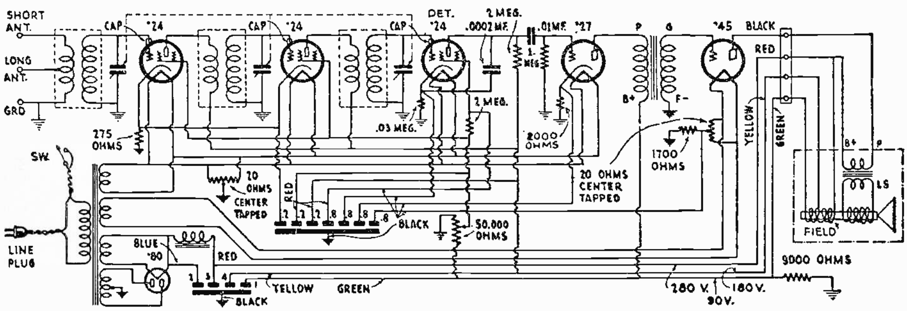
RADIO-TRICIAN
REG. U. S. PAT. OFF.

Service Sheet

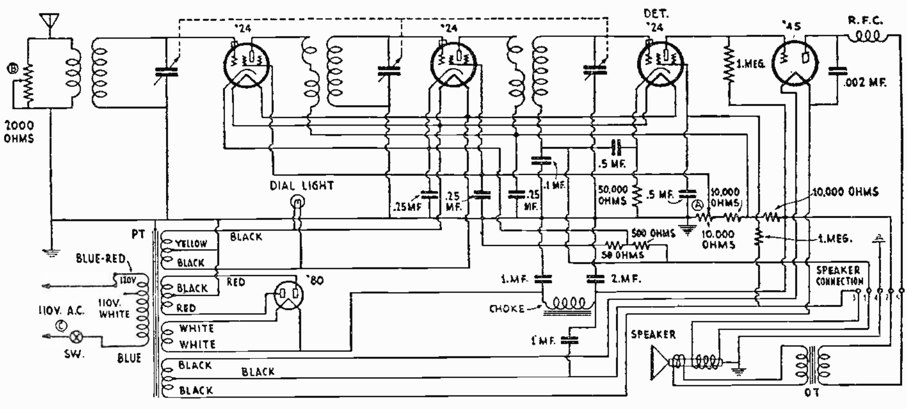
Compiled Solely for Students and Graduates

NATIONAL RADIO INSTITUTE, WASHINGTON, D. C.

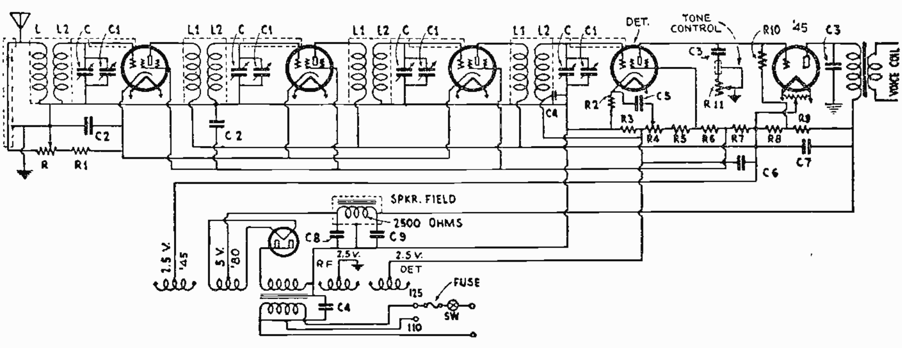
WIRING DIAGRAMS OF MIDGET RECEIVERS



Pilot Midget.

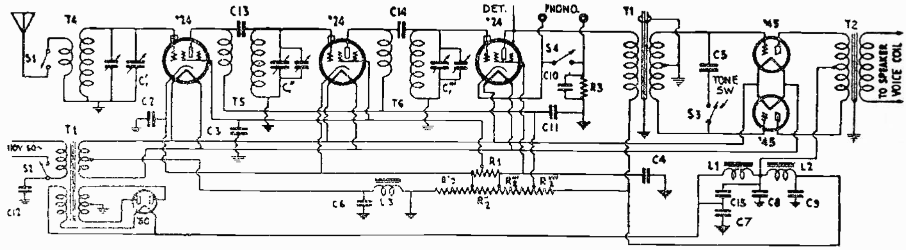


Model G, Jesse French, Jr.

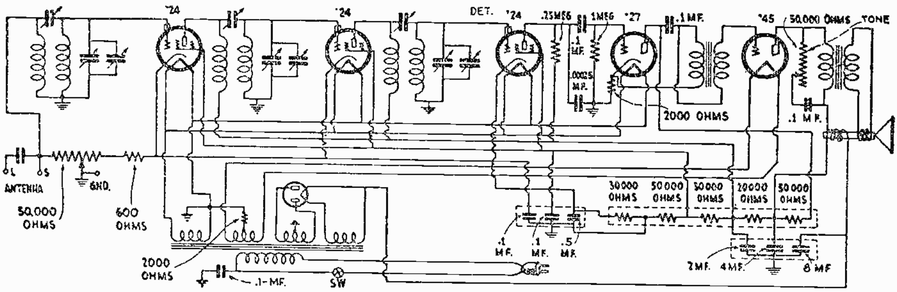


Master, Model 424.
(Courtesy Radio Craft.)

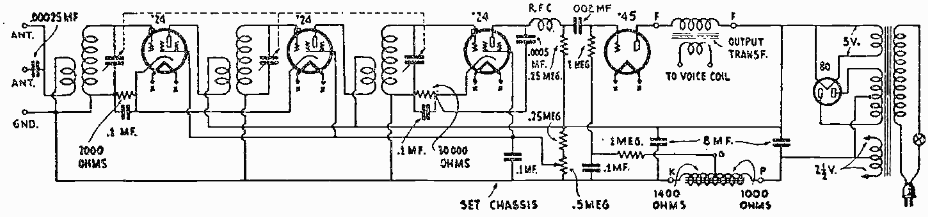
WIRING DIAGRAMS OF MIDGET RECEIVERS



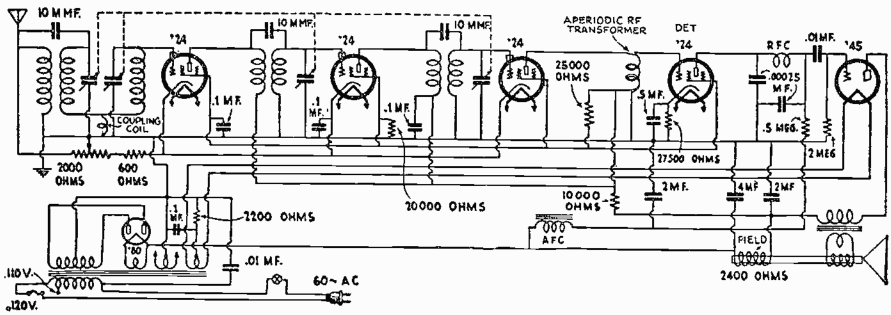
Clarion, Jr., Model 60.



Remler Cameo, Model 14.



Melorad "Cathedral Tone."



RADIETTE, MODEL 14F.
(Courtesy Radio Craft)

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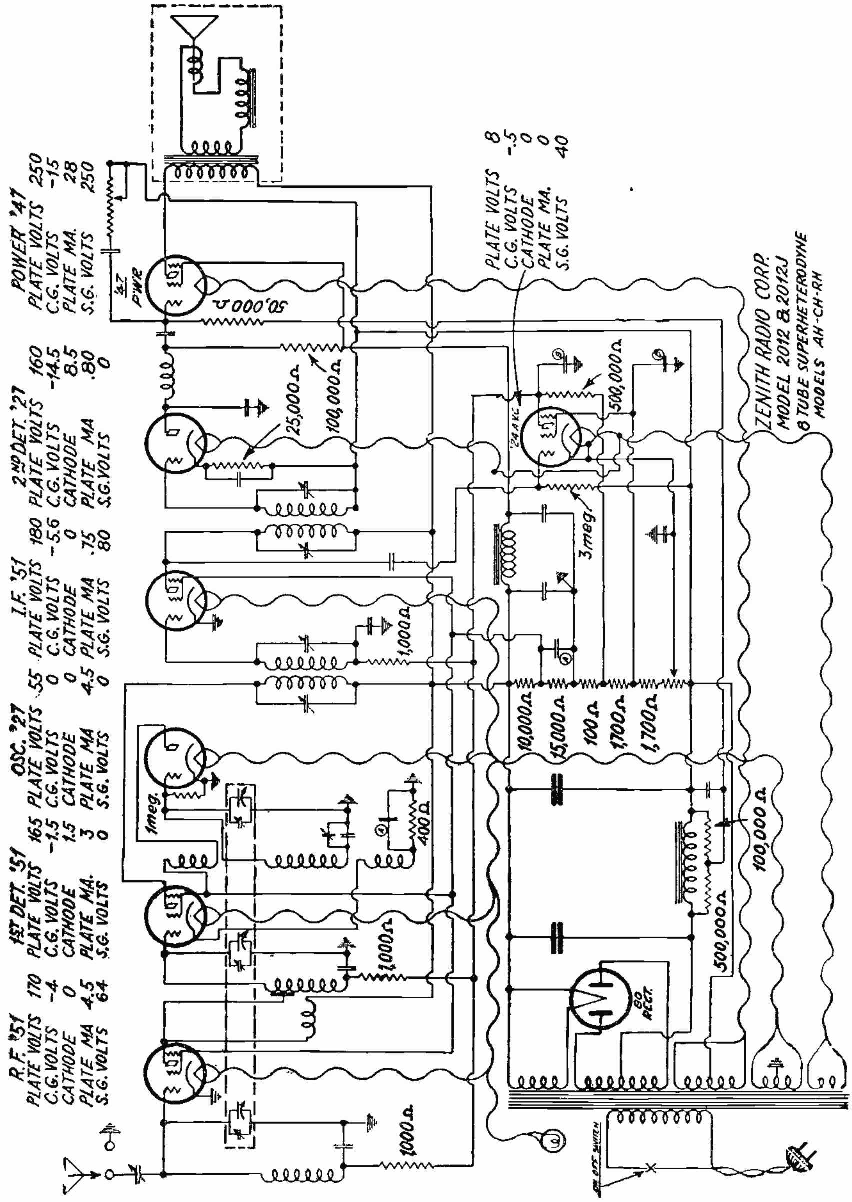
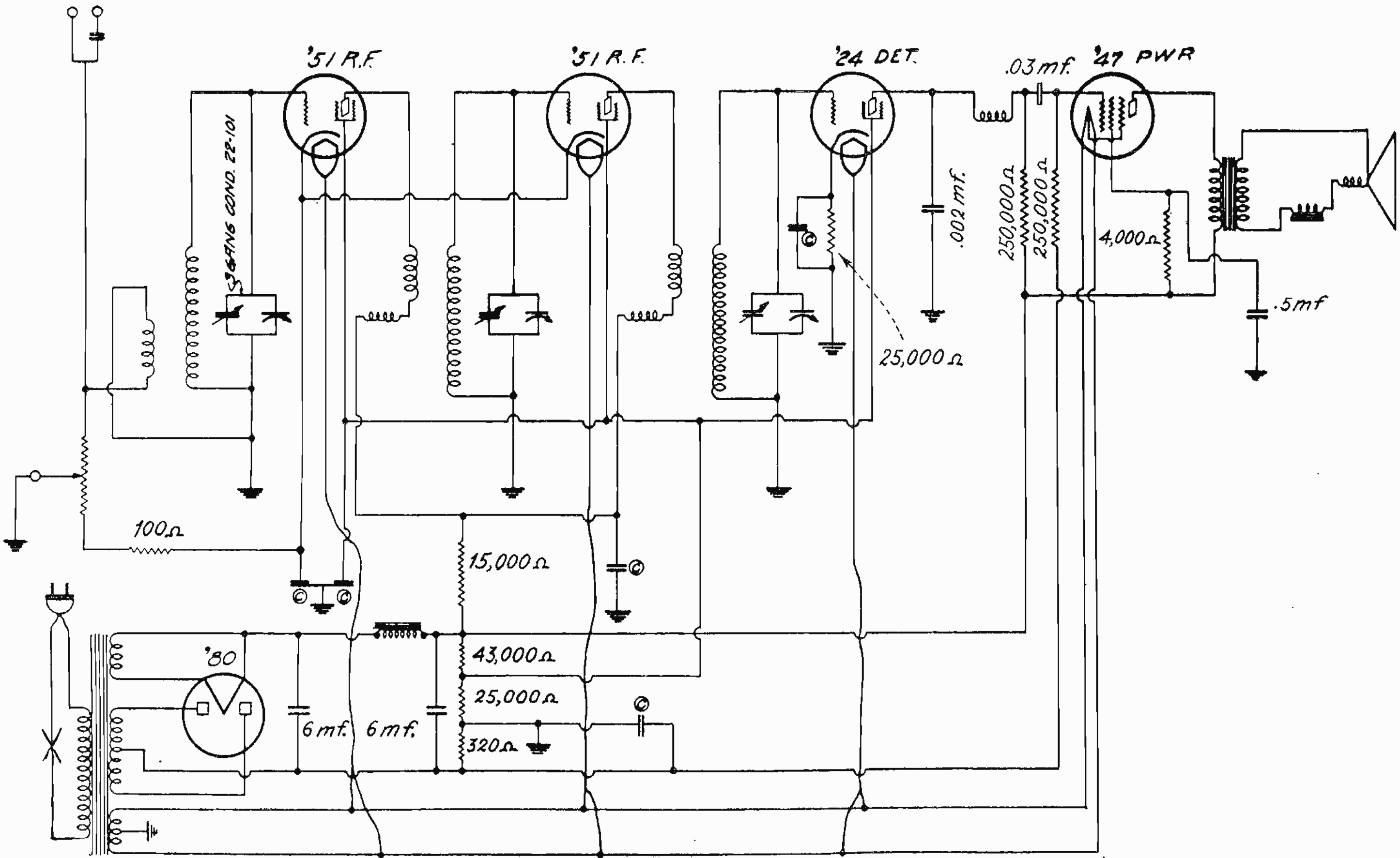
ZENITH MODELS AH-CH-RH (2012 and 2012J) and Model L.P. (2009-CP)





ALL FIXED CONDENSERS MARKED © INCLOSED IN ONE CONTAINER PART

ZENITH, (Model L.P.)
2009-C-P

RADIO-TRICIAN
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Service Sheet

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NATIONAL RADIO INSTITUTE, WASHINGTON, D.C.

FADA RA RECEIVER—MODELS 74, 76, 83, 87, 88, 89

CONTINUITY AND VOLTAGE READINGS ON FADA RA RECEIVER - MODELS 74, 76, 83, 87, 88, 89

Line voltage 115 A.C. (60 Cycle) -- Wattage 95
No signals -- Ant. & Ground leads tied together

TYPE OF TUBE	POSITION OF TUBE	PLATE VOLTS	PLATE (MA) CURRENT	CONTROL GRID VOLTS	SCREEN GRID VOLTS
F-58	R.F. & I.F.	180	7.0	4.2	110
F-58	1st Detector	173	1.1	11.0	103
F-56	Oscillator	70	4.0	--	--
F-56	2nd Detector	--	--	--	--
F-56	1st Audio	164	2.0	10.0	--
F-247	P.P. Audio	248	34.0	15.0	262
F-280	Rectifier		112 total		

Note:- Bias readings are to be taken across each respective bias resistor. Correct readings cannot be obtained at control grids due to use of series resistors.

VOLTAGES ACROSS VOLTAGE DIVIDER AND BLEEDER RESISTORS

Voltage across	280 ohm	AF filter choke	(1933-X)	31 volts
" "	800 "	speaker field	(3-1266-Ms)	95 "
" "	7,000 "	Resistor	(3-1264-Ms)	92 "
" "	25,000 "	Resistor	(3-1450-Ms)	161 "
" "	30,000 "	Neon control	(3-1440-Ms)	115 "
" "	200 "	Bias resistor	(3-1283-Ms)	15 "
" "	300 "	Bias resistor	(3-1444-Ms)	4.2 "
" "	5,000 "	Bias resistor	(3-1445-Ms)	10 "

VOLTAGES ACROSS ELECTROLYTIC CONDENSERS

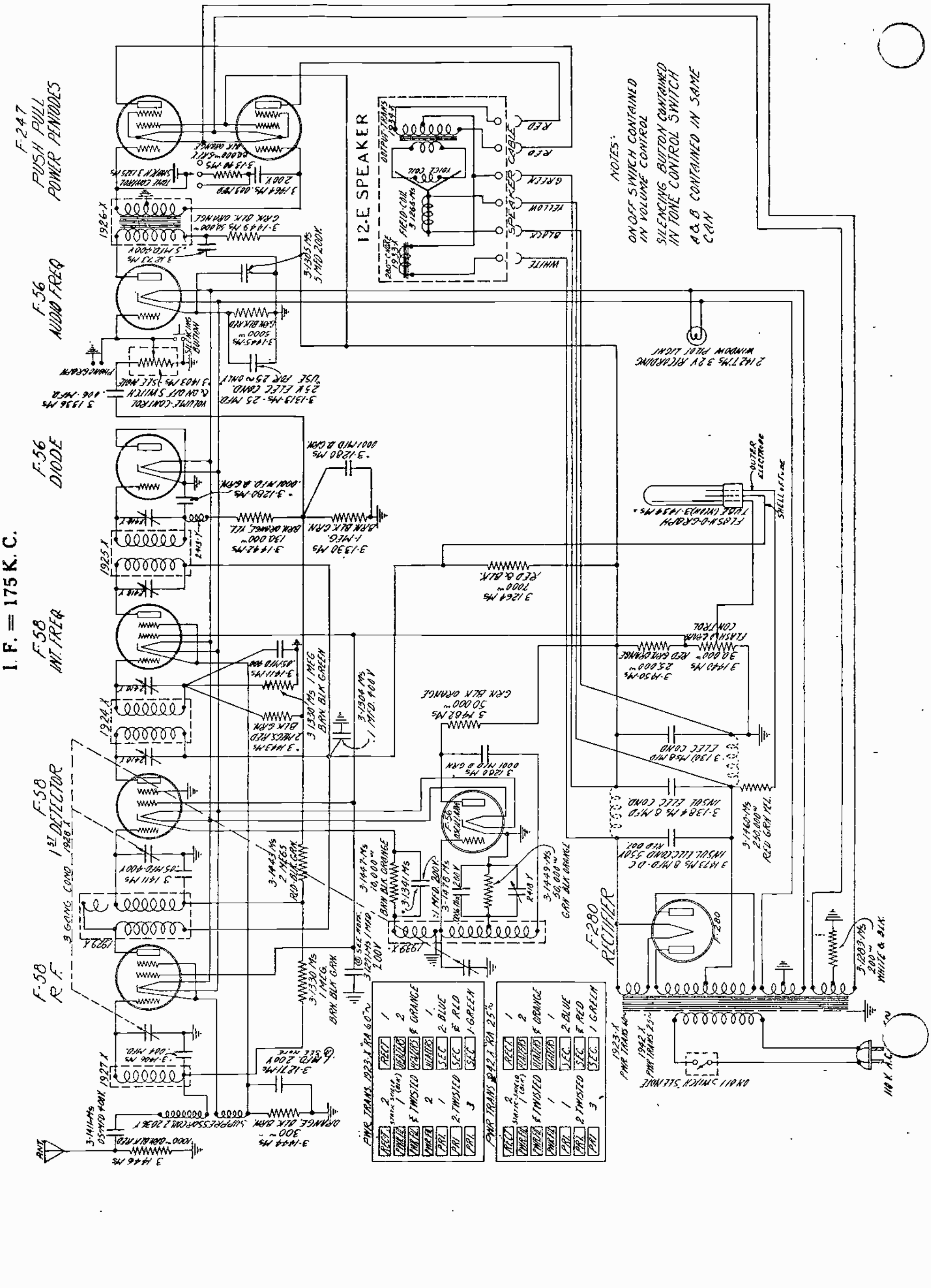
1st -- 402 2nd -- 371 3rd -- 276

DC RESISTANCE VALUES

		PRIMARY	SECONDARY
1927-X	Antenna coil	-- ohm	3.5 ohm
1929-X	R.F. Coil	71 "	3.5 "
1939-X	Oscillator coil	.8 "	3.5 "
1924-X	I.F. transformer	97 "	97 "
1925-X	I.F. transformer	97 "	97 "
2-2036-Y	Suppressor coil	15.5 "	1.47 "
1926-X	Input AF transformer	2933 "	9600 "
1934-X	Output AF transformer	745 "	.75 "
933-X	Choke ---------------- 280 ohms		
2413-Y	R.F. choke ----------- 134 "		
3-1266-Ms	12-E speaker field -- 800 "		

The foregoing voltage and current readings were taken beneath the chassis with the meters available in an ordinary set analyzer with the idea in mind of approximating the conditions the average service man has to contend with. Permissable variations in tube characteristics as well as commercial tolerance allowable in portable test equipment may result in a deviation from the above readings.

