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LESSON TRA - 1

A. C. PRINCIPLES

PART 1

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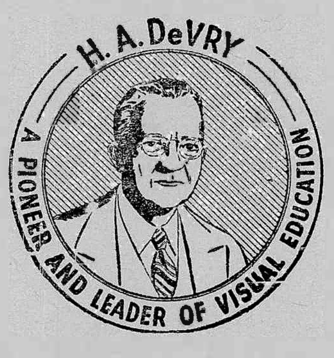

TUBES - RECEIVERS - AMPLIFIERS

Lesson 1

A. C. PRINCIPLES

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The secret of success is actually not a secret. It is a simple matter of hard work, concentration and ability. There has never been any question about there being room at the top in any profession or in every line of business. Your problem is how to get there. There are always a few in business who stand near the top but there are always a greater number at and near the bottom. Should you fail to ascend, the fault is not in your luck, but in yourself.

-- Daniel Willard

A.C. PRINCIPLES

In the Radio Fundamental Section of this training program, most of the explanations were based on direct current, D.C., because its actions form the foundation for all of the advance subjects. For those circuits carrying a uniform value of direct current, there are but three factors to consider, Voltage, Current and Resistance with a relationship expressed by Ohm's Law.

The effects of variations in the value of the direct current were brought out in the Lessons on Induction and Condensers while, in the Lesson on Current Generation, the explanations included a few principles of alternating current. As all Radio Energy, as well as most Signals, are alternating, for this Lesson we are going to continue our explanations of A.C. and will start with a brief review.

To begin, in the earlier Lessons you learned that an E.M.F. is induced in a conductor whenever it cuts, or is cut by, magnetic lines of force. Then we showed how a loop of wire, like Figure 1 of this Lesson, can be revolved in a magnetic field to provide an induced E.M.F. or what is commonly considered as a Voltage.

However, as the loop is turned, the induced voltage changes in value from "O", when its sides are moving parallel to the flux, to maximum, when they cut the flux at right angles.

Tracing the action for one complete turn of the loop, we find that the induced voltage rises from "O" to its highest value in the first quarter turn and then drops back to "O" in the second quarter turn. In the third quarter turn, the induced voltage rises again to its highest value but is in the opposite direction because the sides of the loop are passing magnetic poles with a polarity opposite to that of the first quarter turn. In the last quarter turn, the voltage again drops to zero and the loop is back to its starting position.

To show graphically, the relative strength, or value of induced voltage for all parts of a complete turn of the loop, it is customary to lay out or plot a curve on the plan of Figure 2.

DIFFERENCE BETWEEN A.C. AND D.C.

When the loop of Figure 1 is equipped with slip rings, connected to the external circuit by brushes, the change of direction of the induced E.M.F. will cause a like change of direction in the current. The current will go first one way, then the other, or alternate, therefore, we call it "Alter-

nating". As a definition, we can say that direct current is a current of electricity that passes always in the same direction through a conductor.

Alternating current is a current of electricity which, at regular intervals, reverses its direction in a conductor.

A SIMPLE ALTERNATOR

The single coil of wire of Figure 1, with a slip ring connected to each end and revolving in a magnetic field, is called a simple Alternator. In general you can think of an Alternator as an electric generator that supplied its external circuit with alternating current.

CYCLES

In the study of alternating current, the word "cycle" is used very often and we want you to understand its meaning clearly before going further.

You can think of a cycle as a series of events which take place over and over again in regular order. The days of a week, months or seasons of the year are cycles. Take the seasons for example.

Starting in the summer, we pass through fall, winter and spring which brings us back to summer when we start all over again.

If you have ever studied or worked on gasoline engines, you know the series of events which take place in each cylinder. First, intake, second, compression, third, power and fourth exhaust. Those four events complete the cycle and if it requires four strokes of the piston to complete the four events, we have a "Four Cycle" engine.

Here, for each revolution of the simple alternator of Figure 1, the E.M.F. will start at 0, rise to its highest value, fall back to 0, rise to its highest value in the opposite direction and then drop to 0 again. This same series of events happen over and over, once for each revolution as the loop is turned and, like the series of events in the gasoline engine cylinder, they are called a cycle.

Get all of these events clearly in mind, by studying Figure 2 because, in our explanations of the actions of alternating current, we are going to use more curves or graphs.

For convenience in measuring, we divide a circle into 360 equal parts called degrees and, as a simple alternator pro-

duces one cycle for each complete revolution, we divide an electrical cycle into 360 degrees also.

The curve of Figure 2 represents the value of the induced E.M.F. for one cycle of 360 degrees and its length is shown by the arrow C. At 90 degrees, the voltage has reached its highest value and at 180 degrees is back to 0 again. At 270 degrees it is again at its highest value in the other direction and at 360 degrees, the end of the cycle, is back to 0 once more.

FREQUENCY

Remembering that each revolution of the loop of Figure 1 completes one cycle, the length of time required for each cycle will depend on how fast the loop is turned. For example, if the loop is driven at a speed of 1000 revolutions per minute, it will produce 1000 cycles a minute. The number of cycles that occur in a given time is called the "Frequency" of the current or voltage so that here, the frequency will be 1000 cycles a minute.

In practical Electrical and Radio work, much higher frequencies are used and one second istaken as the standard length of time. The ordinary 110 volt A.C. used for house lighting circuits has a frequency of 60 cycles. That means there will be 60 complete cycles each second or the induced E.M.F. and the current it causes will rise to their highest values in each direction, 60 times each second.

To produce this frequency, the simple loop of Figure 1 will have to turn at the rate of 60 revolutions a second. There are 60 seconds to a minute therefore, a speed of 60 revolutions a second will be 60 times 60 or 3600 revolutions per minute.

For all Radio and other Electronic work, frequency means the number of cycles per second.

ALTERNATIONS

Going back to Figure 2 again, you can see a cycle is made up of two parts which are exactly alike but one is above and the other is below the base line. Each of these parts is called an "Alternation" and curves are drawn this way to show the reversal of direction. Thus, a cycle is made up of two alternations and the 60 cycle A.C. we mentioned a minute ago has 2 times 60 or 120 alternations a second.

Just go back and read those figures over again, because at first glance, they may be somewhat difficult to grasp.

Suppose you had a circuit a mile long and were using 60 cycles a-c. The direction of current here would have to change 120 times a second and while it sounds pretty fast, you must remember that under the proper conditions electricity has the ability to travel at the rate of 186,000 miles a second.

PHASE

Another term, commonly used with alternating current, is Phase. Any point of a cycle is called a certain phase. Take the cycle of Figure 2 for instance, where the curve starts at "0" over at the left and rises to its highest point at 90 degrees.

Where the 90 degree line crosses the curve is the 90 degree phase, marked by the arrow "P-90". Coming down to the point where the curve crosses the 45 degree line, we have the 45 degree phase, marked by the arrow "P-45".

We do not have to stop at any particular line however because any point of the cycle is a phase. For example, in Figure 2 we show also the 30 degree, 60 degree, 150 degree and 300 degree phase with arrows and, in each case, have drawn a broken line to the base to show their position in degrees.

The main point we want you to remember here is that the degrees are measured along the zero, or horizontal line and not along the curve. The 30 degree phase is directly above a point one third of the distance between 0 and 90 degrees as shown by the dotted line. Keep this in mind because we will have more to say about it later.

If the voltage, represented by the curve of Figure 2, has a frequency of 60 cycles, then arrow "C" represents one sixtieth of a second and arrows "A" and "B" are one, one hundred and twentieth of a second. However, all the cycles are exactly the same and in Figure 3 we have continued the curve for two complete cycles.

The arrows "A", "B" and "C" are the same as those of Figure 2, and again A and B show the alternations while C shows the cycle. For the second 360 degrees, we again have the same series of events and show the alternations by arrows "A1", "B1", and the cycle of "C1".

Thinking of the usual 60 cycle alternating current, the curve of Figure 3 would have to be continued for 60 times the length of arrow C to show the action for one second unit but, as all cycles are alike, you will seldom find a curve longer than that of Figure 2.

We want you to notice that arrows C2, C3 and C4, are also complete cycles. From 0 to 360 degrees, or for arrow C, the curve starts at 0, rises to its highest value, drops to 0, reverses, rises to its highest value and drops to 0 again, when the action is repeated.

Now, if you start at 90 degrees and trace through to 450 degrees, you will pass through all the events and therefore arrow C2, also represents one complete cycle.

In the same way, arrow C3 again shows a complete cycle because it covers 360 degrees and includes all the events. No matter at what phase you start, by following the curve, for 360 degrees, you will pass through one complete cycle.

For a curve of this type, a cycle includes the part between any two points such that, at these points, the curve is the same distance from the base, or 0, line and going in the same direction.

MAXIMUM VALUES

Going back to Figure 2, as the curve represents the value of the induced E.M.F. for one cycle, you can see it not only changes direction, but also keeps changing in value.

At 90 degrees and again at 270 degrees the curve is at the greatest distance from the base line and represents the highest voltage. We call these high points "Maximum", and the amount of E.M.F. at that phase is the "Maximum Value".

Don't let the word scare you as maximum means largest or greatest and, as the maximum value of the induced voltage lasts for but a very short fraction of the complete cycle, it is not used very much in regular everyday work. It is important only in that the insulation of the circuit will have to withstand this highest voltage.

AVERAGE VALUES

Looking at the curve of Figure 2 in another way, for the first 180 degrees, the voltage starts at 0, rises to maximum at 90 and then drops to 0 again. Taking this 180 degrees, or alternation, as a whole, the value of the E.M.F. will not be 0, nor will it be maximum, but will be somewhere in between for what is known as the Average Value.

You can think of an average value like this. Suppose you study 2 hours on Monday night, 1 hour on Tuesday, 3 hours on Wednesday, do nothing on Thursday but come back strong with 4 hours on Friday. For the five days you have put in

a total of 10 hours study. You then take the 10 hours and divide it by the 5 days which gives you an average of 2 hours study each day.

In Figure 4, we again have the curve of Figure 2 but, to find out more about the actual values at the different phases, have drawn the scale over at the left. To make the figures simple, we start with 0 at the base line and go up to 100 for the maximum value.

To find the value at any phase we simply draw a vertical line, up to the curve, and from the point they cross, draw a horizontal line over to the scale. For example, half way between the 20 and 40 degree lines we drew the broken line up to the curve and from there, the horizontal line passes through the 50 mark on the scale. From this, you can see that with a maximum value of 100 at 90 degrees, the value at the 30 degree phase will be 50.

To find the average value of the induced voltage, we simply take the values at different phases, or points, and then average them up. The values at different points are called Instantaneous Values and their average is .636 of the Maximum Value.

While it requires some higher mathematics to figure this out exactly, the curve of Figure 4 will give you a good idea. Taking the values, as shown by the broken lines, we have the following.

PHASE		VALUE
10 degrees	-	16
30 "	-	50
50 "	-	76
70 "	-	94
90 "	-	100
110 "	-	94
130 "	-	76
150 "	-	50
170 "	-	16

To find the average we simply add the values and divide by 9 because there are nine phases given. Adding, the total value is 572 and dividing by 9, the average is 63.55. While this value is a little low, it shows how the correct value of 63.6 is found.

As a general rule, no matter what the actual figures may be "Average Value equals Maximum Value times .636".

EFFECTIVE VALUES

Going back to the early Lessons again, you will remember that according to Ohm's Law, Current equals Voltage divided by Resistance. Then, if the alternating voltage, shown by the curve of Figure 2 was connected to a circuit, the current would vary the same as the E.M.F.

To illustrate, we will imagine the alternator of Figure 1 is connected across a circuit which contains nothing except resistance. By that we mean there are no coils to produce a self induced E.M.F. and no capacity to charge and discharge. Under these conditions, the current will vary with the voltage and at 0 degrees, with no E.M.F. there will be no current, at 90 degrees, with maximum voltage, there will be maximum current, and at 180 degrees both will be at 0 again.

Under these conditions, the current and voltage will be in Phase, and you can think of the curve of Figure 2 as showing the values of current for one cycle. Like the voltage, the average value of the current will be .636 of the Maximum.

Current is measured in amperes and you will remember that one coulomb per second equals one ampere. In other words, an ampere is the unit of measure for a steady rate of flow but, for each cycle, alternating current is not steady, it keeps changing in value and also changes direction.

Instead of setting up a new unit for measuring this alternating current, we use the ampere and therefore, in some way must find out how much alternating current is equal to an ampere of direct current. Like all other electrical measurements, here again we will have to compare the effects and find out how much alternating current it will take to produce the same effect as one ampere of direct current.

In order to do this, we compare the heating effects of the two currents and consider them the same when, under the same conditions, they produce the same heating effect. We have already explained the maximum and average values for alternating current and you may think that the average value will hold good here but it does not work out that way. The heating effect can not be measured in current alone because it requires voltage to force current through a resistance or circuit. In other words, it requires power to heat a conductor and power is measured in Watts.

You know Volts times Amperes equal Watts or as a formula

$$W = E \times I$$

As we are not interested in the voltage, we go back to Ohm's Law which states, Volts equal Amperes times Ohms or, as a formula,

$$E = I \times R$$

It is a generally accepted fact that things equal to the same thing are equal to each other therefore if E equals "I x R" we can use that value instead of E in the first formula.

Making these changes, or to be more correct, "substituting this value", the formula for watts can be written,

$$W = (I \times R) \times I$$
$$W = I \times I \times R$$
$$W = I^2R$$

To find the value of watts in terms of current and resistance, the value of current has to be multiplied by itself, which we called "Squared" and show by the small figure 2, written above and to the right of the letter I. If we use the same circuit for both the direct and alternating current, the resistance will be the same, therefore we can forget it and say the heating effect will be proportional to the square of the current.

To find the value of direct current that will have the same heating effect as the current of one alternation, we will first have to square the values at the different phases. Taking those we used for finding the average value, we have-

PHASE	VALUE	CURRENT SQUARED
10 degrees	16	16 x 16 = 256
30 "	50	50 x 50 = 2500
50 "	76	76 x 76 = 5776
70 '	94	94 x 94 = 8836
90 "	100	100 x 100= 10000
110 "	94	94 x 94 - 8836
130 "	76	76 x 76 = 5776
150 "	50	50 x 50 = 2500
170 "	16	16 x 16 = 256

Adding these values, we find a total of 44,736 and, dividing by 9 as before, arrive at an answer of 4971. As previously explained, this is the average but, as the original values were equal to the "Current Squared", we call it the "Mean Square".

Then, to find the average or "mean" value of current we extract the square root of the mean square to find the "Root Mean Square". (R.M.S.). The square root of 4971 works out to 70.5 which is a little low because, had all the instantaneous values been included in the calculations, the R.M.S. value would have been 70.7 amperes.

In other words, the alternating current of the first alternation of Figure 4, with a maximum value of 100 amperes, will have the same heating effect as 70.7 amperes of direct current. Therefore we call this the "R.M.S.", effective, or virtual value of the alternating current and it is the value which most A.C. meters are calibrated to read.

As a general rule, no matter what the actual figures may be, "Effective Value equals Maximum Value times .707".

The things for you to get clearly in mind are the Maximum, Average and Effective values of alternating Voltage and Current and their relation to each other. We have already told you that the Average values are .636 of the maximum and the Effective values are .707 of the maximum. In the form of formulas we can write.

Average value equals .636 times Maximum value, or
Maximum value equals 1.57 times Average value.

Effective value equals .707 times Maximum value, or
Maximum value equals 1.414 times Effective value.

Average value equals .901 times Effective value, or
Effective value equals 1.11 times Average value.

Suppose we connect an Ammeter in an A.C. circuit and obtain a reading of 10 amperes.

We know the 10 amperes is the effective value and according to the formulas above, the maximum value is 1.414 times the effective value which will be 1.414 times 10 or 14.14 amperes.

The average value equals .636 times maximum or .636 times 14.14 which is 8.99 or approximately 9 amperes. We also have a formula which states that Average value equals .901 times Effective value. Using this, we have .901 times 10 amperes which is 9.01 or approximately 9 as before.

The reason that these last two do not agree exactly is because the figure 1.414 is not absolutely correct.

For usual figuring, 1.414 will be close enough for the square root of 2, while for many calculations, the value of 1.4 is sufficiently accurate.

Right now, you may not see much sense to all of this but, like many of the rules we explained in the early Lessons, these figures will be necessary as we go along with our alternating current explanations. Learn them now, and you won't have to come back later on.

SINGLE PHASE

The word phase, as we explained in the early part of the Lesson, means any point of the cycle but it is used in other ways with alternating current circuits. Sometimes the wires of the circuit are called phases and there are other common expressions therefore, if we use the word in some places where it does not check up with our first meaning, remember that this first explanation is the correct one.

The simple alternator of Figure 1, when the armature is revolved, produces an alternating emf and when a circuit is completed across the brushes, it will cause an alternating current in the circuit. As far as the actual connections are concerned, they are the same as for the simple generator, with each side of the circuit connected to a brush.

We call this a single phase system because, at any point in the revolution of the loop, there is but one value of voltage or current. Most of the lighting circuits in use today are Single Phase, connected like the direct current circuits we have explained. For a-c power, there are also Two Phase and Three Phase circuits which require more than two wires. However, at this time we are interested mainly in a-c principles and therefore, for the next Lesson will continue our explanations of this subject.

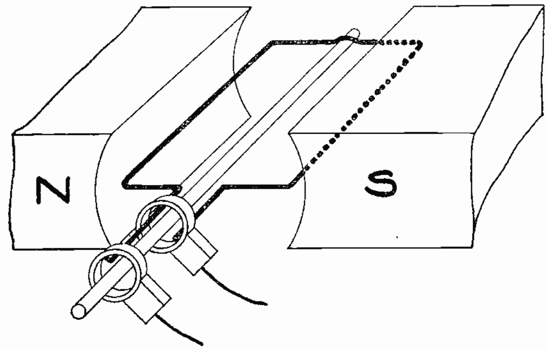

FIGURE 1

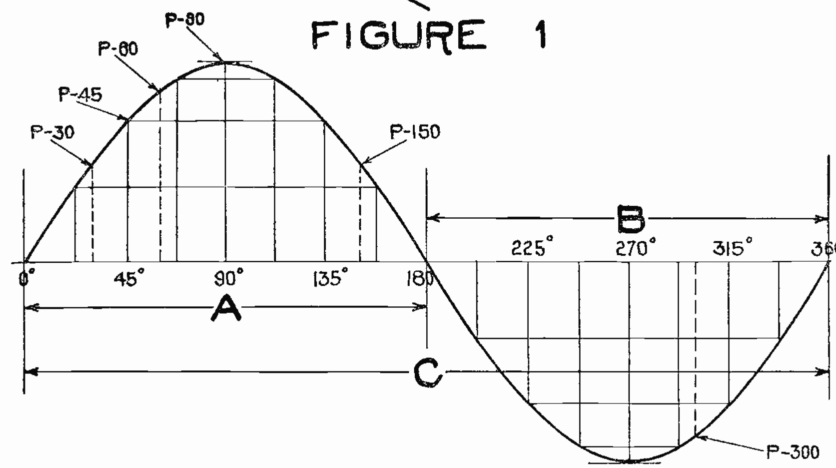

FIGURE 2

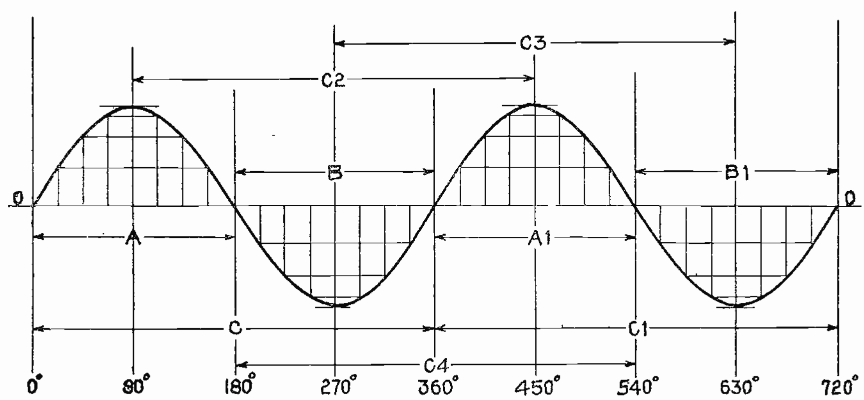

FIGURE 3

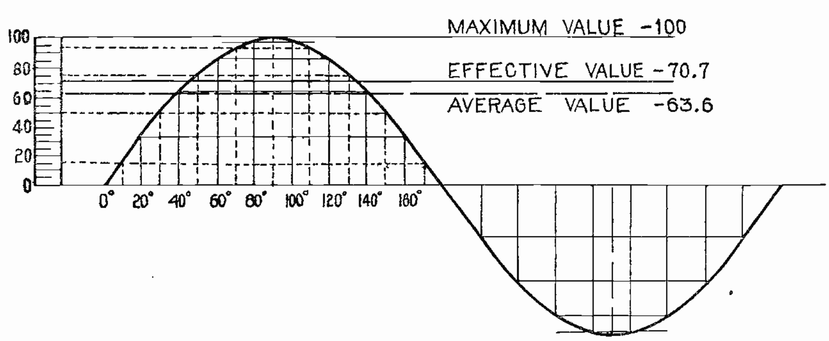

FIGURE 4

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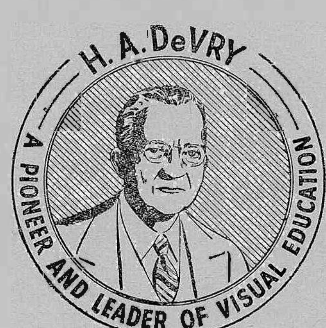

TUBES - RECEIVERS - AMPLIFIERS

Lesson TRA-2

A-C PRINCIPLES

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You want a better position than you now have in business, a better and fuller place in life. All right; think of that better place and you in it as already existing. Form the mental image. Keep the image constantly before you, and-- no, you will not suddenly be transported into the higher job, but you will find that you are preparing yourself to occupy the better position in life -- your body, your energy, your understanding, your heart will grow up to the job -- and when you are ready, after hard work, after considerable preparation, you will get the job and the higher place in life.

-- Joseph H. Appel

The various values and actions of alternating current are usually a little hard to keep clearly in mind, therefore, as a short review, we will go through them once more.

A. C. TERMS

You will remember how alternating current is continually changing in value and reverses its direction at regular intervals. As these events take place in regular order we call each complete change a cycle.

For each cycle the voltage or current starts at zero, rises to maximum in one direction, drops back to zero, rises to maximum in the other direction and drops back to zero.

A complete cycle is made up of two like parts each of which we call an "Alternation". From zero to maximum to zero is one alternation and from zero to maximum to zero in the opposite direction is the other alternation.

Another common A.C. term, "Frequency" is used to denote the number of cycles per second. For example, the ordinary lighting circuits have a frequency of 60 cycles which means there are 60 complete cycles or 120 alternations every second.

You will hear the word "Phase" used a great deal and we want you to remember it simply means some certain point of a cycle. It usually has some explanation to show what point is meant. Thus we might say the "45 degree" or "90 degree" phase and would mean that point of the cycle 45 or 90 degrees from the zero line.

When we say that two currents, or the voltage and current, are in phase we mean that, when varying in the same direction, they both reach their maximum and zero values at the same instant. While the values need not be equal, they must occur at the same instant in order to be "in phase".

"Difference in Phase" or "Phase Displacement" simply means the number of degrees of the cycle between the maximum or the zero values of two currents, two voltages or voltage and current.

A.C. VALUES

In order to measure alternating current, with direct current units, there are several points to keep in mind.

During each alternation, the values change from zero to maximum and back to zero and the highest point reached

is called the "Maximum" value, while that at any point or phase is known as the "Instantaneous" value.

As the instantaneous values keep changing, we average them up for an alternation or cycle and find the "Average Value" to be .636 of the Maximum.

To use the direct current units of Volts and Amperes however, we compare the heating effects of A.C. and D.C. and find what we call the "Effective Values". The effective values are those which are always used, unless the others are named, and are equal to .707 of the maximum.

To sum this all up we will repeat the formulas.

Average Value equals .636 Maximum Value
Maximum Value equals 1.57 Average Value
Effective Value equals .707 Maximum Value
Maximum Value equals 1.414 Effective Value
Effective Value equals 1.11 Average Value
Average Value equals .9 Effective Value

VECTORS

On account of the constant change of A.C. values, we often work out the various actions by means of graphs that are made up in two general ways. One of these we have already shown and explained in the various curves and the other is by means of "Vectors".

By definition, a vector is a straight line of definite length, drawn from a given point in a given direction therefore, it can represent various values, such as voltage and current, which have both amplitude and direction.

To determine the proper length of a vector, we draw a scale on the plan of the upper part of Figure 1, in which each inch or fraction of an inch, represents a definite numerical value. This is exactly the same plan used for the "Scale of Miles", drawn in one corner of most maps. To find the distance between any two cities, towns or other points on the map, you measure the number of inches between them and then checking on the scale, find how many miles are represented by the measured inches.

Following this idea, vector "A" of Figure 1 represents an amplitude or magnitude of 50 volts because its length is equal to 50 divisions of the scale. In the same way, vector "B" represents 30 volts because its length is equal to 30 divisions of the scale.

As drawn in Figure 1, approximately 3/8 of an inch represents 10 volts on the scale therefore, as 5 x 10 volts equal 50 volts, vector A is 5 x 3/8 = 15/8 = 1 7/8 inches long while vector B, representing 30 volts, is 3 x 3/8 = 9/8 = 1 1/8 inches long.

There is no definite rule about the size of the scales and you can make them to suit your own needs. The one thing to remember however is that you must make all the vectors in any diagram to the same scale. For example, if you decide to let one inch represent 100 volts or 100 amperes but find one of the vectors too long, you will have to make a new scale and shorten them all.

Vectors A and B are drawn as arrows to indicate their direction. Thus, if we assume the arrowhead is positive, then the 50 volts, represented by vector A is in the opposite direction, or of opposite polarity, to the 30 volts represented by vector B. As you will learn a little later, vectors are drawn at definite angles to each other or to some common line used as a reference. In addition to being drawn at some definite angle, we assume a vector can rotate around a center as shown at the left of Figure 2.

Here, we have drawn vector AB of a length which represents the maximum value of induction in the rotating coil of a simple generator. The end at "A" is the center and, a horizontal line drawn through "A" will be considered as the base line or zero axis. The position of the vector can be stated as the angle it makes with the base line.

As the vector is rotated, the relative strength, of the instantaneous values of induction, can be found by drawing a line, at right angles to the base, through the outer or "B" end of the vector. This is shown by line "BC" of Figure 2 and the instantaneous value of induction, at any position of the vector, will compare to the maximum value of induction as the length of line BC compares to the length of Vector AB.

Still thinking of vector AB as the maximum value of induction in the loop of a simple generator, it will have to make one complete turn for each complete cycle. The frequency of the generated A.C. will depend on the time required for each cycle and that, in turn, will depend on the speed at which the vector, or loop it represents, is revolved. Regardless of the frequency, each complete cycle will consist of 360 electrical degrees which, in this case, coincides with one complete revolution of 360 mechanical degrees.

To follow the action for one cycle, we extend the zero axis from A through DE and divide it in equal parts which represent a certain number of degrees. Saying it in another way, for distances along the line DE represent the time it takes for the revolving vector to move the indicated number of degrees.

The vertical lines are called "Ordinates" and by projecting the position of the outer end of the vector over to these lines, we can find the instantaneous values. As shown in Figure 2, vector AB is in the 45 degree position, giving an instantaneous value proportional to BC. By projecting over to the 45 degree ordinate, we can lay off this same value.

Then, by projecting the different positions of the end of the revolving vector, over to the proper ordinates, and joining these projections with a line, we have a curve like those already explained in your earlier Lessons. To make a little easier to follow, by dotted lines we show the 315 degree position of the vector and its projection.

In general, rotating vectors always represent maximum values, but effective values can be shown in other kinds of vector diagrams.

REFERENCE LINES

Before any vectors are laid out or plotted on a diagram, we usually draw two lines at right angles to each other and call them "Reference Lines". In Figure 3, for example, we drew the horizontal line x-x and then the vertical line y-y. With these in place, we can easily locate or plot the vector AB of Figure 2, because we know its position in degrees and can measure from the reference lines.

ANGLES

As we explained for Figure 2, a vector can be revolved around a center but there are several more points we want to explain about this type of diagram.

In this connection we want to remind you once more that a complete circle is divided into 360 equal parts called degrees and these degrees are divided into 60 parts called minutes. However, many problems are worked out by dividing the degrees into decimals instead of minutes.

We can, of course, carry the vector of Figure 4 around for a complete circle the same as we did for Figure 2 with the position on the reference line x-x as the starting point, or the Initial line. Starting with line x-x and revolving the vector to the position AC, as shown by the

curved arrow, we say that an angle has been generated.

Going around this circle anti-clockwise, the reference lines divide it into four parts, called quadrants, identified by the numbers shown. With the line AB turned to position AC of Figure 4, we have generated an angle and, as AC is in quadrant 2, we say the angle is in the second quadrant.

For your work here, you can think of the values, represented by vectors in quadrants 1 and 2 as positive and those in quadrants 3 and 4 as negative. Or if you want to think of the line x-x as being 0 degrees, usually written "0°", then all angles from 0° to 90° will be in the first quadrant, angles from 90° to 180° will be in the second quadrant, angles from 180° to 270° will be in the third quadrant and angles from 270° to 360° will be in the fourth quadrant.

With these things in mind, let's look at Figure 5 where we have the line AB rotated to position AC through an angle that we will call ϕ or phi. The distance AD on the line AC is the length we are interested in, therefore we drew a line down from D at right angles to the line AB and the point these lines cross is marked E. That gives us triangle A-D-E and, as the line DE was drawn at right angles to AB, the angle at E is 90° which makes a right angle triangle.

TRIGONOMETRIC FUNCTIONS

Looking again at Figure 5, which is similar to the left part of Figure 2, line AB is the initial or starting line and therefore, line AE is called the "Base" of the triangle. Line DE, at right angles to the base, is the "Altitude" while line AD is the "Hypotenuse".

As line AB is rotated around point A, point D will trace a path as shown by the circular line. Starting in the position AE, the angle at A will increase as line AC is rotated for the 90 degrees of the first quadrant. Lines drawn from point D, at right angles to AB, like line DE of Figure 5, will increase in length as the angle at A increases and, for any given angle at A, line DE will have some definite length in respect to the length of Line AD.

In Trigonometry, we think mainly of a triangle, such as ADE, and the fraction which is found by dividing the length of line DE by the length of the line AD is known as the "sine" of the angle at A.

To use more general terms, DE is the side opposite the angle at A, AE is the side adjacent while AD is the hypotenuse as explained before. Thus, we can state that the sine of an angle is equal to the side opposite divided by the hypotenuse.

As the angle at A increases and side DE becomes larger, as long as the 90° angle is maintained at E, side AE will become shorter and thus, for each angle at A, there will be a definite ratio between the length of lines AD and AE. This ratio is known as the "cosine" of the angle and is equal to the side adjacent divided by the hypotenuse.

With the length of lines DE and AE both varying in respect to line AD, for every angle at A, there will be a definite ratio between their lengths. This is known as the tangent of the angle and is equal to the side opposite divided by the side adjacent.

These we call the functions of the angle and you will usually see them written "sin" for sine, "cos" for cosine and "tan" for tangent.

Thus, for the angle at "A", Figure 5, we can write: -

$$\text{Sin } A = \frac{DE}{AD}$$

$$\text{Cos } A = \frac{AE}{AD}$$

$$\text{Tan } A = \frac{DE}{AE}$$

To list all possible ratios of the lengths of the sides of the triangle, to the functions listed above, we can add: -

$$\text{(Cosecant)} - \csc A = \frac{AD}{DE}$$

$$\text{(Secant)} - \sec A = \frac{AD}{AE}$$

$$\text{(Cotangent)} - \cot A = \frac{AE}{DE}$$

The easiest way to remember these last three is that

$$\text{Cosecant} = \frac{1}{\text{sine}}$$

$$\text{Secant} = \frac{1}{\text{cosine}}$$

$$\text{Cotangent} = \frac{1}{\text{Tangent}}$$

Going back to Figure 2, each instantaneous value will be equal to the value represented by vector AB times the sine of the angle at A! That is why the right half of Figure 2 is called a "Sine Wave" or "Sine Curve".

The size of the triangle does not change these ratios as you can prove quite easily. Close to one edge of a sheet of paper, about the size of this page, draw a line exactly 6 inches long. Then, at one end, and at right angles to this line, draw a second line 3 1/2 inches long. Compared to Figure 5, this will give you AE of six inches and ED of 3 1/2 inches.

Next, draw in line AD, across the outer ends of these lines and mark it off in inches. From each of these inch marks, draw lines, parallel to DE and down to line AE. Measuring now, you will find any of the DE lines is exactly one half as long as the distance from A to the point it crosses line AD.

Thus, for any point along line AD, the hypotenuse of the triangle is twice as long as the side opposite angle A and therefore the sine of the angle is 1/2 or .5.

The outside triangle of your sketch has a 6 inch base, a 3 1/2 inch altitude and a 7 inch hypotenuse therefore the functions of the angle, equivalent to A of Figure 5 are -

$$\sin = \frac{3.5}{7} = .5$$

$$\cos = \frac{6}{7} = .8571$$

$$\tan = \frac{3.5}{6} = .583$$

The angle is 30° and, to be accurate, the cos should be .866 and the tangent .577 but the values above are close enough to illustrate the ratios.

Moving to the angle at D, of this same triangle, the functions are -

$$\sin = \frac{6}{7} = .8571$$

$$\cos = \frac{3.5}{7} = .5$$

$$\tan = \frac{6}{3.5} = 1.71$$

Here, the angle is 60° and the more exact values are, sin = .866, tan = 1.73.

Most mathematical hand books contain tables of the functions of all angles from 0° to 90° therefore, at this time, instead of going further into their calculations, we want to give you an idea of how they are used.

Going back to Figure 2, we will assume vector AB is drawn to a length which represents 100 volts. Then, the instantaneous values will be equal to 100 volts times the sine of the angle between AB and the base line ACDE. From your sketch, the sin 30° is equal to .5 therefore, when AB is at an angle of 30° to the base line the instantaneous value will be

100 volts x sine 30°

100 volts x .5 = 50 volts

The sine of the 45° angle, shown in Figure 2, is .707 therefore, the instantaneous value will be

100 volts x .707 = 70.7 volts

For angle of 60°, the sine is .866 and thus the instantaneous value will be

100 volts x .866 = 86.6 volts

Thus, for a sine wave voltage, the instantaneous values vary as the sine of the angle between the rotating vector and the base line.

Now one thing more about a right triangle, the square of the base plus the square of the altitude equals the square of the hypotenuse. Or we can say that the hypotenuse is equal to the square root of the sum of the squares of the base and altitude.

That sounds pretty deep, but in Figure 6 we have a right angle triangle, ABC, with the 90°, or right angle at A.