FADA RA RECEIVER—MODELS 74, 76, 83, 87, 88, 89



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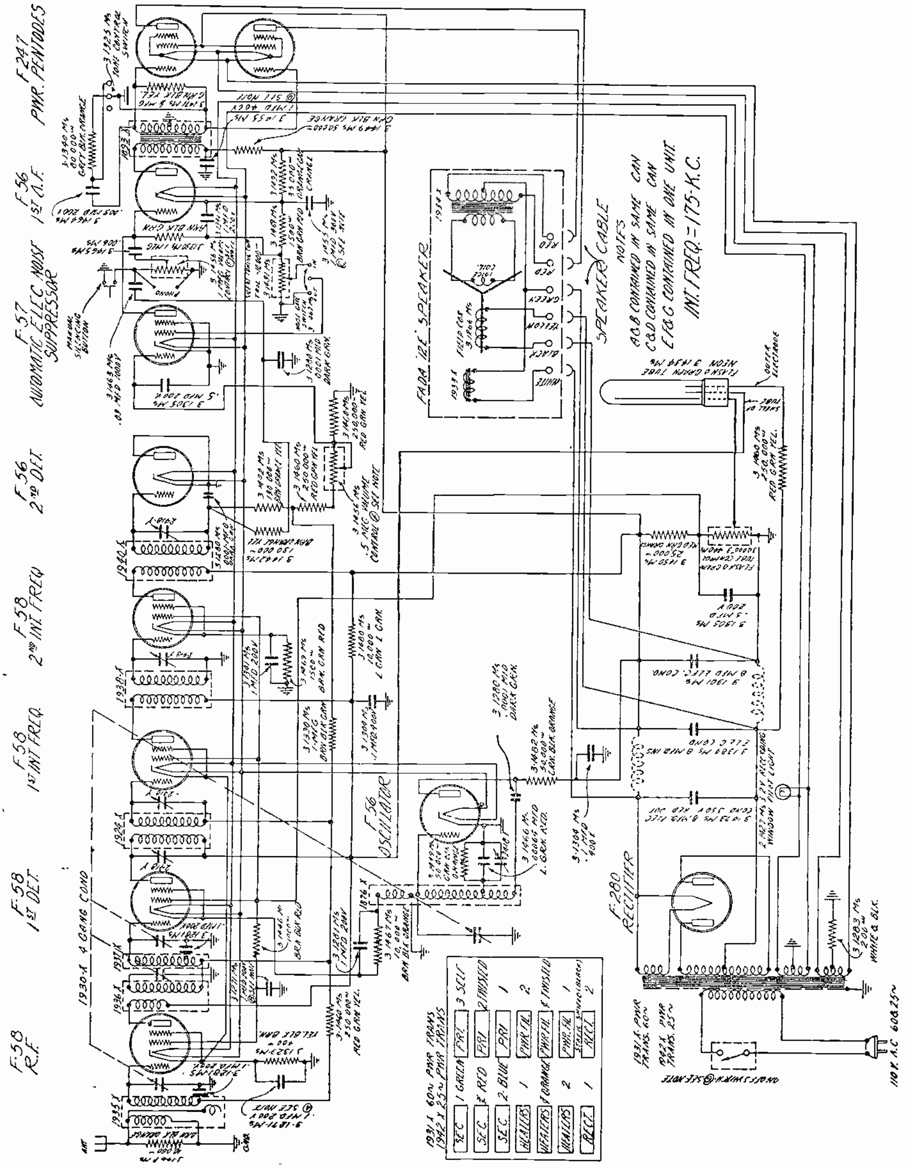
FADA RC RECEIVER—MODELS 78 AND 79 (60 CYCLES)



FADA RC RECEIVER—MODELS 78 AND 79 (60 CYCLES)

CONTINUITY AND VOLTAGE READINGS ON
FADA RC RECEIVER - MODELS 78 and 79 (60 CYCLES)

Line voltage 115 A.C. -- Wattage 110
No signals -- Ant. & ground leads tied together

TYPE OF TUBE	POSITION OF TUBE	PLATE VOLTS	PLATE MA CURRENT	CONTROL GRID VOLTS	SCREEN GRID VOLTS
F-58	R.F. & 1st I.F.	175	4.1	3.5	105
F-58	1st Detector	166	1.2	12.0	96
F-56	Oscillator	70	4.0	--	--
F-58	2nd I.F.	264	4.0	6.0	102
F-56	2nd Detector	--	--	--	--
F-57	Noise suppressor	--	--	--	--
F-56	1st Audio	140	1.0	--	--
F-247	Pwr Pentode	245	32.0	15.0	255
F-280	Rectifier		110. total		

Note:- Bias readings are to be taken across each respective bias resistor. Correct readings cannot be obtained at control grids due to series resistors.

VOLTAGES ACROSS VOLTAGE DIVIDER AND BLEEDER RESISTORS

Voltage across	280 ohm	AF filter choke	(1933-X)	32 volts
" "	800 "	Speaker field	(3-1266-Ms)	100 "
" "	10,000 "	Resistor	(3-1480-Ms)	92 "
" "	25,000 "	Resistor	(3-1450-Ms)	162 "
" "	30,000 "	Neon control	(3-1440-Ms)	108 "
" "	400 "	Bias resistor	(3-1329-Ms)	3.5 "
" "	200 "	Bias resistor	(3-1283-Ms)	15 "

VOLTAGES ACROSS ELECTROLYTIC CONDENSERS

1st -- 402 2nd -- 370 3rd -- 270

DC RESISTANCE VALUES

		PRIMARY		SECONDARY	
1935-X	Antenna coil	22	ohms	3.4	ohms
1936-X	R.F. coil	70	"	3.4	"
1937-X	Post selector coil	--	"	3.4	"
1876-X	Oscillator coil	.74	"	3.4	"
1924-X	I.F. transformer	97	"	97	"
1938-X	I.F. transformer	50	"	100	"
1940-X	I.F. transfomer	150	"	125	"
1893-X	Input P.P. transformer	2,860	"	6,660	"
1934-X	Output P.P. transformer	734	"	.75	"
1933-X	AF filter choke ----------------	280 ohms			
3-1266-Ms	12-E speaker field -------------	800 "			

The above voltage and current readings were taken beneath the chassis with the meters available in an ordinary set analyzer with the idea in mind of approximating the conditions the average service man has to contend with. Permissable variations in tube characteristics as well as commercial tolerance allowable in portable test equipment may result in a deviation from the above readings.

How To Test the Defective Stage with a Voltmeter

All radio servicemen do not service alike, and some prefer the voltmeter in checking the defective stage. In the multimeter that, in the next job sheet, I am going to show you how to build, you will have a multi-range voltmeter as well as a multi-range ohmmeter. Therefore, either device may be used. Personally, I believe that the beginner should start with an ohmmeter test and later learn the voltmeter method, for these reasons.

In checking with an ohmmeter, the set is not connected to the power outlet, hence the service technician cannot receive a shock; the meter reading cannot read down-scale or very much more than full-scale. Therefore, the ohmmeter cannot be damaged.* The reason why some servicemen prefer the voltmeter reading is because the service sheets and manuals for receivers give the electrode voltages for a correctly operating stage, making it easier to locate some defects. However, I feel that you should know both methods, as there are a large number of modern radio circuits in which a voltmeter test would so alter circuit voltages that the readings obtained would be meaningless. Learn both methods so that either may be used as is needed. You will not have any difficulty in knowing when one or the other method should be used. An ohmmeter may be used with any circuit, but a voltmeter should not be used in circuits over 100,000 ohms, except for continuity.

Here is how I would use the voltmeter. After isolating the defective stage by the "circuit disturbance test," I would check the tube either by trying a new one, or testing the original tube in a tube checker. If the new tube makes the receiver play, the service job is completed; otherwise an internal defect exists and the chassis is then removed from the cabinet.

However, before the chassis is taken out, some servicemen are required to give an estimate on the repair cost. To do this some men check the plate supply to the tube in the defective stage by pulling the tube out, connecting the —voltmeter terminal to the chassis and the + voltmeter terminal in the plate hole of the socket. If they obtain a reading slightly higher than rated value (and this is normal), they are led to believe that a defect exists in some other circuit such as the input (grid or grid bias). If no reading is obtained, but the power pack checks O.K. then a plate circuit defect is indicated. By referring to the circuit diagram they are in a position to give a rough estimate of the repair. Of course, they must, to protect themselves, quote a price fixed on a breakdown of the most expensive part.

To my way of thinking, it is wiser to insist on removing the chassis from the cabinet and make a thorough check before giving a price. Then if you figure the cost of the job on a fair basis, there should be no objection on its completion. If permission is not granted, an ohmmeter check as explained in another job sheet plus a circuit diagram may give you a closer check on the probable defect.

Assume we are going to do the job the correct way, and have removed the chassis from the cabinet. With the receiver connected to its loudspeaker and its power cord plugged into the power outlet, set the machine on one end so you can see and work on the under-side of the chassis, and with a little effort get to the upper side of the chassis. Turn on the power.

Let us assume that the ouput stage (No. 2) in Fig. 1 is isolated as being defective. How are we going to test the defective stage by the voltage-measuring method? First set the selector switch of the multi-meter in the highest D.C. voltage position. Put the —test lead probe on the chassis and place the + test lead probe on the plate terminal of the output tube (point *a* in Fig. 1). If a reading is obtained, the primary of the output transformer and everything between it and the cathode of the rectifier is conducting a D.C. current, and very likely is in good condition. Should we obtain no reading, put the + probe on the screen grid (b). A reading at this point but not on the plate indicates an open in the output transformer primary, because this is the only thing between the plate, where we obtain no reading, and the screen which is properly supplied with voltage.

In the same manner, a correct reading at +B but not at the screen would indi-

* If you attempt to use an ohmmeter on a receiver whose power is turned on you will destroy the tester.

cate an open in resistor R. Low screen and plate voltage and slightly below normal +B voltage would lead me to believe that C was leaking excessively.

How about the control grid circuit—shall we make a test between the grid and the chassis? If we do we will measure about 1 or 2 volts instead of 30 volts (which is the normal value). The resistors in the grid circuit have a very high value and when our meter is connected, current will flow in the circuit as it is now complete. This will cause a voltage drop to occur across the resistors and we will read a voltage far below normal. A more nearly correct reading will be obtained directly across the bias resistor R_1. Yet, a grid to chassis voltage measurement does have some value. It at least proves that continuity exists.

A positive voltage between the control grid and chassis would indicate a leaky coupling condenser C_1, and a defect here would result in excessive plate current and consequently overheating of the tube.

Suppose stage *No. 1* was isolated as defective. The plate and screen voltage of the detector tube is measured in the same way as on the power tube except that the —probe is placed on the cathode of the tube. If there is no cathode to screen or plate voltage place the —probe on the chassis. If voltages are then available, the bias resistor R_2 is open.

When measuring the plate and screen voltages we again have high value resistors to deal with. However, your reading will be about the same as the manufacturer's specifications if your meter has a resistance of 1,000 ohms per volt or more, as this is the type of meter generally used in making the reference voltage charts.

Suppose we tested from cathode to screen and obtained no voltage and a test from cathode to point D indicates proper voltage. Resistor R_3 is, of course, open. The interesting thing is that a connection of our meter across the defective part will enable the set to play because the meter will complete the circuit.

The control grid voltage is, of course, measured between the control grid and cathode. First, place the negative probe to control grid and the positive probe to the cathode. Now, the same voltage should be measured between the cathode and chassis. If we get no voltage in the grid-cathode test and a voltage in the cathode-chassis check, naturally the grid return circuit to the chassis is open.

In either stage, the voltages applied to the tube filaments are measured with the A.C. voltmeter section of the multi-meter using the lowest voltage range which will take care of the recommended filament voltage for that tube.

Suggestions and Cautions.—The plate, screen, control grid, suppressor grid voltages of any defective stage are checked as we have described, always using the cathode as the reference point. Of course, if we used the circuit disturbance test first we go right to the defective stage, thus eliminating the need of testing stages that are more than likely to be in good condition.

Don't expect your measurements to tally exactly with the service sheet; line voltage variations, *your* meter resistance and part value tolerances will prevent this. Don't expect a voltage test to tell you everything. Associated effects may make the meaning of a certain reading vague. A coupling condenser may be open or a grid input may be shorted and this will have no effect on measured voltages—use your ohmmeter and try new condensers.

When in doubt always use the highest range of your meter. If the reading cannot be easily read you can switch to a lower range. This will prevent damage to your meter. If your meter reads backwards you have your probes in the wrong position—reverse them instantly.

Never connect your milliammeter across a voltage source—this will ruin it. Never probe around aimlessly with your meter—you might connect it across a voltage source too high for the range being used.

One final "don't"—don't be alarmed by the "nevers" and "don'ts" mentioned—they are easy to remember and in a short time your observance of these will become automatic.

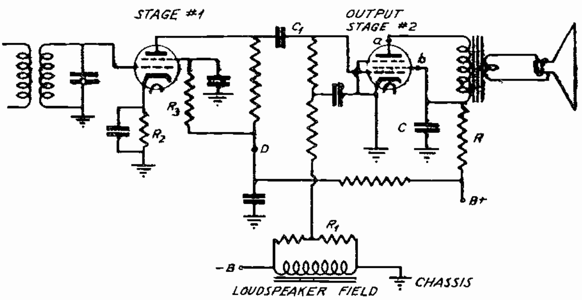


FIG. 1.

How To Isolate the Improperly Operating Stage

The circuit disturbance test is without doubt a valuable procedure in isolating the defective stage of a receiver that does not play. But when a receiver picks up and reproduces a broadcast unsatisfactorily, how are we to isolate the improperly operating stage? By unsatisfactory operation I mean, for example, reception is reproduced with unreasonable distortion, or the set lacks "pep," or the receiver chokes up when tuned to a broadcast. These are only a few of the many things a receiver will do when it works abnormally.

Now the expert learns from a study of radio and radio receivers plus experience what is probably causing the trouble. For example, he recognizes certain distortion as being due to a defective tube, that reception lacks pep because the tuned stages are not aligned, that a receiver may choke up because a grid return connection is open. As you service more and more radio receivers this ability to reason from "effect to cause" will become easier. Earlier in your course you received a reference book containing scores of symptoms of defective receivers and their cause. Study this reference book, because it will improve your ability to recognize the cause of a defect.

What should you do if you cannot reason out the probable cause? Exactly what every expert would do. First, he determines if all of the tubes are working, whether any connection is off or loose, whether the antenna and ground leads are connected properly to the receiver, and if the antenna-ground system looks O.K. He does this almost in a slow but thorough visual sweep. It really does not take long to see that there are no surface defects.

If checking for surface defects does not show up the cause, he reasons that perhaps the main D.C. supply voltage is low. So he connects a high range voltmeter (about a 0 to 500 volt range) to two convenient terminals which will tell him something about the power pack output. He could choose the filament of the rectifier and the chassis, or the plate of one of the power tubes and the chassis. Quite often it is easier to check between a filter choke terminal and the chassis. It all depends on whether the chassis is in the cabinet or on your bench. It is easier to service an improperly operating receiver when the chassis is on your bench, the bottom of the chassis and the wiring in full view.

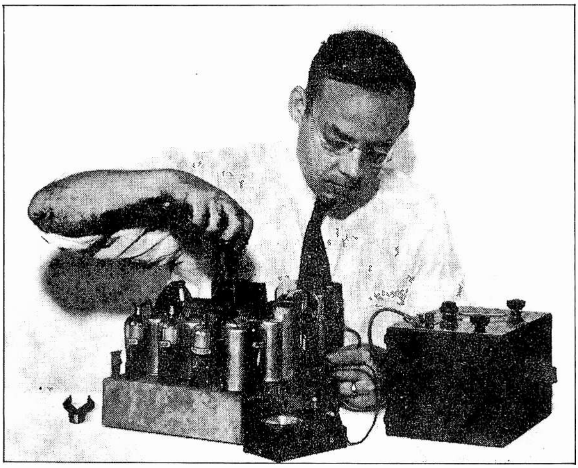


FIG. 2. *Service man checking an improperly operating stage with a signal generator.*

Of course, if the voltage is abnormal, then a voltage check on the various stages and the power pack should be started. If the main D.C. supply is normal, and a thorough inspection of the parts in the chassis and the connections suggest nothing that may be at fault, a "stage by stage elimination" test is made. The expert reasons: "If a defect exists it is very likely in some stage; if I connect a *modulated signal generator* to the inputs of various stages starting from the detector ahead of the audio system and proceeding to ANT-GND connection, I will be able to recognize the trouble when I pass through the improperly working stage." To be sure, matters are greatly simplified if he has a circuit diagram and a tube layout of the chassis.

In a following job sheet I am going to show you how to build a service oscillator, but I suggest you buy one of the all-wave type.

Checking a T.R.F. Receiver.—As the tuned radio frequency receiver is simpler than the super, I have chosen it first to show you how to apply the stage by stage elimination test.

The receiver and signal generator (oscillator) are both tuned to the same frequency, say 1,000 k.c. The signal generator is connected, by means of probes, to the input of the detector (grid-chassis) or the plate-chassis of the R.F. tube ahead of the detector. A strong signal is necessary. Now if the modulating tone of the oscillator is heard from the loudspeaker without any of the distortion, noise or choking up that we are looking for, it is natural to assume that the detector and the audio system is in normal working order. But if the trouble exists, we know that there is a defect from the point of signal application to the loudspeaker.

In checking the detector-audio stages for normal operation, the simplest procedure is to employ a head-set with a series protecting condenser, connected first between the plate and chassis of the detector, then the plate and chassis (for single tube stages) or plate and plate (for twin tube stages) of the following audio stages and in proper order. This check may proceed directly to the voice coil or armature coils of the loudspeaker. The defect will quickly show up if it exists in these stages. When the defective stage is located be sure to check the tubes, either by replacement or in a tube checker, before you condemn the parts or connections in that stage.

Let us assume that the detector and audio system check O. K. We discard our head set, and proceed to connect the signal generator to the grid-chassis of the tube ahead of the detector, or the plate-chassis terminals ahead of the tube previously connected. A plate-chassis connection is generally preferred, as this connection produces the least disturbing load on the stages.

As you pass from one stage to the next, the modulation tone of the signal generator emitted from the loudspeaker, should become louder. This shows that the stage just included in the test is contributing its share of R.F. gain. Of course, if you pass through a stage that introduces the trouble you are looking for, as for example, noise, no or reduction in gain, choking up, hum, etc. the defective stage has been isolated.

Now you may proceed to check the tube, and the circuits of the defective stage with an ohmmeter or voltmeter, depending on your preference.

Checking a Superheterodyne Receiver is not very much different. Because it has a different radio frequency system, a little different procedure is taken. In checking the second detector-audio amplifier system, you should adjust the signal generator to the I.F. frequency. And at this setting you may proceed to eliminate the I.F. stages up to and including the first detector.

You may not get an appreciable gain in output when the signal generator, set to the I.F. value, is connected to the grid-chassis of the first detector. But you should get a signal equal to what is obtained by the previous connection; and this is a check on the operation of the first detector.

Now to check the oscillator of the super. Leaving the signal generator connected to the input of the first detector, adjust the generator and the receiver to some broadcast frequency (say 1,000 k.c.). If the local oscillator is working, the sound from the loudspeaker should go up, if no signal is heard or it is very weak, the oscillator is defective.

From this point to the ANT-GND the test is the same as for a T.R.F. receiver.

Suggestions.—In making a grid connection select a top cap, stator section of a variable condenser, or the socket terminal. Plate connections must always be made at the socket.

When the receiver has an A.V.C., remove the control tube, if possible. Gain can only be judged if the signal generator output level is kept low. It is best to judge gain by using an output meter (to be explained in a later lesson), always adjusting the output of the signal generator to get the same output.

The action of special circuits, such as A.V.C., squelch, automatic tone control, and so forth, must be performed after the normal receiver stages are checked. If you know how a certain stage works and what it should do, you will have no trouble in judging its condition.

Radio Servicing Jobs and how to do them

How to Build an Effective All-Wave Signal Generator

NEXT to the multimeter, the most useful instrument for radio service work is an all-wave signal generator or test oscillator. A signal generator is almost a necessity when doing work on superheterodyne receivers; with it all-wave superheterodyne receivers can be accurately aligned for maximum sensitivity and selectivity, and I.F. amplifiers can be set to the frequency specified by the manufacturer.

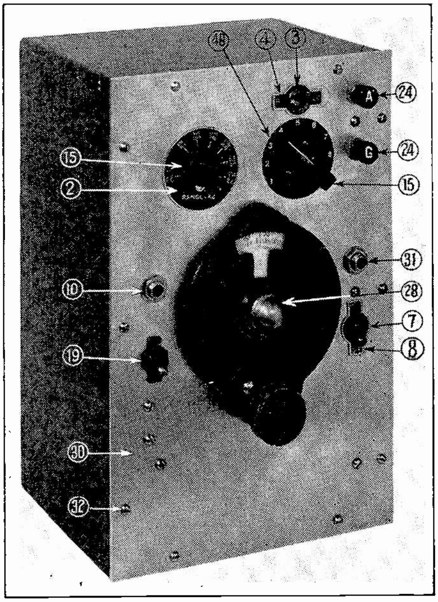


FIG. 1. *The completed signal generator, designed and built in the N. R. I. Laboratory, fits into 7" x 10¾" x 5½" cabinet.*

This job sheet covers the construction and calibration of a signal generator; the use of each control or outlet of the unit is discussed briefly at the end. In other job sheets and in the regular lesson books you will find detailed instructions for using signal generators in radio service work.

Factory-made signal generators will usually be more reliable, more accurate and more impressive in appearance than a kit-assembled unit; I recommend the purchase of a commercial unit, just as I did in the case of the multimeter. However, if you have enough time available to assemble and calibrate your own unit, and feel that the few dollars saved will be important, or you want the experience of making radio equipment, follow closely the instructions given here.

The most difficult part to construct, when building an all-wave signal generator of any kind, is the coil assembly. I suggest, therefore, that you purchase this part. In order to follow through a typical assembly, I have selected the R.C.A. test oscillator kit #9559.*

The frequency range of the signal generator extends from 90 kc. to 25,000 kc. A selector switch allows you to set the generator to any one of the eight overlapping bands listed here:

Band #1—	**90**	**to**	**200 kc.**
Band #2—	**200**	**to**	**400 kc.**
Band #3—	**400**	**to**	**800 kc.**
Band #4—	**800**	**to**	**1,500 kc.**
Band #5—	**1,500**	**to**	**3,100 kc.**
Band #6—	**3,100**	**to**	**6,800 kc.**
Band #7—	**6,800**	**to**	**14,000 kc.**
Band #8—	**14,000**	**to**	**25,000 kc.**

These bands cover all radio frequency and intermediate frequency line-up points of all types of receivers. This frequency range is covered entirely by the fundamental frequency of the oscillator, no harmonics being used. A separate modulator tube putting out about a 500-cycle note is provided to modulate the radio frequency output, a panel switch being included to start and stop modulation.

Parts Included with R.C.A. #9559 Unit

Item #1—Shielded coil assembly.
Item #2—Range switch escutcheon.
Item #3—High-low output switch.
Item #4—High-low output switch escutcheon.
Item #5—220,000 ohm resistor.
Item #6—2,200 ohm resistor.
Item #7—Modulation switch.
Item #8—Modulation switch escutcheon.
Item #9—Dial scale (not used).
Item #10—Sweep condenser jack (open circuit type).
Item #11—Instruction book and drilling template (not used).

* This kit can be obtained from radio parts supply houses. It is sometimes called the "oscillator modernization kit," necessary to convert the R.C.A. TMV-97-B unit for use with the cathode ray oscillograph and frequency wobbulator (frequency modulator).

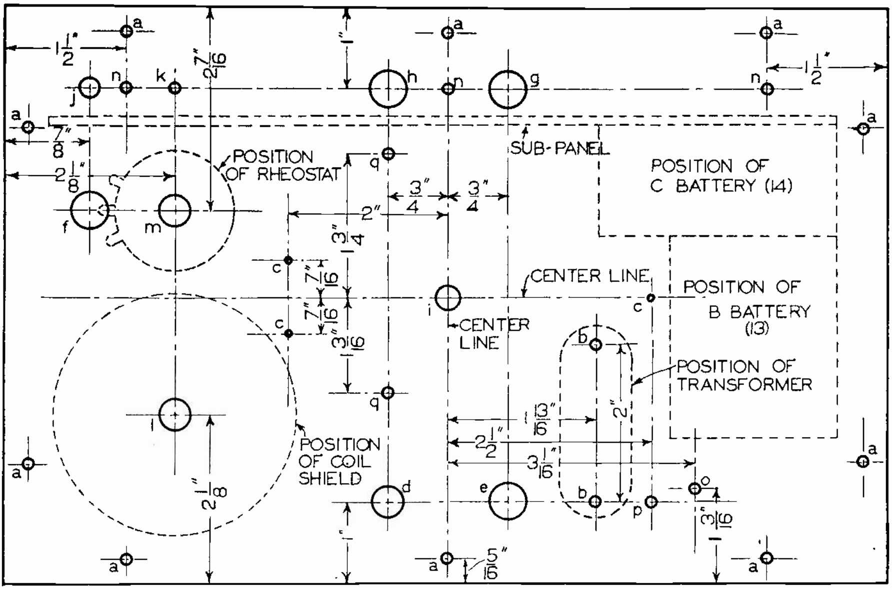


FIG. 2. *Layout for 10-13/16" x 7-1/16" aluminum front panel (front view). Refer to dotted lines when mounting parts on the panel. Locate holes "a" 5/16" from outside edges and 1½" from nearest corner.*

The following are additional parts required, obtainable from mail order supply houses, except those furnished in N. R. I. units.