The base is divided into four equal parts and the altitude is equal to three of these parts. The hypotenuse is then drawn in and is equal to five of these parts.

Now, drawing squares on each of the three sides, we find the square on the altitude contains 9 small squares, that on the base contains 16 small squares, while that on the hypotenuse contains 25 small squares.

You can see here then that the square on the base plus the square on the altitude equals the square on the hypotenuse

which checks up with what we said a minute ago.

Try this for yourself. Draw a line four inches long, and at one end draw another, at right angles to it, three inches long. You will then have the lines AB and AC of our Figure 6. Now take your ruler and measure from B to C. It should be exactly 5 inches.

Working this out by arithmetic, the 4 inch base squared equals 4 x 4 or 16, the 3 inch altitude squared equals 3 x 3 or 9. Then 16 plus 9 equals 25 which is the square of the hypotenuse.

To put this into the form of a formula we can write: -

$$\text{Hypotenuse}^2 = \text{Base}^2 + \text{Altitude}^2 \quad \text{or}$$

$$\text{Hypotenuse} = \sqrt{\text{Base}^2 + \text{Altitude}^2}$$

By simple formulas we can find any of the sides on the same idea as

$$\text{Base}^2 = \text{Hypotenuse}^2 - \text{Altitude}^2$$

$$\text{Altitude}^2 = \text{Hypotenuse}^2 - \text{Base}^2$$

SQUARE ROOT

That brings us to the job of finding the value of any of these after you know what its square is, or in other words to find the square root of a number. Although this procedure has been explained in the "Methods of Solving Problems" Lesson, the following review may be of benefit.

Suppose now that line AC, Figure 6, is 20 inches long and line AB is 15 inches long and we want to find the length of line BC. You can, of course, draw it out on paper and measure it, but you want to use the formula and work it out.

The formula says that $\text{Hypotenuse}^2 = \text{Base}^2 + \text{Altitude}^2$ and, substituting the above figures we find $\text{Hypotenuse}^2 = 15^2 + 20^2$ which can be written

$$\text{Hyp.}^2 = 15 \times 15 \text{ plus } 20 \times 20$$

$$\text{Hyp.}^2 = 225 \text{ plus } 400$$

$$\text{Hyp.}^2 = 625$$

$$\text{Hyp.} = \sqrt{625}$$

To obtain the answer here, we go ahead much like long division in arithmetic and first write down the number 625. Then, starting from the right, we draw a line after the second figure like this, 6/25. Next, we look at the left figure, which in this case is 6, and in our mind think of the largest square that will be less, or go into it. We know that 2 x 2 is 4 and 3 x 3 is 9 so that here, the square of 2 is the largest that will go into 6. So we write 2 as the first figure of the answer and the problem now looks like

```
   ) 6/25 ( 2
```

The square of 2 is written under the 6, subtracted from it and the next group of two figures brought down like this,

```
   ) 6/25 ( 2
     4
     ---
     225
```

We then multiply the answer, that we have so far, by 2 and use that as the first figure of the next divisor like this,

```
   ) 6/25 ( 2
     4
     ---
 4)  225
```

Now we see that 4 goes into the 22 of the 225 about 5 times so write in 5 as the second figure of the answer and also as the second figure of the divisor, giving us

```
   ) 6/25 ( 25
     4
     ---
45)  225
```

The 45 is multiplied by the 5 of the answer, being written under the 225 and subtracted from it. Here there is no remainder so the answer 25 is complete and the square root of 625 is 25. The complete problem will look like this,

```
   ) 6/25 ( 25
     4
     ---
45)  225
     225
     ---
```

For larger numbers the method is exactly the same but, to let you follow it through we will take the square root of 16129. Working the same as before and dividing into groups of 2 figures by starting from the right, or the decimal point, we have three groups her and there will be three figures in the answer.

```
      ) 1/61/29 ( 127
        1
  22)    61
         44
 247)    17 29
         17 29
```

The first number of the answer is 1, because the left group of figures here is only 1 and the square of 1 is 1 x 1 which of course still is 1. For the first figure of the trial divisor we took 2 times the first figures of the answer, or 2 times 1 which is 2.

That made the answer 12, so far, and for the next trial divisor we took 2 times the answer, or 2 times 12 which is 24. Then as 24 goes into 172 about 7 times, we wrote the 7 as the last figure of the trial divisor and the last figure of the answer.

VECTOR DIAGRAMS

You may be wondering how all these diagrams will help you in Radio and other Electronic work but you are going to find them of great use in your study of alternating current. However, before we take up any practical problems, we want to give you a general idea of how vectors are used and plotted.

For a simple example, at the left of Figure 7 we have a boat near a short pier and just a little way from shore. We are going to imagine there are two ropes fastened to the boat and one man, on the shore at "B", is trying to pull the boat in.

At the same time, another man, out on the pier at "C", is trying to pull the boat over that way. We will also assume that "B" is pulling with a force of 80 pounds while "C" is pulling but 60 pounds.

Our problem is to find out which way the boat will start to move and how much the total pull will be. Saying it in another way, there is an 80 lb. force or pull on the boat in the direction AB, a 60 lb. force in the direction AC, and we want to find the direction and value of the combined or "Resultant" force.

Using Vectors, as shown over at the right of Figure 7, we first decide on a scale and then lay off vector AB, parallel to AB over at the left, and of a length equal to 80 pounds on the scale. Vector AC is drawn parallel to AC at the left, but of a length equal to 60 pounds on the scale.

That gives us vectors AB and AC with a 90 degree angle at A. Then we simply draw line BD parallel to AC, and CD parallel to AB making a four sided figure with a 90 degree angle in each corner.

When all the sides are of equal length, we call the figure a square but, when two of the sides are longer, we call it a rectangle.

Next, we draw in the diagonal AD which is the answer to our problem because it shows the Resultant of the combined forces. As we explained for Figure 6, here we have a right angle triangle A-C-D, and AC equals 60 while CD is equal to AB and equals 80.

To calculate the value of AD, we can find the square root of 60 squared plus 80 squared which equals 100. However, as this is a vector diagram, we simply measure the length of AD and check up on the scale to find its value. By its position, line AD shows the direction and, by its length, the value of the combined forces of AB and AC.

The two forces may not always be at right angles to each other and should "B" walk out on the pier and pull with "C", the vector diagram will be like that at the left of Figure 8. Although we follow the plan of Figure 7, vector AB is drawn at the end of AC because they are both in the same direction. The result is the vector AD, which again shows the direction and value of the combined forces.

However, should "B" move around the other way and pull from point "X" of Figure 7, then the vector diagram will be as shown at the right of Figure 8. Here the forces are directly opposite and again the vectors are drawn in line, but the result, vector AD, is the difference of their length.

Using the values of Figure 7, vector AD at the left of Figure 8 has a value of 80 plus 60 or 140 pounds, while that at the right is equal to 80 minus 60 or 20 pounds.

In a great many vector diagrams, the forces are not either in line or at right angles but we make our diagrams on exactly the same general plan.

Suppose for example, that in Figure 7, B walked over to the left and pulled. Then, taking the vectors as before, we would draw them as shown at the left of Figure 9, with AB and AC drawn to the proper length and angle.

Here again, the result is found exactly the same as in Figure 7, CD being drawn parallel to AB and BD parallel

to AC. That makes a four sided figure with each pair of sides parallel but, as the corners are not right angles, figures of this kind are called "Parallelograms". As before, we draw the diagonal AD, from point A to the opposite corner, and it represents the resultant of the two forces.

Should B walk over to the inner end of the pier of Figure 7, then the vectors would be drawn as in the diagram at the right of Figure 9. Again BD is parallel to AC, CD parallel to AB and the diagonal AD is the resultant of the two forces.

At this time we will not bother you with the mathematical methods of finding the value and direction of the resultant force but want you to make up a few problems of your own, drawing the vectors accurately to scale and finding the results by measuring the diagonal line.

When more than two forces enter into a problem, we use the method of Figure 10. Here we have four vectors A1, A2, A3 and A4 drawn to scale and laid off in the proper directions.

Then, as shown over at the right, to find the resultant force, we lay off A1 in the same direction and length. At the end of A1, we lay off A2, at the end of A2 we lay off A3 and so on for all of them. In each case the length and direction of the vectors remain the same to make up the line A-1-2-3-4. To complete the figure, we draw in the side A4, and call it a "Polygon".

The closing side, A4 of the Polygon, indicates the value and direction of the resultant force, therefore, we draw in the line AR over at the left, the same length, and at the same angle as the closing side A4.

While the explanations of this Lesson have been of a somewhat general nature, in the following Lesson we are going to show you how these methods are applied to the various actions which occur in alternating current circuits to affect the values and phase angles of voltages and currents.

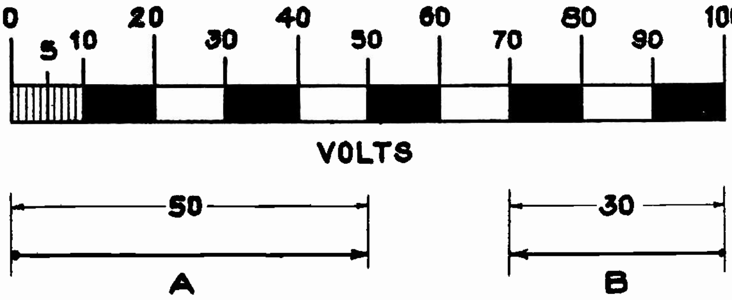

FIGURE 1

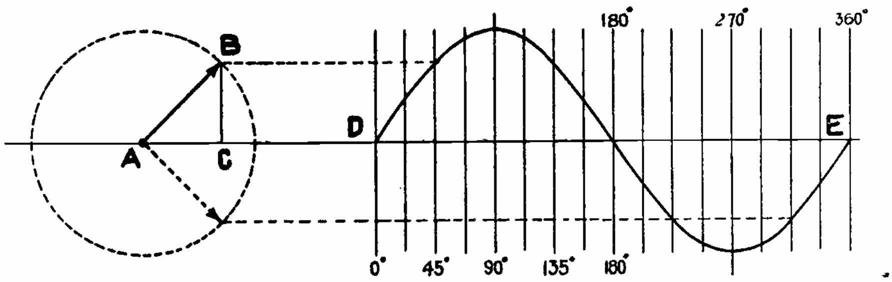

FIGURE 2

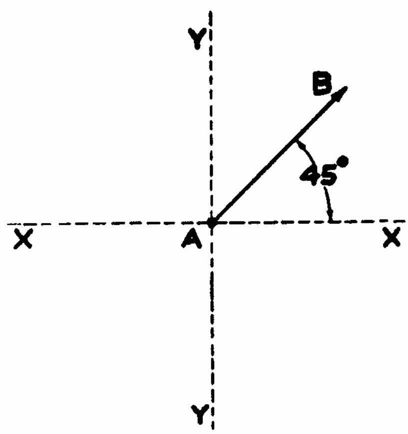

FIGURE 3

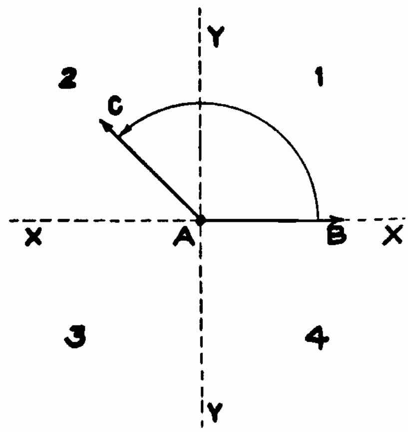

FIGURE 4

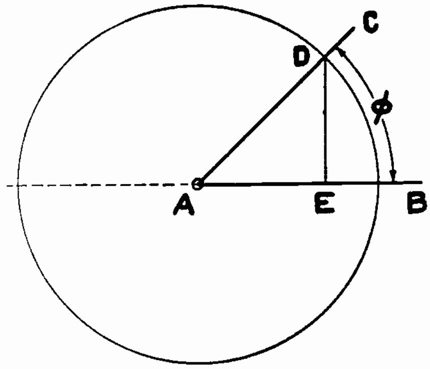

FIGURE 5

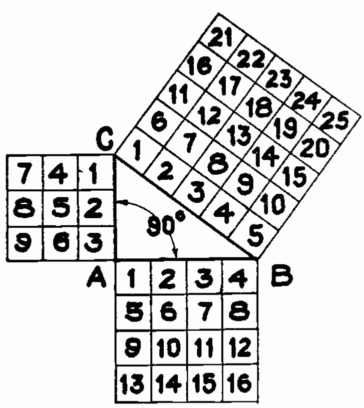

FIGURE 6

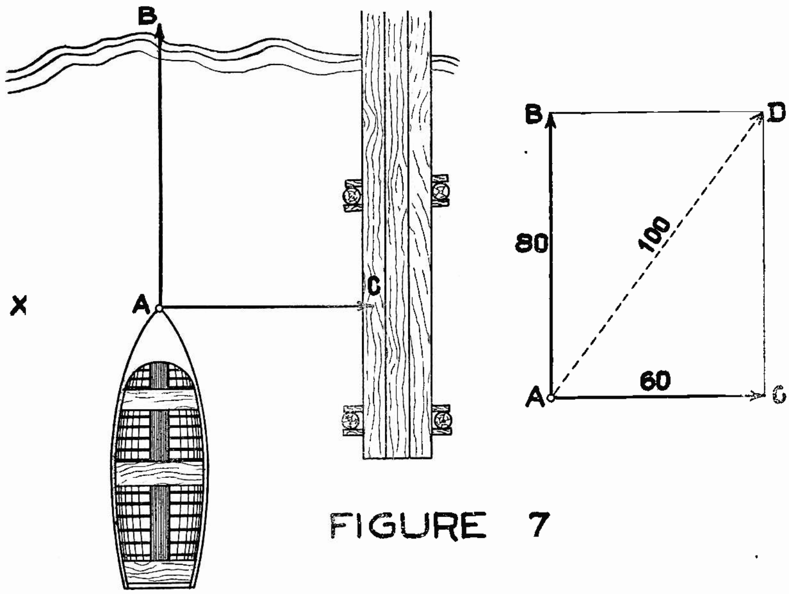

FIGURE 7

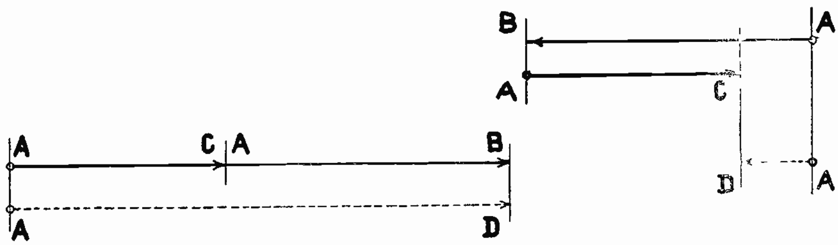

FIGURE 8

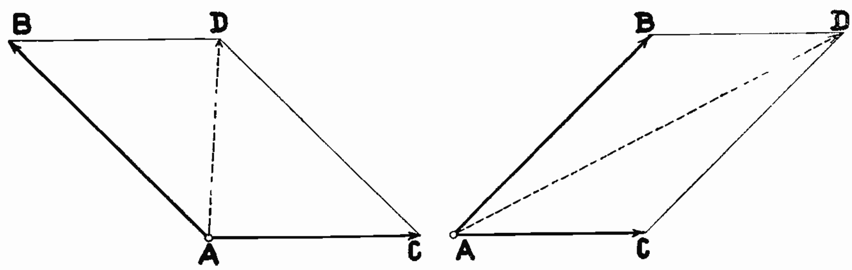

FIGURE 9

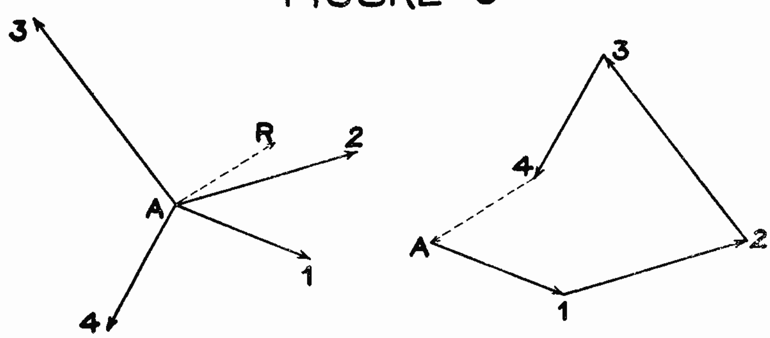

FIGURE 10

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LESSON TRA - 3
IMPEDANCE

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LESSON TRA - 3
IMPEDANCE

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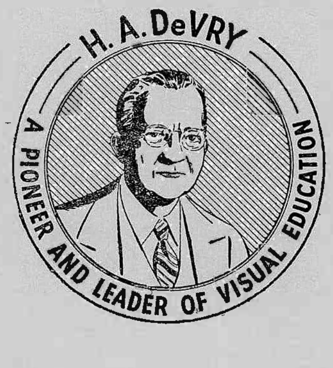


TUBES - RECEIVERS - AMPLIFIERS

Lesson 3

IMPEDANCE

* * * * *

All business as now conducted — particularly those lines of business which embrace the so called industries —— requires specialized training, in fact so much scientific knowledge that the distinctive line between "business" and "profession" is fast disappearing.

Anyone who hopes to achieve success, even the average, must know more, or at least as much, about some one thing as any other one and not only know, but know how to do — and how to utilize his experience and knowledge for the benefit of others.

There is too little idea of personal responsibility, too much of "the world owes me a living", forgetting that if the world does owe you a living, you yourself must be your own collector.

— Theodore N. Vail

In the earlier Lessons, we have explained how the voltage and current of an A.C. circuit are always changing in value and periodically reversing in direction. Thinking back over some of the direct current actions, such as Induction and the charge and discharge of a condenser, you can begin to see that the changes of current and voltage are going to have important effects on all A.C. circuits.

RESISTANCE OF AN A.C. CIRCUIT

To make a start in explaining these effects, we are going to take a simple circuit like Figure 1 which contains nothing but the Alternator "E", and a Resistance "R". Even though the current and voltage are alternating, there is nothing here to cause any self induction, and all we really have is the resistance of the connecting wires and the resistor "R".

Ohm's Law can be applied to this circuit exactly the same as for direct current because it takes care of Voltage, Current and Resistance and that is all we have. Keep this point in mind because, before you complete this Lesson, you may think that Ohm's Law is of little use for alternating current.

Remember here that, as far as resistance alone is concerned, the Current in a circuit is always equal to the Voltage divided by the Resistance, no matter whether the current and voltage are Alternating or Direct.

As we mentioned above, other actions occur in alternating current circuits, actions which are not mentioned in Ohm's Law but are taken care of by other laws we are going to explain.

Going back to Figure 1 again, if the effective voltage of the alternator is 110, and the resistance of the circuit is 55 ohms, by Ohm's Law, the effective current will be 110 divided by 55 or 2 amperes.

Here of course there are the three values for the A.C. voltage, Maximum, Average and Effective. We used the effective voltage and our answer was effective current. Had we used the maximum value of voltage, then our answer would have been the maximum current and, had we used the average voltage, then the answer would have been the average current.

Just to make this a little easier to see, we know that the maximum values are 1.41 times the effective values and the average values are .901 of the effective values, therefore we can list them as follows.

E(effective) = 110 volts
E(maximum) = 110 x 1.41 = 155.1 Volts
E(average) = 110 x .901 = 99.11 Volts

As the value of the resistance does not change appreciably, we can use Ohm's Law and substitute these voltage values to find the corresponding current values.

$$I(\text{effective}) = \frac{E}{R} = \frac{110}{55} = 2 \text{ amps.}$$

$$I(\text{maximum}) = \frac{E}{R} = \frac{155.1}{55} = 2.82 \text{ amps.}$$

$$I(\text{average}) = \frac{E}{R} = \frac{99.11}{55} = 1.8 \text{ amps.}$$

To check the action for a complete cycle, for Figure 2 we have followed the plan explained in an earlier Lesson and drawn a sine curve of the voltage. Then, substituting the instantaneous values of voltage in Ohm's Law, we found the instantaneous values of current and, using them, drew the current or "I" curve.

With "O" voltage, the current is "O" but, as the voltage increases, the current increases in proportion and both reach their maximum values at the same instant. Then, as the voltage decreases, the current decreases in proportion and both reach their zero values at the same instant. Under these conditions, we say the voltage and current are "in phase". As a definition, the current and voltage are "in phase" when, varying in the same direction, they reach their maximum and minimum values at the same instant, or phase of the cycle.

LAGGING CURRENT

For Figure 3, we have a circuit similar to that of Figure 1, but have replaced the resistance with an inductance or a coil of wire. This coil is wound on an iron core, and from the early Lessons on Induction, you know that a change of current in it will induce an emf.

You will also remember that the direction of this induced emf is always such as to oppose the current causing it.

In other words, an increasing current in the coil, induces an emf which opposes, or tries to prevent the increase.

Then, when the circuit is opened, or the current is reducing, the direction of the induced emf reverses and tries to help, or maintain the current.

Going back to Figure 3, the alternator produces an alternating voltage that causes an alternating current in the circuit. On the first 90 degrees of the cycle, the voltage rises and as the current increases, the induced E.M.F. of the coil opposes it.

On the second 90 degrees of the cycle, the voltage reduces and the induced E.M.F. in the coil then tries to maintain the current. You can follow this action in the curves of Figure 4 where the "E", or voltage curve, is exactly like that of Figure 2 but, on account of the action of the induced E.M.F., the current curve, while of the same shape as that of Figure 2, will not be in phase with the voltage.

Starting at 0, the voltage rises and starts a current in the circuit. As long as the current is increasing, the induced E.M.F. in the coil will oppose it so that, when the maximum voltage is reached, the current is still increasing, and has not reached its maximum value.

As the voltage passes its maximum value and the current starts to decrease, the induced E.M.F. reverses and tries to maintain it so that, when the voltage is back to 0, the induced E.M.F. still causes current in the circuit.

On account of this action, the current curve of Figure 4 can not be drawn in phase with the voltage because its 0 and maximum values will occur after those of the voltage. This we call a "Lagging Current", and the number of degrees, or angle, that it lags behind the voltage is generally represented by the Greek letters theta, "θ", or phi, "ϕ".

INDUCTANCE

Now here is a very important point to get clearly in your mind. For the moment, we are going to forget all about the actual resistance of the wire in the circuit of Figure 3 and imagine that it has nothing but inductance. In that case, the alternator will have to develop just enough voltage to overcome the induced E.M.F.

Going back to the Laws of Induction, you will remember that the value of an induced E.M.F. is proportional to the rate of cutting. Then, thinking of the flux set up by the coil, you can see that the magnetic lines will be cutting the wire at the highest rate when the current in the coil is changing at the greatest speed therefore, the greatest E.M.F. will be induced at that instant.

You know that as long as the current remains constant in

a coil of this kind that there is no induction because the flux is not cutting the wires therefore, the value of the induced emf depends, not on the instantaneous value of current but the speed or rate at which it changes value.

Thinking of alternating current of some fixed frequency, the value of the induced emf will vary with the amount of current because the change, from zero to maximum, always occurs in the same period of time. Thus with higher maximum values, which require a larger change in the same period of time, the speed, or rate of change, will be greater.

At this time however, we are interested in the variations of current during each cycle and, looking at the current curve of Figure 4, you can see that the value of the current is changing fastest when its actual value is 0. To see this a little easier, draw a vertical line 5 or 10 degrees each side of the point where the current curve crosses to 0 or base line and you will find that they cross the curve some distance above and below the 0 line. Then draw similar lines 5 or 10 degrees each side of the maximum value, and you will see that the change there is not very large.

To sum it all up then, the induced emf will be greatest when the current is 0, because that is the point of fastest change. When the current is at maximum, it is steady for an instant and therefore there is no induced emf at that time. Therefore, if the circuit contained nothing but Inductance, the current would lag 90 degrees behind the voltage. At maximum supply voltage there would be 0 current, and at 0 supply voltage there would be maximum current.

As all wires offer some resistance to a current of electricity, it is a practical impossibility to construct a circuit with nothing but inductance and therefore the current will not lag 90° behind the voltage. Depending on the relative values of Resistance and Inductance, the angle of lag will have a value somewhere between 0° and 90° therefore, in the curves of Figure 4 we show the angle of lag as 45°.

To check this angle, you read the curve from left to right and, starting at 0°, find the "E" curve crosses the base line and extends upward. Then, moving 45° to the right, the current curve crosses the base line and extends upward. As the horizontal distance along the base line represents the elapsed time, the zero value of current occurs after the zero value of voltage and therefore

we say the current lags the voltage. The lag is usually indicated in degrees of the cycle as indicated by "Ø" of Figure

INDUCTIVE REACTANCE

This opposition, of the induced E.M.F. to the current caused by the alternator voltage, is called "Inductive Reactance" and it is measured in ohms, the same unit as used for resistance.

Back in the Lesson on Induction, we explained that the Henry was the unit of measure for Inductance and that a circuit has an inductance of one Henry when a change of current, at the rate of 1 ampere per second, induces an E.M.F. of 1 volt. Or as a rule, we can state that the induced E.M.F. of a circuit is equal to the Inductance, in Henrys, times the change in amperes per second.

In alternating current, there are four changes for each cycle. The values start at 0 and rise to maximum, from maximum drop back to 0, then change direction and rise to maximum and from this maximum, drop to 0 again.

To find the rate of change, we know the frequency is the number of cycles per second and with four changes in each cycle, the rate of change will be four times as fast. Using the letter f, for frequency, as a formula we can write the time for each cycle as $\frac{1}{f}$ sec. As a rule we say that the length of time for each cycle is equal to one second divided by the frequency.

As an example, the frequency of the ordinary A.C. commercial lighting circuits is 60 cycles and the time for each cycle is $\frac{1}{60}$ second. However, the current makes four changes during each cycle so that the time for each change is but $\frac{1}{4}$ of a cycle. With this in mind, we change the formula above to read $\frac{1}{4f}$ sec.

Taking the rule that we have you a minute ago and writing it in formula form we have,

$$E = L\frac{I}{t}$$

when "E" is the value of the induced E.M.F., "L" is the inductance in henrys, "I" is the change of current in amperes, and "t" is the time in seconds.

From the explanation given above, the rate of change of current in an a-c circuit is 1/4f sec. Substituting this in the formula,

$$E = L\frac{I}{t} = L\frac{I}{1/4f} = 4fLI$$

This is the average value of E and as the maximum value is the one usually used in this work, we have to make a few more changes. You know that the average value is .636 of the maximum so that .636 maximum E equals 4fLI. Then working this out by simple fractions we find,

$$E(max) = \frac{4fLI}{.636} = 6.28\ fLI$$

Back in the early Lessons, we told you that the figure 3.1416, called Pi, and usually represented by the Greek letter "π", is the number by which you multiply the diameter of a circle in order to find the circumference.

As the figure above, 6.28, is just twice 3.14, the formula is usually written,

$$E = 2\pi fLI$$

Compared to Ohm's Law, which states, E = IR, the "R" is replaced by "$2\pi fL$" which is known as the Inductive Reactance, abbreviated "X_L". Its value is measured in ohms and is equal to 2π, or 6.28 times the frequency, in cycles per second, times the inductance in Henrys.

CAPACITY REACTANCE

In Figure 5, we again have a circuit, similar to Figures 1 and 3, but this time there is a condenser connected across the alternator. Going back to the earlier Lessons, you will remember that, when connected across a source of emf, a condenser charged and absorbed a certain amount of electricity.

Then, when the voltage was reduced, the condenser discharged and returned to the circuit, most of the energy it had absorbed. The amount of electricity a condenser can absorb is called its capacity and is measured in Farads.

Connected across the alternator of Figure 5, the condenser will be continually charging and discharging because the alternating voltage is constantly changing. You can see here that, as long as the voltage is rising, there

will be current into the condenser and it will charge. The current will be greatest when the voltage is rising the fastest.

Then, as the voltage falls, the condenser will discharge, and the current from it which will have the greatest value when the voltage is falling at the greatest speed.

From the curves that we have shown, and as we explained for the current in an inductance, the voltage is changing fastest when it has 0 value. This is a little hard to see but suppose we say that the value of the voltage changes fastest as it drops to 0 and reverses. It is not the actual value of the voltage that interests us just now, but the speed at which the value changes.

You can understand this better from the curves that we have shown. For example, suppose that in Figure 4, the voltage has a maximum value of 155. Then checking through, we find the following instantaneous values.

Degree Phase		Inst. Volt.
0	--	0
15	--	40.1
30	--	77.5
45	--	109.5
60	--	134.2
75	--	149.7
90	--	155.0

Check these figures back and remember that each 15 degrees of the cycle takes place in the same length of time. As each cycle consists of 360 degrees, it will take 1/24 of the time of a cycle for each of the divisions in the table.

Starting at 0, in the first 15 degrees the voltage has risen to 40.1. In the next 15 degrees it rises 37.4 volts higher. From 45 to 60 degrees it rises 24.7 volts higher and so on until between 75 and 90 degrees the change is but 5.3 volts. From these figures you can easily see that the fastest rate of change takes place at the 0 value while there is no change at the maximum value.

Assuming the condenser to be completely discharged, the rapid change of voltage, at the zero value, will cause the charging current to rise, almost immediately, to its maximum value. Then, as the rate of voltage change becomes less, the charging current will decrease until at Maximum voltage, the condenser is fully charged and the current is zero.

The result of this action is exactly opposite to that of inductance and, because the current reaches its maximum value before that of the voltage, we say the current "leads" the voltage. With nothing but capacity in the circuit, the current will lead the voltage by 90°.

Here again, a circuit can not be built without resistance therefore, in practice, the lead will be less than 90°. That is why, in the curves of Figure 6, we show the current leading the voltage by 45°.

Compared to Figure 4, here the current has a fairly large value at 0° but, reading to the right, we find it crosses the base line 45° before the voltage curve. Using the 180° ordinate as a reference, the current curve of Figure 4 crosses the base line 45° after the voltage while, in Figure 6, the current curve crosses the base line 45° before the voltage.

This action of the condenser is known as "Reactance" but, to distinguish it from that of the inductance of Figure 3, it is known as "Capacity Reactance" abbreviated "X_c". Like Inductive Reactance, Capacity Reactance is measured in ohms.

To calculate the capacity reactance in terms of capacity and frequency, we remember first that the charge of a condenser is measured in coulombs and that a flow of one coulomb per second is a current of one ampere. As an equation we can write.

$$Q = EC$$

When "Q" is the charge in coulombs, "E" is the voltage across the condenser and "C" is the capacity in farads, (coulombs per volt).

The curves of Figure 6 show the current varies in value therefore, for any complete charge or discharge, the number of coulombs will be equal to the average current multiplied by the time it is present. As an equation,

$$Q = I\ (\text{average}) \times t$$

Looking at the curves of Figure 6, you can see that the condenser will charge and discharge twice during each cycle therefore, the time for each charge or discharge will be equal to 1/4f as explained for the current changes of Figures 3 and 4. Substituting this value for the "t" of the above equation,

$$Q = I\text{average} \times \frac{1}{4f} = \frac{I\,(\text{average})}{4f}$$

but a former equation stated that Q = EC and, as things equal to the same things are equal to each other, we can combine these two equations and find,

$$EC = \frac{I(average)}{4f}$$

and transposing the "C", we have

$$E = \frac{I(average)}{4fC}$$

As previously explained, it is customary to use maximum values and as I(average) = .636 I(maximum), we can write,

$$E = \frac{.636I}{4fC}$$

and, dividing both the numerator and denominator by .636 we have,

$$E = \frac{I}{6.28fC} = \frac{I}{2\pi fC}$$

To separate the current "I", we can think of the equation as,

$$E = \frac{1}{2\pi fC} \times I$$

Notice here, Ohm's Law states that E = R x I, which is resistance times current, and the formula just given says that E equals Capacity Reactance times current. The value of Capacity Reactance in Ohms then is equal to $1/2\pi fC$ where f is the frequency in cycles per second and C is the capacity in Farads.

REACTANCE

Comparing the curves of Figures 4 and 6, you will see that Inductive Reactance and Capacity Reactance have exactly the opposite effect on the phase of the current. Inductive Reactance causes the current to lag and Capacity Reactance causes it to lead.

For your practical work, every a-c circuit will have some of both and, in a simple series circuit, their combined effect is equal to the difference between them. This difference is what we call the Reactance of a circuit and usually represent it by "X".

IMPEDANCE

However, as we have told you many times before, all con-

ductors have resistance, so that any circuit that you may build will have resistance as well as reactance, both of which oppose the current. For an a-c circuit, their combined effect is called the Impedance and is usually represented by the letter "Z".

You can now apply Ohm's Law to your a-c Circuit work, by using the letter Z, for the impedance, instead of the letter R for resistance. The current will equal the voltage divided by the impedance or in formula form we can write,

$$I = \frac{E}{Z}.$$

In the circuit of Figure 7 we have a resistance, a coil with inductive reactance and a condenser with capacity resistance, all connected in series across the alternator.

From our explanations so far, you know the effect of reactance is to make the current lag or lead, while with resistance only, the current and voltage are in phase. To find their combined effect, or the impedance of this circuit, we will have to take all of these things into consideration but we can not simply add them as we did the resistances of a direct current series circuit.

There are several methods by which this can be done and as we are going to give you complete details in the later Lessons a brief explanation will be sufficient at this time.

Checking back on the circuits of this Lesson, for Figure 1, with Resistance only, the Voltage and Current are in phase. For Figure 2, with Inductance only the current lags the voltage by 90°. Thus, we have two forces, acting at 90°, or at right angles to each other and therefore will have to add them as vectors.

However, the capacity reactance of Figure 5 causes the current to lead by 90° which makes it act at 90° to the resistance but opposite to the inductive reactance.

As we have already explained, the value of the Inductive Reactance is equal to $2\pi fL$ and that of the Capacity Reactance to $1/2\pi fC$. Then as their effects are opposite, the combined action, or the reactance of the circuit, will be equal to $2\pi fL$ minus $1/2\pi fC$.

Resistance is shown by the letter R just the same as for direct current and as a rule we can say the impedance of a circuit is equal to the square root of the resistance squared plus the reactance squared.

As a formula we can write: $Z = \sqrt{R^2 + (2\pi fL - 1/2\ \pi fC)^2}$.

Suppose for example that in Figure 7, the resistance has a value of 8 ohms, the coil has an inductive reactance of 15 ohms and the condenser a capacity reactance of 9 ohms.

To find the reactance, we first subtract the capacity reactance of 9 ohms from the inductive reactance of 15 ohms, leaving the reactance of the circuit with a value of 6 ohms.

Then the resistance squared is 8 times 8 or 64, and the reactance squared is 6 times 6 or 36. Adding these squares, we have 64 plus 36 which is 100. Now we have to take the square root of 100, but that is easy, as you know off hand that 10 times 10 equals 100, therefore the answer is 10 ohms which is the value of the impedance for this circuit.