Item #12—Two 4-prong wafer sockets.
Item #13—One 22.5 volt small B battery, Burgess #4156 or its equivalent.
Item #14—One 4.5 volt C battery, Burgess #2370 or its equivalent.
Item #15—Two short arrow-pointer type knobs.
Item #16—One *N.R.I.** A.F. transformer, listed as item #24 in your home experimental outfit.
Item #17—50 feet #22 solid insulated hook-up wire.
Item #18—One *N.R.I.* 10,000 ohm potentiometer, listed as *N.R.I.* item #13.
Item #19—OFF-ON toggle switch (S.P.S.T.).
Item #20—.05 mfd. paper non-inductive condenser listed as item #28 in your *N.R.I.* shipment.
Item #21—One 250 mmfd. fixed mica condenser.
Item #22—Two type 30 tubes, listed as *N.R.I.* item #10.
Item #23—One 100 mmfd. mica fixed condenser.
Item #24—Two binding posts with insulated washers.
Item #25—.000350 mfd. variable condenser, listed as item #23 or #33 for *N.R.I.* units—*1 rotor plate is removed.*
Item #26—One 250,000 ohm, 2 watt resistor, listed as item #45 for *N.R.I.* units.
Item #27—One 50,000 ohm, 2 watt resistor, listed as item #47 for *N.R.I.* units.
Item #28—One 4-inch vernier tuning dial reading from 0 to 100 in a counter-clockwise direction.
Item #29—Six dozen soldering lugs.
Item #30—One panel, aluminum, 7-1/16" x 10-13/16" x 3/32", cut to exact size.
Item #31—Yaxley jack #702, closed circuit type.
Item #32—Ten #6 nickel-plated round head wood screws, ⅝" long (to fasten panel to cabinet).

*All N.R.I. items refer to parts furnished with your Home Experimental Outfits.

Item #33—One subpanel, bakelite, 9⅝" x 4⅞" x ⅛", cut to exact size.
Item #34—One aluminum or brass strap ⅝" wide, 10" long, 1/16" thick (to hold batteries in position).
Item #35—One 50,000 ohm, 2 watt resistor.
Item #36—One 50,000 ohm, 2 watt resistor.
Item #37—One .05 mfd., 200 volt paper condenser.
Item #38—Four angle brackets ⅜" wide, 1/16" thick brass stock, with holes ⅝" from bend; use 3 to mount subpanel, one to hold the C battery in position.
Item #39—Two angle brackets ⅜" wide, 1/16" thick brass stock, with holes 11/16" from bend; used in mounting tuning condenser.
Item #40—Two 6-32 round head brass machine screws ⅝" long.
Item #41—4 dozen #6 lock washers.
Item #42—½" clear white pine lumber for cabinet; 1 piece 7" x 10¾", 2 pieces 5" x 10¾", 2 pieces 5" x 6⅛".
Item #43—One piece ordinary copper screen, 20" x 24", for cabinet lining.
Item #44—4 dozen ⅜" flat head carpet tacks.
Item #45—4 dozen 1¾" long (4-penny) finishing nails.
Item #46—3 dozen ⅜" long 6-32 round head nickel-plated brass bolts.
Item #47—3 dozen ¼" 6-32 hex nuts for above screws.
Item #48—Escutcheon for attenuator control.

Laying Off the Panel and Subpanel. Lay out the holes for both the panel and subpanel with a square and steel scriber, following carefully the dimensions given in Figs. *2* and *4*. Make your lines very lightly and use a center punch to spot the holes. Apply turpentine liberally when drilling or working the aluminum panel, to improve the cutting qualities of the tools you use.

DRILLING DATA—ALUMINUM PANEL

Holes	*Diameter*	*For Item:*
a	**Use #18 drill**	**#32—Panel hold-down screws.**
b	**Use #18 drill**	**#46—Transformer mounting bolts.**

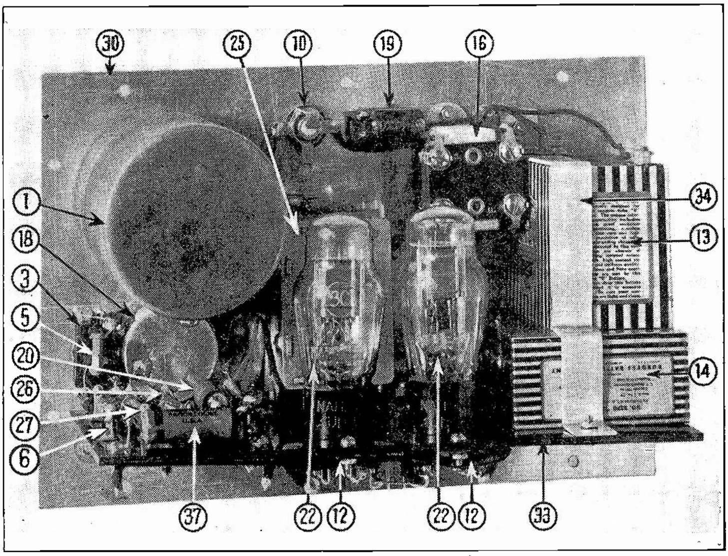


FIG. 6. *Item numbers marked on this photograph assist you in arranging the parts.*

set as low as possible. This will not only eliminate confusion with image frequency response but will increase the selectivity of the receiver should it have AVC.

Beat Method of Calibration

You can accurately check any frequency of a signal generator provided that you can "beat" this frequency against a signal of high precision. Fortunately such precision signals are readily available. All 540 to 1500 kc. broadcasting stations must, according to rulings of the Federal Communications Commission, stay within 50 cycles of their assigned frequency, a precision far greater than you can hope to attain with any service signal generator. With these standard broadcast band frequencies to check against, you can calibrate some ranges of the S.G. directly or by harmonics. Other ranges are calibrated just as accurately by means of a simple unmodulated oscillator.

In the beat note method of calibrating the signal generator, the method which I am about to describe, we make use of beat notes between the known frequency of a broadcast transmitter and either the fundamental or some harmonic of the S.G. frequency. This method is simple and accurate, but requires time and patience. Its principle is simple; when the S.G. is tuned to zero beat with the transmitter, the transmitter frequency is an exact multiple (or a whole number times) the S.G. frequency. This holds true regardless of the setting of the A.W.R., as long as this receiver is tuned to bring in the desired station with sufficient volume for calibrating purposes. The procedure is as follows:

1. Prepare rough calibration curves for each S.G. range by the A.W.R. method described.

2. Connect calibrating apparatus. Use regular antenna on A.W.R., making a ground connection to both A.W.R. and S.G. Connect a three-foot length of wire to the S.G. antenna post if a stronger signal is needed. The other end is free. Do not use modulation on S.G.

3. Tune the S.G. to the low frequency end (condenser plates meshed) of band being calibrated, either band No. 1, 2 or 3.

4. Tune the A.W.R. to a local or nearby station broadcasting on a frequency which will be a harmonic of at least four frequencies within the S.G. range being calibrated.

5. Increase the S.G. frequency until a beat note is heard; tune the S.G. for zero beat (between the whistles).

6. Refer to your rough S.G. calibration graph to determine the approximate S.G. frequency setting; divide the broadcast station frequency by some whole number which gives a quotient closest to this approximate frequency. This quotient is then the exact frequency of the S.G. at that setting. Record the point on a calibration graph (chart).

7. Increase the S.G. frequency until another beat note is heard. Determine this frequency by the same method used above,* log the point and repeat for all other S.G. frequencies in that range which produce harmonics at the broadcast station frequency.

8. Change the S.G. range, and select another broadcast station whose frequency, when divided by whole numbers, gives at least four fundamental frequencies in the range being calibrated. Log the points on a new graph.

9. For ranges #3 and #4, tune to stations whose frequencies you know, beating the fundamental of the S.G. against each until four or five points are secured in each range.

Example: Calibrating range #2—200 to 400 kc.
Location—Washington, D. C.
Local Stations: WJSV—1460 kc.; WOL—1310 kc.; WRC—950 kc.; WMAL—630 kc.

* Or divide by a number one less than the harmonic number used in the previous calculation.

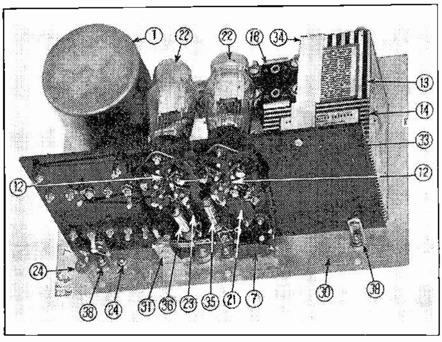


FIG. 7. *Photograph of bottom of subpanel.*

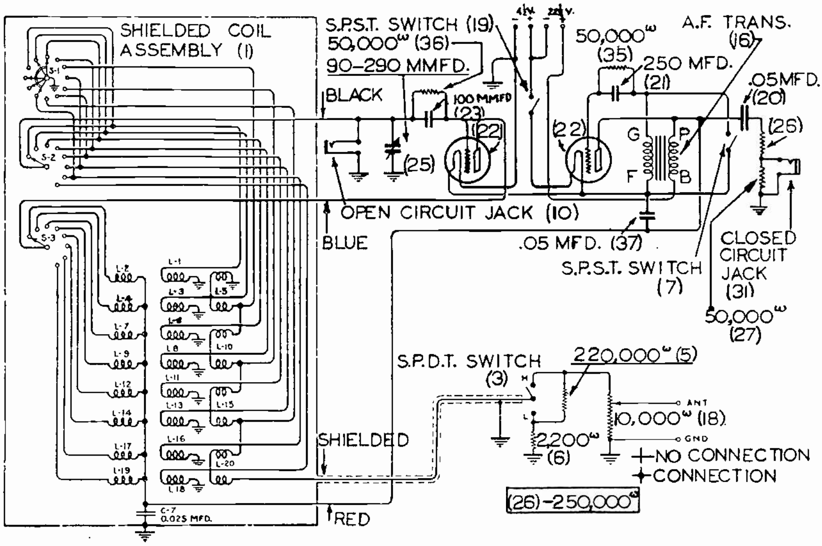


FIG. 5. *Circuit diagram for signal generator. Note colors of RCA coil assembly leads.*

Finish the cabinet exactly the same as the multimeter cabinet, sanding, applying two coats of black enamel, and allowing to dry.

When the enamel is dry, cut out the copper screening to the dimensions given in Fig. *3*. Bend the screen, place in the box, and fasten with the carpet tacks listed as item #44. Solder the screen together in spots about ¾ inch apart along the corners, using rosin core solder (not acid), and a *hot* iron. This insures a completely shielded signal generator.

Calibration of Signal Generator

After completing the assembly of your signal generator (S.G.), calibration is the next step. Unless properly calibrated, the S.G. will be of little value in service work.

There are many ways of calibrating an S.G. if you have laboratory equipment on hand. The methods I shall describe require a minimum of auxiliary equipment.

You may, if you wish, use the calibrations on an all-wave receiver (A.W.R.) as your only guide, this being our first method. In this case the station selector indicator is calibrated in kilocycles. If a superheterodyne receiver is used, choose a set having one stage of preselection. Don't use a skip-band type receiver; it is generally unsatisfactory for calibrating purposes.

The A.W.R. Method. To calibrate ranges 4, 5, 6. 7, 8 and part of 3 by this method, connect the S.G., operating with modulation, to the input of the receiver. To do this, disconnect the A.W.R. antenna, then connect together the Ant. and Gnd. terminals of the A.W.R. and S.G. Set the S.G. dial to at least five evenly distributed points in the above S.G. ranges and tune the A.W.R. in each case until the modulated S.G. note is heard loudest in the receiver. Do not overload the receiver. Record the frequency indicated by the A.W.R. for each S.G. setting.

If your receiver is of the American all-wave type, the lowest frequency on the tuning dial being 540 kc., you will not be able to calibrate the low frequency ranges of the S.G. by this simple direct method. You can, however, make use of harmonics of the S.G. to calibrate the remaining ranges (#1, #2 and #3 up to 540 kc.).

For range #1, set the A.W.R. at 1.000 kc. Set the S.G., operating with modulation as before, to zero dial position (lowest frequency. with condenser plates totally meshed). Now rotate the S.G. dial slowly towards the 100 point, until you hear the first modulated signal in the A.W.R. Tune the S.G. carefully to secure maximum volume of tone. You are now picking up with the A.W.R. a harmonic of the S.G. output. You know this harmonic is at 1,000 kc. (from the A.W.R. dial), and know that the fundamental S.G. signal is about 100 kc., this being about the lowest frequency which the S.G. can produce.

It is important that we determine what harmonic is being heard, for then we can easily determine the fundamental frequency. We know that 1,000 kc. can be a 11th, 10th or 9th harmonic of a basic S.G. frequency. To determine which it is, tune the A.W.R. over the entire dial and record the frequency difference between the modulated S.G. signals heard. The average frequency difference between harmonics will be approximately the fundamental S.G. frequency. Divide 1,000 kc. by 12, 11, 10, 9, etc., until you come closest to this average value. The quotient will be the *fundamental* S.G. frequency, and the number will indicate the harmonic.

Now turn the A.W.R. again to 1,000 kc. and increase the S.G. frequency slowly until another modulated signal is heard. The S.G. frequency will then be 1,000 kc. divided by a number one less than the harmonic in the previous setting. For example, if the first note you heard was a tenth harmonic (indicating an S.G. setting of 100 kc.) the new S.G. setting will be 1,000 ÷ 9 or 111 kc. Repeat for three more points on range #1, dividing 1,000 in each case by a number one less than the previous number.

For band #2 follow exactly the same procedure, but set the A.W.R. each time at 1,400 kc. instead of 1,000 kc. Whenever you are in doubt as to the number of the harmonic being heard, determine the average frequency difference between modulated signals heard as the A.W.R. is tuned across the band, and check this value against your computed fundamental frequency.

You now have enough data to plot a calibration curve for each range of the S.G. Secure at least eight sheets of ordinary graph paper. Lay off the S.G. dial divisions along the bottom of each sheet, and the frequency range along the left side, as in the sample chart in Fig. *9*. Choose a value in kilocycles for each large square vertically which makes the smallest units represent a convenient even number of kc. Plot the data you have on the eight charts, then draw a smooth curve through as many of the points as possible on each chart. Now you can determine the S.G. frequency for any setting of its dial simply by referring to the calibration chart for the range used.

Somewhat greater accuracy can be obtained when using the above calibrating method if the volume controls on both the A.W.R. and the S.G. are

Holes	Diameter	For Item:
c	Use #32 drill	Bolts for mounting dial (#28).
d	3/8"	#10—Open circuit jack.
e	7/16"	#19—OFF-ON toggle switch.
f	7/16"	#3—High-low R.F. output toggle switch.
g	7/16"	#7—Modulation OFF-ON toggle switch.
h	7/16"	#31—A.F. output closed circuit jack.
i	5/16"	#25—Variable condenser shaft.
j	1/4"	#24—Antenna binding post.
k	Use #18 drill	#24—Ground binding post.
l	3/8"	#1—Coil assembly switch.
m	1/2"	#18—Volume control potentiometer.*
n	Use #18 drill	#46—Bolts for subpanel bracket (#38).
o	Use #18 drill	#46—Bolt for battery clamp (#34).
p	Use #18 drill	#46—Grounding lug (Not absolutely necessary).
q	Use #18 drill	#46—Condenser mounting brackets (#39).

DRILLING DATA—BAKELITE SUBPANEL

Holes	Diameter	For Item:
a	Use #18 drill	#46—Subpanel bracket bolts.
b	3/16"	Wire to antenna post.
c	Use #18 drill	#46—Resistor mounting bolts.
d	Use #18 drill	#46—Socket mounting bolts.
e	Use #18 drill	#46—Grid condenser mounting bolts.
f	1-1/4"	#12—Wafer type tube sockets.
g	Use #18 drill	#46—Bolt for battery hold-down bracket (#38).
h	Use #18 drill	#46—Bolts holding "A" battery lead lugs.
i	1/4"	Wiring passing through subpanel.
j	Use #18 drill	#46—Bolt for battery clamp (#34).

Mounting the Parts. There is nothing particularly difficult about the assembly of this unit. The photographs shown in Figs. *1*, *6* and *7* should be studied and all items placed as shown. Follow the shortest routes when wiring the circuit, but keep the wiring as simple and neat as possible. Use only rosin core solder. All connections are given in the circuit diagram in Fig. *5*.

* When mounting this item be sure to use a fibre grommet to insulate the shaft from the panel.

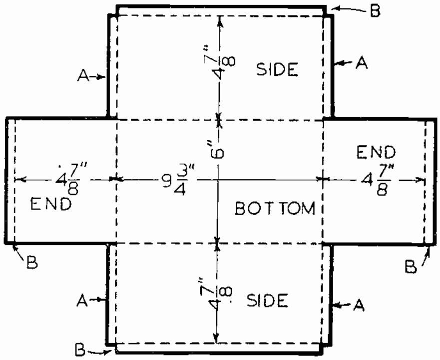


FIG. 3. *Layout of copper shielding screen. Cut on heavy lines. Flaps A and B are ⅜" wide. Bend flaps A up on dotted lines; bend sides and ends up, then place in cabinet and bend flaps B down over the top edges of the S.G. cabinet.*

To secure a maximum tuning condenser capacity of 290 mmfd., break off one rotor plate from your 350 mmfd. condenser by bending it carefully back and forth, finally pulling it out with pliers.

The tuning condenser is supported on the panel by the two large angle brackets, item #39; all other parts are mounted directly on the panel or subpanel. Resistors and condensers are supported by soldering lugs bolted to the subpanel.

A vernier dial is necessary to give accuracy with this signal generator. Adjust the dial to give a zero reading when the plates are completely meshed together, note the position of the set screw on the condenser shaft, and file the shaft flat at that point. Always turn the dial slowly when approaching the 0 and 100 marks, for there are stops on the condenser and the jar of banging against these might shift the position of the dial on the shaft.

Making the Cabinet. Assemble the cabinet for your signal generator with 4-penny finishing nails. The parts list gives the dimensions of the pieces required.

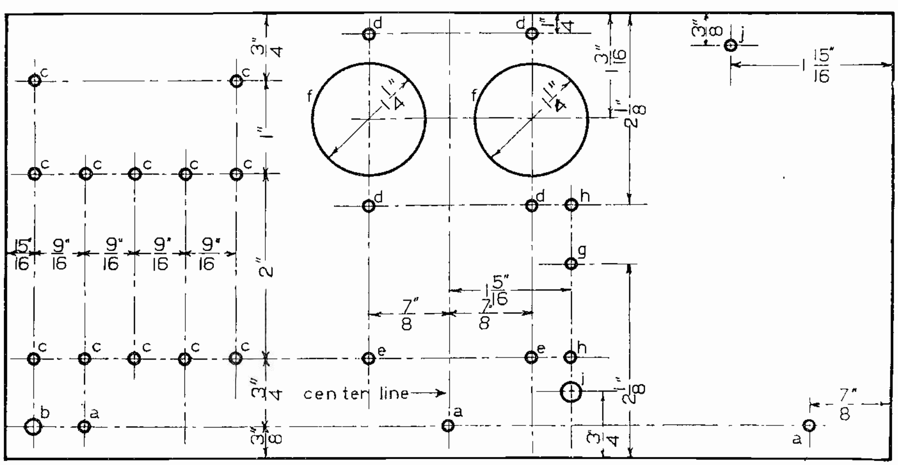


FIG. 4. *Layout for 9⅝" x 4⅞" subpanel (bottom view). See tables for hole diameters.*

Set A.W.R. to 1460 kc. station, which gives four points in range #2, at 365, 292, 243 and 208 kc. Other local stations give only two or three points.

We have now completed the calibration of the S.G. below 1,500 kc., by using as standards broadcast stations whose frequencies are known. To calibrate points above this frequency, you will have to construct a small unmodulated oscillator, tuning from 500 to 1,000 kc. You will need the following parts:

SW—OFF-ON switch, toggle or knife type.
C1—Variable condenser, 350 mmfd.
C2—Fixed condenser, .00025 mfd.
C3—Fixed condenser, .001 mfd.
R1—50,000 ohm, 2 watt resistor.
L1—120 turns #28 D.C.C. wire wound on a 1.5 inch diameter form; 70 turns for section a and 50 turns for section b.
One—45-volt "B" battery.
One—1.5-volt "A" battery; use a #6 dry cell.
One—4-prong tube socket.
One—Type 30 tube.

The complete oscillator unit should be mounted on a ½" board about 6" wide and 8" long, connecting the parts as indicated in the wiring diagram in Fig. 8. This unit is connected to the ground post on the receiver by a 3-foot long wire.

If you use the parts specified above, the test oscillator will produce frequencies between 500 and 1,500 kc. With the rotor plates almost completely meshed with the stator plates, 500 kc. will be obtained; with plates half in 1,000 kc. is produced, and with plates nearly all out 1,500 kc. is obtained.

We will use this test oscillator to produce precise 500 and 1,000 kc. signals, to be used in calibrating all the S.G. bands above 1,500 kc. by means of harmonics. First we will use the harmonics of a precise 500 kc. signal. Connect the S.G. to the input of the A.W.R., which is tuned to 1,000 kc. The test oscillator will transfer its signals to the A.W.R. through the 3-foot ground lead. Set the S.G. to band #3 (already calibrated) and for 500 kc. exactly. Tune the test oscillator to about 500 kc., plates nearly entirely meshed, and adjust this test oscillator carefully to as near zero beat as you can. Under no condition touch this adjustment while you are relying on the accuracy of its 500 kc. adjustment. Harmonics of this test frequency will be picked up on the A.W.R. These harmonic frequencies are: 1st—500 kc.; 2nd—1,000 kc.; 3rd—1,500 kc.; etc.

Knowing that the new oscillator is set at 500 kc. you can then change the selector switch on the

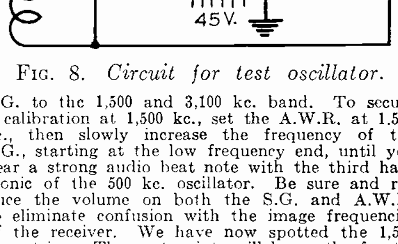


Fig. 8. *Circuit for test oscillator.*

S.G. to the 1,500 and 3,100 kc. band. To secure a calibration at 1,500 kc., set the A.W.R. at 1.500 kc., then slowly increase the frequency of the S.G., starting at the low frequency end, until you hear a strong audio beat note with the third harmonic of the 500 kc. oscillator. Be sure and reduce the volume on both the S.G. and A.W.R. to eliminate confusion with the image frequencies of the receiver. We have now spotted the 1,500 kc. setting. The next points will be on the fourth, fifth and sixth harmonics of the 500 kc. oscillator. It is advisable that you check each new point against the rough calibrations made with modulation, as the image frequency response is rather serious here if an I.F. frequency of 465 kc. is used in the superheterodyne receiver.

The range between 3,100 and 25,000 kc. should be calibrated by using a 1.000 kc. test oscillator frequency. Tune the receiver to 1.000 kc., with reduced sensitivity. Set the unmodulated S.G. at 1,000 kc., then tune the unmodulated test oscillator until you secure zero beat note; the oscillator will now be set at 1,000 kc.; check by tuning the A.W.R. to 2,000 and 3,000 kc., and listening for similar beats.

Knowing that the 1,000 kc. oscillator is functioning properly on exactly 1,000 kc., we may work with its harmonics in locating all frequency settings above 3,000 kc.

Errors in calibration are easily detected, for

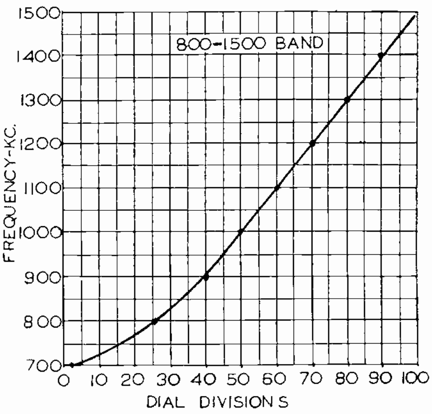


Fig. 9. *Sample S.G. calibration chart.*

they will show as irregularities in the curves plotted on the graph paper. The entire beat method of calibration is reviewed in the following table:

Range — *Method*

#1—90-200 kc.—Beat harmonics of S.G. against station of known frequency near middle of broadcast band (1,000 kc.).

#2—200-400 kc.—Beat harmonics of S.G. against station at high frequency end of broadcast band (1,500 kc.).

#3—400-800 kc.—For 400 to 550 kc., beat 2nd harmonics of S.G. against stations between 800 and 1,100 kc. For 550 to 800 kc., beat fundamentals against broadcast stations.

#4—800-1,500 kc.—Beat fundamentals of S.G. against broadcast stations.

#5—1,500-3,100 kc.—Beat fundamentals against 3rd, 4th, 5th and 6th harmonics of an accurate 500 kc. oscillator.

#6—3,100-6,800 kc.—Beat fundamentals of S.G. against harmonics of accurate 1,000 kc. oscillator.

#7—6,800-14,000 kc.—Beat fundamentals of S.G. against harmonics of 1,000 kc. oscillator.

#8—14,000-25,000 kc.—Beat fundamentals of S.G. against harmonics of 1,000 kc. oscillator.

Purpose of Each Control. Each of the controls or outlets mounted on the front of the S.G. panel has a definite purpose. The selector switch (which is part of the coil assembly) determines the frequency range of the S.G., while the vernier tuning dial (#28) permits tuning to the particular frequency desired in any one range. The OFF-ON toggle switch (#19) is in the battery circuit, and controls the entire S.G.

The sweep condenser jack (#10) located above the OFF-ON switch, is used for sweeping (varying) the radio frequency delivered by the S.G. over the frequency band desired. This jack is provided for cathode ray oscillograph work.

The modulator toggle switch (#7) starts and stops the audio frequency modulation of the S.G. The A.F. output can be used for checking the audio frequency characteristics of radio receivers, by plugging into the closed circuit jack (#31) just above the modulation switch.

The high-low toggle switch (#3) and the potentiometer just below it control the output voltage of the S.G. The potentiometer gives a fine control of this R.F. voltage over each range.

Radio Servicing Jobs and how to do them

NATIONAL RADIO INSTITUTE ▪ WASHINGTON, D. C. ▪ PRACTICAL JOB SHEET

How to Assemble a Professional Looking Multimeter

ONE of the most useful of all radio servicing instruments is the multimeter, a compact meter unit which can measure many different ranges of A.C. and D.C. voltages, D.C. currents, A.F. output voltages and D.C. resistances. If you have to service radios for any period of time with only one test instrument, choose a multimeter.

Without a multimeter radio service work must be done by the hit and miss process, which wastes valuable time. Learn to measure and check the important characteristics of receivers with a reliable multimeter.

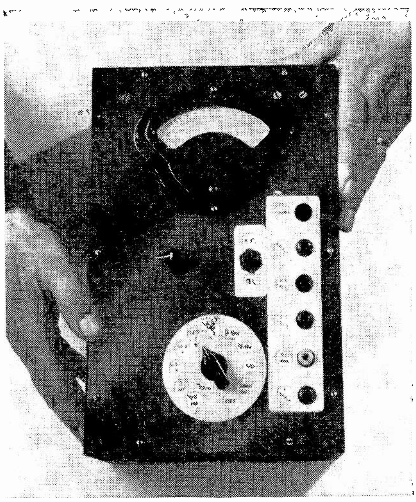


FIG. 1. *Your Completed Multimeter Will Appear Like This.*

Although this job sheet is intended to show how to assemble a reliable professional looking multimeter, frankly, I always recommend that radio service men buy one of the better professional multimeters, which are accurate, dependable, and impressive in appearance. If, however, the few dollars that you will naturally save by building your own unit appeals to you, or you wish to gain valuable experience in assembling test equipment, by all means purchase a multimeter kit. When you purchase all of the required parts in this manner, there will be none of the extra expense and trouble in securing special resistors, and all calculations will have been completed and checked by the manufacturer.

Although I have chosen the Supreme Model 310 Meter, Rectifier and Resistor Kit,* there are many other makes of multimeter kits which might be used. In order to follow through a typical layout it was necessary to select one particular kit.

Your finished Supreme Multimeter will look like Fig. *1*, and will have four ohmmeter ranges—0 to 2,000 ohms, 0 to 20,000 ohms, 0 to 200,000 ohms, and 0 to 2,000,000 ohms. Four ranges are provided for measuring A.C. and D.C. voltages: 0 to 5 volts, 0 to 125 volts, 0 to 500 volts, and 0 to 1,250 volts. D.C. currents may be measured in two ranges: 0 to 5 milliamperes, and 0 to 125 milliamperes.

In any multimeter kit you will find a multi-scale milliammeter, fixed and variable resistors, a fixed condenser and a full-wave copper oxide rectifier unit. Other parts needed, which usually must be purchased separately, include a panel, a box or cabinet for the entire unit, several switches, six or more jacks or binding posts, and several batteries. These parts must be selected and purchased by the individual constructing the service instrument, once he decides upon the style of cabinet to be used. Many men prefer to build test equipment like this right into their work-bench.

The following parts are supplied with the Supreme Model 310 Kit; check against this list when unpacking your kit.

Item #1, Stock #6627: One 5-inch Meter, 0.001-A. 0/5/125 ma. with "OHMS" scale, in fan-shaped case, with 4 meter flange bolts and 4 terminal nuts.

Item #2, Stock #6354: 1 Resistor, attached to meter, series adjustment, to combine with meter resistance, bringing total meter resistance up to 300 ohms.

Item #3, Stock #6650: 1 Rectifier, large full wave instrument, center terminal negative, two end terminals positive, other terminals A.C. input.

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* This kit may be obtained from radio parts supply houses or ordered directly from the Supreme Instruments Corporation, Greenwood, Mississippi.

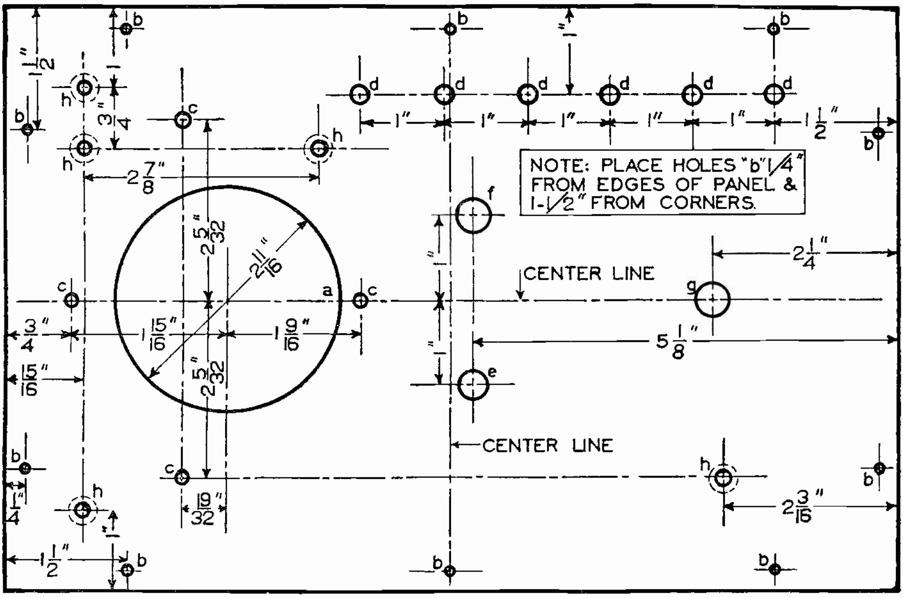

FIG. 2. *Layout of the Front Panel of the Multimeter.*

Item #4, Stock #6715: 1 Resistor, approximately 3,100 ohms, attached to rectifier, used as series adjustment multiplier for 5 volt (A.C.) range.

Item #5, Stock #6736: 1 tubular .5 to 1 mfd. condenser.

Item #6, Stock #822-A: 1 Drawing of Supreme model 310 Meter showing panel layout for panel mounting. (Not needed.)

Item #7, Stock #825-A: 1 Drawing Supreme Meter Kit circuit (Note: this diagram is not used when building this Multimeter).

Item #8, Stock #6333: 1 Potentiometer, 3,600 ohms, with washer and hex nut, but without knob.

Item #9, Stock #6673: 1 Resistor, tapped, containing a 3 ohm and a 72 ohm section, enameled, 5 watt.

Item #10, Stock #6674: 1 Resistor, tapped at 33 ohms, 297 ohms, 700 ohms, 2,698 ohms, and 3,248 ohms. Enameled, 5 watt rating.

Item #11, Stock #6336: 1 Resistor, 4,700 ohms, 1 watt, metallized, for 5 volt (D.C.) range.

Item #12, Stock #6242: 1 Resistor, 20,000 ohms, 1 watt, metallized, for use as rectifier input shunt.

Item #13, Stock #6037: 1 Resistor, 90,000 ohms, 1 watt, metallized, for 125 volt (A.C.) range.

Item #14, Stock #6676: 1 Resistor, 0.12 megohm, 1 watt, metallized, for 125 volt (D.C.) range.

Item #15, Stock #6713: 1 Resistor, 0.28 megohm, 1 watt, metallized, for 500 volt (A.C.) range.

Item #16, Stock #6677: 1 Resistor, 0.375 megohm, 1 watt, metallized, for 500 volt (D.C.) range.

Item #17, Stock #6714: 1 Resistor, 0.56 megohm, 1 watt, metallized, for 1,250 volt (A.C.) range.

Item #18, Stock #6334: 1 Resistor, 0.75 megohm, 1 watt, metallized, for 1,250 volt (D.C.) range.

You will notice that I have numbered each item. These item numbers will be referred to later while describing the assembly of the unit. All of these parts are identified by number on the photographs, to aid you in securing a simple and compact arrangement.

The following additional parts will be required to make the multimeter like that shown in Fig. *1:*

Item #19: 2 Small 22.5 volt "C" batteries, Burgess #4156.*

Item #20: 1 Standard 4.5 volt "C" battery, Burgess #2370.*

Item #21: 1 Double-pole double-throw toggle switch.

Item #22: 1 three-section 11-point rotary non-shorting switch. (The Yaxley #1331 † rotary switch or a switch having the same number of contacts is recommended.)

Item #23: 1—31,500 ohm, 2 watt resistor. (A 30,000 ohm resistor in series with a 1,500 ohm resistor may be used if you are unable to obtain one resistor of the proper value.)

Item #24: 1—50 ohm, 2 watt resistor. (Use two 100 ohm, 1 watt resistors connected in parallel.)

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* Batteries of another make which have the same voltage may be used.

† Yaxley Mfg. Co., 1103 West Monroe Street, Chicago, Illinois.

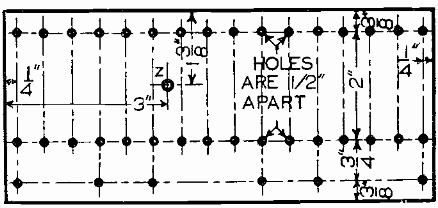

FIG. 3. *Layout for Item #34, a 3½" x 8" bakelite resistor mounting strip.*

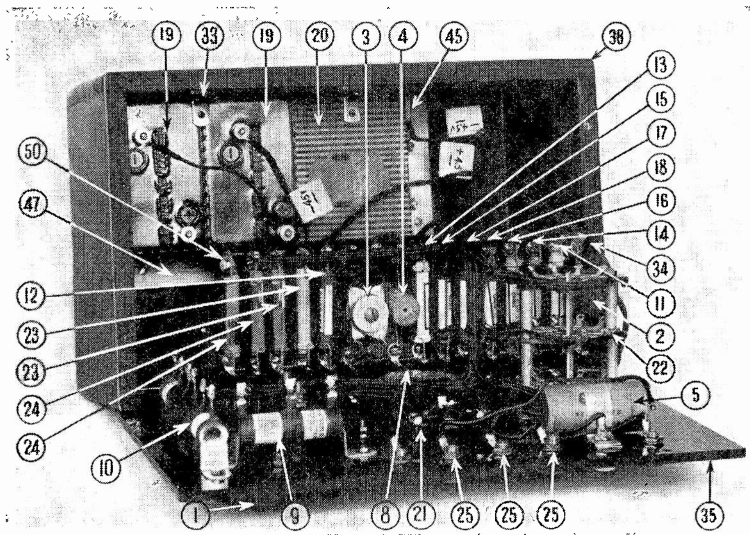

FIG. 6. *Cable-type Wiring Gives a Professional Touch to the Sub-panel Assembly.*

finished with two coats of black enamel. Allow the first coat of enamel to dry thoroughly, sand it down lightly with fine sandpaper, then apply the second coat.

Place the two 22½ volt batteries (item #19) upright in one corner of the cabinet, with item #20 lying flat alongside as shown in Fig. *6*, and fasten the three batteries rigidly in place with the pieces of white pine listed as items #45, #46 and #47, and two of the right angle brackets, #33. Place the four rubber feet (item #37) about ½″ in from the corners on the bottom to complete the cabinet.

Assembly

The panels and cabinet being completed, you are ready to begin the wiring. The photograph in Fig. *6* gives the position of each part and shows how the batteries are placed in the box. Arranging the parts exactly as shown makes the wiring as simple as possible. A very neat appearance is secured by running the wires in cable-like fashion, tying them together when the job is finished, but the unit will work just as well if wires are run directly to the different parts.

Follow the circuit diagram in Fig. *8* closely while making connections. Do not connect the battery wires yet. Note that the resistors are mounted on the subpanel and held in position by the lugs. When soldering to the connecting wires of the rectifier unit, use as little heat as possible, to prevent damage to the sensitive discs.

Testing Your Multimeter

Like all pieces of delicate apparatus, this multimeter must be tested before being used for radio work. To test the ohmmeter section, plug your test prods into the *common plus* and the *ohm* pup jacks. Set the rotary or selector switch, item #22, on the 2,000 ohm tap and place a 2,000 ohm, 2 watt resistor between the free ends of the test prod cords. Now attach the leads going to #20, the 4.5 volt battery.

Place the toggle switch in the D.C. operating position, and rotate the zero adjusting rheostat, item #8, until the meter reads 2,000 ohms on the top scale. The pointer should return to zero when the two test prods are touched together. A slight adjustment of the zero rheostat may be necessary to make the meter read exactly 0 ohms.

The other three resistance scales are checked by testing the highest scale. In this case connect a 100,000 ohm, 2 watt resistor between the free ends of the test prods, turn the rotary switch to the position "X 1,000." and attach the battery leads to the two 22.5 volt batteries connected in series. The

OHMS

OUT-PUT

A.C. VOLTS

D.C. VOLTS

D.C. MA.

COMMON +

A.C.

D.C.

OFF

2000 OHMS

X 10 OHMS

X 100 OHMS

X 1000 OHMS

5 VOLTS

125 VOLTS

500 VOLTS

1250 VOLTS

5 MA.

12 MA.

FIG. 7. *Cut Out These Titles and Paste Them on White Paper for the Front Panel.*

on the panel, place the panel on a smooth, hard surface and center punch each intersection to insure that the twist drill will start at the proper spot.

When drilling through bakelite I usually clamp the panel to a flat ¾" board which is in turn clamped to the work-bench. The twist drill may now be used in a vertical position. Drill all holes first with a #30 drill, ⅛" in diameter. Drilling a small hole first prevents the drill from creeping out of the center punch mark or breaking away the bakelite at the back of the panel.

With the panel still clamped to the board, drill the holes again to the sizes indicated below:

Holes	*Diameter*	*For Item*
a	2-11/16"	#1—Meter
b	Use #18 Drill	#32—Panel holddown screws.
c	Use #18 Drill	Meter mounting screws
d	1/4"	#25—Pup jacks.
e	3/8"	#8—Zero-adjust. potentiometer.
f	7/16"	#21—D.P.D.T. switch
g	7/16"	#22—Rotary switch.
h	Use #18 Drill	Resistor and subpanel brackets.

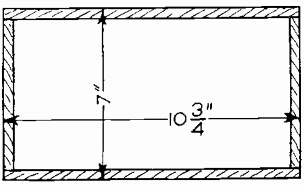

FIG. 5. *Multimeter Cabinet Construction.*

The large meter hole may be made with a fly cutter or by drilling a series of ⅛" diameter holes close together along the circumference. Since the meter flanges cover any irregularities which might show from the front, this latter method is perfectly satisfactory.

Having drilled all holes. clear away the burred edges with the small blade of a knife.

Holes *h* are counter-bored to take the heads of the nickel plated 6/32 brass machine screws, shown as item #40. A large twist drill may be used as a counter-bore.

The panel is now ready to be sanded down, to remove the scribe marks. With a short back and forth stroke go over the entire panel with #00 sandpaper, working only in the lengthwise direction. Wipe off the bakelite dust and apply a little oil with a cloth. This will give the dull black finish so popular on commercial equipment.

Laying Out the Subpanel

Item #34, the bakelite subpanel, is next laid out in the manner shown in Fig. *3*. Make hole *z* 3/16" in diameter (this is used for mounting item #3). All other holes are drilled with a #18 drill.

Laying Out the Escutcheons

The escutcheons shown in Fig. *4* are cut out with tin snips from 1/32" aluminum (item #36). Cut a little outside of the lines and finish with a file. Scratch or scribe intersecting lines as before to mark the center of each hole, then punch each with the aluminum placed on a flat piece of iron. Drill all holes first with a ⅛" diameter drill, using turpentine as a lubricant.

The holes may now be enlarged with a ½" tapered reamer, by placing the unfinished escutcheon in your bench vise, reinforcing the aluminum with a piece of strap iron having a ½" diameter hole centered with the hole you are working on. Apply turpentine liberally to the reamer while turning it slowly through the aluminum. Trim away the burred edges with a knife blade dipped in turpentine.

Sand one side of each escutcheon with #00 sandpaper to remove scratches. Next cut out a piece of stiff white paper and one piece of clear celluloid or heavy cellophane to sizes a little smaller than each of the escutcheons. Cut holes for the pup jacks and shafts of the switches.

Now trace on each paper the positions of the "windows" in the aluminum plates. Cut out the bits of lettering set up in Fig. *7*, and paste these on your sheets of paper in the positions indicated in Fig. *4*. In this way you secure perfect professional lettering for your panel. The celluloid will protect the lettering from dust and dirt. The panel parts will hold the paper, celluloid, and aluminum plates in position.

Making the Box or Cabinet

The cabinet is built from ½" clear white pine boards cut to give the outside dimensions specified in Fig. *5*, assembled with finishing nails, and

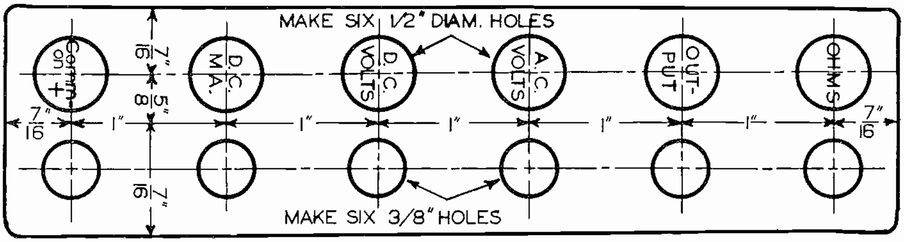

FIG. 4A

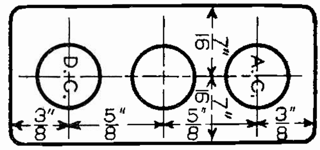

FIG.4B

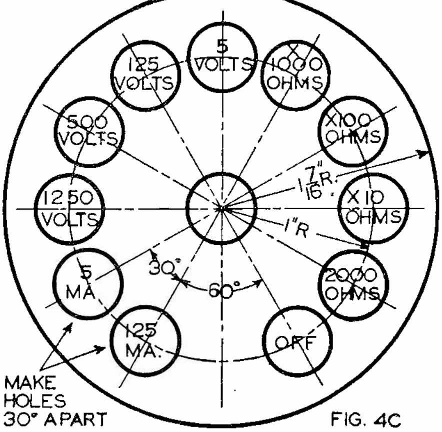

FIG. 4C

Fig. 4a. *Layout for pup jack escutcheon plates.*

Fig. 4b. *Layout for rotary switch escutcheon plate.*

Fig. 4c. *Layout for toggle switch escutcheon plate.*

Item #25: 6 Pup Jacks, #136 made by A.R.H. Co., Inc.‡
Item #26: 2 Test tip prods, #132.‡
Item #27: 2 Test clips, #130.‡
Item #28: 2 End tip prods, #134.‡
Item #29: 2 End tip prods, #135.‡
Item #30: 75 ft. #22 cotton insulated push back wire, tinned.
Item #31: 2 five-foot lengths of special test prod flexible stranded #18 cable or wire, 1 red and 1 black.
Item #32: 10—#6 round head, polished nickel wood screws ⅝" long.
Item #33: 4 Small ½" wide right angle brackets made from 1/16" stock.
Item #34: 1 Piece bakelite 8" x 3½" x 1/16" thick, black.
Item #35: 1 Panel, bakelite, 10-13/16" x 7-1/16" x 3/16" thick, black.
Item #36: 1 Sheet flat aluminum 6" x 6" x 1/32" thick.
Item #37: 4 Small rubber feet. (Can be obtained from your local hardware store.)
Item #38: 1 Cabinet or box 10-¾" x 7" x 5½" (See drawings for exact details).
Item #39: 2 Arrow head knobs for ¼" shafts.
Item #40: 6—⅜"-6/32 (nickeled) flat head brass machine screws.
Item #41: 4—¼"-6/32 round head brass machine screws.
Item #42: 50—#6 lock washers for above machine screws.
Item #43: 50—6/32 nuts for 6/32 machine screws.
Item #44: 4—⅝"-6/32 round head brass (nickeled) machine screws.
Item #45: 1 Piece white pine, 4" x ¾" x ½".
Item #46: 1 Piece white pine, 3" x ¾" x ½".
Item #47: 1 Piece white pine 3¾" x ¾" x ½".
Item #48: 6—#6 wood screws ¾" long, round nickel head.
Item #49: 2—#8 wood screws, 7/16" long, round nickel head.
Item #50: 4 Dozen tinned #6 or #8 soldering lugs.
Item #51: 3 Dozen 4 penny finishing nails.