OHM'S LAW FOR A-C CIRCUITS

As we mentioned a minute ago, after you have found the impedance, you can use Ohm's Law for your a-c work simply by using Impedance, "Z", in place of the Resistance "R". The one thing to remember here however is that you have Maximum, Average and Effective values for both alternating current and voltage. All you have to do is use the same value of each. If you use the effective voltage, then you must use the effective current, or if you use the maximum voltage in solving for current, then your answer will be the maximum current.

We just found that the impedance of the circuit of Figure 7 was 10 ohms so that, if the alternator produces an effective voltage of 110, the current will be equal to the voltage divided by the impedance which here is 110 divided by 10 or 11 amperes. As we used the effective voltage, then the 11 amperes is the effective current.

In our earlier explanations of series circuits we told you that, at any instant, the current is the same in all parts but here, according to the curves of Figures 2, 4 and 6, the phase angle of the current varies in respect to the voltage. However, our former statement is true for a-c series circuits like that of Figure 7.

The curves of this Lesson were drawn with the voltage as the reference but, in Figure 4 for example, had we used the current as the reference then, according to our explanations, the voltage would lead the current. Following the same plan for Figure 6, the voltage would lag the current.

In Figure 7 therefore, with the same current in all parts of the circuit, the voltage drop across the resistance will be in phase with the alternator voltage, the drop across the inductance will lead while the drop across the capacity will lag the alternator voltage. Therefore, the total drop across the circuit will be equal to the vector sum of the voltage drops across the different parts connected in series.

Using the values of the former example, the circuit in Figure 7 carried a current of 11 amperes at 110 volts with a resistance of 8 ohms, an inductive reactance of 15 ohms and a capacity reactance of 9 ohms. To find the voltage drops we follow the plan of Ohm s Law and multiply the current by the resistance or reactance. Here then we will have:-

$$E_R = IR = 11 \times 8 = 88 \text{ volts}$$
$$E_L = IX_L = 11 \times 15 = 165 \text{ volts}$$
$$E_c = IX_c = 11 \times 9 = 99 \text{ volts}$$

Adding these values vectorially, we find

$$\begin{aligned} E(\text{total}) &= \sqrt{E_R^2 + (E_L - E_c)^2} \\ &= \sqrt{(88)^2 + (165 - 99)^2} \\ &= \sqrt{(88)^2 + (66)^2} \\ &= \sqrt{7744 + 4356} \\ &= \sqrt{12100} \\ &= 110 \text{ volts.} \end{aligned}$$

Going back to the earlier Lessons again, in a parallel circuit, the voltage across the branches is the same but the current in them depends on their separate resistances. To check this action for A.C. circuits, in Figure 5 we have taken the units of Figure 7 but connected them in parallel across the alternator.

Using the values of the former example and applying Ohm's Law separately to each branch, we find

$$I_R = \frac{E}{R} = \frac{110}{8} = 13.75 \text{ amps}$$

$$I_L = \frac{E}{X_L} = \frac{110}{15} = 7.33 \text{ amps}$$

$$I_c = \frac{E}{X_c} = \frac{110}{9} = 12.22 \text{ amps}$$

As the applied voltage is the same for all branches, the curves of Figure 2, 4, and 6 show the current will vary in phase according to the type of unit connected in each

branch therefore, the total current will equal the vector sum of the branch currents.

From the values listed,

$$
\begin{aligned}
I(\text{total}) &= \sqrt{I_R^2 + (I_L - I_C)^2} \\
&= \sqrt{(13.75)^2 + (7.33 - 12.22)^2} \\
&= \sqrt{(13.75)^2 + (-4.9)^2} \\
&= \sqrt{189 + 24} \\
&= \sqrt{213} \\
&= 14.59 \text{ amps}
\end{aligned}
$$

The total impedance of the circuit will be equal to the applied voltage divided by the total current,

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

$$Z = \frac{110}{14.59}$$

$$Z = 7.539 = 7.54 \text{ ohms.}$$

From the explanations of this Lesson, you can see that, in many ways, a-c circuits are similar to d-c and, in general, the same laws apply to both. The main differences are that, for a-c, we have reactance in addition to resistance and, for correct results, some values must be added vectorially. Once you have these similarities and differences clearly in mind, you will find a-c is more interesting than d-c. Also, it is of extreme importance because a large part of your Radio and other Electronic work is a-c.

For the next Lesson, we will continue this subject and show you how the phase angle, between voltage and current, affects the Power in a-c circuits.

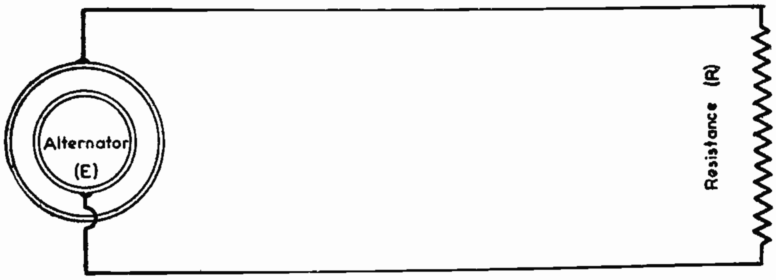


FIGURE 1

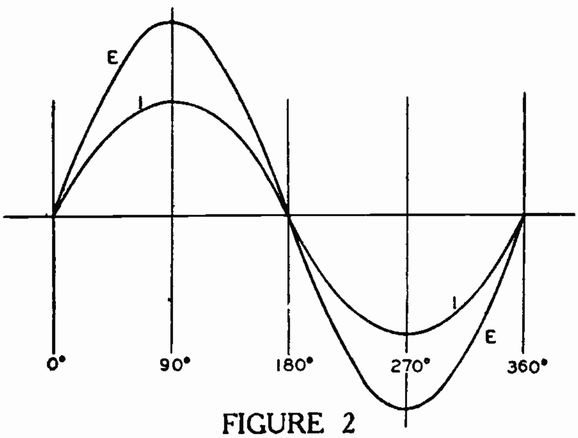


FIGURE 2

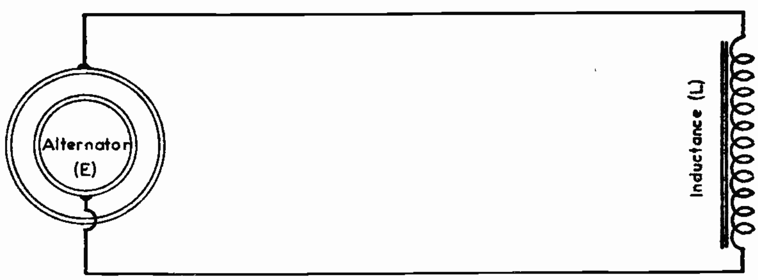
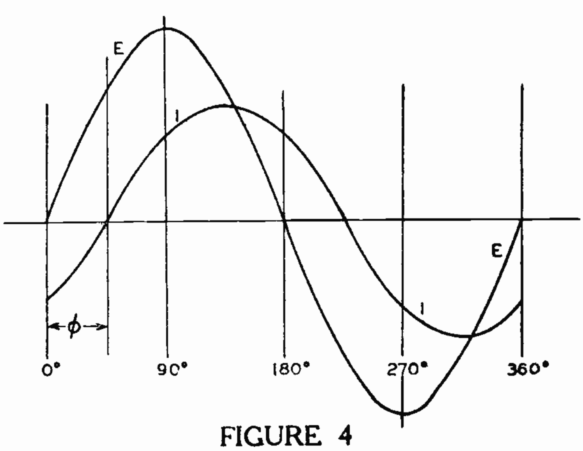


FIGURE 3



TRA-3

FIGURE 4

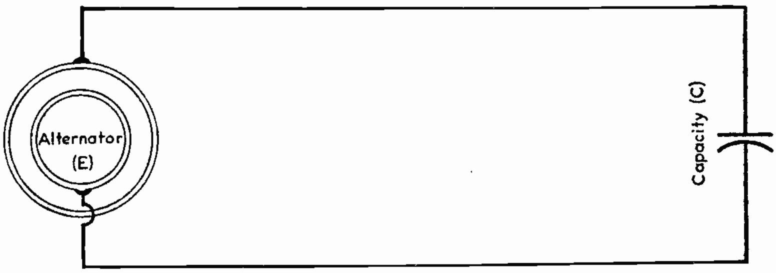


FIGURE 5

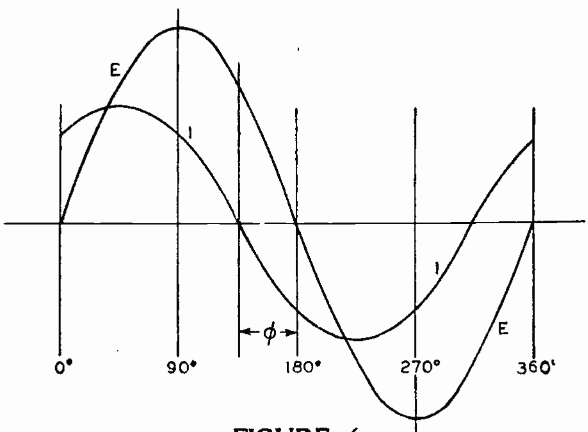


FIGURE 6

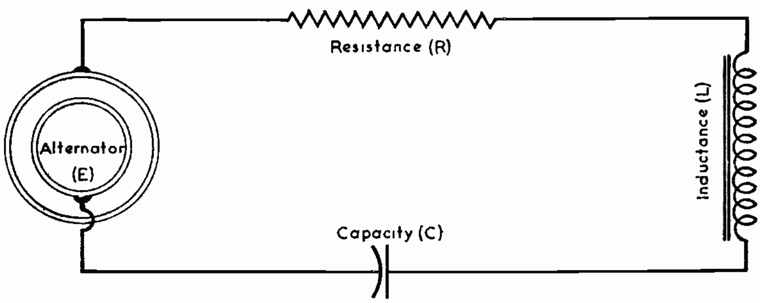
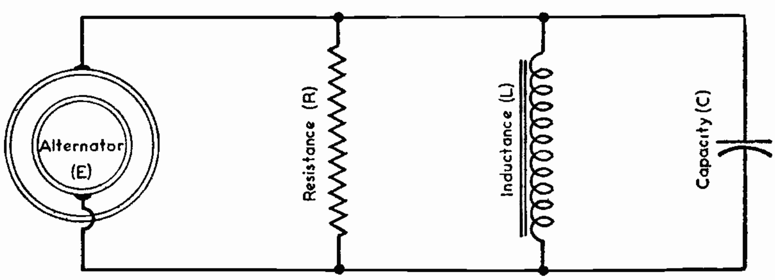


FIGURE 7



TRA-3

FIGURE 8

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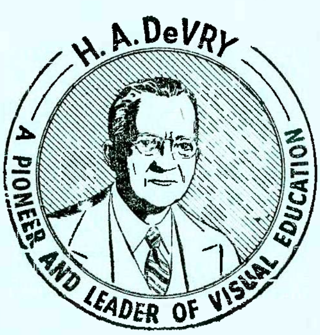

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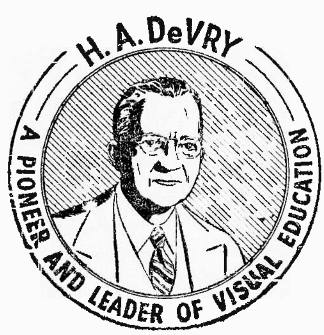

TUBES - RECEIVERS - AMPLIFIERS

Lesson 4

POWER IN A.C. CIRCUITS

* * * *

No matter how well trained you are, how quick your eye and how skilled your hand, your work is not the best unless you put your spirit into it. And the more spirit you put into your work, the more good it does you. It reacts upon you wholesomely. For when you work at work you like, at work where your heart and soul and interest are, then it is not work anymore, it is play.

-- Dr. Frank Crane

VECTOR DIAGRAMS

In our earlier explanations of D.C. circuits, we told you that electrical power, in Watts, was equal to the Product of the E.M.F. in volts and the current in amperes. Should there be any change, in either the voltage or current, the Power would change also. Therefore, when we speak of "Watts", we mean the Instantaneous Power.

For A.C. circuits, in which both the voltage and current continously change in value, the instantaneous Power will be equal to the Product of the volts and amperes at any phase of a cycle. In order to follow this action in detail, we will repeat the plan, explained in the former Lesson, and make use of rotating vectors.

Starting with Figure 1, we assumed an A.C. circuit with an effective voltage of 110, an effective current of 60 amperes and have drawn curves which show the power at all phases of one cycle.

First we laid out the "Volt-Amps" scale but placed the 0 at the center because we know that the direction reverses. Then we drew a long horizontal axis through the 0 of the vertical scale.

For these curves, we assumed the circuit contained nothing but resistance and, as the current and voltage will be in phase, we laid off the vectors along the left end of the horizontal axis. Vector A-B represents the maximum value of current and is equal in length to the effective value of 60 times 1.414 or 84.85 on the "Volts-Amps" scale. Vector A-D represents the maximum value of voltage and is equal in length to 110 times 1.414 or 155.56 on the "Volts-Amps" scale.

As these vectors are to rotate, we took A as the center and drew one dotted semicircle through B and another through D. In reverse order, the instantaneous values of the second 90 degrees are the same as those of the first quarter turn, and those of the third 90 degrees like the fourth quarter, thus we show but half of the circles.

To the right of the "Volts-Amps" scale, we divided the zero line into 16 equal parts and drew ordinates at each point. As a complete circle or cycle contains 360 degrees, each of these divisions represents 22½ degrees.

You will remember that the instantaneous values are equal to the vertical distance from the end of the revolving vector to the base line, therefore we projected these values over to the proper ordinates.

To make the voltage curve, we started with the vector A-D on the base line and its projection is a point where the base line and first, or 0 degree, ordinate cross.

Then, we revolved the vector through an angle of $22\frac{1}{2}$ degrees, or one sixteenth of the circle, and projected over to the $22\frac{1}{2}$ degree ordinate, placing a dot the proper distance from the base line. Next we revolved the vector another $22\frac{1}{2}$ degrees, anti-clockwise, projected the instantaneous value over to the 45 degree ordinate, and following the same plan for the first 90 degrees, projected the instantaneous value for each $22\frac{1}{2}$ degrees.

For the second 90 degrees, the values are the same, but in the reverse order, therefore we projected the $67\frac{1}{2}$ degree value to the $112\frac{1}{2}$ degree ordinate, the 45 degree value to the 135 degree ordinate and so on until we had a zero value of 180 degrees.

The second half of the revolution was done in exactly the same way except that the values were below instead of above the base line.

PHASE

By joining all these projections with a line, we drew the "volts" curve of Figure 1 and, by means of the scale at the left, can find the instantaneous voltage at any phase of the cycle.

Using the current vector A-B in the same way, we laid out the current curve and, as it is in phase with the voltage, they both have the zero and maximum values at the same instant.

As a guide, we drew the projection lines of the maximum, or 90 degree current and voltage values over to the scale to show that the length of the vectors is correct.

We started out to make a power curve and with curves showing the instantaneous values of volts and amperes, were ready to go ahead with it. You remember that Watts equal Volts times Amperes and here with maximum values of 155.56 volts and 84.85 amperes the maximum power will be 13,200 Watts. The scale that we used for the volts and amperes was far too small for these values so we laid out a new Watt scale over at the right.

To obtain the values of watts we had to multiply volts by amperes and, on the $22\frac{1}{2}^{o}$ line, by checking back along the lines parallel to the base, the scale showed about

59.5 volts and 32.5 amperes. That gave us 1933.7 watts so we drew a line from the 1934 mark on the watt scale, over to the $22\frac{1}{2}^{\circ}$ ordinate and put the first dot for the Power curve where they crossed.

Following this idea all the way through, we obtained the value of watts for each of the vertical lines but, even though the current and voltage change direction, we showed the power all above the base line.

That is because electrical power does not depend on the direction of the current but is the product of the voltage and current. Or, if you want to think of that part of the curve above the base line as positive and the part below as negative, then the power is always positive.

That can be explained by telling you that when you multiply two positive or two negative quantities, the result is always positive. However, if you multiply one positive and one negative quantity, then the result is negative.

LEADING AND LAGGING CURRENT

In Figure 1 the voltage and current are in phase and the power is all positive but, when the current lags or leads, conditions are somewhat different as you will see in Figure 2.

Here, we have redrawn the current and voltage curves of Figure 1, and show the current lagging 45° but again, we want to lay out the power, or Watts curve.

Starting on the 0° ordinate as before, we find zero volts with a current value of 60 amperes negative. As watts are the product of volts and amperes, with zero volts there will be zero watts, no matter how large the current. Therefore, at the 0° ordinate the value of watts is zero.

Going over to the $22\frac{1}{2}^{\circ}$ ordinate, we find the voltage has increased to about 59.5, in a positive direction, while the current has reduced to a value of about 32.5 in a negative direction. Multiplying a positive 59.5 volts and a negative 32.5 amperes, the result is 1933 watts negative, therefore, this point is marked off below the base line.

At the 45° ordinate, the voltage has increased to a value of 110 but the current has dropped to zero and therefore the watts are zero. At the next, or $67\frac{1}{2}^{\circ}$ ordinate, both the voltage and current are positive, therefore we follow along, as explained for Figure 1, reading the voltage and current values on each of the vertical lines and multiplying

them to find the number of watts. At the 180° ordinate, the voltage drops to 0 therefore, the watts will be zero regardless of the current.

Notice here, even though the voltage reverses direction at the 180° line, the current does not. In other words, the induced E.M.F. of the circuit is causing the current, not the E.M.F. of the alternator supplying the circuit. That means, instead of the alternator supplying the power to the circuit, the circuit is supplying power to the alternator.

To continue the power curve, the readings on the 112½° ordinate are similar to those on the 22½° ordinate except that there is positive current and negative voltage therefore, again we have to go below the base line and show negative power.

At the 225° ordinate, the current has dropped to zero therefore the power is zero. Except that both the voltage and current are negative, the values between the 225° and 360° ordinates are the same as those between the 45° and 180° ordinates. With negative voltage and negative current, the power is positive as shown.

That gives us two small loops of the power curve below the base line and they are what interest us now. As explained above, the power, represented by these loops is given back to the supply line by the induced E.M.F. of the circuit and therefore can not do any useful work.

To make that a little easier to see, suppose that the curves of Figure 2 were of a circuit consisting of an alternator and a motor. If you were using that motor to run some machinery, you will agree that any power it gave back to the alternator would certainly not help you, and could not help drive your machinery.

POWER FACTOR

It is only that part of the curve above the base line, or which is positive, that drives the motor, or does useful work, yet you can see that if we multiply the volts times the amperes, the results will be equal to the total power both above and below the base line.

The true, or useful power in the circuit will be the positive power only, and we will have to find the difference between it and the total watts as shown by multiplying the effective values of volts by amperes.

You can think of the shaded parts of Figures 1 and 2 as representing the power of a circuit, and those parts above

the base line as the useful or positive power.

In Figure 1, all the power is positive and the outline of the shaded parts was found by multiplying volts by amperes. In Figure 2, however, to find the positive power only, we have to multiply volts by amperes by some fraction or decimal that is less than 1.

This fraction or decimal is what we call the "Power Factor" and as a formula we write:-

Power = Volts x Amperes x Power Factor

To make this come out right, for a circuit with the curves of Figure 1, where all the power is useful, the power factor will equal unity or 1. As we have explained, the curves show a maximum voltage of 155.56 and a maximum current of 84.85 amperes which, by our formula, Watts equal Volts x Amperes gives a maximum of 13,200 Watts.

Using the formula, Power = Volts x Amperes x Power Factor, with a Power Factor of 1 or unity, we have Power = 155.56 x 84.84 x 1 = 13,200 Watts the same as before. For Figure 2 however, although we still have the same maximum values of voltage and current, the difference in phase reduces the useful power and to use the formula here, the power factor is less than 1.

A little later on we will tell you how we know but, at this time, just take our word that the Power Factor of Figure 2 is .7071 or roughly .71 which may also be written 71%.

Then, substituting these values into the formula we have:-

Power = 155.56 x 84.85 x .7071 = 9333.7 Watts

In other words, a maximum voltage of 155.56 and a maximum current of 84.85 amperes with a 45 degree lag, produced a maximum useful power of but 9333 watts. The difference between this figure and the 13,200 watts of Figure 1 is shown by the small shaded loops below the base line of Figure 2.

Checking the maximum power values on Figure 2 we find the negative loops indicate 1933 watts while the positive loops indicate 11,266 watts. As a rough check, subtracting the 1933 negative watts from the 11,266 positive watts leaves 9333 positive watts as stated above. However, adding the 1933 and the 11,266 we find a total of 13,199 watts which corresponds to the 13,200 watts of Figure 1. Thus, neg-

lecting direction, the total is the same in both circuits.

So far, we have based our explanations on maximum values but, using the usual effective values the results are proportional. With effective values of 110 volts and 60 amperes, for Figure 1, the effective power is 110 x 60 = 6600 Watts. Note here, the effective power is exactly one half of the maximum power.

For Figure 2, the effective power is 110 x 60 x .7071 = 4666.8 watts which is one half of the maximum value of 9333 watts mentioned above.

The point we want to bring out here is that the power factor can never be more than 1 or unity and, when the voltage and current are not in phase, will be less than 1. The actual value will depend on the angle of lead or lag.

For the general run of circuits however, there is some reactance and the average power factors are about .95 or 95% for incandescent lighting circuits with no motors, about 85% for mixed circuits with lights and motors and about 80% for circuits with motors only.

However, if we could make a circuit that contained nothing but inductance, then the current would lag 90°, there would be as much positive as negative power and the power factor would be 0. This, of course can never be done in actual practice but, in some circuits, conditions come pretty close to it.

WATTLESS CURRENT

That brings us to the term Wattless Current, which the induced E.M.F. of the circuit returns to the alternator, or that current which does no useful work. While in common use, the term wattless current is not correct therefore we are going to call it the "Reactive Current", but don't form the idea that there are two separate currents, because there are not.

There is only one current but we think of it as being made up of two parts. First, that part which, when multiplied by the voltage, will give us, in watts, the useful power in the circuit. Second, that part which, when multiplied by the voltage, will give us the negative power in watts, known as the Reactive or circulating power.

You may think that if this wattless or reactive current does not provide useful power in the circuit that it will

not make any difference, and in one way it does not. If you are buying power, your meter does not show this current and you do not pay for it. However, the circuit has to carry this extra current and the conductors have to be large enough to handle it without heating.

As we have explained then, the power factor may be anywhere between 0 and 1 and the closer it is to 0 the larger the reactive current will be. A low power factor will have a tendency of heating the conductors and, as the resistance increases with the temperature, the losses in the circuit will increase. This same action in the coils of the alternator will reduce their effective capacity.

KILOVOLT-AMPERES

You will find that most of the alternators and larger power transformers are rated in Kilovolt-amperes instead of Kilowatts. A Kilovolt-ampere is the unit of apparent power in an alternating current circuit and, when the power factor is 1, it is equal to one Kilowatt.

The kilowatt is the large unit of power for alternating current the same as for direct current yet, with a power factor, the alternator will have to carry a larger current to produce the proper amount of power.

Suppose for example, you had an alternator which, according to the meters on the switchboard, was producing 2400 volts at 53 amperes with a power factor of .8. The apparent power then is 2400 x 53 = 127,200 watts or 127 kilowatts.

Multiplying this by the power factor .8 we get 101,760 watts or 101.76 kilowatts which is the true power.

There are a number of methods by which the Power Factor of a circuit may be expressed or calculated yet all of them are based on the ratio of the reactance to the resistance of a circuit. This is because the power actually absorbed in a circuit is that taken by the resistance only.

The reactance in a circuit does not actually absorb power. It stores a certain amount of energy during some parts of an A.C. cycle but returns this energy to the circuit during other parts of the cycle.

From the former explanations of this Lesson we can state

$$\text{Power Factor} = \frac{\text{True Power}}{\text{Apparent Power}}$$

As the impedance of a circuit includes the resistance and the reactance while only the resistance absorbs power, we can state

$$\text{Power Factor} = \frac{\text{Resistance}}{\text{Impedance}}$$

Looking at Figure 2 again, you can see that, if the angle between vectors AB and AD were larger, the negative power loops would be greater and therefore the power factor would be lower.

Therefore, it is not the value of the current but the phase angle, between it and the voltage, which determines the power factor.

As mentioned before, we think of the total, or line current as being made up of two parts or components. First, the ACTIVE current which is that part in phase with the voltage and multiplied by the voltage to find the power. Second, the REACTIVE current which is that part or component which is 90° out of phase with the voltage.

To make a vector diagram of these components, at the left of Figure 2 we have drawn a line from the B end of the current vector A-B up to and at right angles to the voltage vector A-D. Thus, line A-C represents the active current, in phase with the voltage, while line B-C represents the reactive current, 90° out of phase with the voltage.

We now have a right angle triangle, A-B-C in which the current vector A-B is the hypotenuse and, because line A-C is on the base line of the curve, we will consider it as the base of the triangle.

Reviewing our former explanations on the functions of angles, for the angle CAB, line A-C is the side adjacent and vector A-B is the hypotenuse, therefore

$$\text{Cosine Angle A} = \frac{AC}{AB}$$

In many problems, we know the value of vector A-B and the size of the angle but want to find the value of line A-C therefore, by transposing the terms of the above equation, we can write

$$AC = AB\ (\text{cosine angle})$$

The angle here is shown as 45° and a Trigonometric Table shows the cos 45° = .7071. Thus as AB has a value of 84.85

amperes.

AC = 84.85 x .7071
AC = 60 amperes

Thus, with an active current of 60 amperes and a maximum of 155.56 volts, the power will be 155.56 volts x 60 amperes = 9333.6 watts, which coincides with our former calculations.

To show this vector diagram more clearly, at the left of Figure 3 we have an enlarged view but have rotated the vectors until AB is horizontal. Here you can see that, with a 45° angle as shown, the active and reactive components are equal but, thinking of the triangle, the line current, indicated by hypotenuse AB will be equal to the square root of the sum of their squares.

To illustrate the effect of the phase angle, at the right of Figure 3 we have redrawn the diagram but reduced the angle to 30 degrees. Comparing both diagrams of Figure 3, you can see that the smaller angle increases the active current and reduces the reactive current thereby increasing the power factor. As the angle becomes smaller, the power factor increases until, with the current and voltage in phase, the angle is zero, the power factor equals 1 and the active current equals the line current.

In an earlier Lesson, we told you the cosine of 30 degrees was .866 therefore, if vector A-B, in the right diagram of Figure 3 represents 84.85 amperes,

Active Current = 84.85 x .866
Active Current = 73.48 amps.

Checking back then, the cosine of the angle is really the same as the Power Factor, or as a rule, we can say:- The power factor is numerically equal to the cosine of the angle of lead or lag.

In Figure 4 we show another method of making diagrams of this kind and first lay off the vector A-B, or line current, along the base line. Then the line A-C is drawn in at the proper angle and, at right angles to it, the line A-D. From B, we draw a line parallel to A-D across A-C, and a second line from B, parallel to A-C and across A-D.

That gives us a rectangle and the side on A-C represents the active current because it is drawn at the proper angle and is in phase with the voltage.

The side on A-D represents the reactive current and is at right angles to the active current because the reactive

component is 90 degrees ahead or behind.

That gives us a vector diagram with two values at right angles to each other and the resultant is shown by the diagonal of the rectangle.

Here, we started with the value of the diagonal and split it up into the two components which are at right angles to each other. Notice the length, or value, of the reactive current is the same in both Figures 3 and 4, but in Figure 4 we have both vectors in their proper relation to the line current and each other.

You may find these diagrams a little hard to follow but in Figure 5, we have a similar problem worked out with forces that are easier to see and understand.

In the upper right corner we show a boat that is going to cross a river and we know that, in smooth water, this boat can travel at a speed of 8 miles an hour. The river has a current of 6 miles an hour as shown by the arrows.

The boat starts across, with its engine driving it 8 miles an hour, but the current pushes it sidewise at the rate of six miles per hour. You can see then, that its path will be on a diagonal, and we can draw it out on the same plan that we have been explaining.

First we draw the 8 arrow across the stream making its length equal to 8 on whatever scale we use, and at right angles to it, we draw the 6 arrow to the same scale. No matter what scale you use, the arrow across the stream should be 8/6 or 1 1/3 times the length of the one down the stream.

Then we complete the Figure by drawing a line from the other end of each arrow, parallel to the other arrow and have a four sided figure with a 90° angle at each corner. Next we draw a diagonal line across the figure to represent the direction and distance the boat will travel.

From what we have already told you, the diagonal is the hypotenuse of a triangle and will equal the $\sqrt{\text{base}^2 + \text{altitude}^2}$, which here is $\sqrt{8^2 + 6^2}$ or $\sqrt{100}$ which is 10. If the boat ran for one hour under these conditions then, it would travel 10 miles and land 6 miles down stream.

You can think of the extra miles it travels as the reactive component that we mentioned a while ago, because it requires no power from the engine in the boat to go these extra miles.

Or, looking at it from the power factor standpoint, a meter on the boat would show that it traveled 10 miles. The true power, or the distance that the engine actually drove it however, is only 8 miles, so we would have to multiply the 10 miles by .8 in order to find the true distance that the engine drove the boat.

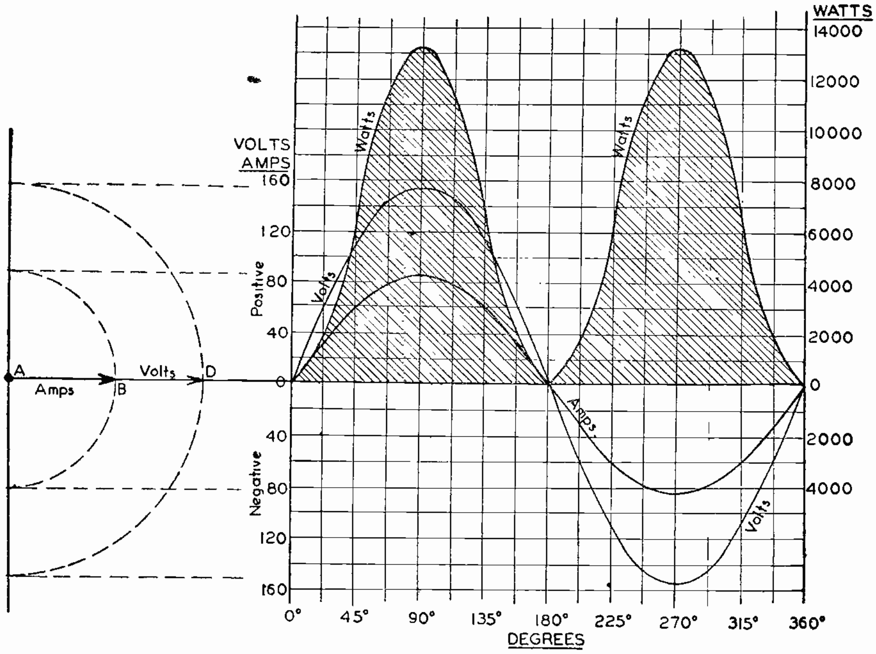

FIGURE 1

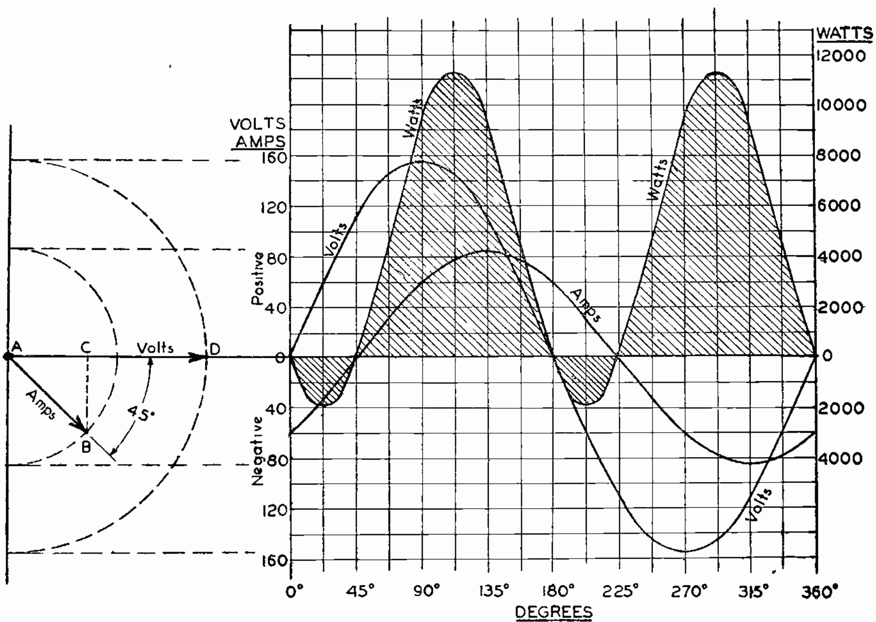

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FIGURE 2

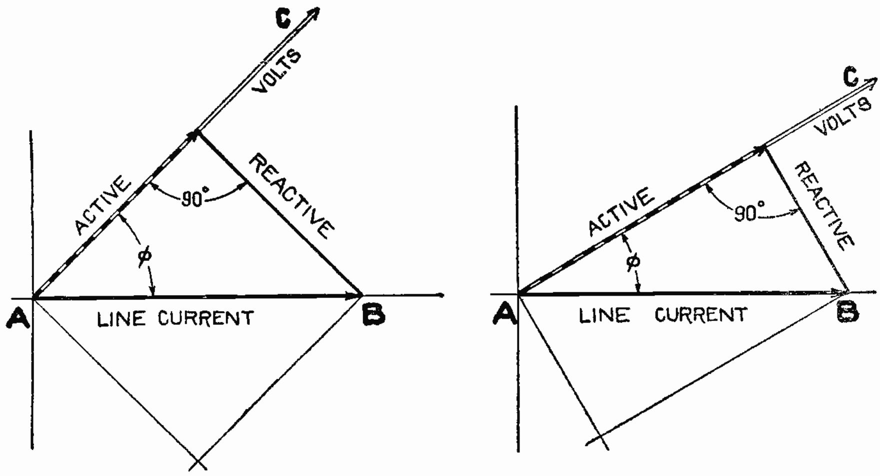

FIGURE 3

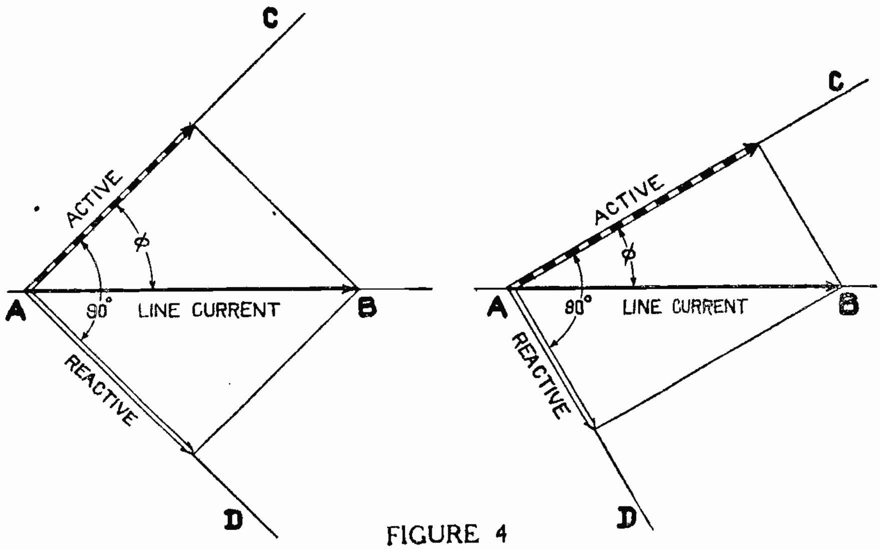

FIGURE 4

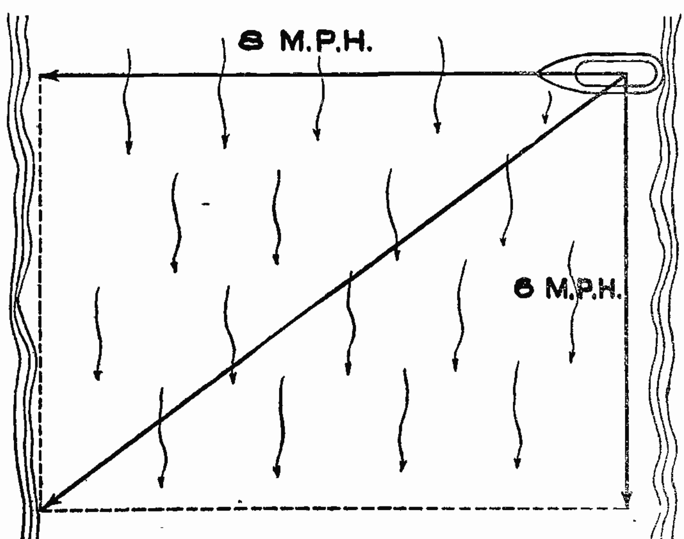

FIGURE 5

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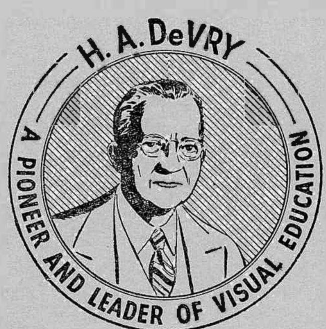

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LESSON TRA - 5

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TUBES — RECEIVERS — AMPLIFIERS

Lesson 5

RESONANT CIRCUITS

* * * * * * * * *

Thinking counts. It isn't so much what you know as what you try to know. It isn't the absolute accuracy of your views on how the whale lost its legs or the bird got its wings as the amount of thinking you do.

— Arthur Brisbane

In the study of A-C Principles, so far we have given you an idea of vectors and vector diagrams with a brief explanation of the common Trigonometric Functions. Then we took up some simple a-c circuits to show the action of inductive and capacity reactances, followed by a Lesson on A-C Power.

As many of these terms and ideas may be new to you, perhaps you are having difficulty in fixing them in your mind therefore, for the first part of this Lesson, we are going to take up some common types of a-c circuits and show the action by means of vector diagrams. In studying these explanations, we want you to pay particular attention to the similarities and differences of d-c and a-c circuits.

INDUCTIVE REACTANCE

To start, for Figure 1 we show an a-c circuit made up of an a-c generator or Alternator", (F), a coil or inductive reactance, (X_L), and resistance (R). As there is but one current path across the alternator, this is a series circuit and therefore, as explained for d-c, at any instant, the current will be the same in all parts of the circuit.

In the former Lesson on Impedance, we explained similar circuits which contained but one unit. However, as all current paths contain resistance, for Figure 1 we show the resistance of the connecting wires, as well as that of the wire in the coil, as a seperate resistor with a value of 8 ohms. This arrangement permits us to consider the coil as a pure inductance which, at some frequency, has an Inductive Reactance of 15 ohms as shown.

To draw a vector diagram for the impedance of this circuit, we first decide on a scale, as shown above the circuit, and then over at the left, on the horizontal axis, lay off a vector equal in length to 8 units of the scale and mark it, "R = 8". As already explained, as far as resistance is concerned, the voltage across it is in phase with the current in it, therefore the R vector is drawn horizontally as the base of the vector diagram. Following conventional practice, the origin of this vector is at the left and it extends to the right as indicated by the arrow.

Going back to the earlier Lessons, we told you that, in a circuit containing nothing but inductance, the current would lag 90° to that of the resistance. To show this action in the diagram, we start at the origin of the resistance vector and draw a second vector at a right angle making its length equal to 15 units of the scale.

That gives us two vectors, of proper length and direction and, to find their sum, from the outer end of each we draw a line parallel to the other. Then, a line is drawn from the origin of the vectors to the intersection of these lines. The complete diagram now consists of a four sided figure, with a right angle at each corner, and a diagonal line between opposite corners.

As the opposite sides of this four sided figure are equal, it is made up of two right triangles and, looking at the one to the right, the base is the "$R = 8$" vector, the altitude is equal to the "$X_L = 15$" vector while the diagonal line is the hypotenuse.

We have previously told you that the hypotenuse of a right angle triangle is equal to the square root of the base squared plus the altitude squared and, applying that rule here, the diagonal, which represents the impedance, is equal to the square root of 8 squared plus 15 squared. As an equation --

$$Z = \sqrt{8^2 + 15^2} = \sqrt{64 + 225} = \sqrt{289} = 17 \text{ ohms}$$

To investigate the actions in this circuit, we will assume the alternator develops 10 volts and, to find the current, we substitute the known values in the general equation.

$$I = \frac{E}{Z} = \frac{10}{17} = .588 \text{ amp.}$$

Then, to find the voltage drop, across the different parts of the circuit, we multiply the current by their resistance or reactance. Here,

$$E_R = IR = .588 \times 8 = 4.7 \text{ volts}$$

$$E_L = IX_L = .588 \times 15 = 8.8 \text{ volts}$$

The resulting voltages have been carried out to the second significant figure only.

As previously explained, for a resistance, the current and voltage are in phase and, for an inductance, the current lags the voltage by 90°. Here, with the same current in both, and maintaining the same phase angle, the voltage across the inductance leads the current by 90°. Therefore, as shown in Figure 1, a vector diagram of the voltage drops will be similar to that drawn for the impedance and the total voltage across the circuit will be equal to the vector sum of the voltage drops across the resistance and reactance. In the form of an equation --

$$E_A = \sqrt{(4.7)^2 + (8.8)^2} = \sqrt{22.09 + 77.44} = \sqrt{99.53} = 10 \text{ v approx.}$$

Because the voltage drop across the resistance is in phase

with the current, the angle between the E_R and E_A vectors is the phase angle between the voltage across the circuit and the current in it. Reviewing an earlier Lesson in a right angle triangle, the cosine of an angle is equal to the side adjacent divided by the hypotenuse and, using the values of Figure 1,

$$\text{cosine of the angle} = \frac{E_R}{E_A} = \frac{4.7}{10} = .47$$

Also, in our explanation of Power Factor, we told you it was numerically equal to the cosine of the angle and also equal to the resistance divided by the impedance. For Figure 1,

$$\text{Power Factor} = \frac{\text{Resistance}}{\text{Impedance}} = \frac{8}{17} = .47$$

By using a protractor, we can measure the angle of the vector diagram or, by checking the value of .47 in a table of cosines, find the angle is 61.7°. Although we have shown the calculations, a carefully drawn vector diagram saves all figuring and, by measuring the vectors, the results are sufficiently accurate for most ordinary work.

CAPACITY REACTANCE

For Figure 2, we have the Alternator and Resistance of Figure 1 but have replaced the inductance with a condenser which has a capacity reactance of 9 ohms. Remember here, although a good condenser does not allow current to pass through, its charges and discharges provide alternating current in the circuit in which it is connected. Therefore, we consider capacity reactance on the same general plan as Resistance and Inductive Reactance.

Following the plan of Figure 1, at the right of Figure 2 we have drawn the vector diagram of the circuit but, as capacity Reactance causes the current to lead the voltage, the "$X_C = 9$" vector is drawn in the opposite direction to the "$X_L = 15$" vector of Figure 1.

Completing the diagram of the "R = 8" and "$X_C = 9$" vectors, we find the diagonal has a value of approximately 12, which means the impedance of the circuit is 12 ohms. By arithmetic

$$Z = \sqrt{8^2 + 9^2} = \sqrt{64 + 81} = \sqrt{145} = 12.04 \text{ ohms}$$

Still assuming the Alternator develops 10 volts, the current in the circuit is

$$I = \frac{E}{Z} = \frac{10}{12} = .8333 \text{ amp.}$$

Then, as explained for Figure 1, the voltage drop will be --

$$E_R = IR = .8333 \times 8 = 6.67 \text{ volts}$$

$$E_C = IX_c = .8333 \times 9 = 7.5 \text{ volts}$$

Laying off these vectors on the diagram of Figure 2, we find their sum is 10 volts. The angle can be found by measurement on the diagram or by calculation --

$$\text{cosine of the angle} = \frac{E_R}{E_A} = \frac{6.67}{10} = .667$$

and as a check --

$$\text{Power Factor} = \frac{R}{Z} = \frac{8}{12} = .667$$

to indicate an angle of 48.18.

It is conventional practice to consider vectors, like those in Figures 1 and 2, as rotating in an anti-clockwise direction therefore, using the resistance vectors as a reference, in Figure 1 the current lags the voltage while in Figure 2, the current leads the voltage.

IMPEDANCE

For Figure 3, we have combined the circuits of Figures 1 and 2 and connected the resistance, capacity reactance and inductive reactance in series. The vector diagram is also a combination of those drawn for Figures 1 and 2 and, as the inductive reactance acts opposite to the capacity reactance, their vector sum is equal to their arithmetical difference.

With "$X_L = 15$" and "$X_c = 9$" their vector sum is "$X = 6$", a quantity known as the "Reactance" of the circuit. Then, following the former plan, the vector sum of the reactance and resistance is the impedance of the circuit. Using the values shown --

$$Z = \sqrt{R^2 + X^2} = \sqrt{8^2 + 6^2} = \sqrt{64 + 36} = \sqrt{100} = 10 \text{ ohms}$$

With the Alternator developing 10 volts --

$$I = \frac{E}{Z} = \frac{10}{10} = 1 \text{ ampere}$$

and the voltage drop across the different units will be --

$$E_R = IR = 1 \times 8 = 8 \text{ volts}$$

$$E_L = IX_L = 1 \times 15 = 15 \text{ volts}$$

$$E_c = IX_c = 1 \times 9 = 9 \text{ volts}$$

With a current of 1 ampere, the voltage vectors for Figure 3 coincide with the reactance and resistance vectors, therefore

$$\text{cosine of the angle} = \frac{E_R}{E_A} = \frac{8}{10} = .8$$

$$\text{Power Factor} = \frac{R}{Z} = \frac{8}{10} = .8$$

and, by measurement or reference to a table, the angle is 36.9°. Notice here, as the inductive reactance is greater than the capacity reactance, the current lags the voltage.

You will find vectors are extremely useful when working with a-c circuits and, as they are included in many technical articles, we urge you to study them with extra care and thoroughness.

PARALLEL CIRCUITS

So far, we have considered only series circuits and, to continue, will assume the same units of Figures 1, 2 and 3 but see what happens when they are connected in parallel. Before explaining the circuits, we want to remind you that while the current is the same in all parts of a series circuit, each branch of a parallel circuit may carry different values of current. However, as all branches of a parallel circuit have the same voltage across them, we will use the voltage as the base, or reference line of the vector diagrams.

For Figure 4, we have the units of Figure 1 but this time show them connected in parallel and, to make the vectors of convenient length, will assume the Alternator develops 100 volts.

As the voltage is the same for both, our first step is to find the value of the currents in the branches of the circuit.

For the resistance,

$$I_R = \frac{E}{R} = \frac{100}{8} = 12.5 \text{ amps}$$

For the inductance,

$$I_L = \frac{E}{X_L} = \frac{100}{15} = 6.67 \text{ amps}$$

As before, the current in the resistance will be in phase with the voltage while that in the inductance will lag the

voltage by 90^o. Therefore, as shown at the left of Figure 4, the I_R vector is drawn horizontally in phase with the voltage (E). Thinking of the vectors as rotating anti-clockwise, the I_L current vector is drawn down at an angle of 90^o from the origin of the I_R vector.

These current vectors are then added, by the former plan, and the length of the diagonal indicates a total current of 14.16 amperes. By arithmetic --

$$I_t = \sqrt{I_R^2 + I_L^2} = \sqrt{(12.5)^2 + (6.67)^2}$$

$$I_t = \sqrt{156.25 + 44.48} = \sqrt{200.74} = 14.16+ \text{ amps}$$

In a series circuit, the total voltage is equal to the vector sum of the voltages across the separate parts but, in a parallel circuit, the total current is equal to the vector sum of the branch currents. Therefore, for Figure 4 with a total current of 14.16 amps, at 100 volts --

$$Z = \frac{E}{I} = \frac{100}{14.16} = 7.06 \text{ ohms}$$

In the study of d-c parallel circuits, we explained the conductance method for finding the total resistance and a similar method can be used for parallel a-c circuits. To include all of the factors, and considering each one separately, the following terms are used.

$$\text{Conductance } (G) = \frac{1}{R}$$

$$\text{Susceptance } (B) = \frac{1}{X}$$

$$\text{Admittance } (Y) = \frac{1}{Z}$$

To illustrate the use of these terms, at the upper left of the vector diagram of Figure 4, we have drawn vectors to represent the reciprocals of the resistance and inductive reactance. To have the vectors of convenient length, for this part of the diagram, the scale was increased 50 times and the addition made as previously explained.

To indicate these vectors are reciprocals, they were drawn in a direction opposite to that of their respective current vectors. Also, as the conductance and susceptance values are numerically equal to the current, at a pressure of 1 volt, the assumed value of 100 volts for "E" gives the current vectors a value 100 times as great as that of their reciprocals. Therefore, the sum of the current vectors is equal to 100 times the sum of the reciprocals.

Working out these values by arithmetic --

$$Y = \frac{1}{Z} = \sqrt{G^2 + B^2} = \sqrt{(\tfrac{1}{R})^2 + (\tfrac{1}{X})^2} = \sqrt{(.125)^2 + (.0667)^2}$$

$$Y = \frac{1}{Z} = \sqrt{.015625 + .00444} = \sqrt{.020074}$$

$$Y = \frac{1}{Z} = .1416$$

$$Z = \frac{1}{Y} = \frac{1}{.1416} = 7.06 \text{ ohms}$$

To find the phase angle here, we divide the in phase current of the resistance by the total current, which can be expressed in formula form by --

$$\text{cosine of phase angle} = \frac{Ir}{It} = \frac{12.5}{14.16} = .8827$$

As previously explained, the Power Factor of a circuit is numerically equal to the cosine of the angle of lag or lead and, looking at the upper left of the vector diagram, you will see the cosine of the angle is equal to 1/R divided by 1/Z. Working this out by fractions, we find the result is Z/R which is the reciprocal of the relationship stated for series circuits. On this basis, for the circuit of Figure 4, when the resistance is a separate branch of a parallel circuit --

$$\text{Power Factor} = \frac{Z}{R} = \frac{7.06}{8} = .8825$$

The slight difference between the cosine and Power Factor is due to the fact that we carried out the various values only to four decimal places and, by measuring the diagram or consulting a table, we find the angle is 28° and the current lags the voltage.

For Figure 5, we have the units of Figure 2 connected in parallel and, again assuming the Alternator develops 100 volts, the branch currents will be --

$$I_R = \frac{E}{R} = \frac{100}{8} = 12.5 \text{ amps}$$

$$I_O = \frac{E}{X_C} = \frac{100}{9} = 11.\dot{1}1 \text{ amps}$$

Using these values, the vector diagram is drawn, as shown at the right but, because the current in the capacity reactive branch leads the voltage, its vector is drawn up from the origin of the I_R vector.

Completing the diagram, we find the vector sum of the currents is 16.73 amperes and, calculating the impedance,

$$Z = \frac{E}{I_t} = \frac{100}{16.73} = 5.98 \text{ ohms}$$

Following the plan of Figure 4, we show the vector diagram of the conductance and susceptance and find their vector sum, the admittance, has a value of .1673. Therefore,

$$Z = \frac{1}{Y} = \frac{1}{.1673} = 5.98 \text{ ohms}$$

the same value as calculated from the total current (I_t) vector.

Taking the values of the current vectors, the phase angle can be calculated.

$$\text{cosine of the angle} = \frac{12.5}{16.73} = .7476$$

$$\text{Power Factor} = \frac{Z}{R} = \frac{5.98}{8.0} = .7475$$

By measurement on the diagram, or checking a table of cosines, we find the phase angle is 41.64° and the current leads the voltage.

Looking at Figure 6, you will find the units of Figure 3 connected in parallel across the alternator. The diagram of the current vectors for Figure 6 is somewhat similar to the impedance vector of Figure 3 but, to retain the proper relationship of position, the "I_L" vector is drawn down and the "I_c" vector is drawn up from the origin of the "I_R" vector.

The total reactive current vector "I_X" is equal in length to the difference of the "I_c" and "I_L" vectors because the currents they represent are 180° out of phase. The "I_X" and "I_R" vectors are added to find the total current vector, "I_t", indicates a value of 13.26 amperes.

To calculate the impedance of the circuit, the assumed voltage is divided by the total current.

$$Z = \frac{E}{I} = \frac{100}{13.26} = 7.54 \text{ ohms}$$

The phase angle can be found by calculating the value of its cosine from the relationships between the current in the

resistance and the total current, or between the impedance and the resistance,

$$\text{cosine of the angle} = \frac{IR}{IZ} = \frac{12.5}{13.26} = .9426$$

$$\text{Power Factor} = \frac{Z}{R} = \frac{7.54}{8.0} = .9425$$

by measurement on the diagram, or checking a table of cosines, we find the phase angle is 19.51° and the diagram indicates the current is leading the voltage.

In all of these explanations, we have assumed that each unit contained but one factor. In practice, this is seldom true because, for example, the wire which makes up the coil shown as X_L, will have resistance. However, in many radio circuits of this kind, the value of the reactance is so large in comparison that the resistance can be ignored for most practical work.

COMMON HIGH FREQUENCY VALUES

So far, our explanations have assumed an a-c with a frequency of 60 cycles, and while the actions hold true, the actual values used in many radio circuits are entirely different.

Although the unit for measuring frequency is cycles, most radio broadcasting is done on frequencies between 540,000 cycles and 1,600,000 cycles and, as these figures are quite large, 1000 cycles is customarily used as the basic unit and is called a Kilocycle. Thus, instead of writing 540,000 cycles, you will find it stated as 540 kc.

Remember here that the a-c curves, explained in former Lessons, still hold good for these higher frequencies, the only difference being in the time. For 60 cycle a-c, there are 60 complete cycles or 120 alternations every second. For a radio frequency of 540 kc, there are 540,000 complete cycles or 1,080,000 alternations every second. These high frequencies are necessary to cause the electrical energy to radiate through space and we generally think of them as waves with each complete cycle forming one complete wave.

However, regardless of the frequency, the speed at which these waves travel through space is always the same as that of light -- 186,000 miles a second. This is a rather awkward figure to work with but, in the metric system, the speed is 300,000,000 meters a second. As a meter is equal to 39.37 inches, you can easily find that 186,000 miles equal 300,000,000 meters.

As the speed remains the same, the number of waves that pass any point in one second will depend on the frequency. Or looking at it in another way, the length of the waves will be governed by the frequency of the current or voltage.

In Figure 7, for example, we have an A.C. curve, like those explained in the earlier Lessons, and now want you to think of it also as a wave traveling through space. As shown by the arrows along the base line, imagine the waves are moving from left to right.

Arrow 1, drawn from the top or crest of one wave to a like point on the next, is equal to the length of one complete wave. Arrow 2 is also equal to the length of one complete wave but is drawn from the beginning of the first wave to the start of the second, while arrow 3, drawn from the bottom or trough of one wave to the next is the same length as arrows 1 and 2.

Now notice, one complete wave is the same as one A.C. cycle and, if a steady stream of waves are traveling past some point, there will be a wave for each A.C. cycle. Just to keep the figures simple, if the current of Figure 7 has a frequency of 1000 cycles, there will be 1000 waves passing each second. Then, as the waves travel at a speed of 299,820,000 or approximately 300,000,000 meters a second, and 1000 pass a given point during each second, the length of each wave must be 300,000,000 divided by 1000 or 300,000 meters.

In Figure 8, we have another wave, much like that of Figure 7, but the frequency has been doubled. Arrow 4 is but half the length of arrow 1, yet both show the length of one complete wave. From our explanations of the curve of Figure 7, you can see that, traveling at the same speed, there will be twice as many of the Figure 8 waves passing a point each second.

If the speed is the same, and the number of waves is doubled, the length of each wave must be but one half. Therefore, arrow 4 is but one half the length of arrow 1, arrow 5 and 6 are half as long as arrow 2 while arrow 7 is half as long as arrow 3.

We found the waves of Figure 7 were 300,00 meters long, therefore those of Figure 8 must be but 150,000 meters. To find the frequency, we simply divide the speed of 300,000,000 meters per second, by 150,000 meters, the length of the wave and get 2000 cycles.

As a general rule or formula we can state: Wave Length in Meters equals 300,000,000 divided by frequency in

cycles. However, as radio frequencies are figures in kilocycles, (1000 cycles) or megacycles, (1,000,000 cycles), the general formula is used in the following forms.

$$\text{Wavelength (Meters)} = \frac{300{,}000{,}000}{\text{cycles per second}}$$

$$\text{Wavelength (Meters)} = \frac{300{,}000}{\text{kilocycles per second}}$$

$$\text{Wavelength (Meters)} = \frac{300}{\text{megacycles per second}}$$

and transposing the terms --

$$\text{Cycles per second} = \frac{300{,}000{,}000}{\text{Wavelength (Meters)}}$$

$$\text{Kilocycles (kc)} = \frac{300{,}000}{\text{Wavelength (Meters)}}$$

$$\text{Megacycles (mc)} = \frac{300}{\text{Wavelength (Meters)}}$$

INDUCTANCE

In our study of a-c, we gave you an explanation of inductance because, with current constantly changing in value, the effect of induction is somewhat the same as resistance. One point we want to bring out here is the common use of the word "Inductance" as a name for various parts. This is apt to be confusing because inductance is the ability of a circuit to produce an emf, by self or mutual induction, when the current in it varies. Therefore, practically all circuits, unless especially built, have inductance and, calling some type of coil "An Inductance" is not exactly correct.

Getting down to the more practical side, the inductance of a circuit depends on the arrangement of the conductors. With a piece of wire stretched out straight, the inductance will be small. Winding it into a coil, the inductance is greatly increased but here, the size and material of the winding form, the number of turns of wire, the spacing between the turns and the length of the entire winding all vary the value of the inductance.

The unit of measure for inductance is the Henry, and when changing the value of the current in a circuit, at

the rate of one ampere per second, induces an emf of 1 volt, the circuit has an inductance of 1 Henry.

As the Henry is a very large unit, for smaller values used in radio and other electronic circuits we split it up like this.

1 Henry = 1000 millihenries
1 Millihenry = 1000 Microhenries
1 Henry = 1000 Millihenries = 1,000,000 Microhenries

CAPACITY

In our earlier Lessons we explained the charge and discharge of a condenser and, in the study of a-c, told you its action in an alternating current circuit.

The unit of measure for a condenser is the Farad and when 1 coulomb of electricity will produce a difference in pressure of 1 volt across its terminals, the capacity of the condenser is 1 Farad.

This is a very large unit and for radio units we split it up like this.

1 Farad = 1,000,000 Microfarads (mfd)
1 Microfarad (mfd) = 1,000,000 Micro-microfarads (mmfd)

RESONANT CIRCUITS

In radio, most of the high frequency circuits consist of a coil and condenser or, to be a little more technical, inductance and capacity, together with the resistance of the wires and other units. In general, they will be connected in series, as in Figure 9, or in parallel, as in Figure 11. The source, or supply, is shown by the alternator E, the inductance is marked L, the capacity C, and the resistance, R.

You will remember also that, when connected in an a-c circuit, an inductance, measured in Henries, produces an inductive reactance, measured in Ohms. This reactance causes the current to lag behind the voltage and its value in ohms is equal to 6.28 times the frequency in cycles per second times the inductance in Henries. As frequency is one of the factors, with d-c or 0 frequency, the inductive reactance will be 0 but, as the frequency increases, the value of the reactance will increase also.

On the other hand, a condenser is a capacity and, when connected in an a-c circuit, it produces what we call Capacity Reactance. Its effect is to cause the cur-

rent to lead the voltage and its value in ohms is equal to 1 divided by 6.28 times the frequency times the capacity in Farads.

In this case, with d-c or 0 frequency the reactance will be infinitely high and, for most practical purposes, will not allow current. However, as the frequency increases, the value of the reactance reduces and, at the usual radio frequencies, provides a low resistance path for the current.

Just keep these two opposite actions in mind because in Figure 9, we have an inductance and capacity in series with the resistance. When E represents a d-c voltage, there will be 0 current in the circuit because the reactance of the capacity is infinitely high.

When E represents a low frequency a-c, the current in the circuit will be small because, while the inductive reactance is low, the capacity reactance is high. When the frequency increases, the inductive reactance also increases but the capacity reactance reduces in value.

Now, because their action is opposite, the total reactance of the circuit is equal to the difference between the inductive reactance and the capacity reactance. From what we have just said, as the frequency is increased, it will reach a point where the inductive reactance has increased and the capacity reactance has reduced until they are exactly equal.

At that particular frequency, the total reactance of the circuit will be 0, the value of the current will depend on the voltage and resistance only and under these conditions, we say the circuit is Resonant or at Resonance.

As the circuit of Figure 9 is essentially the same, the vector diagram of Figure 3 can be used and you will notice that, when X_L is equal to X_C, X will equal zero to make Z equal to R. Therefore, at resonance, the series circuit of Figure 9 will have minimum impedance which will allow maximum current and, as the reactances cancel, the voltage and current will be in phase.

Connecting an a-c ammeter in a circuit of this kind and taking readings at a constant voltage, but with different frequencies, a curve, like that of Figure 10, can be plotted. Notice how the current slowly increases at the lower frequencies, but between 995 and 1000 kc, the increase is so rapid that the curve is almost vertical. At 1000 kc the current reaches its maximum value, then drops rapidly as the frequency is increased

further. The circuit is resonant at 1000 K.C., or as we sometimes say, it has a "resonant frequency of 1000 K.C.

To get down to figures, the inductive reactance is equal to 6.28 fL when "f" is the frequency and "L" the inductance. Capacity reactance is equal to 1/6.28 fC when "f" is the frequency and C the capacity. When the circuit is resonant, the inductive reactance is equal to the capacity reactance, and using the expressions just given,

$$6.28fL = \frac{1}{6.28fC}$$

Here, we have a simple equation and, to change it around to find the value of "f", transpose the denominator of the capacity reactance term making it read,

$$(6.28fL) \times (6.28fC) = 1$$

$$(6.28f)^2 LC = 1$$

$$f^2 = \frac{1}{(6.28)^2 LC}$$

$$f = \frac{1}{6.28 \sqrt{LC}}$$

In our earlier Lessons, we told you 6.28 is equal to 2 times 3.14, and as the value "3.14" or "3.1416" is usually shown by the Greek letter pi, "π", the above equation can be changed to

$$f = \frac{1}{2\pi \sqrt{LC}}$$

Which is the common formula for the resonant frequency of a series circuit. Remember here however, L is the inductance in Henrys and C the capacity in Farads.

For the smaller values, commonly found in Radio circuits, the formula can be simplified to,

$$KC = \frac{159160}{\sqrt{LC}}$$

when:

K.C. is the frequency in Kilocycles
L. is the inductance in microhenrys
C. is the capacity in micro-microfarads

Using the same values of inductance and capacity, the formula for the wavelength at resonance can be written,

$$\text{Wavelength} - (\text{meters}) - 1.884\sqrt{LC}$$

The point we want to emphasize is that the resonant frequency depends on the product of the inductance and capacity. With double the inductance and half the capacity or half the inductance and double the capacity the resonant frequency or wavelength would remain the same.

To illustrate the use of these formulas, we will assume that, in the circuit of Figure 9, "L" has a value of 85 microhenrys and "C" a value of 300 micromicrofarads. Substituting these values in the formulas:

$$f = \frac{1}{2\pi\sqrt{LC}} \quad \frac{1}{6.28\sqrt{.000085 \times .0000000003}}$$

$$f = \frac{1}{6.28\ (.000000159)} = \frac{1}{.000000998}$$

$$f = 1{,}000{,}000 \text{ cycles per second (approx.)}$$

For the second formula:

$$K.C. = \frac{159160}{\sqrt{LC}} \quad \frac{159160}{\sqrt{85 \times 300}}$$

$$K.C. = \frac{159160}{159} = 1000 \text{ (approx.)}$$

As one K.C. equals 1000 cycles, 1000 K.C. equals 1,000,000 cycles

For the third formula:

$$\text{Wavelength (Meters)} = 1.884\sqrt{LC}$$

$$\text{Meters} = 1.884\sqrt{85 \times 300} = 1.884 \times 159$$

$$\text{Meters} = 299.55 = 300 \text{ (approx.)}$$

Comparing these values by a former formula:

$$K.C. = \frac{300{,}000}{\text{Wavelength}}$$

$$K.C. = \frac{300{,}000}{300} = 1000$$

For the series circuit remember, at resonance, the relative value of current is at maximum, the reactance is zero, and the relative value of impedance is at minimum. The voltage across the inductance or capacity may be

greater than that across the circuit and the value of current depends on the resistance only.

For this reason, the resistance is a very important factor in a circuit of this type because, by controlling the current, it also controls the voltage across the inductance and capacity. The lower the resistance, the higher the voltage.

PARALLEL RESONANT CIRCUITS

For Figure 11, we have the units of Figure 9 but, to more nearly approach the conditions of ordinary circuits have shown the resistance in series with the inductance. The turns of wire which make up the unit have an appreciable amount of resistance therefore "R" and "L" in series represent the ordinary form of inductance. The capacity "C" is connected across or in parallel to the inductance.

As explained for the unit of Figure 9, the value of inductive and capacity reactance vary at different frequencies but, the parallel connection causes an entirely different action in the circuit.

Starting with D.C., or 0 frequency, there will be no current in the capacity branch and maximum current in the inductance although both have the power supply voltage across them. As the frequency is increased, the inductive reactance increases and causes a reduction of current while the capacity reactance decreases and allows an increase of current.

Remember here, inductive reactance causes current to lag the voltage by 90° while capacity reactance causes the current to lead the voltage by 90°. Thus, these currents will be 180° out of phase, or opposite to each other and, neglecting the resistance, the current supplied by the alternator will be equal to the difference of their values. This action is shown in the vector diagram of Figure 6.

Thus, as the frequency is increased from zero, the current in the inductance will decrease while that in the capacity branch will increase. Therefore the current supplied by the alternator will decrease, reaching a minimum at the frequency which allows approximately equal amounts in both branches. At higher frequencies, the current in capacity branch will continue to increase while that in the inductance continues to decrease therefore, the current supplied by the alternator will increase.

Thinking of the relationship between current, voltage,

and impedance, in a general way the curve of Figure 10 shows the changing impedance of the circuit of Figure 11, as the frequency is varied.

For a parallel circuit, Resonance can be defined in three different ways.

1. The frequency at which the line or supply current is at minimum.

2. The frequency at which the impedance is a pure resistance of the Power Factor is unity.

3. The frequency at which the inductive reactance, X_L, is equal to the capacity reactance, X_C.

The variations of resonant frequency, calculated by these three definitions, vary to such a small extent that, for most practical purposes, the resonant frequency of a parallel circuit can be found by the formula previously stated for a series circuit.

$$\text{Resonant } (f) = \frac{1}{2\pi\sqrt{LC}}$$

The high value of the impedance or resistance of a resonant parallel circuit often causes confusion and to explain the action we want you to notice that the "R-L" branch of the circuit of Figure 11, is essentially the same as the circuit of Figure 1. Following the plan explained for Figure 1, we can calculate the conditions in the coil of Figure 11.

Repeating the values given for Figure 9, L = 85 microhenries, kc = 1000, we will assume R = 20 and, following the former plan --

$$X_L = 6.28fL = 532 \text{ ohms (approx.)}$$

$$Z = \sqrt{R^2 + X_L^2} = \sqrt{(20)^2 + (532)^2}$$

$$Z = 532.38 \text{ ohms (approx.)}$$

$$\text{Cosine of the angle} = \frac{R}{Z} = \frac{20}{532.38} = .0375$$

$$\text{Angle} = 87.8^\circ$$

Assuming the alternator develops 100 volts

$$I = \frac{E}{Z} = \frac{100}{532.38} = .1878 \text{ amperes}$$

As explained in the Power Factor Lesson, this total amount is made up of an active and a reactive component. The active component is equal to the total amount times the cosine of the angle and thus would be

$$I(\text{active}) = .1878 \times .0375 = .00704 \text{ ampere}$$

Going back to Figure 11 and assuming the frequency is of such value that the reactive currents in the inductance and capacity are equal and cancel out, the alternator will supply only the active current of .00704 ampere and under this condition.

$$Z = \frac{E}{I} = \frac{100}{.00704} = 14,204 \text{ ohms}$$

For other values of frequency, the impedance of the circuit will decrease, therefore the line or supply current will increase.

Thus, at resonance, a parallel circuit has maximum impedance, or resistance, with minimum current from the supply. Another point to remember is that the reactive currents may be many times greater than the line or supply current.

USES OF RESONANT CIRCUITS

Because of their characteristics, there are many Radio applications for both series and parallel resonant circuits and, for Figure 12 we show one common arrangement using both types.

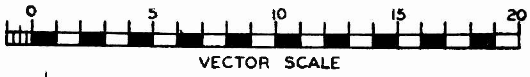
Connected across a source of voltage, the input circuit, L1-C1, is of the parallel resonant type and the condenser, C1, is variable to permit adjustment for the desired resonant frequency. With inputs of various frequencies, the circuit offers a comparatively low impedance to all except the resonant frequency. As explained for Figure 11, at the resonant frequency, the impedance is at maximum and therefore, when connected in series with other units, the voltage drop across the circuit must be at maximum also.

By mutual induction, the energy in coil LI is carried over to coil L2 and induces a voltage in it. The current, caused by this induced voltage, is the same

as if a like voltage were connected in series with the coil therefore, neglecting the "output" connections, we consider L2-C2 a series circuit. With C2 adjusted so that the resonant frequency of L2-C2 is the same as that for L1-C1, the impedance will be minimum and the current will be maximum. Maximum current causes maximum voltage drop across L2 and C2 and thus there is maximum output voltage.