‡ Jacks and tips similar to the ones made by the American Radio Hardware Company, Inc., 135 Grand St., New York City, may be used.

Plan the Layout Before You Build

I usually find it best to lay out all of the parts for the unit in front of me. By doing this I can locate each piece almost instantly as it is needed, and can better judge the space required.

Lay out in front of you every piece of equipment in the multimeter kit, either on your work-bench or on a small table placed nearby. The panels, pup jacks, screws and lugs, etc., should also be on hand.

Laying Out the Panel

Order your panels cut to exactly the correct size, so that you will only have to smooth down the edges with a file. Attempting to cut large pieces of bakelite with a hacksaw wastes time and results in a crude job.

Locate item #35, the front panel, and lay out carefully each of the holes indicated in Fig. 2. A 6-inch steel square or a steel ruler is used for measurements, and the marks made with a steel scriber or a large sewing needle.

The ten holes marked *b* have centers ¼" in from the edges of the panel. Holes *d*, for the pup jacks, are marked next. Locate the center of the meter hole *a*, of the four meter hold-down screw holes *c*, and of the other holes.

After marking the center of each hole by scratching or scribing intersecting lines

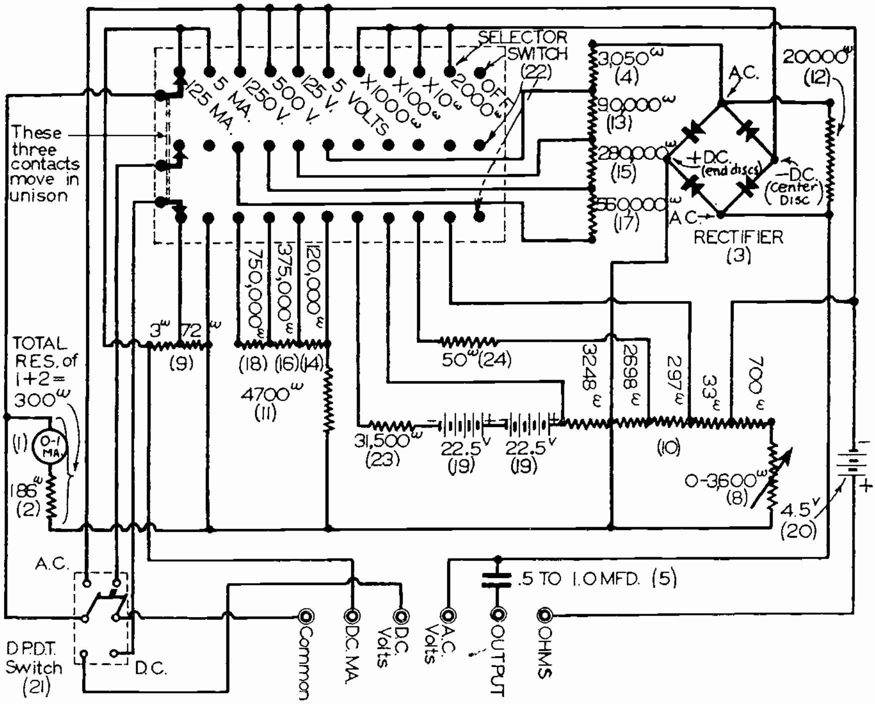

FIG. 8. *Follow this Circuit Diagram Closely when Wiring Your Multimeter.*

pointer should indicate approximately 100,000 ohms. Remove the 100,000 ohm test resistor and short the free test prods, to see if the meter returns to zero again.

Next test the 5 volt D.C. tap. Set the rotary switch at 5 volts and place the test leads in the pup jacks marked *common plus* and *D.C. volts.* The A.C.-D.C. switch is, of course, in the *D.C.* position. Connect the free ends of the test prods across the terminals of a new 1.5 volt dry cell battery. The meter should indicate a little more than 1.5 volts, if this section of your multimeter is connected properly.

The 125 volt D.C. range may be checked by using first a 45 volt B or C battery. If this range is found correct, then test with whatever higher voltages are available. The 500 volt and 1.250 volt ranges should be checked in the same manner with a 45 volt battery before higher voltages are tried. This procedure will prevent overloading of the meter if a mistake in connecting some part has been made.

With the rotary switch setting in the 5 ma. position and the A.C.-D.C. switch still in the *D.C.* position, use the following procedure to check the current-measuring section of the multimeter. A separate 4.5 volt battery, a 1,000 ohm. 2 watt resistor and a 4,500 ohm, 2 watt resistor will be necessary. Connect one of the resistors, in series with the battery, to the free ends of the test prods, and plug the other ends of the test prods into the pup jacks labeled *common plus* and *D.C. MA.* With a 1,000 ohm resistor in this test circuit the meter should indicate a current of approximately 4.5 ma. When the 4,500 ohm resistor is used in the same test circuit, a current of approximately 1 ma. should be indicated by the meter.

The last D.C. test will be the 125 ma. D.C. range. In this case we will use the 4.5 volt battery and a 200 ohm resistor. If everything is in proper working order approximately 22.5 ma. will be indicated by the meter.

Having checked the D.C. scales or ranges of the multimeter we may proceed to check the A.C. sections. Throw the A.C.-D.C. switch to the *A.C.* side and plug the test prods into the pup jacks marked *common plus* and *A.C.* volts. To test the 5 volt A.C. range, place the test prongs across a 2.5 volt filament transformer winding. If the pointer is at or near the mid-scale point, change the selector switch to the *125 volt point.* The pointer of the meter should in this case move almost down to zero. Now apply the free ends of the test prods to a 110 volt A.C. source. The meter should indicate a voltage of between 105 and 120 volts, depending upon the exact line voltage in your community.

The next range can be tested on the same supply voltage. Change the selector switch to 500 volts, the toggle switch still being on the A.C. side. If the 110 volt line reading is correct now to within 5%, place the free ends of the test prods across half the secondary winding of a power transformer supplying a type 80 rectifier tube. The same test voltage can be obtained with one test prod resting on the chassis and the other on one plate of the 80 rectifier tube. A reading of between 200 and 450 volts should be obtained.

The last test on the wiring of your ohmmeter will be on the 1,250 volt A.C. range. Place the selector switch at this setting, then check this range against the 500 volt range by using half the transformer voltage as before. If the readings check within about 5%, turn off the A.C. power and wedge the test prods against the plate terminals of the 80 rectifier tube. When good contacts are secured, stand clear and turn on the power. The reading of the meter should have doubled. Turn off the power before removing the prongs, for *the voltage of any power pack can give a serious shock.*

With this multimeter you can check in a few moments the resistance of any resistor or device, up to the 2 megohm limit of the unit. Voltages and currents can be checked just as easily once you are familiar with the use of this multimeter and can interpret the meter scale readings.

Radio Servicing Jobs and how to do them

NATIONAL RADIO INSTITUTE ■ WASHINGTON, D. C. ■ PRACTICAL JOB SHEET

A Simple Method of Locating the Dead Stage

If you watch an expert radio serviceman repairing a dead receiver, you will see that he pulls a tube out of a socket, pushes it back in place; does the same for one or more other tubes; finally to say: "The defect is in the first detector, or oscillator, or last I.F. stage." His actions make you think of these so-called "sees all, knows all, tells all" persons. It may seem like a "sleight of hand" trick, but this serviceman is working on sound radio principles.

stage is spotted. The test is not a positive check but it comes pretty near telling the truth. Furthermore, you can generally conduct this test with the chassis in the cabinet. Let me discuss the test for a couple of possible receivers.

The Circuit Disturbance Test of T.R.F. Receivers.—In Fig. *1* I have drawn a block diagram of the signal circuits in a typical T.R.F. set. The radio signal feeds into the first R.F. stage and then passes through successive stages to the loudspeaker. If

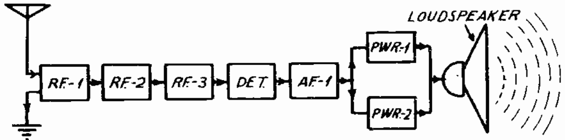

FIG. 1. *Block diagram of signal circuits of a T.R.F. receiver.*

By being more attentive, you will observe that he is listening to the clicks that emanate from the loudspeaker. When a tube is pulled out of and replaced in a socket and a click is not produced, that stage is *considered* dead.

The principle involved is simple. When a tube is pulled out of the socket, the

only one stage is dead the chain is broken and signals cannot get through to be changed to sound waves.

I am going to assume that a defect may exist in any stage. The correct way of tackling this sort of a job is to find the stage in which the breakdown exists, instead of testing every part in every stage

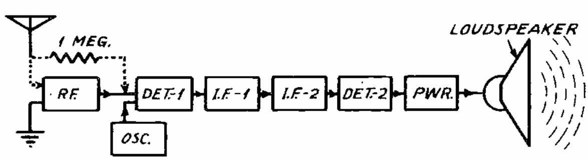

FIG. 2. *Block diagram of signal circuits of a superheterodyne receiver. If pulling out Det-1 produces a click and connecting the antenna to Det-1 does not result in signals, the OSC is probably defective.*

supply current in that circuit stops flowing. This sudden change in current or circuit disturbance is relayed to the following tubes, on to the loudspeaker, which emits a click. That is why I call this testing procedure the "circuit disturbance test." Now by knowing the tube arrangement in the receiver, that is, which is the detector, oscillator, I.F., A.F. or R.F., amplifiers, the location of the defective

of the set, as many self-styled experts will do in solving this difficulty.

Suppose we start at the end instead of the beginning, and pull out and replace one of the power tubes. A click shows that the tube is getting plate current (hence, must have plate and filament voltage); proves that the loudspeaker is working as it reproduces signals passed to it from the output stage. The same test made with the other power tube. If we get no click any of the things we have assumed above may be at fault. For example, the loudspeaker voice coil may be open, the tubes dead, there may be no voltage from the power supply, the output transformer may be open, etc. If the

A commercial multimeter.

tubes are warm to the touch they have plate voltage and current, although only an exact check can be made with meters.

Now if everything so far is tested to be O.K., we should repeat our test for the first A.F. stage. No click indicates trouble in this stage or in the coupling between it and the power stage. A circuit disturbance test on the detector and R.F. stages should be made in turn, until a click is not heard, isolating of course, the defective stage. Then the parts in that stage are tested. Clearly, by using the circuit disturbance test no time is wasted in testing parts which can be proved to be good.

When screen grid tubes are used, the test is even easier to make. Simply touch the control grid with a finger or take off and replace the control grid cap. This will change the plate current just as effectively as pulling out the tube, and is a lot easier. In the tuned R.F. section even a stage using a tube with no control cap can be tested by touching the stator of the variable condenser connected to the tube. Touching the stator will have the same effect as touching the control grid.

A Widely Used T.R.F. Receiver Test.—If you wish, you can use the signal from a local broadcast station for an R.F. check by connecting the antenna lead-in to the grids of the R.F. and detector tubes in succession, starting at the detector and working towards the antenna. To prevent the antenna from detuning the circuits tested, insert a series 100,000 ohm resistor. Again when you go from a signal to a no signal point you have located the defective stage. Furthermore, the signal should get louder as you pass from the detector to the antenna connections.

Still using a local broadcast as our testing signal, a check on the audio system may be made by using a pair of headphones. Of course, the following test would only be made if, in the previous special R.F. test, no signal were heard, indicating that the defect is not in an R.F. stage. Tune the set to a point at which a signal is normally picked up. Place the phones across the plate loads of the tubes, working from the detector to the output stage. A signal to no signal point isolates the defective stage.

Employment of a local broadcast as the test signal is widely made by expert servicemen, so I suggest you learn it. It is more positive a test for a defective stage than the click test. Unfortunately its use in testing supers is quite limited and as these receivers are more common, the click test is more universally used.

The Circuit Disturbance Test for Supers.—In testing for a dead stage in any super such as the one indicated in Fig. 2, the click test is the same as on the T.R.F. receiver until you reach the oscillator. However, if we can get clicks by pulling out the first detector, but no signals can be tuned in even if the antenna is connected to the grid of the first detector, we may safely consider the trouble to be in the oscillator.

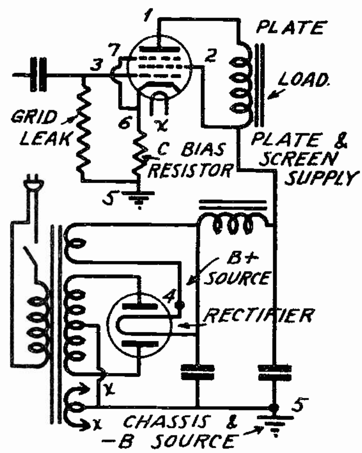

Fig. 3A. *A typical stage connected to the main supply. Continuity tests should be made between 1 and 4, 2 and 4, 3 and 5, 6 and 5, 7 and 5.*

When testing a super do not try to connect the antenna lead to the I.F. stages as no signals will be heard. The antenna lead can be hooked onto the first detector or any of the R.F. inputs. Headphones may be used between the loudspeaker and second detector.

If a super checks O.K. with the click test but no signals are heard, check the alignment, and especially the oscillator adjustments; subjects we will consider in a later job sheet.

A Little Experience Is Required.—The circuit disturbance method of checking for the dead stage is not fool-proof and a certain amount of experience will be required to get the best results. Therefore, whenever you get a set to work on, practice up on this click test.

Here is one of the reasons why a false indication may result. If the regulation of the power supply is poor, removal of a tube may cause a universal increase in plate voltages, and the disturbance may skip around the defective stage. Do not worry too much about this, as most sets have good regulation.

How To Test the Defective Stage with an Ohmmeter

Locating a dead stage is only the beginning of the service job, but a very substantial start, as you are getting nearer to the "sore" spot. A few more steps and you will be able to point to the defective part or connection.

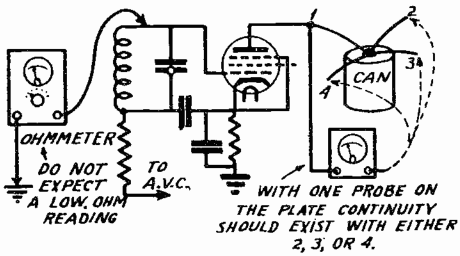

FIG. 3B. *Do not let these conditions baffle you.*

It is almost logical to assume, if you found no surface defects, that the trouble is internal and naturally you will have to get into the chassis if you want to make the repair. But, before I would remove the chassis from the cabinet, I would question the tube in that stage. Of course, you know that a tube may light and yet be defective. For example, its emission may be low (although in general this will show up as distortion or weak signals); the plate may be shorted to the screen, the screen shorted to the grid, or the grid shorted to the cathode. You do not have to worry about this if you test the tube in the dead stage in a tube checker—for shorts and whether it is *good* or *bad*. If you happen to have a good replacement tube try it in the socket. Now if the tube is good, you are sure the defect is internal, and the chassis may be taken to your service bench, if that is the place you prefer to work.

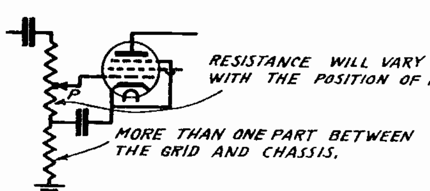

FIG. 3C

A circuit diagram of the receiver while not an absolute necessity is a mighty handy thing to have, especially for a beginner. Suppose you don't have a diagram, is there any way you can start to test the stage? Yes indeed, and here is where your fundamental studies will aid you.

From your lessons you should know that the screen or plate of any tube in use should show continuity (a D.C. path) back to the most positive point in the circuit, the +B source. What is this point? It is the electron emitter of the rectifier, its cathode or filament.

Is there anything else that our studies tell us must be true about a receiver? Yes, since we have a +B source we must also have a −B source. This, in practically every diagram you have seen, is the chassis of the receiver. Furthermore, an electrode at a zero or negative potential must show continuity to it. These electrodes are the cathode or filament, control grid and suppressor grid of all tubes except the rectifier.

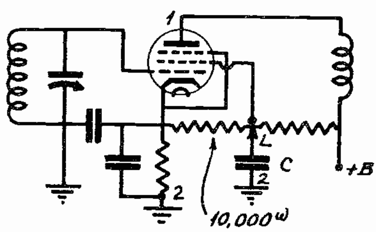

FIG. 3D. *If you suspect a leak or short in C, you must disconnect its connection at L, to test it. For if L is connected a test from 1 to 2 will show resistance regardless of the condition of C; and a test from L to 2 will show a resistance if C is leaky or good.*

Now that we have our general facts in mind let's get started.

Place the chassis and loudspeaker connected to it on the work bench and turn the chassis upside down or on its side, so the parts and the tube socket of the defective stage are easily identified and traced.

Locate the electron emitter prong (cathode or filament) of the rectifier and the plate prong of the defective stage tube. Place the ohmmeter probes on these two points.* A reading should be obtained. If the stage is not resistance coupled the reading should not be more than about 10,000 ohms, or less than 200 or 300 ohms. In a resistance coupled stage the reading may be as much as 500,000 ohms.

Suppose we do not obtain any reading—infinite resistance—we know that there is an open in the plate supply circuit. The filter system is all

* When using any ohmmeter or continuity tester the power cord of the set must be detached from the line. *THIS IS IMPORTANT.*

ut, otherwise we would not get a circuit distance test on stages following the defective ...e. Look at the wire connected to the plate ...ket terminal. By following this wire we will ...u led to the plate load of the tube. It may be a resistor, transformer or a choke. If it is a ...esistor, place the *ohmmeter* probes directly across it. If you get no reading you have found the defective part and a new one will be required. Experience tells us that plate circuit resistors have a resistance between 75,000 and 500,000 ohms, and a power rating of 1 watt. The proper value to use will be found by experiment; a value of 100,000 ohms is generally used.

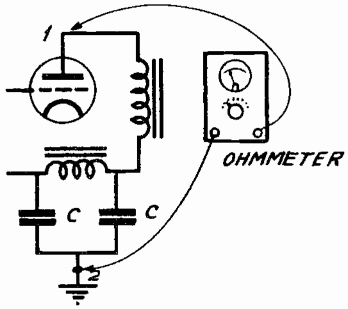

FIG. 3E. *If you test continuity in this case, and C happens to be an electrolytic condenser, the ohmmeter needle may creep up or down scale. Electrolytic condensers have polarity. Always connect the ohmmeter so the needle creeps up scale.*

If we obtained a reading on this resistor we follow the lead from its supply connection to the next object in the circuit and check it in the same way as described above. If it is a filter resistor it will have a value not greater than 100,000 ohms and a rating of 1 watt.

On the other hand, if the plate load was a transformer or coil, it is not possible to immediately spot the supply connection, because the part may be in a metal shield or "can." There will, however, be a number of other leads coming out of the can and we should be able to obtain continuity between one of them and the plate lead. Failure to do so indicates that the open is in the shielded part. Remove the shield as you may be able to resolder the break. Generally it won't hurt to take off a single turn of wire if necessary and by doing so you may save the price of a new part.

Screen circuits are treated in exactly the same way and in these circuits we will rarely find resistors which have a value of over 5,000 ohms. If a resistor is defective what watt rating should it have? A 1 watt rating is safe if the resistor merely connects from the +B supply to the screen. If it connects through another resistor to the chassis or cathode circuit a 5-watt resistor should be used.

If the plate and screen grid circuits test O.K., you should next check the continuity between the minus potential electrodes (control and suppressor grids) and the chassis. Except in resistance coupled circuits and AVC controlled stages, the resistance will be rather low. A resistor connected to the low potential end of an R.F. or I.F. transformer secondary indicates that the stage is A.V.C. controlled. Grid resistors *very* seldom are a source of trouble.

To complete the test of the supply circuit in the defective stage, continuity between the chassis and the cathode or filament should be checked. This will check the C bias resistor. For amplifier tubes the resistor will rarely exceed 500 ohms; for a detector it may check as high as 50,000 ohms. The volume control may be in the cathode circuit so turn the volume control on all the way and note the variation in reading.

Now if the supply circuit tests previously explained check O.K., there is another possibility of trouble which we must not overlook. There may be a short in some of the voltage supply circuits. For example, the screen, plate or cathode by-pass condenser might be broken down. A check with the ohmmeter between each of these elements and the chassis will quickly show up such a condition. A broken down condenser will not show over 100 ohms resistance. Of course, it may be leaky but then the symptom will lead us to look for such a condition. Before finally condemning a part, give it a test when disconnected from the rest of the circuit.

When making supply circuit continuity tests be on the lookout for shorted plate and screen supply parts. A check for continuity takes this in automatically. Experience will soon enable you to determine just about what values to expect. An I.F. transformer primary or secondary will run around 100 ω, an audio transformer primary 500 ω, and its secondary about 1,500 ω. An R.F. primary may run from a low value to 100 ohms, its secondary rarely exceeds 5 ohms.

The Defect May Be Caused by a Defect Elsewhere.—Bias and control grid parts usually burn out because of some defect in themselves. Of course, an open grid return resulting in excessive plate current might damage bias, plate and screen supply parts but this is rather unlikely. However, in the high voltage circuits we have another situation. A short between the low potential end of a supply part and the chassis or cathode would burn out the part. So after locating an open high voltage part don't just replace it. See if any shorts are present which might have burned it out. You don't want a new part to go up in smoke as soon as you turn on the power. Here is a simple and sure test. Connect your ohmmeter from the low potential end of the burned out part to the chassis. Unless there is a bleeder system a reading indicates a short. You should look for a broken down condenser or a short in the wiring. The presence of a bleeder system will usually result in a reading of 10,000 ohms or more. A short which will burn out a part is usually a direct short—shows up as zero resistance.

You have noted I have used the words "usually," "probably," etc., quite frequently. This is necessary because we can't be absolutely sure without a diagram. Sometimes we run upon the unexpected and then a diagram is a great time saver. Just as an example, some sets use diode AVC tubes made by connecting together the plate and grid or plate and cathode of a triode such as a 56 or 27. A direct short check on these elements with an ohmmeter might lead us off on a "wild goose chase" if we had no diagram or were unfamiliar with the circuit. Such points are exceptions and should be borne in mind, even though you will seldom meet them.

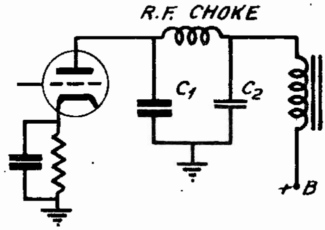

FIG. 3F. *If C^1 is shorted, the choke coil may burn out. In this case both C^1 and the choke must be replaced.*

A number of interesting tests and cases are given in Figs. *3A* to *3F*.

Although our discussion on how to test the defective stage with an ohmmeter was from the tube socket prongs under the chassis, you know that you could check the circuits (not parts) from the top of the chassis with the tubes removed and the chassis in the cabinet. On finding an open or short circuit you will be able to tell pretty well what might be the trouble. This procedure is necessary if the customer demands an estimate before the chassis can be removed from the cabinet.

Characteristics Chart

AND

Socket Connections

OF

RCA

The RC-13 MANUAL ready about January 15th

RECEIVING TUBES

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• The information on RCA radio tubes given in this booklet has been compiled in chart form from the RCA RECEIVING TUBE MANUAL (RC-13). Consisting of 192 pages, the RC-13 MANUAL covers in detail the theory and application of RCA receiving tubes. Characteristics data are supplemented by curves; special sections are devoted to the subjects of circuits and resistance-coupled amplifier operating conditions. This MANUAL will be found valuable by radio service men, experimenters, radio amateurs, and all others technically interested in radio tubes. It may be obtained from RCA radio tube dealers or direct from Commercial Engineering Section, RCA Radiotron Division, Harrison, N. J., at a price of twenty-five cents a copy.

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RCA RADIOTRON DIVISION

CA MANUFACTURING CO., INC.

Printed in U.S.A.

Form 1275 B

TYPE	NAME	BASE	SOCKET CONNEC-TIONS	DIMENSIONS MAXIMUM OVERALL LENGTH X DIAMETER	CATHODE TYPE ■	RATING: FILAMENT OR HEATER VOLTS	FILAMENT OR HEATER AMPERES	PLATE MAX. VOLTS	SCR MAX. VO
00-A	DETECTOR TRIODE	MEDIUM 4-PIN Bayonet	4D	$4\frac{11}{16}'' \times 1\frac{13}{16}''$	D-C FILAMENT	5.0	0.25	45	—
01-A	DETECTOR★ AMPLIFIER	MEDIUM 4-PIN Bayonet	4D	$4\frac{11}{16}'' \times 1\frac{13}{16}''$	D-C FILAMENT	5.0	0.25	135	—
1A4	SUPER-CONTROL R-F AMPLIFIER PENTODE	SMALL 4-PIN	4M	$4\frac{17}{32}'' \times 1\frac{9}{16}''$	D-C FILAMENT	2.0	0.06	180	67.5
1A6	PENTAGRID CONVERTER ◘	SMALL 6-PIN	6L	$4\frac{17}{32}'' \times 1\frac{9}{16}''$	D-C FILAMENT	2.0	0.06	180	67.5
1B4	R-F AMPLIFIER PENTODE	SMALL 4-PIN	4M	$4\frac{17}{32}'' \times 1\frac{9}{16}''$	D-C FILAMENT	2.0	0.06	180	67.5
1B5/25S	DUPLEX-DIODE TRIODE	SMALL 6-PIN	6M	$4\frac{1}{4}'' \times 1\frac{9}{16}''$	D-C FILAMENT	2.0	0.06	135	—
1C6	PENTAGRID CONVERTER ◘	SMALL 6-PIN	6L	$4\frac{17}{32}'' \times 1\frac{9}{16}''$	D-C FILAMENT	2.0	0.12	180	67.5
1F4	POWER AMPLIFIER PENTODE	MEDIUM 5-PIN	5K	$4\frac{11}{16}'' \times 1\frac{13}{16}''$	D-C FILAMENT	2.0	0.12	135	135
1F6	DUPLEX-DIODE PENTODE	SMALL 6-PIN	6W	$4\frac{17}{32}'' \times 1\frac{9}{16}''$	D-C FILAMENT	2.0	0.06	180	67.5
1-v	HALF-WAVE RECTIFIER	SMALL 4-PIN	4G	$4\frac{1}{4}'' \times 1\frac{9}{16}''$	HEATER	6.3	0.3	—	—
2A3	POWER AMPLIFIER TRIODE	MEDIUM 4-PIN	4D	$5\frac{3}{8}'' \times 2\frac{1}{16}''$	FILAMENT	2.5	2.5	250 300	— —
2A5	POWER AMPLIFIER PENTODE	MEDIUM 6-PIN	6B	$4\frac{11}{16}'' \times 1\frac{13}{16}''$	HEATER	2.5	1.75	—	—
2A6	DUPLEX-DIODE HIGH-MU TRIODE	SMALL 6-PIN	6G	$4\frac{17}{32}'' \times 1\frac{9}{16}''$	HEATER	2.5	0.8	250	—
2A7	PENTAGRID CONVERTER ◘	SMALL 7-PIN	7C	$4\frac{17}{32}'' \times 1\frac{9}{16}''$	HEATER	2.5	0.8	250	10
2B7	DUPLEX-DIODE PENTODE	SMALL 7-PIN	7D	$4\frac{17}{32}'' \times 1\frac{9}{16}''$	HEATER	2.5	0.8	250	1[illegible]
5W4	FULL-WAVE RECTIFIER	SMALL OCTAL 5-PIN	5T	$3\frac{1}{4}'' \times 1\frac{5}{16}''$	FILAMENT	5.0	1.5	—	—
5Z3	FULL-WAVE RECTIFIER	MEDIUM 4-PIN	4C	$5\frac{3}{8}'' \times 2\frac{1}{16}''$	FILAMENT	5.0	3.0	—	—
5Z4	FULL-WAVE RECTIFIER	SMALL OCTAL 5-PIN	5L	$3\frac{1}{4}'' \times 1\frac{5}{16}''$	HEATER	5.0	2.0	—	—
6A4/LA	POWER AMPLIFIER PENTODE	MEDIUM 5-PIN	5B	$4\frac{11}{16}'' \times 1\frac{13}{16}''$	FILAMENT	6.3	0.3	180	1[illegible]
6A6	TWIN-TRIODE AMPLIFIER	MEDIUM 7-PIN ■	7B	$4\frac{11}{16}'' \times 1\frac{13}{16}''$	HEATER	6.3	0.8	300	—
6A7	PENTAGRID CONVERTER ◘	SMALL 7-PIN	7C	$4\frac{17}{32}'' \times 1\frac{9}{16}''$	HEATER	6.3	0.3	250	10
6A8	PENTAGRID CONVERTER ◘	SMALL OCTAL 8-PIN	8A	$3\frac{1}{8}'' \times 1\frac{5}{16}''$	HEATER	6.3	0.3	250	
6B7	DUPLEX-DIODE PENTODE	SMALL 7-PIN	7D	$4\frac{17}{32}'' \times 1\frac{9}{16}''$	HEATER	6.3	0.3	250	125
6B8	DUPLEX-DIODE PENTODE	SMALL OCTAL 8-PIN	8E	$3\frac{1}{8}'' \times 1\frac{5}{16}''$	HEATER	6.3	0.3	250	125
6C5	DETECTOR★ AMPLIFIER TRIODE	SMALL OCTAL 6-PIN	6Q	$2\frac{5}{8}'' \times 1\frac{5}{16}''$	HEATER	6.3	0.3	250	
6C6	TRIPLE-GRID DETECTOR AMPLIFIER	SMALL 6-PIN	6F	$4\frac{15}{16}'' \times 1\frac{9}{16}''$	HEATER	6.3	0.3	250	

USE …es to right give …ating conditions and characteristics for …ated typical use	PLATE SUP-PLY VOLTS	GRID BIAS ■ VOLTS	SCREEN SUPPLY VOLTS	SCREEN CUR-RENT MA.	PLATE CUR-RENT MA.	A-C PLATE RESIS-TANCE OHMS	TRANS-CONDUC-TANCE (GRID-PLATE) µMHOS	AMPLIFI-CATION FACTOR	LOAD FOR STATED POWER OUTPUT OHMS	POWER OUT-PUT WATTS	TYPE
GRID-LEAK DETECTOR	45	Grid Return to (−) Filament			1.5	30000	666	20	——	——	00-A
…SS A AMPLIFIER	90 135	− 4.5 − 9.0	——	——	2.5 3.0	11000 10000	725 800	8.0 8.0	——	——	01-A
…ASS A AMPLIFIER	90 180	{− 3.0 min.}	67.5 67.5	0.9 0.8	2.2 2.3	600000 1000000	720 750	425 750	——	——	1A4
CONVERTER	135 180	{− 3.0 min.}	67.5 67.5	2.5 2.4	1.2 1.3	400000 500000	Anode-Grid (#2): 180 max. volts, 2.3 ma. Oscillator-Grid (#1) Resistor. Conversion Conductance, 300 micromhos.				1A6
…ASS A AMPLIFIER	90 180	− 3.0 − 3.0	67.5 67.5	0.7 0.6	1.6 1.7	1000000 1500000	600 650	550 1000	——	——	1B4
…LASS A AMPLIFIER	135	− 3.0	——	——	0.8	35000	575	20	——	——	1B5/25S
CONVERTER	135 180	{− 3.0 min.}	67.5 67.5	2.0 2.0	1.3 1.5	550000 750000	Anode-Grid (#2): 180 max. volts, 3.3 ma. Oscillator-Grid (#1) Resistor. Conversion Conductance, 325 micromhos.				1C6
…ASS A AMPLIFIER	135	− 4.5	135	2.6	8.0	200000	1700	340	16000	0.34	1F4
…NTODE UNIT AS R-F AMPLIFIER	180	− 1.5	67.5	0.6	2.0	1000000	650	650	——	——	1F6
…ENTODE UNIT AS …-F AMPLIFIER	135 ✱	− 2.0	Screen Supply, 135 volts applied through 0.8-megohm resistor. Grid Resistor,** 1.0 megohm. Voltage Gain, 46.								1F6
	Maximum A-C Plate Voltage.......350 Volts, RMS Maximum D-C Output Current......50 Milliamperes										1-V
…SS A AMPLIFIER	250	−45.0	——	——	60.0	800	5250	4.2	2500	3.5	2A3
PUSH-PULL …S AB₁ AMPLIFIER	300 300	Self-bias, 780 ohms −62 volts, fixed bias			80.0 80.0	——	——	——	5000 3000	10.0† 15.0†	2A3
…AMPLIFIER	For other ratings and characteristics, refer to Type 42.										2A5
…ODE UNIT AS AMPLIFIER	For other characteristics, refer to Type 75.										2A6
…ONVERTER	For other characteristics, refer to Type 6A7.										2A7
…MPLIFIER	For other characteristics, refer to Type 6B7.										2B7
	Maximum A-C Voltage per Plate......350 Volts, RMS Maximum D-C Output Current......110 Milliamperes										5W4
	Maximum A-C Voltage per Plate......500 Volts, RMS Maximum D-C Output Current......250 Milliamperes										5Z3
	Maximum A-C Voltage per Plate......400 Volts, RMS Maximum D-C Output Current......125 Milliamperes										5Z4
CL… A AMPLIFIER	100 180	− 6.5 −12.0	100 180	1.6 3.9	9.0 22.0	83250 45500	1200 2200	100 100	11000 8000	0.31 1.40	6A4/LA
…MPLIFIER	For other characteristics, refer to Type 6N7.										6A6
…CONVERTER	100 250	{− 3.0 min.}	50 100	2.5 2.2	1.3 3.5	600000 360000	Anode-Grid (#2): 250 max. volts, 4.0 ma. Oscillator-Grid (#1) Resistor. Conversion Conductance, 520 micromhos.				6A7
C…VERTER	100 250	{− 3.0 min.}	50 100	1.5 3.2	1.2 3.3	600000 360000	Anode-Grid (#2): 250 max. volts, 4.0 ma. Oscillator-Grid (#1) Resistor. Conversion Conductance, 500 micromhos.				6A8
PEN… …E UNIT AS R-F AMPLIFIER	100 250	− 3.0 − 3.0	100 125	1.7 2.3	5.8 9.0	300000 650000	950 1125	285 730	——	——	6B7
PENTODE UNIT AS A-F AMPLIFIER	90 ✱ 300 ✱	Self-bias, 3500 ohms. Screen Resistor = 1.1 meg. Self-bias, 1600 ohms. Screen Resistor = 1.2 meg.					Grid Resistor,** 0.5 megohm.		Gain per stage = 55 Gain per stage = 79		6B7
PENTODE UNIT AS R-F AMPLIFIER	250	− 3.0	125	2.3	10.0	600000	1325	800	——	——	6B8
PENTO…E UNIT AS …MPLIFIER	90 ✱ 300 ✱	Self-bias, 3500 ohms. Screen Resistor = 1.1 meg. Self-bias, 1600 ohms. Screen Resistor = 1.2 meg.					Grid Resistor,** 0.5 megohm.		Gain per stage = 55 Gain per stage = 79		6B8
…MPLIFIER	250 250 ♥	− 8.0 − 5.0	——	——	8.0 1.0	10000 Gain per stage = 14	2000	20	——	——	6C5
…ECTOR	250	{−17.0 approx.}	——	——	Plate current to be adjusted to 0.2 milliampere with no signal.						6C5
…IER …TOR	For other characteristics, refer to Type 6J7.										6C6

TYPE	NAME	BASE	SOCKET CONNEC-TIONS	DIMENSIONS MAXIMUM OVERALL LENGTH X DIAMETER	CATHODE TYPE ■	RATING FILAMENT OR HEATER VOLTS	AMPERES	PLATE MAX. VOLTS	SC[illegible] M[illegible]X. V[illegible]
6D6	TRIPLE-GRID SUPER-CONTROL AMPLIFIER	SMALL 6-PIN	6F	$4\frac{15}{16}'' \times 1\frac{9}{16}''$	HEATER	6.3	0.3	250	1[illegible]
6E5	ELECTRON-RAY TUBE	SMALL 6-PIN	6R	$4\frac{1}{4}'' \times 1\frac{9}{16}''$	HEATER	6.3	0.3	250†	—
6F5	HIGH-MU TRIODE	SMALL OCTAL 5-PIN	5M	$3\frac{1}{8}'' \times 1\frac{5}{16}''$	HEATER	6.3	0.3	250	—
6F6	POWER AMPLIFIER PENTODE	SMALL OCTAL 7-PIN	7S	$3\frac{1}{4}'' \times 1\frac{5}{16}''$	HEATER	6.3	0.7	315	31[illegible]
								250	—
								375	25[illegible]
								350	—
6F7	TRIODE-PENTODE	SMALL 7-PIN	7E	$4\frac{17}{32}'' \times 1\frac{9}{16}''$	HEATER	6.3	0.3	100	—
								250	100
								250	10[illegible]
6G5	ELECTRON-RAY TUBE	SMALL 6-PIN	6R	$4\frac{1}{4}'' \times 1\frac{9}{16}''$	HEATER	6.3	0.3	250†	—
6H6	TWIN DIODE	SMALL OCTAL 7-PIN	7Q	$1\frac{5}{8}'' \times 1\frac{5}{16}''$	HEATER	6.3	0.3	—	—
6J7	TRIPLE-GRID DETECTOR AMPLIFIER	SMALL OCTAL 7-PIN	7R	$3\frac{1}{8}'' \times 1\frac{5}{16}''$	HEATER	6.3	0.3	250	1[illegible]
6K7	TRIPLE-GRID SUPER-CONTROL AMPLIFIER	SMALL OCTAL 7-PIN	7R	$3\frac{1}{8}'' \times 1\frac{5}{16}''$	HEATER	6.3	0.3	250	[illegible]
6L6	BEAM POWER AMPLIFIER	SMALL OCTAL 7-PIN	7AC	$4\frac{5}{16}'' \times 1\frac{5}{8}''$	HEATER	6.3	0.9	375	250
								375	25[illegible]
								400	300
								400	[illegible]00
6L7	PENTAGRID MIXER & AMPLIFIER	SMALL OCTAL 7-PIN	7T	$3\frac{1}{8}'' \times 1\frac{5}{16}''$	HEATER	6.3	0.3	250	150
								250	100
6N7	TWIN-TRIODE AMPLIFIER	SMALL OCTAL 8-PIN	8B	$3\frac{1}{4}'' \times 1\frac{5}{16}''$	HEATER	6.3	0.8	300	—
6Q7	DUPLEX-DIODE HIGH-MU TRIODE	SMALL OCTAL 7-PIN	7V	$3\frac{1}{8}'' \times 1\frac{5}{16}''$	HEATER	6.3	0.3	250	
6R7	DUPLEX-DIODE TRIODE	SMALL OCTAL 7-PIN	7V	$3\frac{1}{8}'' \times 1\frac{5}{16}''$	HEATER	6.3	0.3	250	
6X5	FULL-WAVE RECTIFIER	SMALL OCTAL 6-PIN	6S	$3\frac{1}{4}'' \times 1\frac{5}{16}''$	HEATER	6.3	0.6	—	
10	POWER AMPLIFIER TRIODE	MEDIUM 4-PIN Bayonet	4D	$5\frac{5}{8}'' \times 2\frac{3}{16}$	FILAMENT	7.5	1.25	42[illegible]	

USE ...s to right give ...ing conditions ...aracteristics for ...ted typical use	PLATE SUPPLY VOLTS	GRID BIAS ■ VOLTS	SCREEN SUPPLY VOLTS	SCREEN CURRENT MA.	PLATE CURRENT MA.	A-C PLATE RESISTANCE OHMS	TRANSCONDUCTANCE (GRID-PLATE) μMHOS	AMPLIFICATION FACTOR	LOAD FOR STATED POWER OUTPUT OHMS	POWER OUTPUT WATTS	TYPE
...CREEN-GRID ...F AMPLIFIER	100 250	−3.0 min.	100 100	2.2 2.0	8.0 8.2	250000 800000	1500 1600	375 1280	—	—	6D6
MIXER IN ...RHETERODYNE	100 250	−10.0 −10.0	100 100	—	—	Oscillator Peak Volts = 7.0					6D6
VISUAL INDICATOR	Plate & Target Supply = 100 volts. Triode Plate Resistor = 0.5 meg. Target Current = 4.5 ma. Grid Bias, −3.3 volts; Shadow Angle, 0°. Bias, 0 volts; Angle, 90°; Plate Current, 0.19 ma.										6E5
VISUAL INDICATOR	Plate & Target Supply = 250 volts. Triode Plate Resistor = 1.0 meg. Target Current = 4.5 ma. Grid Bias, −8.0 volts; Shadow Angle, 0°. Bias, 0 volts; Angle, 90°; Plate Current, 0.24 ma.										6E5
...SS A AMPLIFIER	250 250✖	−2.0 −0.3	—	—	0.9 0.4	66000 Grid Resistor, 0.25 meg.** Gain per stage = 52	1500	100	—	—	6F5
PENTODE ...SS A AMPLIFIER	250 315	−16.5 −22.0	250 315	6.5 8.0	34.0 42.0	80000 75000	2500 2650	200 200	7000 7000	3.0 5.0	6F6
TRIODE □ ...SS A AMPLIFIER	250	−20.0	—	—	31.0	2600	2700	7	4000	0.85	6F6
...TODE PUSH-PULL ...S AB_2 AMPLIFIER	375 375	Self-bias −26.0	250 250	8.0 5.0	54.0 34.0	Self-Bias Resistor, 340 ohms —	—	—	10000 10000	19.0† 19.0†	6F6
...DE PUSH-PULL □ ...SS AB_2 AMPLIFIER	350 350	Self-bias −38.0	—	—	50.0 45.0	Self-Bias Resistor, 730 ohms —	—	—	10000 6000	14.0† 18.0†	6F6
...RIODE UNIT AS ...SS A AMPLIFIER	100	−3.0	—	—	3.5	16000	500	8	—	—	6F7
...NTODE UNIT AS ...ASS A AMPLIFIER	100 250	−3.0 min.	100 100	1.6 1.5	6.3 6.5	290000 850000	1050 1100	300 900	—	—	6F7
...NTODE UNIT AS MIXER	250	−10.0	100	0.6	2.8	Oscillator Peak Volts = 7.0. Conversion Conductance = 300 micromhos.					6F7
VISUAL INDICATOR	Plate & Target Supply = 100 volts. Triode Plate Resistor = 0.5 meg. Target Current = 4.5 ma. Grid Bias, −8 volts; Shadow Angle, 0°. Bias, 0 volts; Angle, 90°; Plate Current, 0.19 ma.										6G5
VISUAL INDICATOR	Plate & Target Supply = 250 volts. Triode Plate Resistor = 1.0 meg. Target Current = 4.5 ma. Grid Bias, −22 volts; Shadow Angle, 0°. Bias, 0 volts; Angle, 90°; Plate Current, 0.24 ma.										6G5
TWIN-DIODE DETECTOR RECTIFIER	Maximum A-C Voltage per Plate....................100 Volts, RMS Maximum D-C Output Current.................... 4 Milliamperes										6H6
...CREEN-GRID ...F AMPLIFIER	100 250	−3.0 −3.0	100 100	0.5 0.5	2.0 2.0	1000000 1.5 +§	1185 1225	1185 1500+	—	—	6J7
...REEN-GRID ... AMPLIFIER	90✖ 300✖	Self-bias, 2600 ohms. Screen Resistor = 1.2 meg. Self-bias, 1200 ohms. Screen Resistor = 1.2 meg.				Grid Resistor,** 0.5 megohm.		Gain per stage = 85 Gain per stage = 140			6J7
...S DETECTOR	250	−4.3	100	Cathode current 0.43 ma.		—	Plate Resistor, 500000 ohms. Grid Resistor,** 250000 ohms.				6J7
...REEN-GRID ... AMPLIFIER	90 250	−3.0 min.	90 125	1.3 2.6	5.4 10.5	315000 600000	1275 1650	400 990	—	—	6K7
MIXER IN ...UPERHETERODYNE	250	−10.0	100	—	—	Oscillator Peak Volts = 7.0					6K7
SINGLE-TUBE CLASS A_1 AMPLIFIER	250 250	−14.0 Self-bias	250 250	5.0 5.4	72.0 75.0	— Self-Bias Resistor, 170 ohms.	—	—	2500 2500	6.5 6.5	6L6
PUSH-PULL CLASS A_1 AMPLIFIER	250 250	−16.0 Self-bias	250 250	10.0 10.0	120.0 120.0	— Self-Bias Resistor, 125 ohms.	—	—	5000 5000	14.5† 13.8†	6L6
PUSH-PULL CLASS AB_1 AMPLIFIER	400 400	−25.0 Self-bias	300 300	6.0 7.0	102.0 112.0	— Self-Bias Resistor, 200 ohms.	—	—	6600 6600	34.0† 32.0†	6L6
PUSH-PULL CLASS AB_2 AMPLIFIER	400 400	−20.0 −25.0	250 300	4.0 6.0	88.0 102.0	—	—	—	6000 3800	40.0† 60.0†	6L6
MIXER IN SUPERHETERODYNE	250	−3.0	100	6.2	2.4	Oscillator-Grid (#3) Bias, −10 volts. Grid #3 Peak Swing, 12 volts min. Conversion Conductance, 350 micromhos.					6L7
CLASS A AMPLIFIER	250	−3.0 min.	100	5.5	5.3	800000	1100	880	—	—	6L7
...LASS A AMPLIFIER (As Driver)°	250 294	−5.0 −6.0	—	—	6.0 7.0	11300 11000	3100 3200	35 35	20000 or more	exceeds 0.4	6N7
CLASS B AMPLIFIER	250 300	0 0	—	—	Power Output is for one tube at stated plate-to-plate load.				8000 10000	8.0 10.0	6N7
...RIODE UNIT AS ...SS A AMPLIFIER	100 250	−1.5 −3.0	—	—	0.35 1.1	87500 58000	800 1200	70 70	—	—	6Q7
	100°° 250■	−1.1 −2.0	—	—	0.25 0.5	Grid Resistor, ** 0.5 megohm		Gain per stage = 35 Gain per stage = 43			6Q7
...D... ...IT AS ...S A A...PLIFIER	250 250♥	−9.0 −6.0	—	—	9.5 1.3	8500 Grid Resistor, ** 0.5 meg. Gain per stage = 12	1900	16	10000	0.28	6R7
	Maximum A-C Voltage per Plate....................350 Volts, RMS Maximum D-C Output Current.................... 75 Milliamperes										6X5
...LIFIER	350 425	−32.0 −40.0	—	—	16.0 18.0	5150 5000	1550 1600	8.0 8.0	11000 10200	0.9 1.6	10