At other frequencies, the impedance of L2-C2 in series is greater, the current is lower and therefore the voltage is reduced. In both cases, we have made use of the effects of resonance to increase the strength of the desired frequency and reduce the value of other frequencies. This is the action by which it is possible to "Tune" a radio receiver so that it will reproduce the signals of one carrier frequency only, because each resonant circuit acts to build up the desired or tuned frequency and reduce all others.

In Radio and all other electronic devices, the importance of resonant circuits can not be overemphasized therefore, before leaving this Lesson, be sure you understand the main characteristics of series and parallel resonance.



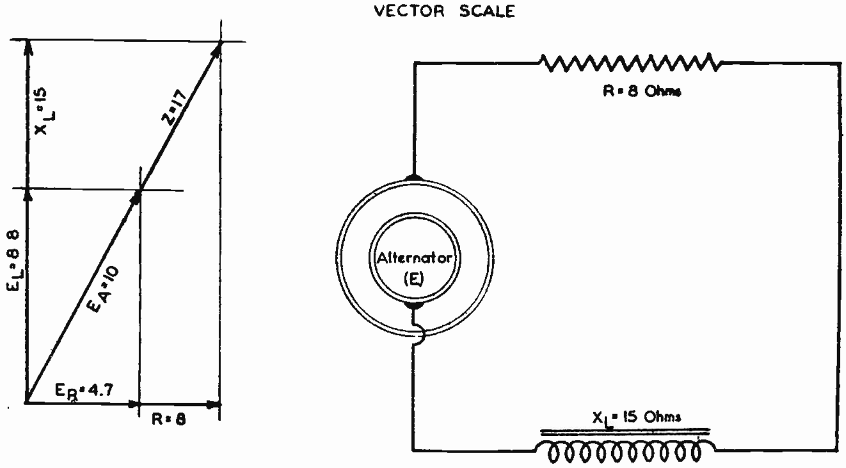


FIGURE 1

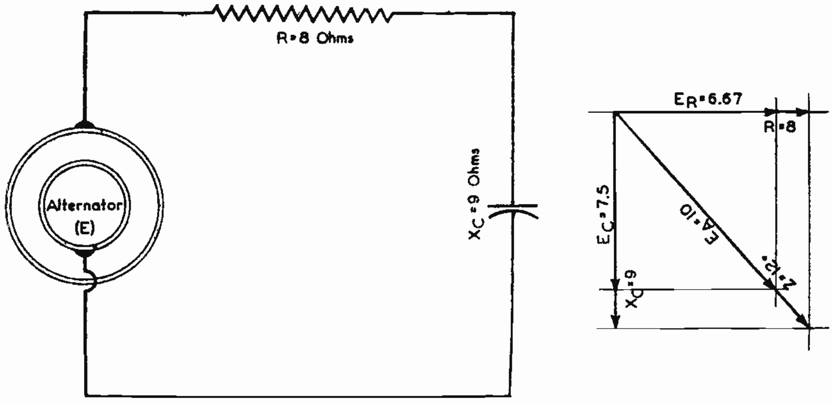
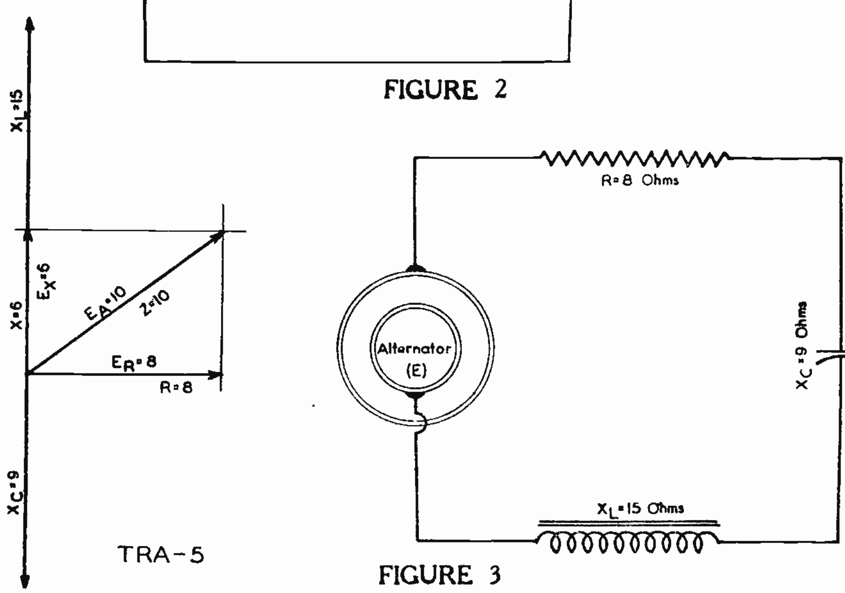


FIGURE 2



TRA-5

FIGURE 3

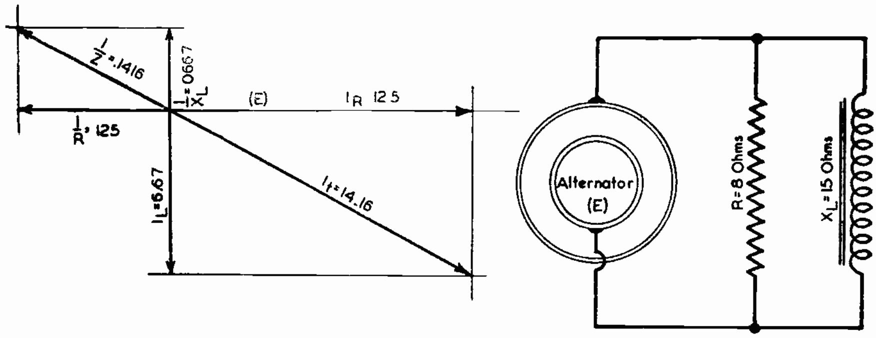


FIGURE 4

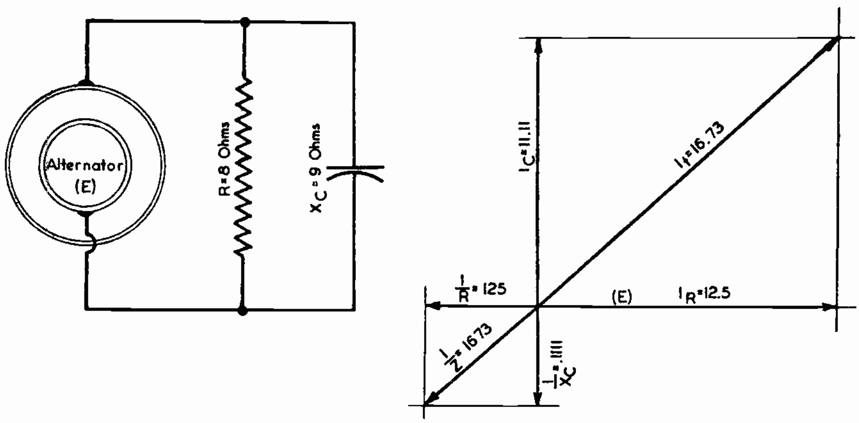
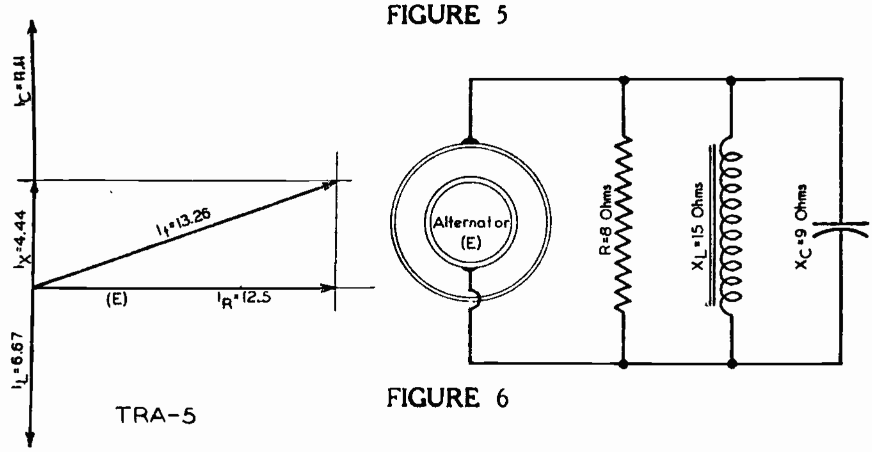


FIGURE 5



TRA-5

FIGURE 6

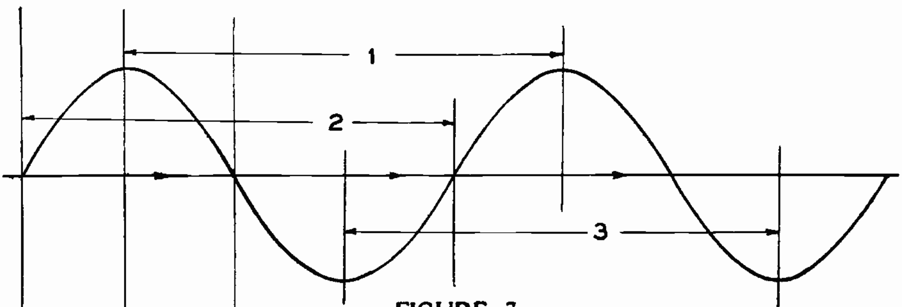


FIGURE 7

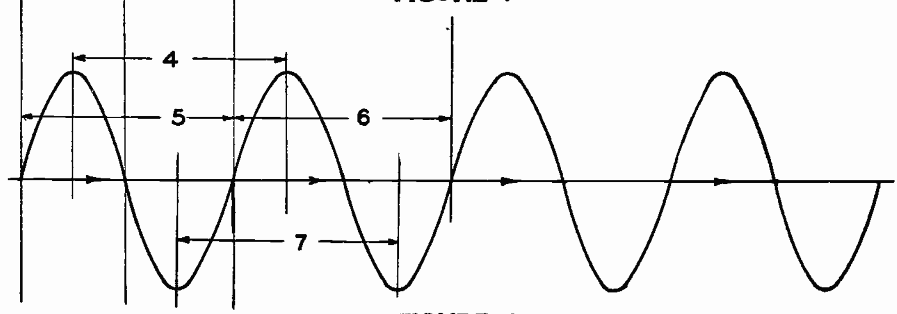


FIGURE 8

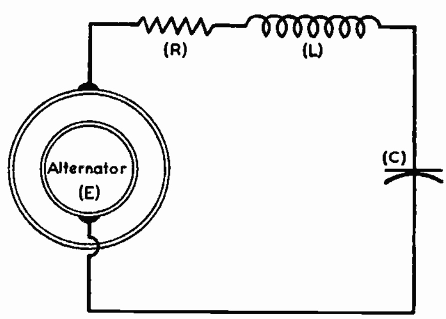


FIGURE 9

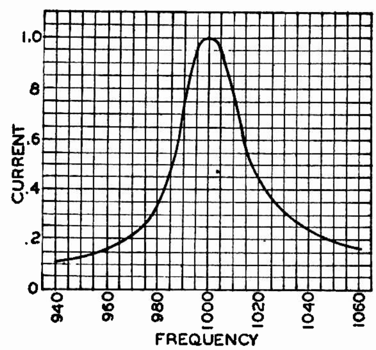
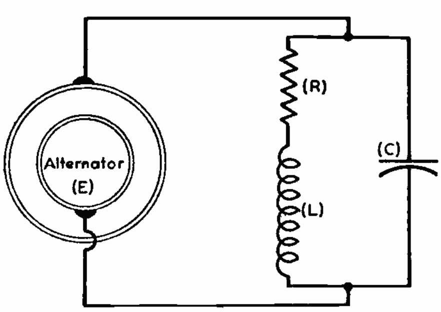


FIGURE 10



TRA-5

FIGURE 11

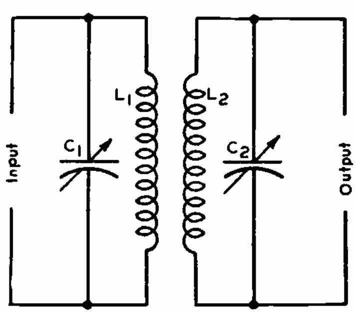


FIGURE 12

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LESSON TRA - 6
POWER TRANSFORMERS

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TUBES - RECEIVERS - AMPLIFIERS

Lesson 6

POWER TRANSFORMERS

*   *   *   *

The secret of happiness is not in doing what one likes, but in liking what one has to do.

---- James M. Barrie

REVIEW OF INDUCTION

In the former "Mutual - Self Induction" Lesson, we explained the action by which a change of current, in a wire or coil, caused a change of flux which induced an E.M.F. in the conductors it cut through. We want to mention several important points regarding this action and, if they are not clear in your mind, a review of the former lesson will be necessary to refresh your memory.

First: There are two main classes or types of induction: SELF INDUCTION which occurs in the wire carrying a current and MUTUAL INDUCTION which occurs in a wire not electrically connected to the wire carrying current, but placed in its magnetic field.

Second: Induction occurs only while the current, and the magnetic field it sets up, are changing in value.

To obtain sustained induction with a direct current supply, it is necessary to install some device which will vary the current but, in the "Current Generation" Lesson, we explained the production of A.C. which continually changes in value and periodically changes direction.

In Figure 1 here, we show two coils of wire, and the one connected to the source is the primary. The other, not connected to the primary electrically, but placed in its magnetic field, is the secondary. In order to induce an E.M.F. in the secondary, the primary current must be varied so that the flux it sets up, will change in value and cut the turns of the secondary.

Should we connect the primary of Figure 1 across an alternating current circuit, the value of the current in it will continually change during each alternation and reverse during each cycle. The magnetic field set up by the primary will act in the same way and continually cut the turns of the secondary.

When the alternating current in the primary changes direction, the magnetic field reverses also, which means the direction of induced E.M.F. in the secondary will reverse. The result is that the secondary E.M.F. will be alternating and have the same frequency as that of the circuit supplying the primary.

Analyzing this action brings out the reason why transformers can not be used on direct current circuits. Suppose we connected the primary of Figure 1 to a direct current circuit. When the circuit was first closed, the current would rise and as it did so, the flux would build up,

cut the secondary and induce an E.M.F. in it. However, that would take but a very short time and, as soon as the primary current reached its full value, it would remain steady. The magnetic field would also remain steady, the lines would not cut the secondary and there would be no further induction.

In Figure 2, we again have the same general arrangement, but have wound the coils on an iron core. While the iron will carry more magnetic lines and thus produce greater induction in the secondary, there are other actions to consider. It takes a certain amount of time for the primary current to magnetize the iron core and also for the core to lose its magnetism after the current drops to zero.

Of course, the actual time is very small, figured in seconds, but with the high frequencies used in Radio, it becomes an important factor. In general, transformers which carry currents with frequencies above 10,000 cycles, are made on the plan of Figure 1, with air, or other insulating materials as the core. Those which carry currents with frequencies below 10,000 cycles are made with an iron core on the plan of Figure 2.

In general then, you can think of a transformer as a device used only with alternating or pulsating current and made up of three main parts. 1, the core, 2, the primary winding, and 3, the secondary winding.

CORES AND CORE CONSTRUCTION

In Figure 2, the core is of the simplest possible form and can be made up of a bundle of iron wires. This is not a very good plan because the magnetic lines have to complete their circuit and here, will have to pass around through the air in order to get from one pole to the other.

As we have explained before, the reluctance of the magnetic circuit can be greatly reduced and the flux increased by making the circuit all iron. Suppose we made the core in the shape of Figure 3 and put a winding on each side. Then, the magnetic lines will have a complete and endless iron path and the action will be improved.

We have already explained how the laminations reduce the eddy currents in the core and, for transformers, the laminations are made of a special grade of silicon steel. This steel not only has low hysteresis losses, but will last almost indefinitely. The rapid and continual change of flux will cause a change in ordinary iron or steel and, after being in use for a while, the hysteresis

losses increase and reduce the efficiency. We say then that the core has "aged".

CORE TYPES

The transformer in Figure 3 has a closed core with the primary wound on one leg and the secondary on the other. This however, is not the best arrangement for the coils as we will explain later. The point we want to make now is that the form of Figure 3 is called a Core Type transformer.

There are several ways of thinking of this and you can say that a Core Type of transformer is one in which the coils are placed so that they surround the iron but have their outsides exposed to the air or other cooling medium.

Or you can think of them as having a long magnetic circuit with a short average length of winding.

SHELL TYPES

The other main form of core is what we call a "Shell Type" and it is made on the order of Figure 4. The core here is built around the outside of the coils as well as being through their center and really forms a sort of a shell around the windings.

Compared to the core type, the shell type of transformer will have a shorter magnetic circuit and a longer average length of winding. The way we have Figures 3 and 4 drawn this does not show up very well but, if you will imagine we wanted to make the core of Figure 4 with the same amount of iron as that of Figure 3, you can see that we would have to make the magnetic circuit shorter.

Both of these types have their advantages and it is impossible to say that either one is the better in all respects. As a general rule, however, you will find that most iron core transformers, used in Radio and other Electronic equipment, are built on the general plan of Figure 4.

BUILDING CORES

Perhaps, after looking at these first few Figures, you are beginning to wonder how the windings are put in their proper place on the core, but that is a purely mechanical job.

As the cores are laminated they have to be built up of

the proper number of pieces of steel that are cut to shape and size. Suppose, just as an example, that you have to assemble a transformer like that of Figure 3 and have both coils already made.

The laminations will be cut out "L" shaped and each complete square will be made up of two of the L-shaped pieces. One of these will start at the upper left, go down the left side and across the bottom only as far as the right side of the center opening. The other L will start at the lower right, go up and across the top only to the left side of the center opening, where it will complete the square by touching the first piece.

To show this arrangement on Figure 3, take your pencil and draw one line from the upper left corner of the center opening on up to the top of the core, and another from the lower right corner of the center opening down to the bottom.

The next complete lamination, or square, will also consist of two L-shaped pieces but one will start at the lower left corner, go up the left side, and across the top only as far as the right of the center opening. The other L will start at the upper right, go down the right side and across the bottom to the left of the center opening.

In building up the core, we will make two L-shaped piles of laminations, each arranged so that there is first a long and then a short extension at each end. After the piles are the proper height, we can slip a coil on each and then, by fitting these long and short piece extensions into each other, make the complete job look like Figure 3.

MAGNETIC LEAKAGE

In most of the transformers you will work with, the primary and secondary coils will not be placed on different legs of the core, as in Figure 3, because of the action shown in Figure 5.

Here, if you will think of the right hand coil as the primary, and the direction of current, at this particular instant, as shown by the arrows, a flux will be set up as indicated by the arrows through the core. There will also be a field, shown by the broken lines around the primary, which will not cut the secondary and will not do any good.

We call this extra field the magnetic leakage and, to reduce this loss, you will find that the secondary is generally placed on the same leg as the primary, on

the plan of Figure 4, but wound over or on top of it.

In some cases, with a core like Figure 5, you will find half of the primary on each leg and half of the secondary wound over each half of the primary to make use of both legs but reduce the magnetic leakage mentioned above.

The main idea is to locate the secondary winding as close as possible to the primary so that the greatest number of magnetic lines will cut the secondary and thus reduce the magnetic leakage.

Figure 6 will give you a better idea of the arrangement of parts in the common type of transformers because we have the core of Figure 4 with one end removed and have cut away half of the windings.

Notice here, the windings practically fill the space between the legs of the core and the secondary is wound over the primary. Each complete lamination consists of one "E" and one "I" shaped piece and these are stacked alternately to make up the core. The audio transformers of Radio equipment are also built on this plan but, before explaining them, we are going to tell you more about the various actions.

POWER TRANSFORMERS

Most Radio and other Electronic equipment operates on A.C. circuits and we will base the explanations of this Lesson on the type of power transformers they use. While all transformers can be placed in the two general groups of Voltage and Current, you will work mainly with Voltage transformers.

From the explanations of the earlier "Battery Connections" Lesson, you know the "A" or filament circuits of electronic tubes require low voltage and comparatively high current. The "B", or plate circuits, require comparitively high voltage with low current. The "C" or grid circuits, require medium voltage with little or no current.

The power is secured from the house lighting circuit which is usually 110 to 120 volts with a frequency of 60 cycles. In some localities the frequency is 25 cycles and occasionally you may find a 220 volt circuit. The transformer will be plainly marked because it must be connected to a circuit of correct voltage and frequency.

To illustrate the effect of a change in frequency, suppose

a coil is designed so that, when connected a 110 volt 60 cycle circuit, it allows but .1 ampere of current. With .1 ampere at 110 volts the impedance is 110 ÷ .1 or 1100 ohms but, in this case, the impedance consists of the resistance and inductive reactance. However, the resistance is comparatively low therefore, let's imagine the entire impedance consists of the inductive reactance.

In an earlier "Impedance" Lesson, we told you that the inductive reactance, X_L, was equal to two pi times the frequency times the inductance. Written in the form of an equation,

$$X_L = 2\pi f L$$

Where

π = 3.1416
f = frequency in cycles
L = inductance in henrys

As we assume that X_L is 1100 ohms and f is 60 cycles, we can transpose the formula to

$$L = \frac{X_L}{2\pi f}$$

and solve for the value of L by substituting the numerical values of X_L and f.

$$L = \frac{X_L}{2\pi f} = \frac{1100}{2 \times 3.1416 \times 60} = \frac{1100}{376.992}$$

$$L = 2.92 \text{ henry, approximately.}$$

Now, if this same coil is connected across a 110 volt, 25 cycle circuit, the inductive reactance will be equal to 6.28 fL or 6.28 x 25 x 2.92 which is only 458.44 ohms, and the current will be 110 divided by 458.44 or about .24 ampere.

In other words, the 110 volt 60 cycle coil, designed for a current of .1 ampere, when connected across a 110 volt, 25 cycle circuit will allow .24 ampere. This is over double the design value of current and will cause the coil to heat up and perhaps burn out.

From the values of this example, you can see why, as a general rule, a 25 cycle transformer will not be damaged and may operate satisfactorily on a 60 cycle circuit but, a 60 cycle transformer will be damaged if connected in a 25 cycle circuit.

TRANSFORMER ACTION

In our Lesson on "Mutual - Self Induction" we explained why the secondary E.M.F. is to the primary E.M.F., as the number of turns on the secondary are to the number of turns on the primary.

Take the circuits of Figure 7, for example, which show the wiring diagram symbol with common connections of a Power Transformer used in Electronic equipment. The primary is at the left and, by means of taps, is arranged to operate at 100 volts, 110 volts, or 120 volts. This is done to take care of the variation of lighting circuit voltages and all we want you to notice now is that the higher voltage connections include a larger number of turns.

To explain the action, just imagine that the primary has 1,000 turns between the connections of the "100" arrowed line. When connected to a circuit with a pressure of 100 volts, there will be a drop of 1 volt across each 10 turns.

There are three separate secondary windings, all of which are wound around the primary on the plan of Figure 6. The upper secondary supplies the heaters or filaments of the tubes with current at a pressure of 6.3 volts. According to the figures above, there is 1 volt for each 10 turns of the primary, therefore, as all the windings are cut by the same flux, to produce 6.3 volts, this winding will have 10 x 6.3 or 63 turns.

Another way to figure, is to remember the ratio between the number of turns and voltage of the primary and secondary, which can be written:

Primary Turns:Secondary Turns: : Primary Voltages: Secondary voltage or in a little handier form, we can state,

Pri. Turns x Sec. Volts = Pri. Volts x Sec. Turns

Substituting the figures just given for the transformer of Figure 7, we have,

1000 x 6.3 = 100 x Sec. Turns
6300 = 100 x Sec. Turns
63 = Sec. Turns

The center secondary, marked 500, is for the high voltage plate current and to figure the number of turns it has, we again substitute in the formula, giving us,

$$1000 \times 500 = 100 \times \text{Sec. Turns}$$
$$500{,}000 = 100 \times \text{Sec. Turns}$$
$$5000 = \text{Sec. Turns}$$

The point we want to bring out here is that the 6.3 volt secondary produces approximately one sixteenth of the voltage across the primary and has one sixteenth the number of turns. The 500 volt secondary produces five times the voltage across the primary and has five times the number of primary turns. Figuring the same way, the lower 5 volt secondary must have 50 turns.

TURNS RATIO

The relation between the number of turns on the primary and secondary windings is called the "Turns Ratio" and, as explained for Figure 7, the primary voltage may be raised or lowered.

When the voltage is raised, we have a "Step-Up" transformer and when it is lowered, we call it a "Step-Down" transformer. As the terms are used in Radio, a 3 to 1, 5 to 1, or 10 to 1 transformer means the ratio between the number of secondary turns to the number of primary turns.

With this in mind, you will be able to understand the action of the extra connections, or taps shown in Figure 7. We imagined there were 1000 turns between the primary connections shown by the "100" arrow.

Suppose now the primary is connected across a 110 volt circuit, yet we want to keep the secondary voltages exactly as marked.

The center secondary has 5000 turns and, with this 5 to 1 ratio, 110 volts on the primary would cause an induced E.M.F. of 550 volts. However, if we increased the primary winding to 1100 or 4-6/11 to 1 and with 110 volts across the primary, the secondary E.M.F. would again be 500 volts.

By adding another 100 turns to the primary, the ratio would be 4-1/6 to 1 and 120 volts across the primary would induce 500 volts in the secondary.

In some A.C. electronic equipment, you will find the primary of the power transformer is equipped with a switch or plugs so that the ratio can be adjusted to suit the line voltage. Regardless of the actual line voltage, it is a good plan to always make this adjustment for the highest voltage at which the equipment will operate satisfactorily.

For example, if the primary of Figure 7 is connected so that all its turns are across a 110 volt line, the secondary voltages will be slightly low. However, this lower secondary voltage usually means longer life for the tubes and better protection against sudden surges of line voltage.

We will give you details of this action a little later after we have explained electron tubes but now, want you to remember that by making extra connections, or taps, to either the primary or secondary windings, the turn ratio can be changed and the secondary voltage adjusted.

POWER RATIO

Another point we want you to keep in mind is the fact that a transformer does not produce any electrical power. Instead, it requires a certain amount of power to operate a transformer and, figured in watts, there will always be more power in the primary than the secondary.

For example, suppose the transformer of Figure 7 is in use and supplying 4 amperes at 6.3 volts, 2½ amperes at 5 volts and 50 milliamperes at 500 volts. The total secondary power will be,

4 Amps	x	6.3 volts	=	25.2 Watts
2.5 Amps	x	5.0 volts	=	12.50 Watts
.05 Amps	x	500 volts	=	25.00 Watts
		Total	=	62.7 Watts

But by means of meters, we see the primary power is 75 watts. As the primary power is the "Input" and the secondary power is the "Output", we find it requires an input of 75 watts to produce an output of 62.7 watts.

EFFICIENCY

Although it is not important in your work, the efficiency of a transformer is found by dividing the output by the input. From the values above, 62.7 divided by 75 gives us approximately .84 or 84% as the efficiency of the transformer. In other words, for every 100 watts of power in the primary we are able to have but 84 watts in the secondary.

ACTION ON OPEN SECONDARY

With the primary of a transformer connected across a power circuit, it looks as if there would be current in it whether the secondary circuit was being used or not. That is true but, when the secondary circuit is

open, the current in the primary is very small.

To follow the action, suppose we have a transformer, the primary connected across a line and the secondary circuit open. The alternating current in the primary will set up an alternating flux that cuts both windings and induces an E.M.F. in them.

The induced E.M.F. in the primary is caused by self induction, while that in the secondary is caused by mutual induction but, as the secondary circuit is open, there will be no current in it.

The self induced E.M.F. in the primary is called the Reverse Pressure and, from your laws of induction, you know that it will oppose the voltage that is causing the current.

As the primary is wound on an iron core, the induction will be high and the reverse pressure will be almost as great as the line, or impressed pressure. The difference between them is the effective voltage, and is the only pressure that can cause current. With a small effective voltage, the primary current is very small.

ACTION WITH CLOSED SECONDARY

When the secondary circuit is closed, then the induced E.M.F. in the secondary winding will cause a current. This current sets up a flux which, like that of the primary, opposes the flux that causes it.

As we mentioned several times before, you can not set up two distinct magnetic fields, in the same place at the same time. Whenever you try, they simply combine and form one resultant field.

Here then, the flux set up by the secondary current will oppose the primary flux which induces the secondary E.M.F. with the result that the primary flux will be weakened. With a weaker primary flux, the reverse voltage of the primary will be lower and thus the effective voltage will be higher.

A higher effective voltage means more primary current, and the whole action works out so that the primary current will vary with the secondary current.

Many men have the idea that a transformer can supply almost any amount of current at its rated voltage but that is not true. As the amount of current increases,

the voltage available across the windings decreases, making it necessary not to exceed the current values for which the transformer is made.

A change of voltage takes place in the secondary and, as the current, or load, is increased, the voltage will fall. The amount of this drop is called the Regulation and is usually figured as the percentage of increase in the secondary voltage as the load is cut down from its proper value to 0. As an equation:

$$\% \text{ Regulation} = \frac{100 \text{ (No load Voltage - Full load voltage)}}{\text{Full load voltage}}$$

When used in respect to a generator, transformer or other source of voltage, the term "Load" refers to the power delivered to the circuit by the source. However, you may find the "Load" described as "so many amperes", "so many Ohms" or perhaps in terms of the power consuming units.

To avoid confusion, always keep the "Power" idea in mind. Then, if expressed in amperes, an increased of current will cause an increase in load but, if expressed Ohms, a decrease of resistance will allow an increase of current and, therefore, an increased load.

In some Electronic circuits, the power is dissipated in a Resistor which should be called, The "Load Resistance" but unfortunately, is often referred to as the "Load". However, an examination of the circuit will usually indicate what is meant and, as explained above, an increase in the value of the "Load resistance" will reduce the "Load" on the supply.

IMPEDANCE RATIO

As explained earlier in this Lesson, a transformer does not produce any electrical energy and the secondary power will always be as less than that in the primary. However, to bring out another important point we will assume a perfect transformer with the 10 volt primary and 5 volt secondary of Figure 7. In this "perfect" transformer, the power in the secondary will be equal to that in the primary.

Connecting a 5 ohm load across the secondary, we will have

Current = E/R = 5/5 = 1 ampere
Power - EI = 5x1 = 5 watts

For equal power in the primary

Current = W/E = 5/100 = .05 amps.
Impedance = E/I = 100/.05 = 2000 ohms.

Suppose we connect a 10 ohm load across the secondary, Then, for the secondary,

Current = E/R = 5/10 = .5 ampere
Power = E/I = 5x.5 = 2.5 watts

For equal power in the primary,

Current = W/E = 2.5/100 = .025 amp.
Impedance = E/I = 100/.025 = 4000 ohms

Comparing these values, we find,

Voltage Ratio = 100/5 = 20

With the assumed "perfect" transformer, the voltage ratio, is equal to the turns ratio, a condition which is approximately true in many actual circuits. Comparing the secondary and primary impedance, we find,

Impedance Ratio = 2000/5 = 400

and for the second example,

Impedance Ratio = 4000/10 = 400

Checking back on these various values, we see the impedance ratio is equal to the square of the voltage ratio. As an equation we can write

$$\frac{Z_p}{Z_s} = \frac{(E_p)^2}{(E_s)}$$

When

Z_p = Primary Impedance
Z_s = Secondary Impedance
E_p = Primary Voltage
E_s = Secondary Voltage

Notice also, that the primary impedance is equal to the secondary load impedance multiplied by the impedance ratio, the square of the voltage ratio or the square of the turns ratio. This primary impedance is known as the "Reflected Impedance" or the "Reflected Load".

Keep these relationships in mind because they are of importance in respect to some transformer applications which will be taken up in the later Lessons.

COMMON TRANSFORMER UNITS

In Figure 8, we show a number of transformer units which may be employed in various types of Radio Equipment. Although they have different mechanical appearances, the electrical action, as explained in this Lesson, is the same for all.

The two upper rows of units are known as "Power Transformers" and are used to supply the proper voltage and current to the various elements of the tubes employed in the electronic field. As shown, you will find them in many different styles of mountings. They can generally be distinguished from other transformers by their size and large number of connections.

The bottom row of units are referred to as "Audio Transformers" and they obtain their name from the fact that they are designed to operate at audible frequencies which are generally assumed to be between 50 and 10,000 cycles. Audio transformers may be used in Radio to transfer the audible signal from one stage to the next.

This Lesson completes the series on general principles, therefore we are ready to take up their application to actual Radio systems. In the next Lesson we are going to explain the original methods by which Electrical Energy is radiated through space and "Received" over long distances without the use of connecting wires. In the explanations of the following Lessons, we assume you know your general principles therefore, at this time a review may be of benefit.

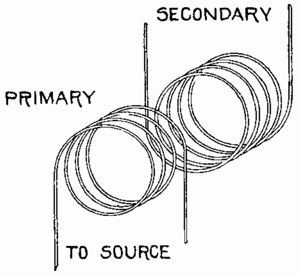

FIGURE 1

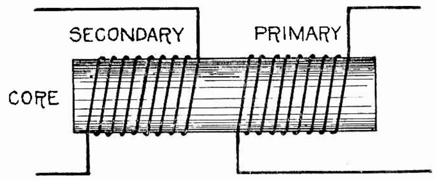

FIGURE 2

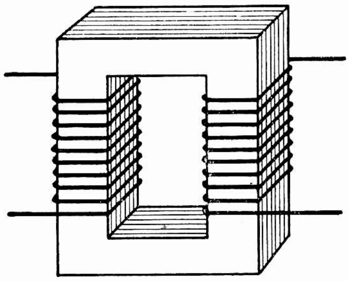

FIGURE 3

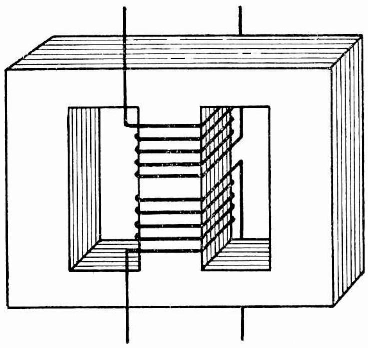

FIGURE 4

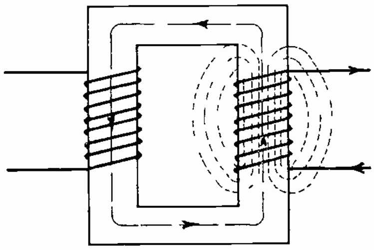

FIGURE 5

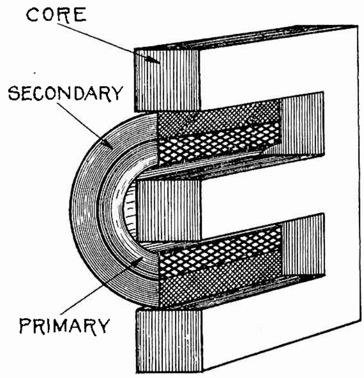

FIGURE 6

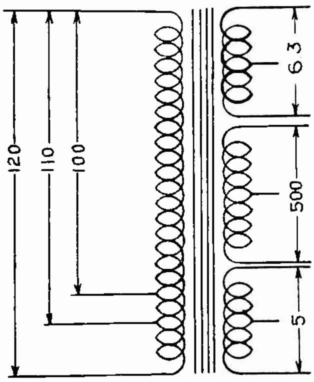

FIGURE 7

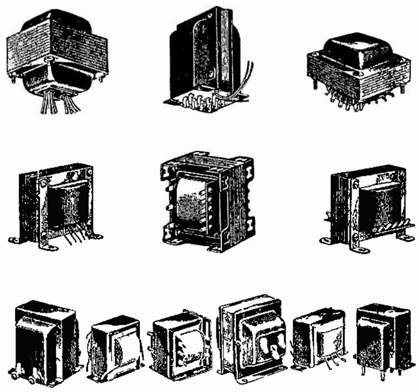

FIGURE 8

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LESSON TRA - 7

RADIO PRINCIPLES

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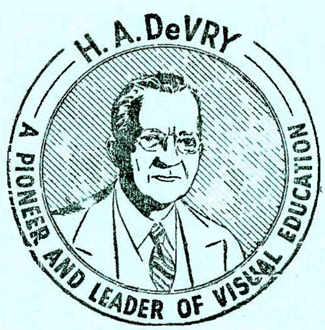

DE FOREST'S
TRAINING, Inc.

LESSON TRA - 7
RADIO PRINCIPLES

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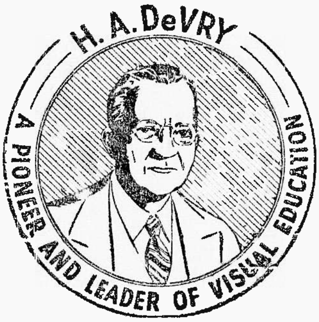


TUBES - RECEIVERS - AMPLIFIERS

Lesson 7

RADIO PRINCIPLES

* * * * * *

He who is silent is forgotten; he who abstains is taken at his word; he who does not advance falls back; he who stops is overwhelmed, distanced, crushed; he who ceases to grow greater becomes smaller; he who leaves off, gives up; the stationary condition is the beginning of the end.

--- Amiel

RADIO PRINCIPLES

Dr. Lee DeForest is known as the "Father of Radio" because his invention of the "Audion" tube, back in the year 1905, was the key which unlocked the door to the enormous development and application of Radio and other Electronic systems. However, we must remember that it was Dr. DeForests research to improve the operation of existing "Wireless Telegraph" systems that led to his now famous invention of the tube.

The wireless systems of that day were extremely crude, compared to modern apparatus, and operated entirely by the dots and dashes of the telegraph code but, the basic principles of their operation have not changed and are still employed.

For this Lesson therefore, we will explain these principles by showing their application in the older systems which operated without the use of tubes. By this plan, we can not only simplify our explanations but, later on, when we take up the subject of tubes, you will appreciate their applications more readily.

First of all, in order to send or transmit messages by Radio it is necessary to operate A.C. with a frequency of 10,000 cycles or more. It is only these high, or Radio frequencies which will radiate through space and provide the desired action.

Thinking of a simple alternator, as explained in the earlier Lessons, you can readily calculate that the frequency it generates will be equal to the number of pairs of poles multiplied by the revolutions per second.

By building an alternator with a large number of poles and running it at a very high speed, frequencies as high as 100,000 cycles and even up to 200,000 cycles have been produced. That however, seems to be about the limit by this method and the machines are very costly. However, 400 to 500 cycle alternators are successful and in fairly common use.

Another method that was formerly quite common, and in fact the first Radio Telephony was accomplished through it, is the electric arc. By this method, the variation of voltage across an arc were used to produce high frequency in a second, or oscillating circuit. Due to the greater efficiency and convenience of modern tubes, this method is obsolete today.

SPARK TRANSMISSION

One of the earliest, and perhaps the simplest method of producing radio frequency currents, is by means of an induction coil and a spark gap. Like the arc, spark transmitters are obsolete but as the action is easy to follow, we want you to look at the circuit of Figure 1. Think of this as a telegraph set which can transmit the dots and dashes of the code and send them through space by means of radio frequency waves.

Starting at the left, we have a 500 cycle alternator supplying energy to the primary of a transformer. This transformer has a high ratio and steps up the voltage to a value sufficiently high to jump a gap in the secondary circuit and produce a spark.

Tracing the circuits here, there is a path, from the upper alternator brush through the key, through the transformer primary and back to the lower alternator brush. The key here is the ordinary telegraph type and controls this circuit.

From the upper end of the transformer secondary, there is a circuit over to the right, across a spark gap, down through a coil, called an Inductance, and back to the lower end of the secondary. Also, there is a condenser connected across the spark gap and the inductance.

Then, close to the inductance, there is a second coil, one end of which connects to the antenna, and the other to the ground. That completes the circuits and now we will follow the action.

When the key is pressed, the primary circuit is closed and the alternator forces current through the primary circuit. This has a frequency of 500 cycles and induces a high voltage, of the same frequency, in the secondary. The condenser is connected right across the secondary therefore, as the secondary voltage rises during each alternation the condenser is charged until the pressure reaches a point where the resistance of the air in the spark gap can no longer hold it.

Current is then forced across the gap, producing a spark and, as long as the spark continues, the resistance of the gap is comparatively low, allowing the condenser to discharge through the gap and the inductance.

Now here is the idea. When discharging, the action of the condenser is to equalize the potential of its plates and the plate at high pressure discharges through the

gap and inductance to the low pressure plate. As the current rushes from the high potential plate, it overdoes the job, with the result that the plate which was low, becomes highly charged.

Still trying to equalize the potential of its plates, the condenser then immediately discharges around the circuit in the other direction and the action is repeated. These discharges, first one way and then the other, continue until the plates are at equal potential, or the difference in voltage between them is not great enough to force current across the gap.

Remember here, this action is very fast and the condenser discharges take place thousands and even millions of times in a second but reduce in amplitude until they can no longer maintain current across the gap. During the next alternation of the supply, the secondary voltage charges the condenser again and the entire action is repeated.

In the circuit consisting of the condenser, spark gap and inductance, the current will be of high frequency because of the speed of the condenser discharges and for this reason, we call it an oscillating circuit. The coil, connected between the antenna and ground, is placed so as to be in the magnetic field of the inductance and thus the high frequency voltage is induced in it.

The inductance is really the primary and the coil in the antenna circuit, the secondary of a transformer and therefore we call these two coils an Oscillation Transformer.

It is this high frequency, in the antenna and its circuit, that sets up the electro-magnetic waves which radiate with the speed of light and carry the messages. Every time the key in the alternator circuit is closed, a series of these waves leave the antenna, in much the same way as the current travels in the ordinary telegraph circuit.

ANTENNAS

To fully understand the action in the antenna, you must remember that there is a rush of current first in one direction, then in the other, and the speed of these changes of direction depends on the frequency.

It may help you to think of the actual antenna, of the circuit of Figure 1, as the straight solid line of Figure 2-A, with the upper part in the air, and

imagine that the first part of the high frequency voltage wave causes a rush of current from the bottom to the top.

As this happens, the current sets up a magnetic field around the antenna and, as shown by the circles, you can think of these as magnetic lines of force which spread out in all directions and are produced as long as there is current in the circuit.

You can also think of this action much the same as that of charging a condenser. Although it lasts but a very short time, this rush of current sets up the magnetic field, or magnetic lines of force.

Then, when the voltage can not cause any further current, there is a difference of voltage, between the antenna and ground, which sets up an electrical field. This electrical field is a sort of a strain which is thought of as being made up of lines, much like the magnetic field, and these lines also move out from the antenna as shown in Figure 2-B.

As the antenna current dies out, no further magnetic lines are produced and those that were set up, collapse and fall back. However, before they can all reach the antenna, the high frequency voltage reverses and there is a rush of current from the top to the bottom which, as before, sets up a magnetic field, but in the opposite direction.

As the voltage reverses, the lines of the electric field also die out but, as they are still moving away from the antenna, we have the conditions of Figure 3. Some of the magnetic lines that were produced during the conditions of Figure 2-A are still spreading out and traveling with the electric lines of force.

Then, as the high frequency voltage reverses again, these first lines seem to break off form in separate loops as in Figure 4, and one of these loops, or waves, is thus formed for each cycle of the antenna current.

If you were able to watch these actions, when looking down on the top of the antenna, the magnetic field would appear much the same as the waves set up when you drop a stone into calm water. We show this action in Figure 5 and each band of rings represents the lines set up by each rush of antenna current. Remember, all of the lines are spreading out at a speed of 186,000 miles a second.

The lines of the electric field also spread out at the same

speed and at a distance from the antenna would look like Figure 6. First, those lines set up when the antenna was positive, or at a potential higher than ground and next, those when the antenna was negative, or at a potential lower than ground. In the same way, the bands of magnetic lines of Figure 5 are alternate in their direction.

A little later on, we are going to explain how these magnetic waves, cutting across the antenna of your Radio receiver produce current of the same frequency as that which caused them but now, we want to show you a little more about the waves themselves.

KIND OF WAVES

All of the complicated wave actions, shown in Figures 2, 3, 4, 5 and 6 are generally drawn with simple curves like those explained in the earlier Lessons, the part above the straight or base line being considered as positive and the part below, as negative. A line drawn perpendicular from the base line to the peak of the wave is the amplitude and represents the strength or intensity of the wave.

When all of the waves have the same height, or amplitude, we call them continuous, or write CW meaning continuous waves. It is waves of this type which are used for broadcasting and they are also in common use for wireless telegraphy.

In the circuit of Figure 1 however, with the high frequency oscillations caused by the discharges of the condenser, a different form of wave is produced. It requires a high voltage to force current across the gap, which means a voltage wave of high amplitude. As the condenser discharges back and forth, the voltage gradually becomes lower and lower, and the amplitude of the waves is less and less.

Laying out this action, in the form of a curve, we have a wave train on the order of Figure 7. Notice here that the first cycle, "A" is like those of a simple alternator but, in the next cycle the voltage is lower, the next one still lower and so on until it dies out.

This we call a Damped Wave and, while it is of very little, if any use for speech or music, it was in general use for telegraphy but, as we said before, has gone out in favor of C.W.

SPARK GAPS

Before leaving these damped waves, we want to mention the various types of spark gaps that were used in the circuits producing them. One of the simplest forms, on the order of Figure 8 and consisted of two uprights with an electrode supported by each.

One of these electrodes was threaded into the support so that the distance between them could be carefully adjusted. This type of gap was made in many forms, some of them being provided with disks or collars on the electrodes to help radiate the heat that was caused by the spark. On account of this heat, most of the electrodes were made of zinc, because it does not arc. In making the adjustment of a gap of this type, the electrodes were set just far enough apart so that a good fat spark would pass between them.

QUENCHED AND ROTARY GAPS

The action of one of these simple open spark gaps could be improved by using a series of smaller gaps. This type was called a quenched gap and was made of a series of metal disks, shaped so that they were held a short distance apart, and the spark was enclosed entirely.

All of these different types of gaps were made with the idea of producing a better form of wave and the better models of spark type telegraph sets included a rotary gap built on the order of Figure 9. Here, the electrodes were mounted about the same as in the simple open gap, but a notched, motor driven disk was placed between them.

As the disk revolved, the notches passed close to the electrodes, allowing the spark to occur but, between the notches, the gap between the electrodes and the disk was too large to permit a spark. With the disk running at a good speed, the sparks occurred very rapidly, but regularly, producing a wave that caused a musical and distinctive note in the receiver.

RECEIVERS

Now to get back to continous waves, we told you many human ears would not respond to frequencies over 10,000 cycles, yet that was where the Radio frequencies started.

In other words, should we connect a telephone receiver in a high frequency circuit, we would not hear a sound because, even if the diagraphm did vibrate at the frequency of the current, the air waves it preduced would

not effect our ears and we could not hear them.

However, we know that the action of the diaphragm of a telephone receiver is very slow, compared to electricity and magnetism, and usually think of the reversals of high frequency current as happening so fast that the diaphragm can not follow them and therefore does not move at all.

The problem then is this. We must have high frequency to cause the waves that travel through space, but need a low frequency in order to hear them, and the problem is solved by using the high frequency waves to carry the low, or audio frequencies.

For example, in Figure 10 we show a curve of high frequency waves, but the amplitudes are not all the same. Starting at the left, the amplitude is quite low, but rises with each high frequency cycle until it reaches a high, or maximum point, when it lowers again, after which the action is repeated.

By drawing a line across the tops of the high frequency waves, you will have a curve, or wave, of an entirely different frequency. We can explain this by saying that the high frequency wave is carrying the waves of lower frequency and therefore, the high frequency is often called the Carrier Wave, or Carrier Frequency. Don't worry just now as to how we can control the amplitude of these high frequency waves as we will explain that later.

According to our former explanations, those parts of the wave above the center are considered positive while those below are negative and as we have mentioned before, there are rectifiers which allow current in one direction only. Suppose then we connect a rectifier, in the circuit carrying the waves of Figure 10, which will allow the positive current but not the negative.

That will simply wipe out all of the negative parts of the curve and leave us with the waves of Figure 11. This is still high frequency but a telephone receiver in a circuit carrying this form of current will produce sound. It can not follow the changes of the high frequency but, with its slower action, will respond to the changes of amplitude and cause the diaphragm to vibrate with the frequency of the curve drawn across the tops of the high frequency waves.

By connecting a condenser across the telephone receiver, and allowing it to charge and discharge, the actual circuit current in the receiver will resemble the

waves of Figure 12. The tops of the curves of Figure 11 charge the condenser, which then discharges and fills up the gaps of Figure 12, to produce a current change, or wave like Figure 13.

To sum it all up, you can think of Wireless, or Radio, as the production of a high frequency carrier wave, the amplitude of which is controlled, or modulated by a lower frequency. Then, at the receiving end, the high frequency is rectified, or demodulated, and passed through a telephone receiver which responds to the lower frequency and produces sound waves.

RADIO RECEIVERS

By the curves of Figures 10 to 13, we have indicated how the modulated Radio Frequency waves are changed to a lower, audio frequency in order that we may hear them and in Figure 21, we have the circuits of the simplest form of Radio receiver. It is commonly known as a crystal set and employs a single tuning coil, wound on a form, with one end connected to the antenna while the other connections are made by means of sliding contacts. Notice, there is a direct path from the antenna through the coil to the ground and it is in this circuit that we want to start our explanation.

To begin, we will have to go back to the laws of electromagnetic induction and remind you that whenever a conductor cuts a magnetic field, or magnetic lines of force, an E.M.F. or voltage is induced. It makes no difference whether the conductor cuts the field, or the field cuts across the conductor, as long as they cut across each other, a voltage will be induced in the conductor.

We have already explained how the high frequency electro-magnetic waves are sent out from the transmitting antenna in all directions, traveling at the speed of light. No matter where you are, right now there are undoubtedly a number of these waves passing through the room and through your body. Of course they are very weak and do not produce any sensation at all.

You can not see, hear, taste, smell or feel them but, should you hold a piece of wire in your hand and let it hang down, these waves would cut through and induce a voltage in it as they went by.

RECEIVING ANTENNAS

First of all, we want to arrange a wire so that there

will be the greatest possible induced voltage and provide a circuit for the current it will cause. This we call an antenna and, like the transmitting antenna, in its simplest form is nothing but a vertical wire, insulated at the upper end and connected to ground at the lower end.

Going back to the principles again, you will remember that the value of the induced voltage depends on the rate of cutting therefore, you can see that the higher the antenna is placed the greater the number of magnetic lines that will cut it and thus the induced voltage will be stronger.

Like everything else, there are practical limits and with the frequencies used in broadcasting today, the vertical wire could be from 100 to 200 feet high. That would mean a high and expensive tower beyond the means of the ordinary man and therefore, other plans are in common use.

Usually, the antenna wire is stretched horizontally between poles on a roof, between two buildings or any other handy supports. Then, at one end or in the center of the horizontal wire, a connection is made to a second wire which extends down vertically to the receiver. Inside the receiver, the circuit is completed to ground through some sort of a coil.

As the current in the transmitting antenna travels up and down, it produces the magnetic lines of force that travel through space and cut your receiving antenna. The action at the receiving antenna is reversed because it induces a voltage which, when a path is provided, causes a current like that in the transmitting antenna.

With the large number of transmitting and broadcasting stations now in operation, the waves sent out by several and perhaps many of them will cut the receiving antenna and each of them will induce voltages in it. Naturally, you can not listen to them all at once and, picking out only the one you want, is what we call "Tuning".

TUNING

We have already told you how the high frequency waves are used to carry the low, or audio frequencies but it is also by the use of these carrier waves that we are able to select, or tune to the sending station that we

want to hear.

Looking at Figure 21 once more, over at the left we have a circuit made up of nothing but the antenna, a coil of wire and a connection to ground. You can think of the upper triangular part of the symbol as the flat top of the antenna and the connection between it and the coil as the lead in. Or, you can think of the antenna and ground as a pair of condenser plates, with the lead in and coil connected between them.

As the waves from the sending station cut the lead in, a high frequency voltage is induced which, in turn, causes a high frequency current in the circuit. This may be a little hard to see but, thinking of the antenna as a condenser plate, it will charge or discharge, when the induced voltage reverses, and these charges form the current in the circuit.

The coil however, has a different effect. Current in it sets up a magnetic flux which cuts the turns of wire making up the coil and therefore induces and E.M.F. in the coil. This E.M.F. is in a direction to buck or oppose the E.M.F. which causes the current that sets up the flux.

As the current builds up in one direction, the magnetic lines spread out and induce a voltage that tries to prevent the current. Then, as the current dies out, the magnetic flux collapses, again inducing a voltage, but this time its direction is such that it will try and maintain the current.

The value of the voltage induced in the coil will depend on the number of turns of wire, the space between them and so on, but now, we want you to remember that it will have quite an effect on the amount of current in the circuit. As in any A.C. circuit, we call the coil an inductance and its action is to make the current lag behind the voltage.

The other thing that interests us here is the capacity of the antenna, or the amount of electricity it can absorb. Capacity acts opposite to inductance and will cause the current to lead the voltage.

That gives us three things to keep in mind about this circuit. First, we have the voltage induced by the passing waves and the current caused by it. Second, the inductance of the coil which causes the current to lag and third, the capacity which causes the current to lead the voltage.

Suppose now that a train of waves with some certain frequency comes along and induces a voltage of the same frequency in the antenna. On account of the capacity, the voltage will cause a current having a frequency the same as its own.

Here is the point. If the capacity and inductance are of such values that the capacity will discharge just as the induced antenna voltage reverses, the current will be greatly increased.

As a good example of this action, suppose you are pushing someone in a swing. You stand behind them and the swing comes toward you but you do not push until it stops and then starts away from you. By pushing at just exactly that instant, every time the swing comes back, you can keep it going quite high with very little effort.

However, if you should push while the swing was still coming toward you, it would very soon stop and, on the other hand, if you waited until it had a good start away from you, your push would not do much good.

Depending on the length of the rope, the swing will move back and forth at some certain rate or have some certain frequency. If your pushes are at the same rate, or frequency, and come at the right time, you can make the swing go quite high with little effort.

The same idea holds here in our antenna circuit which you can think of as acting somewhat like the swing. Depending on the values of capacity and inductance, the charges and discharges will occur at some certain rate and produce oscillations of some certain frequency. That is what we call the natural frequency, or wave length of the circuit.

When a series of waves, of this same frequency, come along and cut the antenna, they induce a voltage which pushes at just the right instant and a comparatively large current is produced. Waves of other frequencies may be inducing voltages in the antenna at the same time, but their "push" does not come at the proper instant. Therefore little if any current is caused by them.

Tuning them, means changing the inductions or capacity of a circuit so that its natural frequency will be the same as that of the passing wave that we want. All of the tuning units used in radio work are nothing but inductances or capacities whose value can be changed

or varied.

To tune the circuit of Figure 21 we move the slider connected to ground, until there are the proper number of turns in the circuit to tune it to the frequency of the wave we want.

In parallel to the coil, there is another circuit from the upper slider, through the crystal and phones to ground. Like any parallel circuit, the current will divide, some passing through the tuning coil and some through the crystal and phones.

CRYSTAL DETECTORS

The crystal detector has a rather peculiar action as it offers a fairly low resistance to current in one direction but an extremely high resistance to current in the opposite direction. In practice, however, we generally think of the crystal as allowing current in but one direction.

With radio frequency current in the tuning coil, there will be current in the phones also but, on account of the crystal, it will be in one direction only. In other words, the current in the tuning coil has a wave form like that of Figure 10, while the current in the phone circuit has a wave form like that of Figure 11.

The movable contact, or slider, shown at the upper right of the coil, allows us to balance the tuning coil and phone circuits so as to have the greatest current in the phones.

A small condenser, usually about .002 M.F., is connected across the phones and, as it charges and discharges, due to the changes of voltage, it smooths out the waves, giving them the form of Figure 12 and 13. Because the diaphragm of the phones cannot respond as quickly as the carrier frequency current changes, its movements correspond to the shape along the tops of the waves.

RECEIVER UNITS

Although this explanation of tuning has been made for the simplest type of Radio Receiver, we want you to study it carefully because it includes the principles by which all Radio Transmitters and receivers are tuned. Technically, the action is nothing but an application of the principles of resonance, explained in an earlier Lesson. Instead of the slides shown in Figure 21,

many methods have been developed by which the inductance of a coil can be varied. Still following the development of Radio, we want to explain a few of these, all of which were popular at one time but some of which are no longer in general use.

VARIO-COUPLERS

For example, the component shown as Figure 14, is called a vario-coupler and consists of an outer tube, made of insulating material, with a coil of wire wound on the outside. This we call the stator, or primary winding and there may be a small loop, called a tap, every few turns. By connecting these taps to a switch, the number of turns, used in the circuit, can be varied.

Supported on a shaft, mounted in bearings fastened to the stator, we have a second, smaller tube, which also carries a coil, or winding. As the shaft is free to turn, the smaller tube can be turned inside of the larger one, therefore as the outer tube is called the stator, the inner one is the rotor.

You can think of this as a form of transformer with the rotor carrying the secondary and the stator the primary winding. When there is current in the primary, the resulting magnetic flux cuts the secondary but, by changing the position of the rotor, you can control the angle at which the flux cuts the secondary.

In this way, by changing the magnetic coupling between the coils, the amount of induction in the secondary can be controlled. In the position of Figure 14, the induction will be the lowest, or the coupling at minimum. Turning the rotor one quarter way around, the induction in the secondary will be highest, or the coupling at maximum. Instead of maximum, we often say tight coupling, and for minimum, use the words, loose coupling.

Because Radio circuits are very sensitive, a slight change in the position of the rotor often makes a big difference in the action and, as the entire adjustment is made in one quarter turn, the coupler of Figure 14 is sometimes very hard to "tune".

In order to make the adjustment, or tuning, easier, variocouplers are built on the plan of Figure 15. The parts and windings are exactly like those of Figure 14 but, by placing the stator and rotor tubes in the positions shown, it takes a half turn to move the rotor

from the maximum to the minimum coupling positions.

For this reason, Figure 14 is called a 90° varic-coupler, while Figure 15 is a 180° varic-coupler. Couplers are generally connected so that the primary is in one circuit and the secondary in another. Remember however, even though the windings are not electrically connected, they are still coupled by the magnetic flux of the primary which cuts the turns of the secondary winding.

VARIOMETERS

Built along quite similar lines, another form of variable inductance is called a variometer. In the older models, the stator was made of two blocks of insulating material, hollowed out on the inside and held apart by small plates, which also carried the rotor shaft. The stator winding was placed in the hollow.

The rotor was made in the shape of a ball, mounted on a shaft and carried its winding on the outside. Turning the rotor produced the same coupling effects as in the coupler of Figure 14 and the main difference between the two is in their use.

In the coupler, the primary and secondary windings are generally parts of separate electrical circuits, while in the variometer, the stator and rotor winding, usually connected in series, are part of the same circuit.

As the rotor is turned, the magnetic fields, set up by each part of the winding, aid or oppose each other. When the rotor is turned so that the flux combines, the induced E.M.F. is high and the inductance is large. When the rotor is turned so that its field is in a direction to oppose that of the stator, the induced E.M.F. is low and the inductance is small. By changing the value of its induced E.M.F., the variometer can be used as a variable inductance.

There are also many circuits which require an inductance of some certain value and there you will find a winding on a tube, like the stators of Figure 14 and 15. Or perhaps a fixed coupling is needed in which case the primary and secondary may both be wound on the same tube, with the required distance between them.

All coils of this kind are called cylindrical or solenoid and the turns are close and parallel to each other. As the voltage in these circuits changes rapidly in value and direction, there will be a dif-

ference in voltage between the turns. The wire is a conductor and the turns are insulated from each other therefore, a difference in voltage between the turns, causes a condenser action which is called "Distributed Capacity".

HONEYCOMB COILS

As distributed capacity causes losses of energy, many different forms of windings have been made to reduce it. One of the earliest of these was the honeycomb coil with the turns of wire wound in a zig-zag pattern, leaving open spaces between them.

The coils are made quite narrow and the turns are put on in layers but, the turns in each layer cross the turns of the layers next to them at an angle. In this way, the distributed capacity is reduced and this type is wound in a large variety of sizes.

SPIDER-WEB COILS

The same effect is produced in another form of winding, known as the spider web, where a circular piece of card-board, fibre or other insulator, had an odd number of slots cut in it.

Then, starting at the center, the wire is wound in and out of the slots, or over and under the segmets between them. The odd number of slots brings the adjacent turns on opposite sides of the segments and wires cross at an angle in the slots. This type of winding is very easy to make and, like the honeycomb, has a low distributed capacity.

Instead of using a permanent form, some coils of this type are wound on a form that has wooden pegs set in the center, like the spokes of a wheel. The wire is wound on in the same manner as the spider-web type and, after the coil is complete, it is given a coat of col-lodion and the form is removed.

Then again, the pegs may be placed in a circle, at right angles to a base, and the wire wound around the circle, either in and out like the spider-web or in-side of one and then outside of two pegs. This we call a basket weave or Lorenz coil and it is also coated with collodion, after which it is removed from the form.

It has been found that the best of electrical insulating materials allow a loss at the high radio frequencies

and air seems to be the best material for an insulator. Of course, we cannot build a coil that will be entirely insulated by air but some types are wound on lattice work forms or supported only by thin strips of insulation like the 180° vario-coupler of Figure 16.

There have been several makes of balloon or doughnut coils in which a long solenoid winding is bent around to form a closed circle. These are called toroidal coils and their main advantage is that the magnetic field they set up is contained inside the circle and will not effect other units placed near them.

Also, any passing radio waves that cut through them, will induce an E.M.F. in each side in such a direction that they will oppose each other and be neutralized. This feature is a great help in keeping out all waves except those of the frequency for which the coil circuit is tuned.

In spite of the many advantages claimed for these special types of windings, the general tendency has been to replace the couplers of Figures 14 and 15 with coils of the general form of Figure 17.

Here there are two tubes, with a small air space between them, the inner one carrying the primary and the outer the secondary. Electrically, the conditions are the same as for the couplers of Figures 14 and 15 but the windings are always in maximum coupling position. This type of coil, or Radio Frequency Transformer, was used in nearly all the older models of neutrodyne receivers.

Perhaps you are wondering why we have been explaining the electrical action of these older type coils, some of which are nearly obsolete but here is the reason.

All of the coils, or high frequency transformers, in use today, are their descendants and about the only difference is the mechanical construction.

To bring out the size of modern coils, in comparison to the older types, we have shown those of Figure 18 quite small. Notice also, these coils are enclosed by a metal cover, known as a "shield", the purpose of which is to keep out the fields set up by other circuits of a radio receiver.

In Figure 18, the two windings are on the same form, instead of the two tubes shown in Figure 17. Both of the windings are on the outside of the form, a space

between providing the proper coupling. In some types, the primary winding has a comparatively small number of turns, to provide a low inductive reactance and a unit of this type is known as a "low impedance" primary, radio frequency transformer.

In other similar units, the primary winding is made up of a number of layers of small wire and, because of its small size and large amount of wire, has quite a high inductance. The inductive reactance will therefore be high and a coil of this type is known as a "high impedance" primary, radio frequency transformer. The performance of this transformer is an improvement over that of the low inductance primary type, in that the signal strength may be held more nearly constant over the entire tuning range.

In the coil of Figure 18-B, the primary and secondary are both wound on the same plan as the high impedance primary of Figure 18-A. Instead of being placed on a tube, they are wound on a solid piece of insulating material, called a "dowel", and the amount of coupling depends on the space between the primary and secondary windings. Here, both windings have a comparatively high inductance and, as you will learn later, units of this type are used as Intermediate Frequency, (I.F.) transformers.

As we explained earlier, in some circuits it is necessary to have a fixed amount of inductance which can be obtained by a single winding. In modern receivers, you will find these inductances, commonly called R.F. choke coils, quite small in size with the general size and shape of the coils of Figure 18-B. As we will explain in a later Lesson, Radio frequency chokes are generally used as a part of filter systems in high frequency circuits.

CONDENSERS

All of these coils and windings are merely different forms of inductance and, just as important, are the capacities to be used in the circuits. Here there is not so much variation as all the common units are condensers of either fixed or variable capacity.

While either the inductance or capacity may be varied, most Radio Receiver tuning has been done with variable condensers, as good tuning results are secured by having the largest possible inductance of the fixed type and changing the capacity.

For this purpose, we have variable plate condensers, like that of Figure 20-A, made up with two sets of

plates, one of which is mounted on a movable shaft and slides or saw toothes into the other. One set of plates, called the stator, is held in position by the frame but insulated from it. The other set, called the rotor, is fastened to the shaft and its plates can be turned in or out between the stator plates.

As the rotor plates are turned in between the stator plates, the effective area becomes larger and thus the capacity is increased. You can see that the change will be gradual and steady which is one of the reasons for using this type of condenser for tuning. While all condensers of this kind look somewhat alike, they are made in three distinct types known as Straight Line Capacity, Straight Line Wave Length and Straight Line Frequency.

Those with half round rotor plates and the shaft at the center of the flat side, are the straight line capacity. In this type, each degree that the rotor shaft is turned, changes the capacity some certain amount. If you were to draw a curve plotting the capacity against the position of the rotor, it would give you a straight line, from which we get the name.

As we have already explained, on account of the difference in frequency, the stations broadcasting on the shorter wave lengths are much closer to each other than those on the longer waves. The result is that when tuning with a condenser of this type, the shorter wave lengths are all crowded at one end and it is very hard to separate them.

To get away from this condition, by using plates of special shape, the capacity of the condenser can be made to vary so that each degree the rotor is turned will cause the same change in the wave length of tuning. These we call straight line wave length and they will overcome the crowding on the shorter waves to a certain extent.

The third design has the plates shaped so that each degree the rotor is turned causes the same change in the frequency of the circuit it is tuning. As all of the broadcasting stations are separated in frequency by at least 10 kilocycles, with a condenser of this type the tuning will be uniform no matter what the wavelength may be.

Practically all variable condensers require a half turn of the rotor plates and shaft to change from maximum capacity positions. Various arrangements of

dials and pointers are attached to the shaft so that the actual position of the rotor plates can be accurately adjusted. The markings on the dial may run from 1 to 100 in equal divisions but as the broadcast wavelengths are from 200 to 550 and the frequencies from 1600 K.C. to 545 K.C., the numbers on the dial have to be "Logged" in order to know where to find the various stations.

However, you will find the tuning dials of modern receivers are calibrated directly in kilocycles and megacycles. While these markings are not always exactly correct, they are quite close and do make it easier to tune for the various stations.

In the present day receivers, using more than one tuning circuit a variable condenser is needed for each and to operate these with a single dial, the units of Figure 20-A are built together or "Ganged" like Figure 20-B. Terminals are provided so that each section of the gang is connected in its own circuit but the rotors are all mechanically fastened to a single shaft and moved by a single dial.

FIXED CONDENSERS

There are other conditions which require a capacity to form a path for high frequency current, or make use of its charges and discharges. For this purpose you will find fixed condensers like those of Figure 19.

Their capacity can not be varied and they are commonly made with tinfoil or copper plates using waxed paper, oil or mica for the dielectric. You can obtain mica condensers in capacities from .00005 M.F. up to .02 M.F. and for the other types, almost any capacity you may need.

Right here we want to remind you again that the unit of capacity, the Farad, is so large that we usually use one millionth of it which is a Micro-farad, M.F. The condensers we have been explaining have capacities of several thousandths of a microfarad, which are rather hard figures to say therefore for high frequency work, you will find one millionth of a microfarad, called a micro-microfarad, and abbreviated Mmf, used as a unit of measure for capacity. Thus, a .001 Mf condenser has a capacity of 1000 Mmf. (Micro-Mikes).

The arrangement of Figure 21 is a Radio Receiver in every sense of the word, because it performs the three essential functions of any Receiver.

1. It receives and selects the desired modulated carrier by means of a tuned circuit. 2. It demodulates the carrier and produces the signal frequencies. 3. It includes a unit for converting the signal frequencies into sound of like frequencies.

Keep these basic functions in mind because, in the later Lessons, we are going to show you how by means of tubes, all of these actions are not only improved but the strength of the signals can be increased enormously before they reach the detector and after they leave it.