TYPE	NAME	BASE	SOCKET CONNECTIONS	DIMENSIONS MAXIMUM OVERALL LENGTH X DIAMETER	CATHODE TYPE ■	RATING FILAMENT OR HEATER VOLTS	AMPERES	PLATE MAX. VOLTS	SC[illegible] M[illegible] V[illegible]
11 12	DETECTOR★ AMPLIFIER TRIODE	WD 4-PIN MEDIUM 4-PIN Bayonet	4F 4D	$4\frac{1}{8}''$ x $1\frac{3}{16}''$ $4\frac{11}{16}''$ x $1\frac{7}{16}''$	D-C FILAMENT	1.1	0.25	135	—
12Z3	HALF-WAVE RECTIFIER	SMALL 4-PIN	4G	$4\frac{1}{4}''$ x $1\frac{9}{16}''$	HEATER	12.6	0.3	—	—
15	R-F AMPLIFIER PENTODE	SMALL 5-PIN	5F	$4\frac{17}{32}''$ x $1\frac{9}{16}''$	HEATER	2.0	0.22	135	67.[illegible]
19	TWIN-TRIODE AMPLIFIER	SMALL 6-PIN	6C	$4\frac{1}{4}''$ x $1\frac{9}{16}''$	D-C FILAMENT	2.0	0.26	135	—
20	POWER AMPLIFIER TRIODE	SMALL 4-PIN	4D	$4\frac{1}{8}''$ x $1\frac{3}{16}''$	D-C FILAMENT	3.3	0.132	135	—
22	R-F AMPLIFIER TETRODE	MEDIUM 4-PIN	4K	$5\frac{1}{32}''$ x $1\frac{13}{16}''$	D-C FILAMENT	3.3	0.132	135	67.[illegible]
24-A	R-F AMPLIFIER TETRODE	MEDIUM 5-PIN	5E	$5\frac{1}{32}''$ x $1\frac{13}{16}''$	HEATER	2.5	1.75	275	9[illegible]
25A6	POWER AMPLIFIER PENTODE	SMALL OCTAL 7-PIN	7S	$3\frac{1}{4}''$ x $1\frac{5}{16}''$	HEATER	25.0	0.3	180	135
25Z5	RECTIFIER-DOUBLER	SMALL 6-PIN	6E	$4\frac{1}{4}''$ x $1\frac{9}{16}''$	HEATER	25.0	0.3	—	—
25Z6	RECTIFIER-DOUBLER	SMALL OCTAL 7-PIN	7Q	$3\frac{1}{4}''$ x $1\frac{5}{16}''$	HEATER	25.0	0.3	—	—
26	AMPLIFIER TRIODE	MEDIUM 4-PIN	4D	$4\frac{11}{16}''$ x $1\frac{13}{16}''$	FILAMENT	1.5	1.05	180	—
27	DETECTOR★ AMPLIFIER TRIODE	MEDIUM 5-PIN	5A	$4\frac{1}{4}''$ x $1\frac{9}{16}''$	HEATER	2.5	1.75	275	—
30	DETECTOR★ AMPLIFIER TRIODE	SMALL 4-PIN	4D	$4\frac{1}{4}''$ x $1\frac{9}{16}''$	D-C FILAMENT	2.0	0.06	180	-
31	POWER AMPLIFIER TRIODE	SMALL 4-PIN	4D	$4\frac{1}{4}''$ x $1\frac{9}{16}''$	D-C FILAMENT	2.0	0.13	180	—
32	R-F AMPLIFIER TETRODE	MEDIUM 4-PIN	4K	$5\frac{1}{32}''$ x $1\frac{13}{16}''$	D-C FILAMENT	2.0	0.06	180	67.5
33	POWER AMPLIFIER PENTODE	MEDIUM 5-PIN	5K	$4\frac{11}{16}''$ x $1\frac{13}{16}''$	D-C FILAMENT	2.0	0.26	180	180
34	SUPER-CONTROL R-F AMPLIFIER PENTODE	MEDIUM 4-PIN	4M	$5\frac{1}{32}''$ x $1\frac{13}{16}''$	D-C FILAMENT	2.0	0.06	180	67.5
35	SUPER-CONTROL R-F AMPLIFIER TETRODE	MEDIUM 5-PIN	5E	$5\frac{1}{32}''$ x $1\frac{13}{16}''$	HEATER	2.5	1.75	275	90
36	R-F AMPLIFIER TETRODE	SMALL 5-PIN	5E	$4\frac{17}{32}''$ x $1\frac{9}{16}''$	HEATER	6.3	0.3	250	90
37	DETECTOR★ AMPLIFIER TRIODE	SMALL 5-PIN	5A	$4\frac{1}{4}''$ x $1\frac{9}{16}''$	HEATER	6.3	0.3	250	—
38	POWER AMPLIFIER PENTODE	SMALL 5-PIN	5F	$4\frac{17}{32}''$ x $1\frac{9}{16}''$	HEATER	6.3	0.3	250	25[illegible]
39/44	SUPER-CONTROL R-F AMPLIFIER PENTODE	SMALL 5-PIN	5F	$4\frac{17}{32}''$ x $1\frac{9}{16}''$	HEATER	6.3	0.3	250	[illegible]
40	VOLTAGE AMPLIFIER TRIODE	MEDIUM 4-PIN Bayonet	4D	$4\frac{11}{16}''$ x $1\frac{13}{16}''$	D-C FILAMENT	5.0	0.25	180	—
41	POWER AMPLIFIER PENTODE	SMALL 6-PIN	6B	$4\frac{1}{4}''$ x $1\frac{9}{16}''$	HEATER	6.3	0.4	25[illegible]	[illegible]

USE …ues to right give …rating conditions characteristics for …icated typical use	PLATE SUPPLY VOLTS	GRID BIAS ■ VOLTS	SCREEN SUPPLY VOLTS	SCREEN CURRENT MA.	PLATE CURRENT MA.	A-C PLATE RESISTANCE OHMS	TRANSCONDUCTANCE (GRID-PLATE) µMHOS	AMPLIFICATION FACTOR	LOAD FOR STATED POWER OUTPUT OHMS	POWER OUTPUT WATTS	TYPE
SS A AMPLIFIER	90 135	−4.5 −10.5	—	—	2.5 3.0	15500 15000	425 440	6.6 6.6	—	—	11 12
	Maximum A-C Plate Voltage....250 Volts, RMS Maximum D-C Output Current.... 60 Milliamperes										12Z3
ASS A AMPLIFIER	67.5 135	−1.5 −1.5	67.5 67.5	0.3 0.3	1.85 1.85	630000 800000	710 750	450 600	—	—	15
ASS B AMPLIFIER	135 135	0 −3.0	—	—	Power Output is for one tube at stated plate-to-plate load.				10000 10000	2.1 1.9	19
ASS A AMPLIFIER	90 135	−16.5 −22.5	—	—	3.0 6.5	8000 6300	415 525	3.3 3.3	9600 6500	0.045 0.110	20
SCREEN-GRID R-F AMPLIFIER	135 135	−1.5 −1.5	45 67.5	0.6* 1.3*	1.7 3.7	725000 325000	375 500	270 160	—	—	22
SCREEN-GRID R-F AMPLIFIER	180 250	−3.0 −3.0	90 90	1.7* 1.7*	4.0 4.0	400000 600000	1000 1050	400 630	—	—	24-A
IAS DETECTOR	250●	−5.0 approx.	20 to 45	—	Plate current to be adjusted to 0.1 milliampere with no signal.						24-A
ASS A AMPLIFIER	95 180	−15.0 −20.0	95 135	4.0 7.5	20.0 38.0	45000 40000	2000 2500	90 100	4500 5000	0.9 2.75	25A6
VOLTAGE DOUBLER	Maximum A-C Voltage per Plate....125 Volts, RMS Maximum D-C Output Current....100 Milliamperes										25Z5
HALF-WAVE RECTIFIER	Maximum A-C Voltage per Plate ❢....250 Volts, RMS Maximum D-C Output Current per Plate.... 85 Milliamperes										25Z5
VOLTAGE DOUBLER	Maximum A-C Voltage per Plate....125 Volts, RMS Maximum D-C Output Current.... 85 Milliamperes										25Z6
HALF-WAVE RECTIFIER	Maximum A-C Voltage per Plate ❢....250 Volts, RMS Maximum D-C Output Current per Plate.... 85 Milliamperes										25Z6
LASS A AMPLIFIER	90 180	−7.0 −14.5	—	—	2.9 6.2	8900 7300	935 1150	8.3 8.3	—	—	26
LASS A AMPLIFIER	135 250	−9.0 −21.0	—	—	4.5 5.2	9000 9250	1000 975	9.0 9.0	—	—	27
BIAS DETECTOR	250	−30.0 approx.	—	—	Plate current to be adjusted to 0.2 milliampere with no signal.						27
ASS A AMPLIFIER	90 135 180	−4.5 −9.0 −13.5	—	—	2.5 3.0 3.1	11000 10300 10300	850 900 900	9.3 9.3 9.3	—	—	30
SS B AMPLIFIER	157.5	−15.0	—	—	1.0	—	—	—	8000	2.1†	30
LASS A AMPLIFIER	135 180	−22.5 −30.0	—	—	8.0 12.3	4100 3600	925 1050	3.8 3.8	7000 5700	0.185 0.375	31
SCREEN-GRID R-F AMPLIFIER	135 180	−3.0 −3.0	67.5 67.5	0.4* 0.4*	1.7 1.7	950000 1200000	640 650	610 780	—	—	32
BIAS DETECTOR	180♥	−6.0 approx.	67.5	—	Plate current to be adjusted to 0.2 milliampere with no signal.						32
CLASS A AMPLIFIER	180	−18.0	180	5.0	22.0	55000	1700	90	6000	1.4	33
SCREEN-GRID R-F AMPLIFIER	135 180	−3.0 min.	67.5 67.5	1.0 1.0	2.8 2.8	600000 1000000	600 620	360 620	—	—	34
SCREEN-GRID R-F AMPLIFIER	180 250	−3.0 min.	90 90	2.5* 2.5*	6.3 6.5	300000 400000	1020 1050	305 420	—	—	35
SCREEN-GRID R-F AMPLIFIER	100 250	−1.5 −3.0	55 90	— 1.7*	1.8 3.2	550000 550000	850 1080	470 595	—	—	36
BIAS DETECTOR	100● 250●	−5.0 −8.0	55 90	—	Grid-bias values are approximate. Plate current to be adjusted to 0.1 milliampere with no signal.						36
CLASS A AMPLIFIER	90 250	−6.0 −18.0	—	—	2.5 7.5	11500 8400	800 1100	9.2 9.2	—	—	37
BIAS DETECTOR	90 250	−10.0 −28.0	—		Grid-bias values are approximate. Plate current to be adjusted to 0.2 milliampere with no signal.						37
LASS A AMPLIFIER	100 250	−9.0 −25.0	100 250	1.2 3.8	7.0 22.0	140000 100000	875 1200	120 120	15000 10000	0.27 2.50	38
SC EN-GRID R-F AMPLIFIER	90 250	−3.0 min.	90 90	1.6 1.4	5.6 5.8	375000 1000000	960 1050	360 1050	—	—	39/44
CLASS A AMPLIFIER	135✕ 180✕	−1.5 −3.0	—	—	0.2 0.2	150000 150000	200 200	30 30	—	—	40
SS APLIFIER	100 250	−7.0 −18.0	100 250	1.6 5.5	9.0 32.0	103500 68000	1450 2200	150 150	12000 7600	0.33 3.40	41

TYPE	NAME	BASE	SOCKET CONNEC-TIONS	DIMENSIONS MAXIMUM OVERALL	CATHODE TYPE ■	RATING			
						FILAMENT OR HEATER		PLATE	SCR
				LENGTH X DIAMETER		VOLTS	AMPERES	MAX. VOLTS	MA VO
42	POWER AMPLIFIER PENTODE	MEDIUM 6-PIN	6B	$4\frac{11}{16}''$ x $1\frac{13}{16}''$	HEATER	6.3	0.7	315	31
								315	—
								375	25
								350	—
43	POWER AMPLIFIER PENTODE	MEDIUM 6-PIN	6B	$4\frac{11}{16}''$ x $1\frac{13}{16}''$	HEATER	25.0	0.3	180	135
45	POWER AMPLIFIER TRIODE	MEDIUM 4-PIN	4D	$4\frac{11}{16}''$ x $1\frac{13}{16}''$	FILAMENT	2.5	1.5	275	—
46	DUAL-GRID POWER AMPLIFIER	MEDIUM 5-PIN	5C	$5\frac{5}{8}''$ x $2\frac{3}{16}''$	FILAMENT	2.5	1.75	250	—
								400	—
47	POWER AMPLIFIER PENTODE	MEDIUM 5-PIN	5B	$5\frac{3}{8}''$ x $2\frac{1}{16}''$	FILAMENT	2.5	1.75	250	250
48	POWER AMPLIFIER TETRODE	MEDIUM 6-PIN	6A	$5\frac{3}{8}''$ x $2\frac{1}{16}''$	D-C HEATER	30.0	0.4	125	100
49	DUAL-GRID POWER AMPLIFIER	MEDIUM 5-PIN	5C	$4\frac{11}{16}''$ x $1\frac{13}{16}''$	D-C FILAMENT	2.0	0.12	135	—
								180	—
50	POWER AMPLIFIER TRIODE	MEDIUM 4-PIN Bayonet	4D	$6\frac{1}{4}''$ x $2\frac{7}{16}''$	FILAMENT	7.5	1.25	450	—
53	TWIN-TRIODE AMPLIFIER	MEDIUM 7-PIN ♯	7B	$4\frac{11}{16}''$ x $1\frac{13}{16}''$	HEATER	2.5	2.0	300	—
55	DUPLEX-DIODE TRIODE	SMALL 6-PIN	6G	$4\frac{17}{32}''$ x $1\frac{9}{16}''$	HEATER	2.5	1.0	250	—
56	SUPER-TRIODE AMPLIFIER DETECTOR★	SMALL 5-PIN	5A	$4\frac{1}{4}''$ x $1\frac{9}{16}''$	HEATER	2.5	1.0	250	—
57	TRIPLE-GRID DETECTOR AMPLIFIER	SMALL 6-PIN	6F	$4\frac{15}{16}''$ x $1\frac{9}{16}''$	HEATER	2.5	1.0	250	100
58	TRIPLE-GRID SUPER-CONTROL AMPLIFIER	SMALL 6-PIN	6F	$4\frac{15}{16}''$ x $1\frac{9}{16}''$	HEATER	2.5	1.0	250	100
59	TRIPLE-GRID POWER AMPLIFIER	MEDIUM 7-PIN ♯	7A	$5\frac{3}{8}''$ x $2\frac{1}{16}''$	HEATER	2.5	2.0	250	—
								250	250
								400	—
71-A	POWER AMPLIFIER TRIODE	MEDIUM 4-PIN Bayonet	4D	$4\frac{11}{16}''$ x $1\frac{13}{16}''$	FILAMENT	5.0	0.25	180	—
75	DUPLEX-DIODE HIGH-MU TRIODE	SMALL 6-PIN	6G	$4\frac{17}{32}''$ x $1\frac{9}{16}''$	HEATER	6.3	0.3	250	—
76	SUPER-TRIODE AMPLIFIER DETECTOR★	SMALL 5-PIN	5A	$4\frac{1}{4}''$ x $1\frac{9}{16}''$	HEATER	6.3	0.3	250	—
77	TRIPLE-GRID DETECTOR AMPLIFIER	SMALL 6-PIN	6F	$4\frac{17}{32}''$ x $1\frac{9}{16}''$	HEATER	6.3	0.3	250	100
78	TRIPLE-GRID SUPER-CONTROL AMPLIFIER	SMALL 6-PIN	6F	$4\frac{17}{32}''$ x $1\frac{9}{16}''$	HEATER	6.3	0.3	250	125

USE ...lues to right give rating conditions ... characteristics for ...icated typical use	PLATE SUPPLY VOLTS	GRID BIAS ■ VOLTS	SCREEN SUPPLY VOLTS	SCREEN CURRENT MA.	PLATE CURRENT MA.	A-C PLATE RESISTANCE OHMS	TRANSCONDUCTANCE (GRID-PLATE) µMHOS	AMPLIFICATION FACTOR	LOAD FOR STATED POWER OUTPUT OHMS	POWER OUTPUT WATTS	TYPE
PENTODE ...SS A AMPLIFIER	250 315	−16.5 −22.0	250 315	6.5 8.0	34.0 42.0	80000 100000	2350 2600	190 260	7000 7000	3.0 5.0	42
TRIODE □ ...SS A AMPLIFIER	250	−20.0	—	—	31.0	2700	2300	6.2	3000	0.65	
...TODE PUSH-PULL ...S AB₂ AMPLIFIER	375 375	Self-bias −26.0	250 250	8.0 5.0	54.0 34.0	Self-Bias Resistor, 340 ohms —	 —	 —	10000 10000	19.0† 19.0†	
...ODE PUSH-PULL □ ...SS AB₂ AMPLIFIER	350 350	Self-bias, 730 ohms −38.0 volts, fixed bias			50.0 45.0	—	—	—	10000 6000	14.0† 18.0†	
...ASS A AMPLIFIER	95 180	−15.0 −20.0	95 135	4.0 7.5	20.0 38.0	45000 40000	2000 2500	90 100	4500 5000	0.90 2.75	43
...ASS A AMPLIFIER	180 275	−31.5 −56.0	—	—	31.0 36.0	1650 1700	2125 2050	3.5 3.5	2700 4600	0.82 2.00	45
...SS AB₂ AMPLIFIER	275 275	Self-bias, 775 ohms −68.0 volts, fixed bias			72.0 28.0	—	—	—	5060 3200	12.0† 18.0†	
...SS A AMPLIFIER □	250	−33.0	—	—	22.0	2380	2350	5.6	6400	1.25	46
...SS B AMPLIFIER ◆	300 400	0 0	—	—	8.0 12.0	—	—	—	5200 5800	16.0† 20.0†	
...ASS A AMPLIFIER	250	−16.5	250	6.0	31.0	60000	2500	150	7000	2.7	47
TETRODE ...LASS A AMPLIFIER	96 125	−19.0 −20.0	96 100	9.0 9.5	52.0 56.0	— —	3800 3900	— —	1500 1500	2.0 2.5	48
...TRODE PUSH-PULL ...LASS A AMPLIFIER	125	−20.0	100	—	100.0	—	—	—	3000	5.0†	
...ASS A AMPLIFIER □	135	−20.0	—	—	6.0	4175	1125	4.7	11000	0.17	49
...LASS B AMPLIFIER ◆	180	0	—	—	4.0	—	—	—	12000	3.5†	
CLASS A AMPLIFIER	300 400 450	−54.0 −70.0 −84.0	—	—	35.0 55.0 55.0	2000 1800 1800	1900 2100 2100	3.8 3.8 3.8	4600 3670 4350	1.6 3.4 4.6	50
AMPLIFIER	For other characteristics, refer to Type 6N7.										53
TRIODE UNIT AS AMPLIFIER	For other characteristics, refer to Type 85.										55
AMPLIFIER DETECTOR	For other characteristics, refer to Type 76.										56
AMPLIFIER DETECTOR	For other characteristics, refer to Type 6J7.										57
AMPLIFIER MIXER	For other characteristics, refer to Type 6D6.										58
TRIODE ¶ ...LASS A AMPLIFIER	250	−28.0	—	—	26.0	2300	2600	6.0	5000	1.25	59
PENTODE** CLASS A AMPLIFIER	250	−18.0	250	9.0	35.0	40000	2500	100	6000	3.0	
TRIODE ◆ CLASS B AMPLIFIER	300 400	0 0	—	—	20.0 26.0	—	—	—	4600 6000	15.0† 20.0†	
CLASS A AMPLIFIER	90 180	−19.0 −43.0	—	—	10.0 20.0	2170 1750	1400 1700	3.0 3.0	3000 4800	0.125 0.790	71-A
TRIODE UNIT AS CLASS A AMPLIFIER	250✖	− 1.35	—	—	0.4	—	—	Gain per stage = 50-60			75
CLASS A AMPLIFIER	100 250 250♥	− 5.0 −13.5 − 9.0	—	—	2.5 5.0 1.0	12000 9500 —	1150 1450 —	13.8 13.8 —	—	—	76
BIAS DETECTOR	250	−20.0 approx.	—	—	Plate current to be adjusted to 0.2 milliampere with no signal.						
SCREEN-GRID R-F AMPLIFIER	100 250	− 1.5 − 3.0	60 100	0.4 0.5	1.7 2.3	650000 1500000	1100 1250	715 1500	—	—	77
BIAS DETECTOR	250	− 1.95	60	Cathode current 0.65 ma.		—	Plate Resistor, 250000 ohms. Grid Resistor,** 250000 ohms.				
AMPLIFIER MIXER	For other characteristics, refer to Type 6K7.										78

TYPE	NAME	BASE	SOCKET CONNEC-TIONS	DIMENSIONS MAXIMUM OVERALL LENGTH X DIAMETER	CATHODE TYPE ■	RATING: FILAMENT OR HEATER VOLTS	AMPERES	PLATE MAX. VOLTS	SC[REEN] M[AX.] VO[LTS]
79	TWIN-TRIODE AMPLIFIER	SMALL 6-PIN	6H	$4\frac{17}{32}'' \times 1\frac{9}{16}''$	HEATER	6.3	0.6	250	—
80	FULL-WAVE RECTIFIER	MEDIUM 4-PIN	4C	$4\frac{11}{16}'' \times 1\frac{13}{16}''$	FILAMENT	5.0	2.0	—	—
81	HALF-WAVE RECTIFIER	MEDIUM 4-PIN Bayonet	4B	$6\frac{1}{4}'' \times 2\frac{7}{16}''$	FILAMENT	7.5	1.25	—	—
82	FULL-WAVE ➤ RECTIFIER	MEDIUM 4-PIN	4C	$4\frac{11}{16}'' \times 1\frac{13}{16}''$	FILAMENT	2.5	3.0	—	—
83	FULL-WAVE ➤ RECTIFIER	MEDIUM 4-PIN	4C	$5\frac{3}{8}'' \times 2\frac{1}{16}''$	FILAMENT	5.0	3.0	—	—
83-v	FULL-WAVE RECTIFIER	MEDIUM 4-PIN	4L	$4\frac{11}{16}'' \times 1\frac{13}{16}''$	HEATER	5.0	2.0	—	—
84/6Z4	FULL-WAVE RECTIFIER	SMALL 5-PIN	5D	$4\frac{1}{4}'' \times 1\frac{9}{16}''$	HEATER	6.3	0.5	—	—
85	DUPLEX-DIODE TRIODE	SMALL 6-PIN	6G	$4\frac{17}{32}'' \times 1\frac{9}{16}''$	HEATER	6.3	0.3	250	—
89	TRIPLE-GRID POWER AMPLIFIER	SMALL 6-PIN	6F	$4\frac{17}{32}'' \times 1\frac{9}{16}''$	HEATER	6.3	0.4	250	—
								250	250
								250	—
V-99 X-99	DETECTOR★ AMPLIFIER TRIODE	SMALL 4-NUB SMALL 4-PIN	4E 4D	$3\frac{1}{2}'' \times 1\frac{1}{16}''$ $4'' \times 1\frac{3}{16}''$	D-C FILAMENT	3.3	0.063	90	—
112-A	DETECTOR★ AMPLIFIER TRIODE	MEDIUM 4-PIN Bayonet	4D	$4\frac{11}{16}'' \times 1\frac{13}{16}''$	D-C FILAMENT	5.0	0.25	180	—
874	VOLTAGE REGULATOR	MEDIUM 4-PIN Bayonet	4S	$5\frac{5}{8}'' \times 2\frac{3}{16}''$	——	—	—	—	—
876	CURRENT REGULATOR	MOGUL SCREW	—	$8'' \times 2\frac{1}{16}''$	FILAMENT	—	—	—	—
886	CURRENT REGULATOR	MOGUL SCREW	—	$8'' \times 2\frac{1}{16}''$	FILAMENT	—	—	—	—

★For Grid-leak Detection—plate volts 45, grid return to + filament or to cathode.