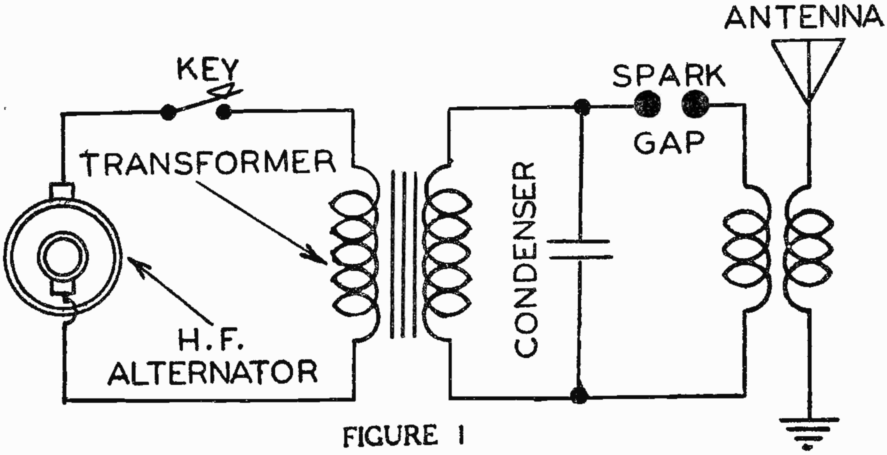


FIGURE 1

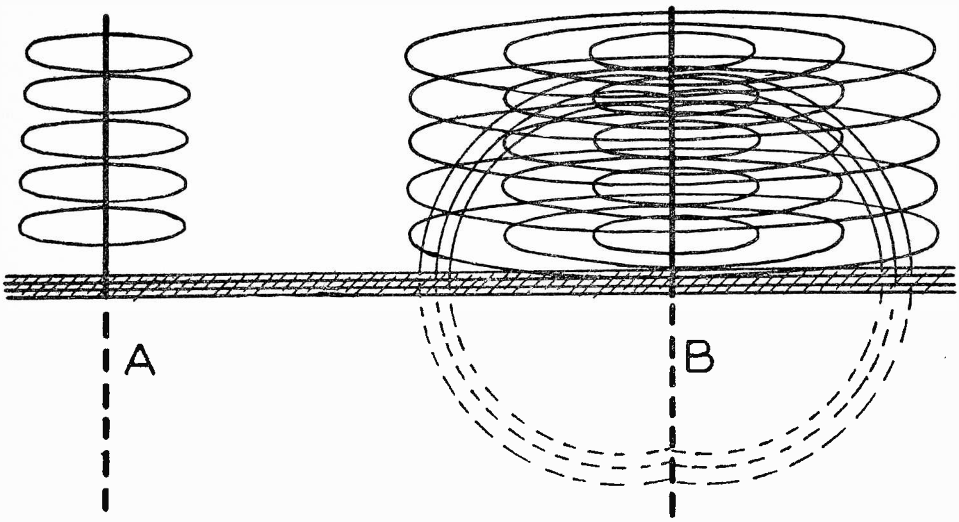


FIGURE 2

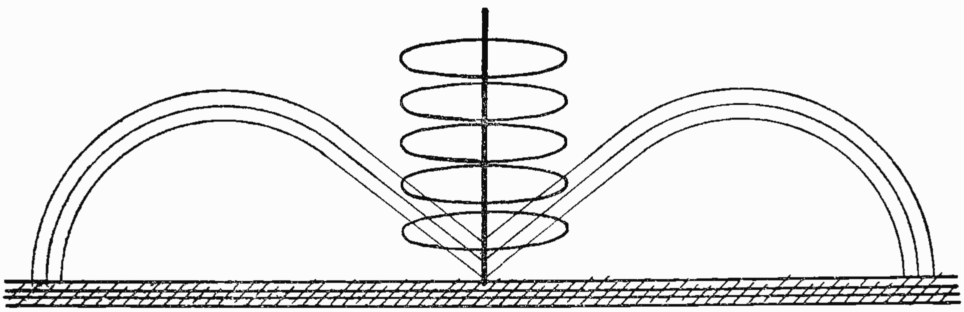


FIGURE 3

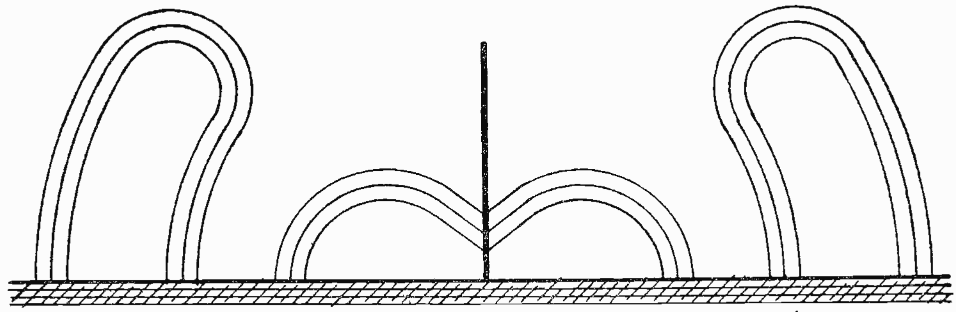


FIGURE 4

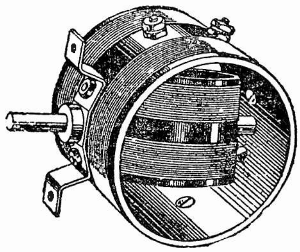


FIGURE 14

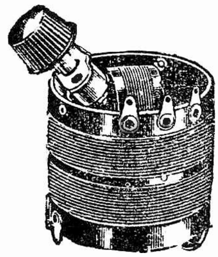


FIGURE 15

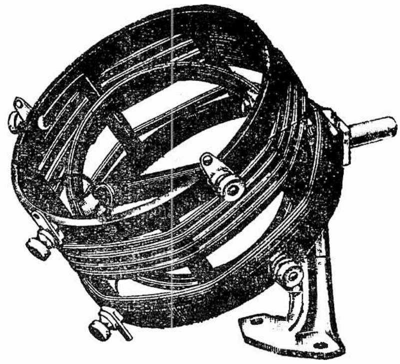


FIGURE 16

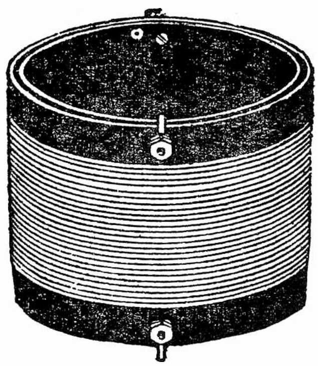
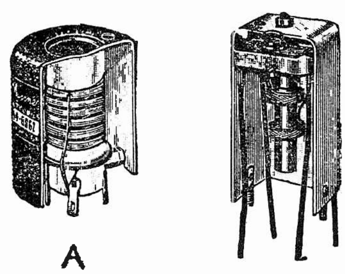


FIGURE 17



A

B

FIGURE 18

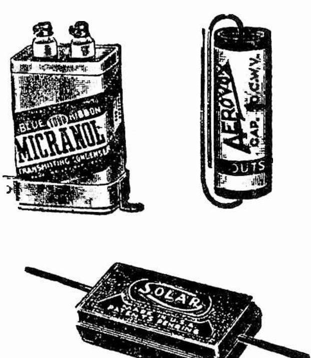
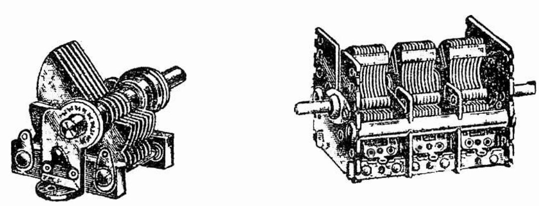


FIGURE 19



A

B

FIGURE 20

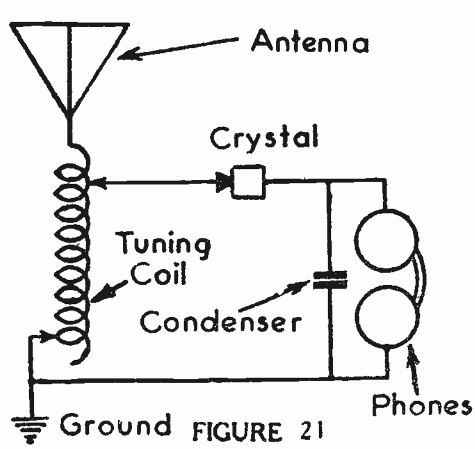


FIGURE 21

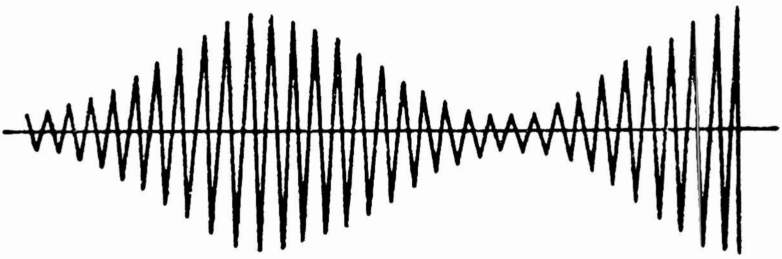


FIGURE 10

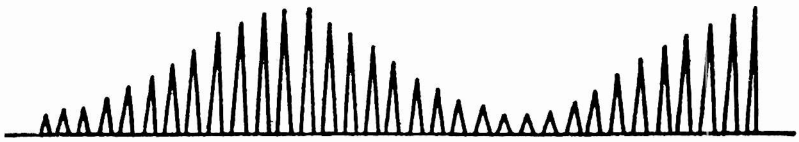
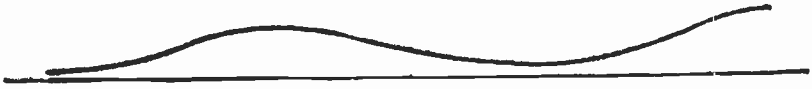


FIGURE 11

FIGURE 12



P21

FIGURE 13

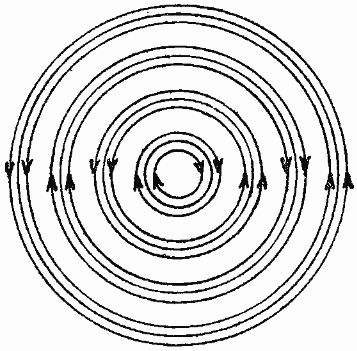


FIGURE 5

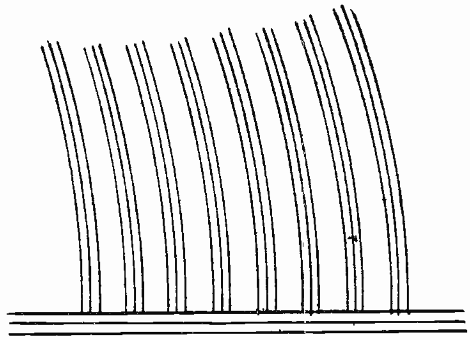


FIGURE 6

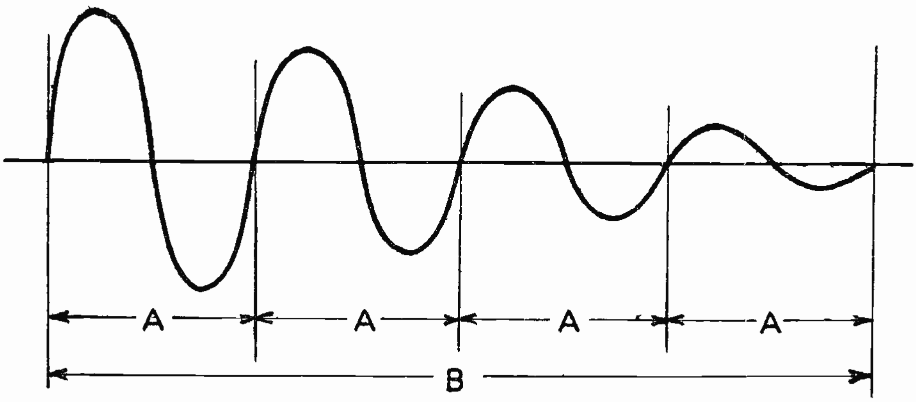


FIGURE 7

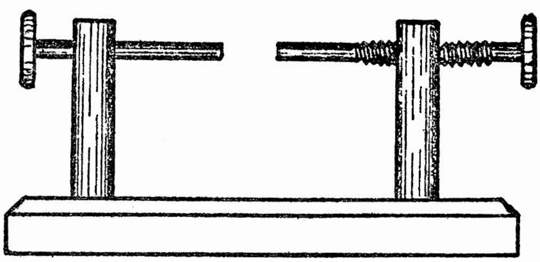


FIGURE 8

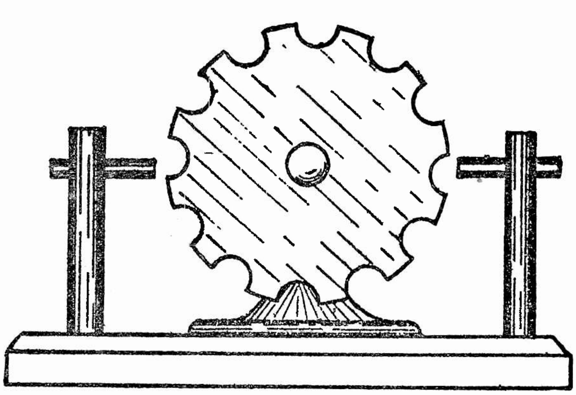


FIGURE 9

DE FOREST'S
TRAINING, Inc.

LESSON TRA - 8
CIRCUIT DIAGRAM SYMBOLS

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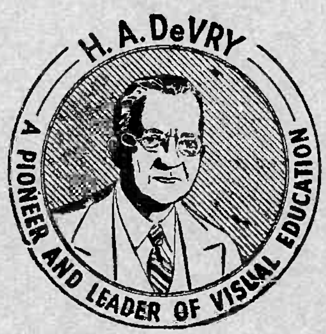
DE FOREST'S
TRAINING, Inc.

LESSON TRA - 8
CIRCUIT DIAGRAM SYMBOLS

• • Founded 1931 by • •



TUBES - RECEIVERS - AMPLIFIERS

Lesson 8

CIRCUIT DIAGRAM SYMBOLS

*   *   *   *   *   *   *

I won't, is a Tramp.
I can't, is a Quiter.
I don't know, is too Lazy
I wish I could, is a Wisher.
I might, is Waking Up.
I will try, is on his Feet.
I can, Is on his Way.
I will, Is at Work.
I did, Is now the Boss.

Lesson TRA-8

CIRCUIT DIAGRAM SYMBOLS

Checking through the earlier Lessons, you will find that every electrical unit is a part of some circuit therefore, from a technical standpoint, the circuits are most important because they include all of the units. This may sound like a very obvious or self evident statement, yet it contains the reason for the universal use of circuit diagrams in Radio and other Electronic work.

Every machinist and many other classes of technicians must be able to read blue prints and, in much the same way, every one in the technical phases of Radio must be able to read circuit diagrams quickly and accurately.

Realizing the importance of circuit diagrams, most of our illustrations have been drawn in circuit form to help you obtain the necessary information with a minimum of effort. Also, we have introduced a number of "symbols" which are used to represent the ordinary forms and types of component parts.

By using these symbols, all circuits can be drawn in simplified form, with a minimum of effort, and yet contain all the essential data. Circuit diagrams of this type, known commonly as "schematics", indicate all of the electrical connections of a Radio and can be followed or "read" with much greater ease than by inspecting the actual assembly of parts. Therefore, as mentioned before, schematic diagrams are in universal use.

As the following Lessons will contain explanations of circuits which include a greater number of component parts, at this time we are going to give you a brief description of the more common units. In addition to showing their general appearance, we will include the symbol by which they are represented in the usual form of wiring diagram.

Study these illustrations very carefully because, in the following Lessons, we will base our explanations on circuit diagrams in which the symbols are used. By this plan we will help you develop the all-important ability to read diagrams.

UNITS AND SYMBOLS

Looking at Figures 1 and 2, you will find they both contain two columns of rectangles, each of which has a picture of some unit, at the left, with its

wiring diagram symbol at the right. To simplify our explanations, the following paragraphs will be listed in the same way as the units of the Figures.

AERIAL, also known as an Antenna and abbreviated "ant.", refers to all of the many arrangements of both indoor and outdoor wires which are used to transmit Radio energy or, for a Receiver to intercept or "pick-up" the signal energy sent out by a transmitting or broadcast station.

GROUND, abbreviated "gnd", represents a connection to the earth but, as shown at the left, the common method of securing a ground is to attach a wire to a clamp which, in turn, makes contact with a cold water pipe of a city water system. Where no water pipes are available, the ground may consist of a metal rod driven several feet into moist earth. In other cases, metal sheets or plates are buried to form the ground.

In the case of an automobile, which is insulated from the earth by its rubber tires, the frame of the machine is considered as the ground for any Radio equipment it may carry. For certain types of installations which require no antenna, and frequently no actual ground, the metal framework or chassis, on which the parts are mounted, is considered as the ground. Therefore, the symbol is used to represent an actual or "external" ground as well as a chassis or "internal" ground.

BINDING POST, sometimes known as a terminal, is merely an arrangement by which external wires can be conveniently connected to the internal circuits of a unit. Usually, the external wire is clamped in place by means of a threaded nut or a spring clip.

TIP JACK is really a form of binding post and used for the same general purpose. In this case, the end of the external wire is fitted with a metal tip which makes the proper connections when pushed into the tip jack.

PHONOGRAPH JACK is used for the same general purpose as the tip jack but carries springs so that, when the proper type of plug is inserted, two or more connections are made. Although listed as a phonograph jack, units of this general type are made in a variety of styles and models for various purposes.

Additional arms may be mounted on the jack frame and some of them equipped with contacts so that other circuits will be opened or closed as the plug is inserted or removed.

FIXED CONDENSERS have many applications in Radio Circuits and will be found in a wide variety of sizes and shapes. In general they consist of two thin sheets of metal foil, spearated by an insulator. To save space, the foil and insulation are usually wound up in the form of a roll or cylinder and enclosed in either a cardboard or metal container.

The common forms of insulation are waxed paper, sheet mica, oil, or an electrolyte which may be a paste or liquid. Thus there are "Paper", "Mica", "Oil" and "Electrolytic condensers.

CONDENSER BLOCKS are nothing but a convenient mechanical assembly of a number of fixed condensers and are made in a similar variety of sizes, shapes and capacities.

The common unit of measure for the capacity of a condenser is the Microfarad, abbreviated "mfd" or the smaller unit, Micro-microfarad, "mmfd", equal to one millionth of a Microfarad. The commercial units are rated both in capacity and working voltage.

VARIABLE CONDENSERS have the same electrical action as the fixed condensers but, in order that their capacity may be readily changed, are made up of two sets of metal plates. One set of plates is attached to the frame while the other set is mounted on a shaft which is free to turn.

As the shaft is turned, the plates which it carries, mesh between those of the stationary plates and thus, in effect, the size of the plates can be changed in order to vary the condenser capacity. In general, this type is used for "Tuned" circuits.

CONDENSER GANG is the name given to an assembly of two or more variable condensers arranged with all of the movable plates mounted on a single shaft. As this shaft is turned, all of the condensers are varied at the same or proportional rates. Made up in this way, each condenser is a "Section" or "Gang". Thus, the illustration of Figure 1 shows a 3 gang unit.

This is the type of unit used for tuning the common models of Radio Receivers in which several tuned circuits are controlled by means of a single shaft and dial.

ANTENNA AND RADIO FREQUENCY COILS are found in the high frequency amplifiers of Short Wave, Broadcast and Communication Receivers. As already mentioned, antenna is abbreviated "ant" and now we can add that Radio Fre-

quency is abbreviated "r-f".

As shown in Figure 1, the common type of unit for this use is made up of two coils wound on, or supported by, a tube of insulating material. As each of the coils are a part of different circuits, the assembly is often called a transformer. The coil in the circuit which supplies the energy is the "Primary" and the other coil is the "Secondary".

I-F TRANSFORMER is a unit, similar to the "ant. and r-f coils", but designed to operate at a lower or intermediate frequency, abbreviated i-f. The complete assembly, consisting of two coils and two condensers, is usually housed in a metal can or shield. You will also find the ant. and r-f coils are frequently mounted in a shield or "Can", similar to that shown for the i-f transformer.

For reasons which we will explain later, these coils require more turns of wire than those used for r-f and, as shown, are often made up in sections. A small condenser is permanently connected across each coil in order to tune the circuit.

These condensers are a sort of compromise between the fixed and variable types which have been mentioned. They consist of a number of plates, similar to those of the variable type and, by means of a threaded screw, the distance between the plates can be varied to cause a change of capacity.

This change is made only at intervals, when service is required, and therefore the condenser is known as a "Semi-Fixed" or "Trimmer" type. You will find i-f transformers used in most modern receivers.

AUDIO TRANSFORMER is a unit which, like the r-f coils and i-f transformers, has two separate windings or coils. It is designed to operate at the low, or audio, frequencies, which we are able to hear and, to provide the proper conditions, the coils have a larger number of turns and are wound on an iron core. For the symbol, parallel lines indicate an iron core.

Although the different types of transformers are made in a variety of sizes and shapes, they follow the general plan shown in Figure 1 and are therefore not at all hard to recognize or identify.

IRON CORE CHOKE is a unit quite similar to the Audio Frequency or "a-f" transformer except that it has but

one coil or winding. It also has an iron core and is designed for use in low or Audio Frequency circuits.

You will find both a-f transformer and Iron Core Chokes built on either of the plans shown but the choke can be easily recognized because it has only two connections while the transformer has four or more.

RADIO FREQUENCY CHOKE is similar to the iron core choke in that it has but a single coil or winding. However, it is designed for operation in high or r-f circuits and therefore, in most types, the coil has no iron it its core.

In the upper illustration we show a Universal or Lattice wound choke, mounted on insulating material while, in the lower illustration, the winding is divided into several sections.

POWER TRANSFORMER is the unit which, in equipment operated by the ordinary alternating current lighting circuit, provides the necessary high and low voltages. It usually contains a number of coils or windings and the one connected to the supply, is the primary. All of the other windings are "Secondaries" and, like the Audio Transformer, all of the coils are mounted on an iron core.

Although made in a variety of shapes and sizes, some of which are like that shown for the a-f Transformer, the Power Transformer is usually larger and can be identified by the larger number of terminals which it carries.

KNIFE SWITCH. In the earlier Lessons we told you it was necessary to "break" or open a circuit, in order to stop the current and the knife switch is merely one common arrangement which permits one or more circuits to be opened and closed conveniently and repeatedly.

The illustration shows a switch with six separate points of connection and two blades, each of which can complete, or break, a circuit between the center and either outer point.

As each blade is known as a "Pole" and each closed position as a "Throw", the switch we show is a Double Pole, Double Throw, abbreviated, "dpdt". You will find this type of switch made up in a wide variety of number of poles and number of throws.

TOGGLE SWITCH is really nothing but a special and common form of a knife switch and receives its name from the mechanical or "Toggle" arrangement by which the switch blades are made to operate.

You will find toggle switches in common use, not only for Radio equipment but also for most household appliances such as Vacuum Cleaners, Fans, and so on. Like the knife switches, toggle switches are available in a variety of poles and throws.

ROTARY TAP SWITCH, as shown in Figure 2, serves the general purpose of all switches, which is to open and close one or more circuits. For Radio applications, there are common conditions which require that one wire, or circuit, be connected frequently to each of a number of other wires or circuits.

In this particular case, the switch blade is mounted on a shaft and can be rotated in order to make contact with a number of other points or connections. You will find switches of this general type in common use, especially in the modern types of "All Wave" Radio Receivers.

RHEOSTAT. In the earlier Lessons, we told you that, with the voltage remaining the same, a change of resistance would cause a change of current. As it is often necessary to control the amount of current by changing the value of resistance, a variable resistance unit, known as a "Rheostat" is in common use.

The mechanical construction here is much like that of the Rotary Tap Switch except that the moving arm makes contact with the turns of a circular coil of wire. Actually, the position of the moving arm controls the amount or length of wire in the circuit but, as the resistance per foot of the wire is uniform, the effect is a change of resistance.

As shown by the symbol, a rheostat has but two external terminals. One, connected directly to the moving contact or arm and the other, to one end of the wire or resistance material.

POTENTIOMETER is a unit having about the same electrical and mechanical arrangement as the rheostat. The main difference is that it includes a third terminal so that connections may be made to both ends of the resistance as well as the moving arm.

As you will learn later, this third terminal makes

many additional circuit arrangements possible and you will find potentiometers used for the control of volume, tone, voltage and so on.

FIXED RESISTOR is the name given to a very common unit which provides desired values of resistance. It may be made of a coil of wire and known as a "Wire Wound" type. It may be made of a compound of carbon and other materials and known as a Carbon type. It may be made of a glass rod covered with a thin coating of metal and known as a "METALLIZED" type.

You will find these three general types in values from a fraction of one ohm up to several million ohms and in sizes to carry various amounts of current.

DYNAMIC SPEAKER is one of the common devices for converting the electrical signal energy into sound. It consists of a comparatively large electro-magnet, called the field, and a smaller winding, known as the Voice Coil, mounted at the center of a movable cone.

When the signal energy is present, in the voice coil, its magnetic attraction and repulsion, in respect to the field, causes the cone to vibrate and produce the sound waves in the air.

Dynamic speakers are made with cones of various diameters and field coils to suit the circuit conditions.

MAGNETIC SPEAKER is a unit for the same purpose as the dynamic speaker and the present models are quite similar. Instead of an electro magnet, the Magnetic speaker has a permanent magnet for its field.

Looking at the symbols, you will notice there are four connections to the dynamic speaker and only two connections to the magnetic speaker.

MICROPHONE is a unit, the action of which is opposite to that of the speakers. Sound Waves, which enter the microphone, cause changes of the electrical energy in its circuit and thus, in general, it converts sound energy into electrical energy.

There are many types, styles, shapes and sizes of microphones and, as we will explain in the later Lessons, there are several distinct principles of operation. The one shown in Figure 7 is known as a "Carbon" microphone and its action is much like that of a rheostat.

The left hand symbol indicates a "Single Button" and

the right hand symbol, a "Double Button", type of carbon microphone. Other common types of microphones are, Crystal, Dynamic, Ribbon, Velocity, and Condenser.

WIRES are used to connect the various units to each other and to the sources of energy as well as to the various output and input devices. Therefore, the various assemblies contain a number of wires but, for economical reasons, each piece of wire is arranged to serve the greatest number of circuits. As a result, circuit diagrams show wires which cross each other but must distinguish between those which are connected and those which are not.

As shown in Figure 2, crossed wires, which are not electrically connected, are shown by drawing a half circle for one of them. When the crossed wires are electrically connected, both wires are shown straight with a small circle or dot at their intersection.

In commercial diagrams, you will find either or both of these methods used. Sometimes, when the dot indicates a connection, the half circle is omitted for the crossed wires which are not connected. In other diagrams, where the half circle is used, the dot is omitted for crossed wires which are connected. In the later Lessons however, we use both symbols as shown in Figure 2.

CELL AND BATTERY. Contrary to a common idea that all battery operated Radio Receivers and other apparatus are obsolete, there are perhaps more of this type in use today than ever before. Practically all Portable, as well as Automobile and Airplane equipment can be placed in the battery operated class to say nothing of the increased number of Radio receivers being sold and used in localities without electrical light and power service.

Also, as we will explain later, all the common types of vacuum tubes are primarily direct current devices and the ordinary types of cells and batteries are one of the simplest and most convenient sources for this type of electrical energy.

As we have already explained the action and construction of cells and batteries, no further details are necessary at this time.

FUSE. In any electrical device, it is possible for trouble to develop in such a way that the current will increase sufficiently to cause serious damage.

To furnish protection under these conditions, most apparatus is equipped with a fuse, connected so that it carries the total current. As you perhaps know, an electric current has a heating effect upon the conductor through which it passes and the fuse is made of such size or material that an excess amount of current will heat it sufficiently to cause it to melt.

When the fuse material melts, it falls away from its supports and opens the circuit the same as a switch. In practice, this action is so rapid that the excess current "blows" the fuse before any damage is done.

In Figure 2, we show two common types of fuses, the upper one is known as a "Cartridge" and the lower one as a "Plug".

HEADPHONES belong in the same general class as speakers because they convert electrical energy into sound energy. In construction, they are similar to those used with ordinary telephones and contain a permanent magnet with coils or windings to produce an action like that explained for the magnetic speaker. Instead of a cone, the headphone has a metal disk, called a diaphragm, which vibrates and sets up the sound waves which are heard.

PHONOGRAPH PICK UP, as its name implies, is a unit which is used for the reproduction of Phonograph Records. It can be thought of as a special form of microphone because it converts the mechanical vibration of the needle into corresponding changes of electrical energy.

Here again, you will find a variety of makes, models and types. The upper one, shown in Figure 2, contains a permanent magnet and a coil of wire. Therefore it is known as a "Magnetic Pick Up". The lower one operates on an entirely different principle and is known as a "Crystal Pick-Up".

METERS have already been explained and, in most circuit diagrams, they are represented by a circle with a letter enclosed to show their type. Thus, "V" stand for voltmeter, "A", for ammeter, "MA" for milliammeter and so on.

TUBES. As you will soon learn, practically all Radio Equipment is built around the various types of vacuum tubes and, in Figure 2, we show the symbol for one of the simplest types. All tubes have the same general appearance, connections being made to pins ex-

tending below the base or to a metal cap placed on top.

In actual practice, the circuit connections are made to a "socket" which has openings, of proper number and position, to fit the "pins" or "prongs" which extend below the tube base. This arrangement permits the tubes to be removed and replaced without disturbing any of the wires or their connections.

Although several later Lessons will be devoted entirely to the circuits, actions and operation of the many types of tubes, at this time we want to explain the tube symbol of Figure 2.

The lines, inside the circle, represent the parts inside the tube. The rectangle represents the "Plate", the zig-zag line the "Grid" and the loop or inverted "V" the filament or heater.

STANDARD CIRCUIT SYMBOLS

With these various components made in a wide variety of types, makes, and sizes, used in an even wider variety of commercial apparatus, it followed naturally that wiring diagram symbols were drawn in different ways by the different manufacturers. Most of these differences were not great enough to cause confusion and any one, knowing the symbols shown in Figures 1 and 2, can read the circuit diagrams published for any Radio apparatus.

However, the symbols used by the Radio Industry did not coinside with those used by the Electrical Power Industry but, as long as Radio apparatus was simply plugged into existing Light and Power circuits, the difference of symbols did not cause any difficulty.

With the increasing use of Radio and other Electronic tubes as integral parts of Electrical Power apparatus, some manufacturers drew their circuits with Radio symbols, some used Power symbols and some used both. As a result, it was extremely difficult for anyone, even with a knowledge of both systems, to read a circuit diagram accurately.

For example, on Power diagrams, the fixed condenser symbol of Figure 1 represents a pair of open contacts while, for closed contacts the symbol was the same as that of the variable condenser of Figure 1. Also, in Power diagrams, the fixed resistor symbol of Lesson 2 was used to represent transformer windings and choke coils.

To remedy this situation, the American Standards Association worked out a compromise series of "Standard Circuit Symbols", the important ones of which are shown in Figure 3. As these symbols have been accepted by all parties concerned, they should be found in all new diagrams but it would be unreasonable to expect the manufacturers to redraw the many older diagrams of existing equipment. Therefore, for some time to come, it will be necessary to know both the old and the new "standard" symbols.

Comparing the symbols of Figure 3 with those of Figure 1 and 2, the main difference is in those for capacity and contactors. From now on all capacity symbols should consist of one curved and one straight line with the addition of a slanting arrow to indicate variable capacity.

This symbol has been used quite extensively in Radio circuit diagrams and will be recognized readily. The standard symbols for open and closed contactors will no doubt, be contained in all power circuit diagrams but, to prevent confusion, it is most likely that the modified switch type of standard contactor symbol will be used for Radio circuit diagrams.

Notice the choice of symbols for resistance. The "zigzag" line has been the Radio symbol but the rectangle symbol is easier to draw and the space provided for the value will simplify the reading of circuit values.

The inductance symbol, shown in Figures 1 and 2 is retained as a standard unit, in addition there is a new symbol consisting of a series of semi-circles. While these symbols are sufficiently similar to prevent confusion, the new standard is easier to draw and may gradually supercede the older one.

For both symbols parallel lines are added to indicate an iron core while the arrows, used to indicate variable values follow the plan employed for the resistance symbols.

Perhaps many of those units are new, as far as you are concerned therefore we do not expect you to understand their actions completely at this time. Instead, we suggest you study each picture carefully, compare it to the corresponding symbol and check both with the brief explanation we have given.

To help you further, we suggest you look inside the cabinet of all available Radios and see how many of the component parts you can identify from the pictures of Figures 1 and 2.