■Either A. C. or D. C. may be used on filament or heater, except as specifically noted. For use of D.C. on A-C filament types, decrease stated grid volts by ½ (approx.) of filament voltage.

◣Supply voltage applied through 20000-ohm voltage-dropping resistor.

➤Mercury-Vapor Type.

▪▪Grid #1 is control grid. Grid #2 is screen. Grid #3 tied to cathode.

¶Grid #1 is control grid. Grids #2 and #3 tied to plate.

❁Grids #1 and #2 connected together. Grid #3 tied to plate.

▣Grids #3 and #5 are screen. Grid #4 is signal-input control grid.

▲Grids #2 and #4 are screen. Grid #1 is signal-input control grid.

✢Triode Plate-Supply Voltage and Max. Target Voltage; Min. Target Voltage = 90 volts.

°Both grids connected together; likewise, both plates.

†Power output is for two tubes at stated plate-to-plate load.

USE alues to right give erating conditions characteristics for licated typical use	PLATE SUP-PLY VOLTS	GRID BIAS ■ VOLTS	SCREEN SUPPLY VOLTS	SCREEN CUR-RENT MA.	PLATE CUR-RENT MA.	A-C PLATE RESIS-TANCE OHMS	TRANS-CONDUC-TANCE (GRID-PLATE) μMHOS	AMPLIFI-CATION FACTOR	LOAD FOR STATED POWER OUTPUT OHMS	POWER OUT-PUT WATTS	TYPE
SS B AMPLIFIER	180 250	0 0	—	—	Power Output is for one tube at stated plate-to-plate load.				7000 14000	5.5 8.0	79
-C Voltage per Plate (Volts RMS).......... 350 400 550)-C Output Current (Maximum MA.) 125 110 135					The 550-volt rating applies to filter circuits having an input choke of at least 20 henries.						80
Maximum A-C Plate Voltage....................................700 Volts, RMS Maximum D-C Output Current.................................. 85 Milliamperes											81
Iaximum A-C Voltage per Plate......500 Volts, RMS Iaximum D-C Output Current..........125 Milliamperes					Maximum Peak Inverse Voltage......1400 Volts Maximum Peak Plate Current.... ..... 400 Milliamperes						82
Iaximum A-C Voltage per Plate......500 Volts, RMS Iaximum D-C Output Current..........250 Milliamperes					Maximum Peak Inverse Voltage......1400 Volts Maximum Peak Plate Current.......... 800 Milliamperes						83
Maximum A-C Voltage per Plate.................................400 Volts, RMS Maximum D-C Output Current..................................200 Milliamperes											83-V
Maximum A-C Voltage per Plate.......... ....350 Volts, RMS Maximum D-C Output Current.................................. 60 Milliamperes											84/6Z4
RIODE UNIT AS ASS A AMPLIFIER	135 250	−10.5 −20.0	—	—	3.7 8.0	11000 7500	750 1100	8.3 8.3	25000 20000	0.075 0.350	85
AS TRIODE ¶ LASS A AMPLIFIER	160 250	−20.0 −31.0	—	—	17.0 32.0	3300 2600	1425 1800	4.7 4.7	7000 5500	0.30 0.90	89
AS PENTODE ■■ ASS A AMPLIFIER	100 250	−10.0 −25.0	100 250	1.6 5.5	9.5 32.0	104000 7000	1200 1800	125 125	10700 6750	0.33 3.40	89
AS TRIODE ♥ LASS B AMPLIFIER	180	0	—	—	6.0	—	—	—	13600 9400	2.50† 3.50†	89
LASS A AMPLIFIER	90	− 4.5	—	—	2.5	15500	425	6.6	—	—	V-99 X-99
LASS A AMPLIFIER	90 180	− 4.5 −13.5	—	—	5.0 7.7	5400 4700	1575 1800	8.5 8.5	—	—	112-A
Minimum D-C Starting Supply Voltage........125 Volts D-C Operating Voltage.......... .... 90 Volts					D-C Operating Current.......................................10-50 Ma. Maximum Current (Continuous)...........................50 Ma.						874
Voltage Range.......................................40 to 60 Volts					Operating Current............................1.7 Amperes						876
Voltage Range.......................................40 to 60 Volts					Operating Current..........................2.05 Amperes						886

● Applied through plate resistor of 250000 ohms or 500-henry choke shunted by 0.25-megohm resistor.
♥ Applied through plate resistor of 100000 ohms.
✖ Applied through plate resistor of 250000 ohms.
● 50000 ohms.
✱ Requires different socket from small 7-pin.
□ Grid #2 tied to plate. ♦ Grids #1 and #2 tied together. **For grid of following tube.
❢ Plate voltages greater than 125 volts RMS require 100-ohm series-plate resistor.
°° Applied through plate resistor of 150000 ohms.
¶ For signal-input control-grid (#1); control-grid #3 bias, −3 volts.
▣ Applied through 200000-ohm plate resistor.

*Maximum.
§ Megohms.

Note 1: Types with octal bases have *Miniature Metal Cap;* all others have *Small Metal Cap.*

Note 2: Subscript 1 on class of amplifier service (as AB_1) indicates that grid current does not flow during any part of input cycle.
Subscript 2 on class of amplifier service (as AB_2) indicates that grid current flows during some part of the input cycle.

INDEX OF TYPES BY USE AND BY CATHODE VOLTAGE

Tubes of All-Metal construction are shown in BOLD FACE

CATHODE VOLTS	RECTIFIERS	VOLTAGE AMPLIFIERS *Including Duplex-Diode Types*	POWER AMPLIFIERS
1.1	——	11, 12	——
1.5	——	26	——
2.0	——	1A4, 1A6, 1B4, 1B5/25S, 1F6, 15, 30, 32, 34	1F4, 19, 31, 33, 49
2.5	82	2A6, 2B7, 24-A, 27, 35, 55, 56, 57, 58	2A3, 2A5, 45, 46, 47, 53, 59
3.3	——	22, 99	20
5.0	**5W4,** 5Z3, **5Z4,** 80, 83, 83-v	01-A, 40, 112-A	71-A, 112-A
6.3	**6H6, 6X5,** 1-v, 84/6Z4	6B7, **6B8, 6C5,** 6C6, 6D6, **6F5,** 6F7, **6J7, 6K7, 6L7, 6Q7, 6R7,** 36, 37, 39/44, 75, 76, 77, 78, 85	6A4, 6A6, **6F6, 6L6, 6N7,** 38, 41, 42, 79, 89
7.5	81	——	10, 50
12.6	12Z3	——	——
25.0	25Z5, **25Z6**	——	**25A6,** 43
30.0	——	——	48

CATHODE VOLTS	CONVERTERS IN SUPERHETERODYNES	DETECTORS	MIXER TUBES IN SUPERHETERODYNES	INDICATOR (Visual)
1.1	——	11, 12	——	——
1.5	——	——	——	——
2.0	1A6, 1C6	1A6, 1B5/25S, 1F6, 30, 32	1A6, 1C6, 34	——
2.5	2A7	2A6, 2B7, 24-A, 27, 55, 56, 57	2A7, 35, 58	——
3.3	——	99	——	——
5.0	——	00-A, 01-A, 40, 112-A	——	——
6.3	6A7, **6A8**	6B7, **6B8, 6C5,** 6C6, 6F7, **6J7, 6H6, 6Q7, 6R7,** 36, 37, 75, 76, 77, 85	6A7, **6A8,** 6D6, **6K7, 6L7,** 39/44, 78	6E5, 6G5
7.5	——	——	——	——
12.6	——	——	——	——
25.0	——	——	——	——
30.0	——	——	——	——

* * * * * *

Concluded from page 15.

RCA-25B6-G:

Characteristics:

Heater Voltage	25.0 a-c or d-c	Volts
Heater Current	0.3	Ampere
Plate Voltage	95	Volts
Screen Voltage	95	Volts
Grid Voltage	-15	Volts
Plate Current	45	Milliamperes
Screen Current	4	Milliamperes
Plate Resistance	Subject to considerable variation	
Transconductance	4000	Micromhos
Load Resistance	2000	Ohms
Power Output (10% Distortion)	1.75	Watts

* * * * * *

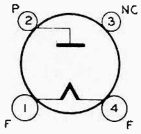
KEY TO TERMINAL DESIGNATIONS OF SOCKETS

Alphabetical subscripts D, P, and T indicate, respectively, diode unit, pentode unit, and triode unit in multi-unit types.

Numerical subscripts are used (1) in multi-grid types to indicate relative position of grids to cathode or filament, and (2) in multi-unit types to differentiate between two identical electrodes which would otherwise have the same designation.

BP = **Bayonet Pin** **H** = **Heater** **P** = **Plate**
F = **Filament** **K** = **Cathode** **P_{BF}** = **Beam-Forming Plates**
G = **Grid** **NC** = **No Connection** **TA** = **Target**

SOCKET CONNECTIONS
BOTTOM VIEWS



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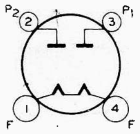

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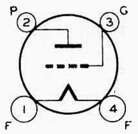

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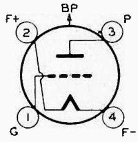

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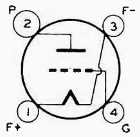

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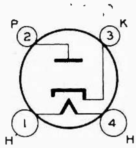

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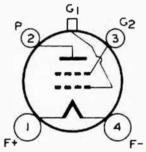

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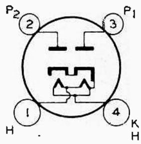

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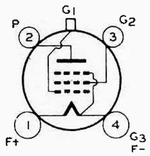

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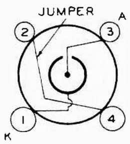

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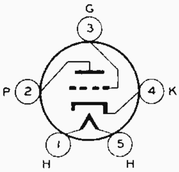

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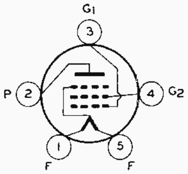

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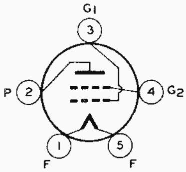

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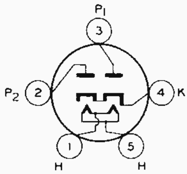

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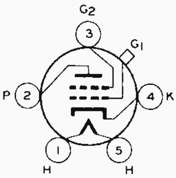

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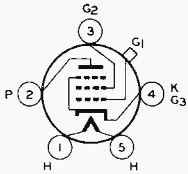

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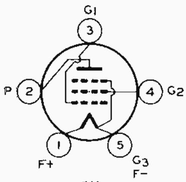

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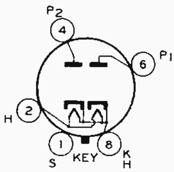

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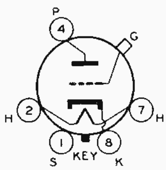

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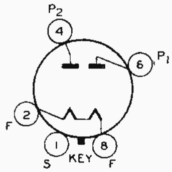

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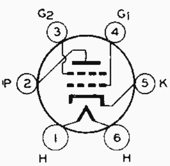

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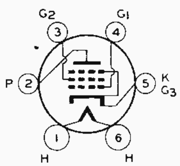

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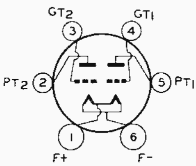

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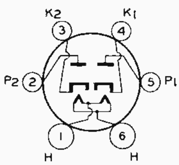

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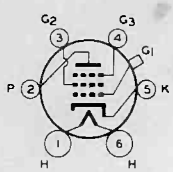
SOCKET CONNECTIONS

BOTTOM VIEWS



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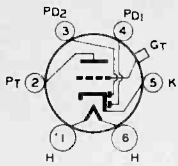

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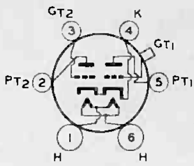

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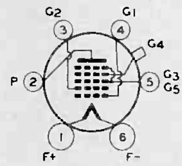

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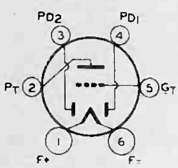

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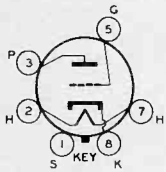

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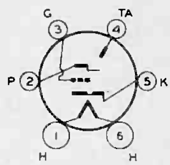

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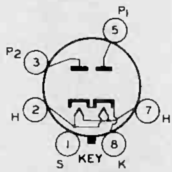

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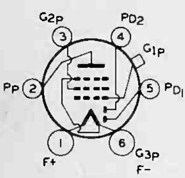

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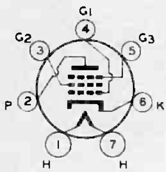

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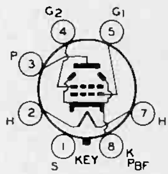

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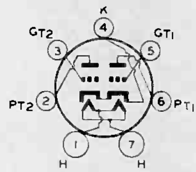

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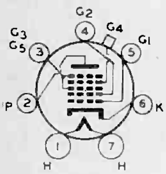

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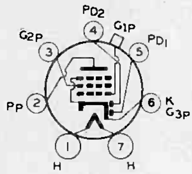

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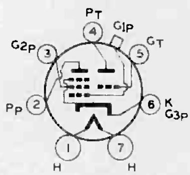

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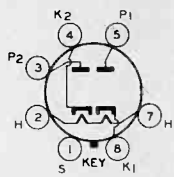

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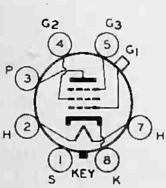

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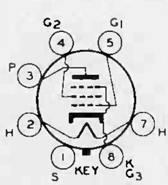

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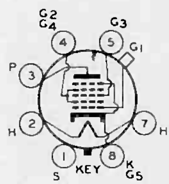

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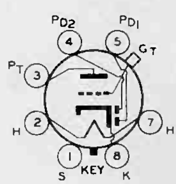

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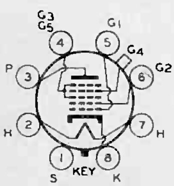

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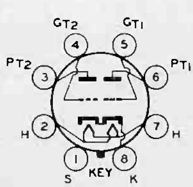

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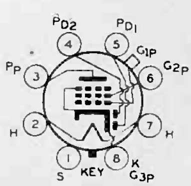


8E

RCA G-TYPE RADIO TUBES

(OCTAL-BASE, GLASS-BULB TYPES)

In addition to the types of tubes shown on the preceding pages, the following octal-base, glass-bulb types are also available. These types are identified by the letter "G" following the type number. For each of these types, the corresponding glass or metal types are indicated below, together with socket connections and overall dimensions. Characteristics data for the G-types, except for some differences in capacity values, are the same as those for the corresponding types.

G-Series Type	Corresponding Glass Type	Corresponding Metal Type	Socket Connections	Max. Overall Dimensions Length x Diam.
1C7-G	1C6	—	G-7Z	$4\frac{15}{32}''$ x $1\frac{9}{16}''$
1D5-G	1A4	—	G-5Y	$4\frac{15}{32}''$ x $1\frac{9}{16}''$
1D7-G	1A6	—	G-7Z	$4\frac{15}{32}''$ x $1\frac{9}{16}''$
1E7-G	§	—	G-8C	$4\frac{1}{8}''$ x $1\frac{9}{16}''$
1F5-G	1F4	—	G-6X	$4\frac{5}{8}''$ x $1\frac{13}{16}''$
1F7-G	1F6	—	G-7AD	$4\frac{15}{32}''$ x $1\frac{9}{16}''$
1H4-G	30	—	G-5S	$4\frac{1}{8}''$ x $1\frac{9}{16}''$
1H6-G	1B5/25S	—	G-7AA	$4\frac{1}{8}''$ x $1\frac{9}{16}''$
1J6-G	19*	—	G-7AB	$4\frac{1}{8}''$ x $1\frac{9}{16}''$
5V4-G	83-v	—	G-5L	$4\frac{5}{8}''$ x $1\frac{13}{16}''$
5X4-G	5Z3	—	G-5Q	$5\frac{5}{16}''$ x $2\frac{1}{16}''$
5Y3-G	80	—	G-5T	$4\frac{5}{8}''$ x $1\frac{13}{16}''$
5Y4-G	80	—	G-5Q	$4\frac{5}{8}''$ x $1\frac{13}{16}''$
6A8-G	—	6A8	G-8A	$4\frac{15}{32}''$ x $1\frac{9}{16}''$
6C5-G	—	6C5	G-6Q	$4\frac{1}{8}''$ x $1\frac{9}{16}''$
6F5-G	—	6F5	G-5M	$4\frac{15}{32}''$ x $1\frac{9}{16}''$
6F6-G	—	6F6	G-7S	$4\frac{5}{8}''$ x $1\frac{13}{16}''$
6H6-G	—	6H6	G-7Q	$4\frac{1}{8}''$ x $1\frac{9}{16}''$
6J7-G	—	6J7	G-7R (6J7-G)	$4\frac{15}{32}''$ x $1\frac{9}{16}''$
6K5-G	See data below		G-5U	$4\frac{15}{32}''$ x $1\frac{9}{16}''$
6K6-G	41	—	G-7S	$4\frac{1}{8}''$ x $1\frac{9}{16}''$
6K7-G	—	6K7	G-7R (6K7-G)	$4\frac{15}{32}''$ x $1\frac{9}{16}''$
6L6-G	—	6L6	G-7AC	$5\frac{5}{16}''$ x $2\frac{1}{16}''$
6L7-G	—	6L7	G-7T	$4\frac{15}{32}''$ x $1\frac{9}{16}''$
6N7-G	—	6N7	G-8B	$4\frac{5}{8}''$ x $1\frac{13}{16}''$
6Q7-G	—	6Q7	G-7V	$4\frac{15}{32}''$ x $1\frac{9}{16}''$
6R7-G	—	6R7	G-7V	$4\frac{15}{32}''$ x $1\frac{9}{16}''$
6X5-G	—	6X5	G-6S	$4\frac{1}{8}''$ x $1\frac{9}{16}''$
25A6-G	—	25A6	G-7S	$4\frac{5}{8}''$ x $1\frac{13}{16}''$
25B6-G	See data on page 12		G-7S	$4\frac{5}{8}''$ x $1\frac{13}{16}''$
25Z6-G	—	25Z6	G-7Q	$4\frac{1}{8}''$ x $1\frac{9}{16}''$

* Except that filament current is 0.24 ampere. § Two 1F4's in the same bulb.

NOTE: Certain G-types have an internal shield which is brought out to Pin No. 1. Socket connections for such types designate Pin No. 1 as SHIELD. For G-types without SHIELD connections, Pin No. 1 is marked NC. Other symbols on socket diagrams are explained in the KEY TO TERMINAL DESIGNATIONS OF SOCKET CONNECTIONS on page 12.

RCA-6K5-G: Similar to triode section of 6Q7.

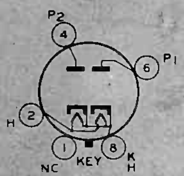
Characteristics:

Heater Voltage	6.3	6.3 a-c or d-c	Volts
Heater Current	0.3	0.3	Ampere
Plate Voltage	100	250	Volts
Grid Voltage	−1.5	−3	Volts
Amplification Factor	70	70 approx.	
Plate Resistance	78000	50000 approx.	Ohms
Transconductance	900	1400	Micromhos
Plate Current	0.35	1.1	Milliamperes

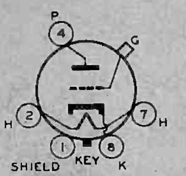
SOCKET CONNECTION DIAGRAMS ARE SHOWN ON THE NEXT PAGE.

SOCKET CONNECTIONS FOR G-TYPES

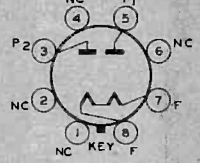
BOTTOM VIEWS



G-5L



G-5M



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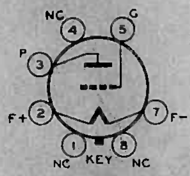
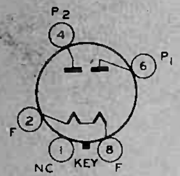


G-5S



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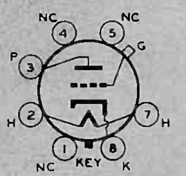

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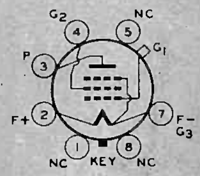

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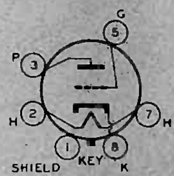
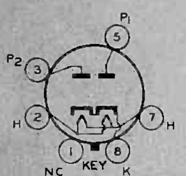


G-6Q



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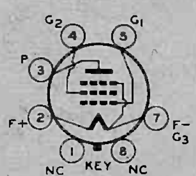

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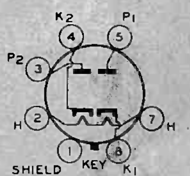

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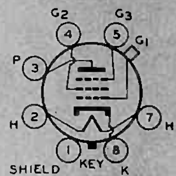
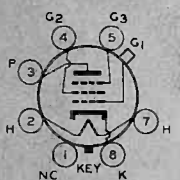
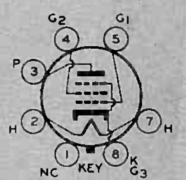


G-7R(6J7-G)



G-7R(6K7-G)



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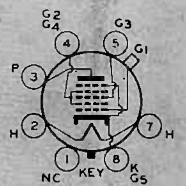

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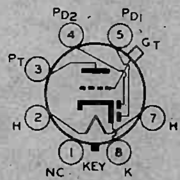

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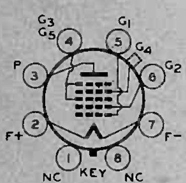

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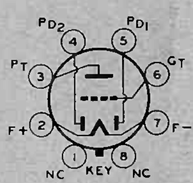

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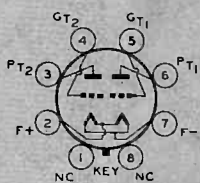

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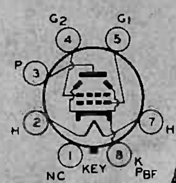

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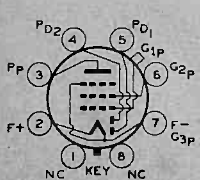

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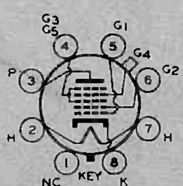

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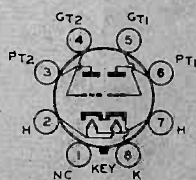

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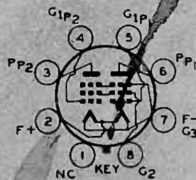

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