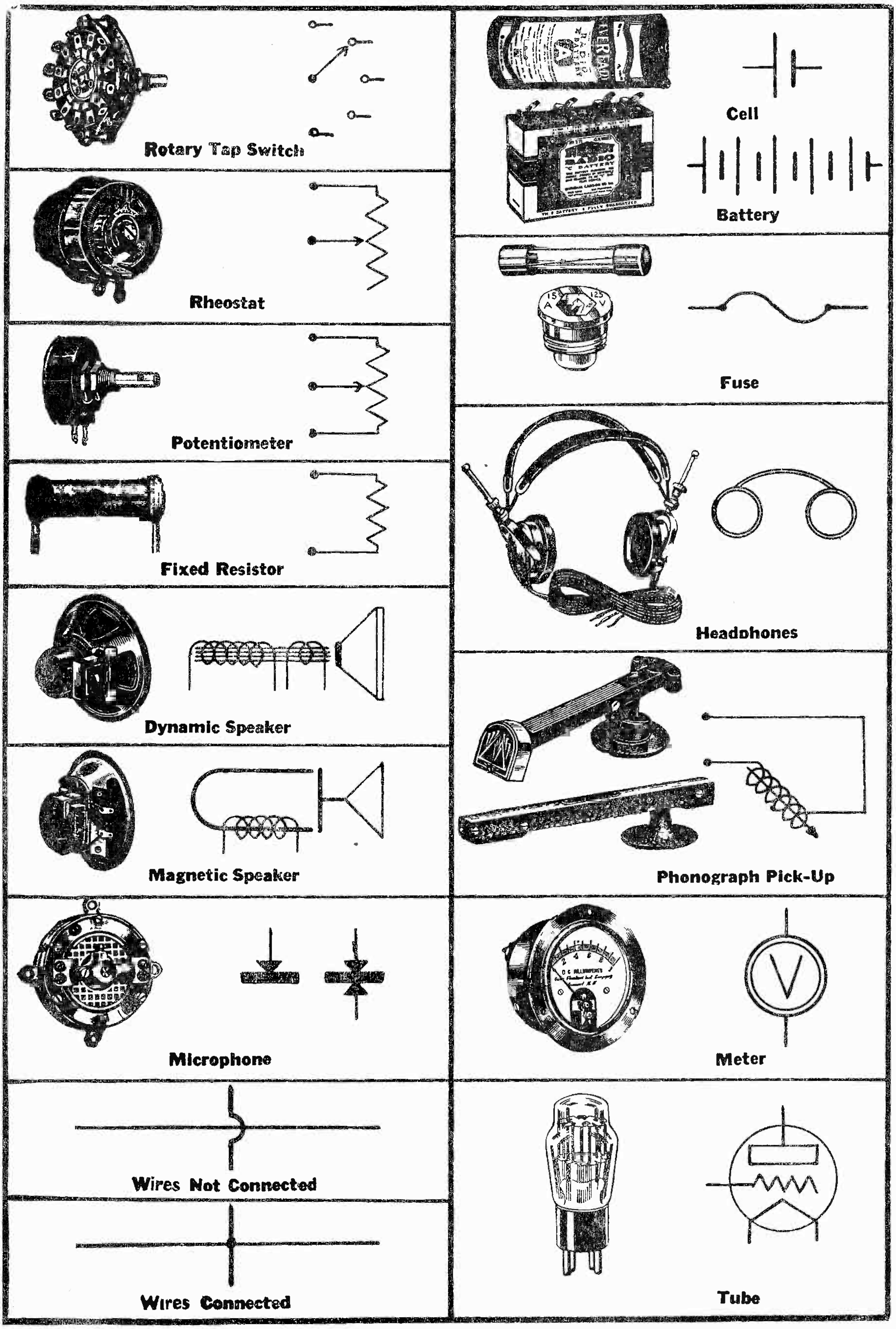

Rotary Tap Switch
Cell
Battery
Rheostat
Fuse
Potentiometer
Fixed Resistor
Headphones
Dynamic Speaker
Magnetic Speaker
Phonograph Pick-Up
Microphone
Meter
Wires Not Connected
Wires Connected
Tube

FIGURE 2

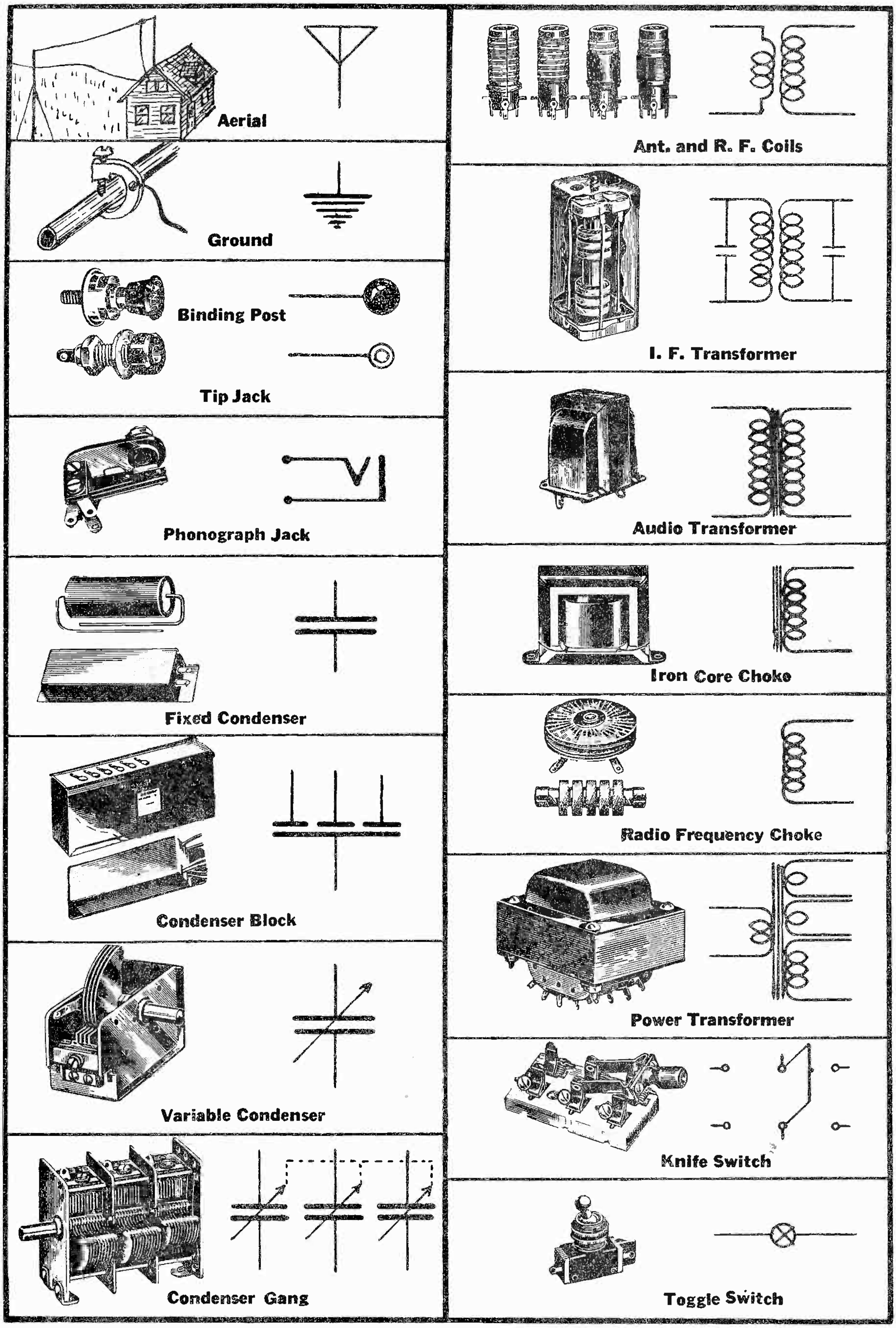

Aerial
Ground
Binding Post
Tip Jack
Phonograph Jack
Fixed Condenser
Condenser Block
Variable Condenser
Condenser Gang
Ant. and R. F. Coils
I. F. Transformer
Audio Transformer
Iron Core Choke
Radio Frequency Choke
Power Transformer
Knife Switch
Toggle Switch

FIGURE 1

STANDARD CIRCUIT SYMBOLS

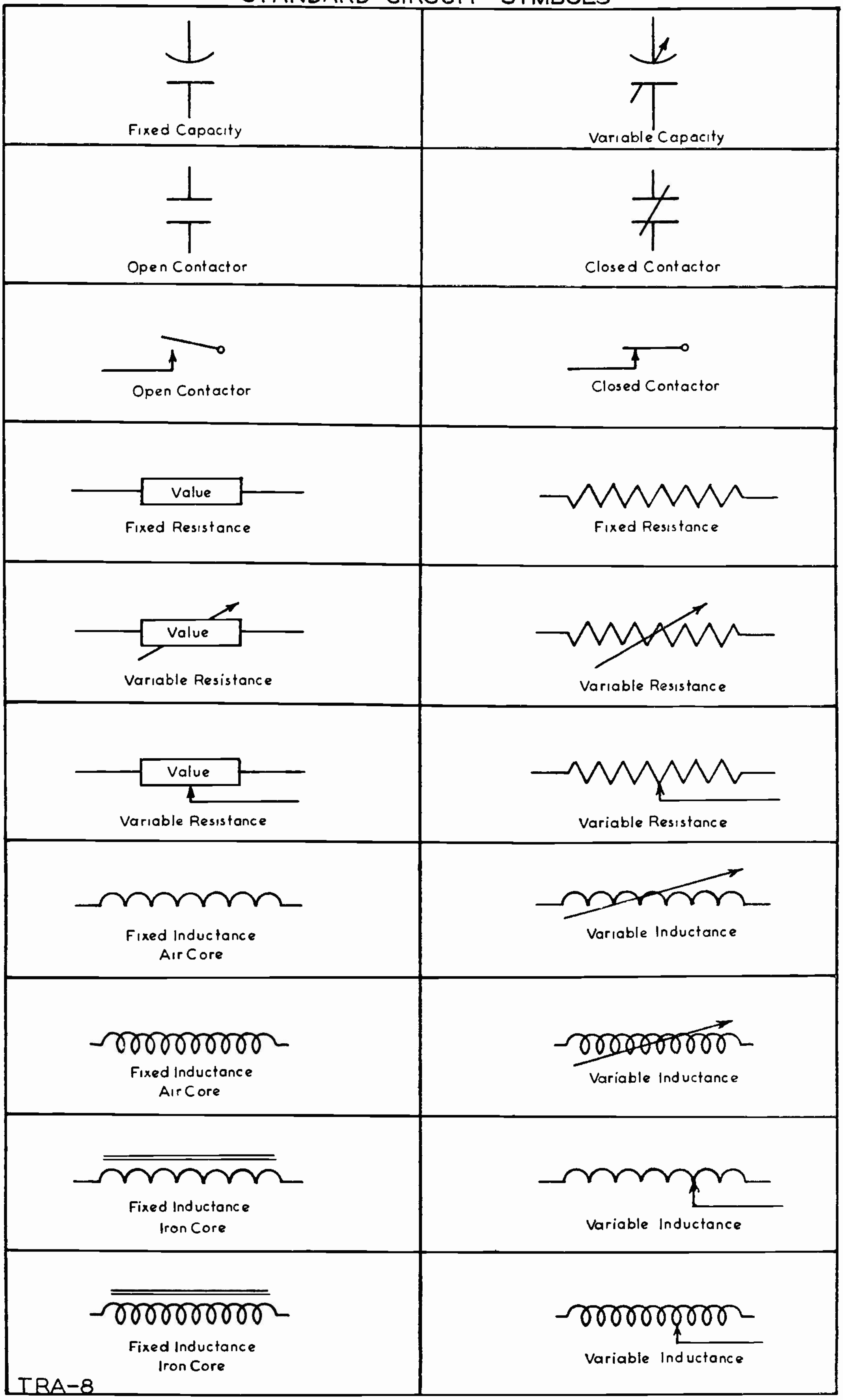


FIGURE 3

DE FOREST'S
TRAINING, Inc.

LESSON TRA - 9
POWER SUPPLY

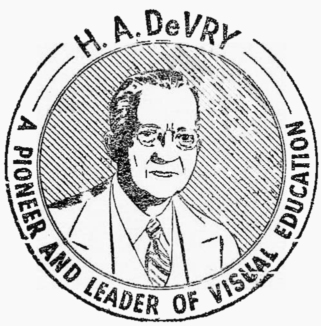
Founded 1931 by

DE FOREST'S TRAINING, Inc.

LESSON TRA - 9

POWER SUPPLY

Founded 1931 by



TUBES - RECEIVERS - AMPLIFIERS

LESSON TRA-9

POWER SUPPLY

# # # # #

Weakness does not prevent success if only the body is weak. The trouble in the average person is not lack of ability, intelligence or health. It is lack of courage that comes from enthusiasm.

--- Arthur Brisbane

ELECTRON THEORY

In our various explanations of the different electrical, chemical and magnetic actions, we have told you that all substances are made up of extremely small parts, called molecules and these, in turn, are made up of still smaller parts called atoms.

An atom is the smallest chemical part of any substance and all of the thousands of different substances are composed of molecules made up of combinations of less than 100 kinds of atoms. The atoms are called the "elements" and can not be divided chemically into other substances.

In electricity however, we consider each atom to be composed of particles of negative electricity, called electrons, which travel around a nucleus of positive electricity called a proton. This conception of the construction of matter is known as the Electron Theory and is assumes that the difference in the atoms of the various elements is due to the number and arrangement of the electrons and protons.

Like the laws of magnetism, in regard to poles, we find that like electrical charges repel each other, while unlike charges attract each other. As every normal atom has enough positive electricity in its nucleus to balance the negative electrons, they are neutralized electrically and do not show any particular electrical action.

If we add, or take away any electrons from an atom, it loses its electrical balance and we call it an Ion. When an ion has too many electrons, we say it is negatively charged, because it repels other electrons, and call it an "Anion".

In the same way, if it does not have enough electrons to balance the positive nucleus, we say an ion is positively charged, because it will attract other electrons and call it a "Cation". However, a negative ion will try and move toward a positive ion because unlike charges attract each other.

Perhaps you have tried, or seen, that old experiment of rubbing a glass rod with a piece of silk cloth and found that the glass would attract and hold small pieces of paper in much the same way that a magnet will attract and hold pieces of iron and steel.

According to the Electron Theory, we can explain this

action by telling you that in rubbing the glass rod, some of the electrons were knocked off, leaving it positively charged. The paper atoms, with a few free electrons, being neutral and having no charge, were attracted by the positively charged ions of the glass.

Like all other electrical actions, the charges try to neutralize, or balance and, as an ion with too many electrons is negatively charged, while one with too few is positively charged, the electrons will have to travel from negative to positive in order to strike a balance.

In our earlier explanations of the simple cell, we told you that the chemical action produced an emf . and the copper became positive while the zinc became negative. Now, we can add that the chemical action transfers electrons from the copper to the zinc therefore, with a deficiency of electrons, the copper has a positive charge while, with an excess of electrons, the zinc has a negative charge.

As far as is known, all electrons are exactly alike and the difference in the various atoms is due to the number of electrons and protons they contain. Each atom is made up of an equal number of electrons and protons while the positive neucleus consists of the protons plus some of the electrons. The remaining electrons move more or less freely around the neucleus. When a circuit is completed across the simple cell mentioned above, the positive charge of the copper attracts and captures some of the free electrons from the atoms of the wire connected to it. Those atoms then have a positive charge and capture electrons from adjacent atoms.

This action continues through the entire circuit until those atoms, in contact with the zinc are supplied with some of the excess electrons. Therefore, the external circuit will carry a stream of electrons from the zinc to the copper and the chemical action of the cell will maintain the stream by transferring electrons from the copper to the zinc, inside the cell.

Considering this flow of electrons as a current of electricity, its direction is opposite to that of our former explanations and this apparent contradiction has caused considerably confusion in the study of Radio and Electronics. However it would seem that this point of difference has been overemphasized because, in a great majority of cases, the direction of current is of secondary importance.

Regardless of the assumed direction of current, any given

circuit remains the same and the current is carried by the same units. The polarity of the supply voltage, as well as the voltage drops across the units, remain exactly the same, and the numerical values of voltage and current are not changed.

It is almost standard commercial practice to trace circuits from Positive to Negative and as Voltage Tests are made in most cases, the direction of current can be ignored. However, there are some electrical actions, such as that which takes place inside a vacuum tube, which can be explained more readily by the Electron Theory and thus we will make use of it in this and the following Lessons.

To avoid confusion in the later explanations, the term "current" will refer to the older "positive to negative" idea while the expression "flow of electrons" will refer to the later Electron Theory. As the term "Current" means a flow of electricity or electrons, the word "flow" will be used only in connection with the movement of electrons. From now on "current" is considered as positive to negative while a "flow of electrons" is from negative to positive.

ELECTRON TUBES

At ordinary temperatures, the atoms of any substance are in constant motion and, as the temperature is raised, the motion increases. This change in motion makes a big difference in the various substances and, as we have done before, we can use water as a good example.

When the temperature is below 32° F., the motion of the atoms of the molecules is so slow that the water becomes a solid which we call ice. When the temperature is raised above this point, the movements of the atoms increase, they become separated further causing the ice to "melt" and change into the liquid we call water.

If we continue to raise the temperature of the liquid water, the movements of the atoms increase until finally they leave the liquid and escape as steam, which is a gas.

When this happens, we say that the water is boiling and you know that boiling water is pretty lively. The only difference between the solid ice, the liquid water and the steam is a matter of temperature, or the difference in the movements of the atoms.

You can think of the movements of the atoms as vibra-

tion and, the higher their temperature, the faster they vibrate, causing them to keep further apart and expand the substance that they compose. When this action is carried far enough, a solid changes to a liquid and a liquid to a gas.

The electrons of an atom are supposed to travel around the positive nucleus at an extremely high rate of speed, much faster than the vibrations of the atom itself. In the case of metals, for instance, where it requires a very high temperature to change the solid into a liquid, the electrons may be made to move fast enough to break away from their atoms and leave the metal in about the same way that steam leaves liquid water.

By heating certain kinds of metal, a stream of electrons will be emitted from the atoms, leaving positively charged ions, and giving the metal a positive charge. This positive charge will attract the free electrons, therefore many of them are drawn back again.

The common method of producing this condition is to form the metal into a thin wire and place it in a glass bulb, like the ordinary incandescent lamp. Connecting this wire, or filament, in an electrical circuit and allowing current in it, heat is produced and the electrons are thrown off.

In order to prevent the filament from oxidizing or "burning up", the air has to be pumped out of the bulb and it also has been found that oxygen, which composes part of the air, will prevent the electrons from leaving the filament.

Usually, the filament is made of tungsten, or platinum-iridium wire, much the same as that of an incandescent lamp but, by giving it a coating of thorium, or other oxides, the number of electrons thrown off is greatly increased at lower values of temperature.

TWO ELEMENT TUBES

To make use of this action, a second element, called the Plate, is placed inside the bulb near the filament. When the filament is heated, the electrons are thrown off and the positive charge of the filament draws many of them back but, some of them travelling around inside the bulb, will strike the plate. To increase this action, we connect the plate to the positive of a battery, or other direct current supply, the negative of which connects to one side of the filament.

The d-c battery voltage will try and cause current in this circuit but there is the gap between the plate and the filament to prevent it. When the plate supply is connected, and the difference of its voltage is across the gap between the plate and filament, you can imagine that a large quantity of electrons have been pulled off the plate, leaving it positively charged.

Under this condition, the electrons thrown off from the heated filament will be attracted to the positively charged plate and there will be a stream of them across the gap. Remembering the directions here, a flow of electrons from the filament to the plate is the same as a current from the plate to the filament.

Should we connect the supply negative to the plate, it becomes charged negatively, repels the electrons and, as none of them pass from the filament to the plate, there will be no current in the plate circuit. This action can be explained by stating that when the plate is positive in respect to the filament, the gap between them is conductive and allows current but when the plate is negative, the gap is non-conductive and will not allow current.

Tubes of this type are called "Two Element" or "Diode" and are used as rectifiers because they will allow current from the plate to the filament, but not from the filament to the plate. The Tungar and other similar bulb rectifiers are good examples of this action.

The amount of current in the plate circuit of these bulbs or tubes, often called the "emission", depends on the number of electrons that leave the filament and reach the plate.

From what we have already explained, you can see that the rate of emission will depend on the material the filament is made of, its size, or surface area, and the temperature to which it is heated. The voltage on the plate will also have an effect because the higher the voltage, the stronger its positive charge will be and the more electrons it will attract.

In many of our former Lessons we have mentioned power supplies and given you some of the circuits with a general idea of their action. They were originally developed so that the common 110 volt a-c lighting circuit could be used as a voltage source for the various elements of the tubes used in Radio and other Electronic equipment.

From the explanation just given for a diode tube, you can see that in order to maintain current in its circuit the plate must be held positive in respect to the filament. As this is true of all tubes, the power supply must provide a d-c voltage which, in most cases, has a value of from about 90 volts to several hundred volts.

In contrast, the filaments or heaters of the common types of tubes are designed to operate at lower values of voltage and, as the current they carry is required only to raise their temperature, in all but battery types, it may be a-c.

Therefore, when using an a-c source, the high voltage or plate section of a Power Supply is made up with the four main parts of Figure 1.

TRANSFORMER

With the common 110 volt a-c as a supply, the power transformer is wound to both raise and lower the voltage. For the filament or heater circuits, the voltage is reduced but for the other circuits, the voltage is increased. Electrically, the transformer primary is connected across the 110 volt a-c supply and there are usually two or more secondaries, each having the proper number of turns to produce the desired voltage.

RECTIFIER

In the second unit of Figure 1, we have the rectifier which changes the a-c output of a transformer secondary to direct current. Although the current which leaves the rectifier is in but one direction, its value changes with the a-c alternations to produce what we call a pulsating d-c. Regardless of its type, or construction, the purpose of the rectifier is to change the a-c so that it will always be in the same direction.

FILTER

The third unit of Figure 1 is the filter which receives the pulsating d-c from the rectifier and smooths out the pulsations. By using a combination of chokes and condensers, the action of the filter is to reduce the high values of current and raise the low values so that the pulsating d-c input is changed to a d-c output of a uniform value.

VOLTAGE DIVIDER

As the various tubes frequently require different values of voltage for their plates, the uniform d-c is carried through the fourth unit, or voltage divider. The divider is made up of resistances which cause a voltage drop when current is in them. By making connections at the proper points, the required values of voltage for the tube circuits are secured.

Keep these four units in mind because every power supply contains some or all of them. Notice that each has a distinct and separate job to perform in order that the a-c input is changed to the necessary d-c output.

POWER TRANSFORMERS

Taking each of these units in detail, we will start with the power transformer. Back in the earlier part of the training, we spent an entire Lesson on transformer action and suggest you study that Lesson over again before going ahead here.

As shown in Figure 2-A, a simple transformer is made up of a primary winding and a secondary winding, both wound on the same iron core. The action here is the same as explained in former Lessons and, depending on the number of turns, the secondary voltage may be higher or lower than that across the primary. In the usual power transformer, employed in Radio equipment, generally there are several secondaries.

The circuits of Figure 2-B are a good example and show the usual arrangement for filament type rectifier tubes. The secondary marked "Plate" has a large number of turns and produces the high voltage used for the plate supply of the other tubes. The other secondary, marked "Fil", produces the necessary filament voltage and is used only to heat the filament of the rectifier tube.

There are many other common arrangements but here, we want to bring out only the differences in the secondary windings. The winding with the largest number of turns produces high voltage at small current values while the filament secondary produces lower voltage but with larger current values.

The real purpose of the transformer is to change the 110 volt a-c supply to other values of voltage which

are needed to properly operate the tubes of electronic equipment.

To more completely meet the circuit requirements, many of the windings are tapped. For example, Figure 2-C has several primary taps because, in some localities, the line voltage is either below or above the normal value of 110. Thus, if a power supply was to operate on a 105 volt, instead of a 110 volt line, the primary connections would be made to the lower and "105" taps.

By the use of these connections, the proper number of active primary turns can be selected to obtain the turn ratio which will keep the secondary voltages at normal values.

Keep this arrangement in mind because low secondary voltages will impair the performance of the unit which is operating on the output of the power supply. On the other hand, high voltages may increase the gain or sensitivity of the electronic unit to such an extent that unwanted coupling will occur and result in oscillation. Also, the high voltage may reduce the life of the tubes.

In Figure 2-C we show a center-tap in the plate or high voltage secondary. This is a very common arrangement and is necessary for the usual full-wave types of tube rectifiers. The filament secondaries are also often center-tapped and, for the rectifier tubé, the tap is used as the positive d-c terminal while, for the other tubes, it is used as a return for the grid and plate circuits.

Figure 2-D shows the circuits of a typical power transformer such as used in a complete power supply. Here, the arrangement is similar to that at B but the plate or high voltage winding is center tapped and there is a third secondary.

Like the circuits of B and C, the "Plate" and "Fil X" secondaries supply the plate and filament circuits of the rectifier tube. The third secondary, marked "Fil Y", is the filament or heater supply for the other tubes of the unit which is obtaining its voltages from the power supply.

There are many other arrangements but those in Figure 2 are common and will give you the idea. Just remember, the common types of transformers will have one primary winding and one or more secondary windings, any or all of which may be tapped.

TYPES OF RECTIFIERS

Nearly all types of rectifiers, from the simple mechanical vibrator to the modern tube, have been used in Radio and other Electronic equipment. Therefore we want to give you a brief explanation of the more common types but remember, the basic purpose of all rectifiers is to allow current in one direction only.

The vibrator type, by a combination of permanent and electro magnets, causes a switch to close with current in one direction and open when the current reverses. The action is not too good and, unless carefully adjusted, the contacts will spark badly. The sparking not only injures the contacts but causes interference in most electronic devices. That is why the vibrator type rectifier is seldom used for a-c operated Radio equipment. However, as will be explained later, vibrators are used in certain types of equipment, such as Auto Radios.

Then, there are the chemical rectifiers, built much like a wet cell, but using a combination of electrodes and electrolyte which offer an extremely high resistance to current in one direction and a low resistance to current in the reverse direction.

Earlier in this Lesson we explained the action of the tube rectifier and will not repeat here. Remember, there are several types of Rectifier Tubes and if the actions are not clear in your mind, go back and review before going ahead.

As previously explained, the dry plate rectifier is used to a great extent in the conversion of d-c meters to read a-c values. However, it is also quite popular as a rectifier in low voltage supplies. It is clean and dry, easily replaced and made in a variety of sizes and types, suitable for many electronic applications.

HALF WAVE RECTIFIER

The rectifier may operate on either half or all of the a-c wave, depending on its construction and circuits but the action can be followed more easily by the simple curves of Figure 3. At A, we have the usual a-c, sine wave, that part above the line being thought of as positive, while that below the center, or base line, is negative.

A simple rectifier, connected in series with the a-c circuit and allowing current in one direction only, will pass current like that of Figure 3-B. Notice here, we have simply cut off the negative alternations of the a-c and call it a half wave rectifier because but half of the a-c wave is allowed to pass through.

By using a double action, the negative parts of the a-c wave can be changed so that the rectifier output will have the wave form of Figure 3-C. The shape of this wave will also help you understand what we meant when we mentioned a pulsating direct current earlier in this Lesson.

Notice here, the values of the curve at A, Figure 3, are not changed in B or C. All the rectifier has done is to eliminate those parts below the base line either by dropping them entirely or bringing them above the base line. When both halves of the a-c wave are used, as at Figure 3-C, we call the action, full wave rectification.

Going on to Figure 4, you will find the circuits of a simple half wave vacuum tube type of rectifier. The transformer is like that of Figure 2-B and the tube is a two element type with a filament and plate. When the primary is connected across an a-c supply, the voltage induced in both secondaries will be like the curve of Figure 3-A.

The filament secondary connects across the filament of the tube and the a-c voltage will cause an alternating current. However, this current is needed only to heat the filament and cause the emission of electrons, therefore does not need to be rectified.

The other secondary connects to the plate at one end and to the negative "Load" terminal at the other. The load terminals are used to connect the unit to the proper circuit and could be marked "OUTPUT".

Because of the electronic emission of the filament, there will be current through the tube only from the plate to the filament, which is equivalent to a flow of electrons from the filament to the plate. The direction of the induced voltage in the plate secondary keeps reversing and when it is "down", in Figure 4, there will be plate current as shown by the arrows. Notice here, the plate current must pass through part of the filament to reach the positive load terminal, therefore the filament is the positive side of the d-c circuit.

When the direction of the secondary voltage reverses, the plate will be negative in respect to the filament and there will be no flow of electrons between them. Therefore we can state that with voltage of this polarity, the resistance of the tube is so high that, for practical purposes, there is no current in the circuit. Then, when the voltage reverses during the next a-c. alternation, there is current in the direction of the arrows.

The circuit of Figure 4 thus changes the a-c. wave of Figure 3-A to the form of Figure 3-B and is a half wave rectifier.

FULL WAVE RECTIFIER

To make use of the other half of the a-c wave, in Figure 5 we have an arrangement which contains two of the half wave rectifiers of Figure 4. The transformer circuits are again like those of Figure 2-B but, each secondary section has a center tap. To make the explanation easier to follow, we will imagine that each half of the plate secondary in Figure 5 has the same number of turns as the entire plate winding of Figure 4.

Looking at the lower half of the plate secondary and the left hand tube of Figure 5, you will see we have nothing but the plate circuit of Figure 4. The action here, of course, will be like that explained for Figure 4.

The upper half of the secondary is already connected to the negative load terminal, through the center tap, and its upper end connects to the plate of the right hand tube.

The filaments of the tubes are connected in parallel across the filament secondary. The center tap of the filament secondary connects to the positive load terminal and thus the plate current may be carried in all parts of the filament instead of but one half as in Figure 4.

When the direction of plate secondary voltage is down in Figure 5, the action of Figure 4 will take place and there will be current through the left hand tube in the direction of the arrows. When the secondary voltage reverses and is "up", we have the proper conditions for the right hand tube and there will be current through it in the direction of the arrows.

Saying it in a different way, one tube allows current when the a-c is in one direction and, when the a-c reverses, the other tube allows current. However, the connections are made so that, no matter which tube supplies it, the direction of current in the load circuit is always the same.

Checking up here, by means of the center tap and two half wave rectifier tubes, the plate seoncdary voltage of Figure 3-A is changed to the wave of Figure 3-C in the output circuit. Taken as a unit, Figure 5 is a full wave rectifier.

Instead of using two tubes, in Figure 6 we again have the circuits and actions of Figure 5, but use one tube with two plates. The output of the unit in Figure 6 will have exactly the same wave form as Figure 5 and is therefore a full wave rectifier.

You will find the circuits of both Figures 5 and 6 in common use. Those of Figure 5 are generally employed in power supplies delivering voltages and currents of higher values while the circuits of Figure 6 are commonly used with the ordinary voltages required for most Radio apparatus.

RECTIFIER TUBE CONNECTIONS

In the various types of Electronic equipment, there are many methods of making connections to secure the action of Figures 4 and 5. For example, in Figure 7-A, we have the circuits of Figure 4 but the positive side of the load circuit connects to a center tap of the filament secondary like that of Figure 5.

In Figure 7B we have another combination in which one end of the plate secondary connects either to one end or the center tap of the filament secondary. While the markings of the load terminal may confuse you at first glance, trace the circuits and you will see the direction of current through the rectifier tube is still from plate to filament.

Although we do not show it, the transformer of Figures 7-B has a core and primary exactly like that of Figure 7-A. The difference between the two is in the secondary connections only.

To bring out the difference of the circuits in Figure 7, suppose the plate secondary develops 650 volts, that there is a drop of 30 volts across the tube and the

load negative is grounded. Under these conditions, for the circuit of Figure 7-A, the connection to the tube plate would be 650 volts above ground potential. Subtracting the 30 volt drop of the tube, the filament would be 620 volts above ground potential. As the resistance of the entire filament circuit is low, the positive load terminal would also be 620 volts above ground potential.

Anyone working around the unit is at ground potential and thus all the tube connections and its filament circuits are "Hot" and will give a bad shock if accidentally touched.

For the circuit of Figure 7-B, conditions are different. Again, with 650 volts across the plate secondary, the positive load terminal will be 620 volts above the ground load negative. Again there is the 30 volt drop across the tube but, the plate is at ground potential and the filament 30 volts below. As we have explained many times, it is the difference of voltage that really counts and a person at ground potential could work around the tube of Figure 7-B without fear of shock.

These two examples show the possibility of various connections to rectifier tubes but we want you to notice that, in every case, the electrical action is the same. The rectifier may be connected in either the negative or positive side of the line but, in either case, its purpose is to change a-c to pulsating d-c.

COLD CATHODE GASEOUS RECTIFIER TUBE

The Raytheon tube was the first full wave rectifier tube to become popular but, unlike those we have been explaining, it has no filament. Although there is no filament or cathode to emit electrons, still it is electrons that cause the action.

The tube has the usual shape of other types but, after the air has been exhausted, some inert gas, such as helium, neon or argon is placed in the bulb to improve the action. By inert gas, we mean one that will not unite or combine chemically with the other elements.

You will remember an electron is considered as a negative charge of electricity and will be attracted by a positive charge. To make use of this action, the Raytheon full wave rectifier has elements, consisting

of small wires or strips of metal, called anodes, which are surrounded by a cylindrical metal cathode.

To explain the operation we can assume there are a few free electrons in the space between the anode and cathode. When the anode is positive, they are attracted and start to move toward it. The closer they get, the faster they move and when enough of them strike the anode, there is a measurable current.

The inert gas is electrically neutral but, when the electrons, moving toward the anode at high speed, strike or collide with the molecules of gas, they knock off other electrons, which also move toward the anode. As their speed increases, the electrons, dislodged from the gas molecules, can collide with other molecules and knock electrons off them, so that the total number of electrons reaching the anode is greatly increased. As the electrons are "knocked off" the gas molecules, the electrical balance is upset, the gas is no longer electrically neutral but becomes "ionized".

In tubes of this type, operating on the principle of gas conduction, it has been found that the current is proportional to the area of the negative electrode. Thus, when the a-c supply causes the large cylindrical cathode to become positive, in respect to the small wire anode, the action is reversed but current in this direction is comparatively small.

In Figure 8 we show the connections for a Raytheon full wave rectifier and want you to compare them with those of Figure 6 which are the customary circuits for the filament type full wave rectifier. The Raytheon tube has no filament and therefore does not require a filament secondary. However, it does have some leakage current during the rectifying action as explained above, which makes the two small "buffer" condensers, C_1 and C_2 necessary.

While the Raytheon tube is not used to any great extent at the present time, other cold cathode rectifiers employ some of the principles explained above.

DRY PLATE RECTIFIERS

It has been found that when certain metallic substances are brought in close contact, or placed under pressure, current will pass through the contact in one direction much more readily than in the other. It is this principle which has been used to make the dry

plate rectifier of which there are three general types on the market. One uses plates of copper and copper oxide, another has plates of copper sulphide and either magnesium or aluminum while the third is assembled from plated iron disks, coated with selenium and sprayed with metal.

They are classed as low voltage rectifiers, but have been made in ranges of from 20 to 50 volts with a current capacity of from .2 to 3 amperes. Higher voltages are secured by placing the elements in series while higher currents are available by connecting the units in parallel.

When operating, this type of rectifier heats up, but high temperatures must be guarded against because, above a certain heat value, current will pass in either direction and the rectifying action stops. The usual dry plate rectifier is made with a flange on alternate plates to increase the radiation of heat and help to keep the temperature at the proper value.

In the copper oxide type, the rectifying action takes place between a plate of metallic copper and a layer of copper oxide, formed on one side of the plate by a special heat treatment. To increase the conductivity, a lead washer is placed between the copper plates. Current can pass quite easily from the oxide to the copper but there is a high resistance to current passing from the copper to the oxide.

The action of the copper sulphide type is somewhat different. Alternate disks of copper sulphide and magnesium or aluminum are assembled alternately under high pressure. When an a-c voltage is connected across the assembly, a film is formed between the disks. This film allows current to pass freely from the copper sulphide to the magnesium or aluminum, but offers an extremely high resistance to current in the other direction.

For the selenium type, a very thin layer of selenium is applied to one side of a roughened iron disk and, after heat treatment, it is covered by a soft metal layer which forms the other electrode. Current will pass freely from the iron to the selenium but not from the selenium to the iron. This construction permits good contact without a high assembly pressure.

Rectifier units of this general type are properly assembled and treated when made and must never be

taken apart. Their life is about the same as that of the average tube but, the larger the current they rectify, the shorter their life.

As each contact forms a half wave rectifier, at least two units must be used in order to secure full wave rectification. This is the arrangement we show in Figure 9-A and we want you to compare it with Figures 6 and 8.

When it is necessary to obtain a higher voltage, or the transformer secondary has no center tap, the circuits of Figure 9-B may be used. To follow the circuit here, the arrows on the wires show the path of current when the a-c voltage is in one direction. With voltage in the other direction, the path of current is shown by the arrows at the side of the wires. You will find these rectifiers made with several contacts for each unit and usually assembled with four or five external connections.

VOLTAGE DOUBLER

Back in the earlier Lessons on condensers, you will remember that when a condenser is placed across a source of voltage, it will charge and, after removing it from the circuit, will have a potential difference between its two terminals equal to the source across which it was charged. In other words, assuming no leakage, if the source is 110 volts, there will be a difference of potential of 110 volts between the terminal, or plates, of the condenser.

Under these conditions then, a charged condenser can be compared to a battery. Keeping this in mind, suppose we have two condensers, each charged to a potential of 110 volts and connect them in series. The total potential difference across the combination will be the sum of the separate potentials or 220 volts. In other words, we have twice the voltage of the charging source and could say we have a voltage doubler.

In Figure 10, we show the simplified circuits of such an arrangement, made up of condensers C_1 and C_2 and two half wave rectifiers X and Y, with the combination connected across an a-c line with a peak voltage of 110 volts. Assuming that the upper lead of the source is positive, there will be current from it, charging condenser C_2. This circuit is completed back to the other side of the line through rectifier Y. On the next alternation, with the

lower lead positive, the current will be through rectifier X, charging condenser C_1, with a circuit back to the upper side of the source.

Both condensers are now charged, with their polarity as indicated, and you will notice that they are connected in series in respect to each other. Therefore the total voltage available across the two condensers will be the sum of their separate voltages. If a load were connected across both the series condensers, they would discharge and provide current for external use. Also, as these discharges would always be in the same direction, the load current would be d-c

From the above explanation, it may appear to you that the condensers are charged by the a-c supply at the same time they are discharging through the load. However, if you will check back on the complete action, you will see that while condenser C_2 is charging, the supply voltage is in series with condenser C_1, which has been charged during the previous alternation, maintaining the "double" voltage across the load.

During the following alternation, while C_1 is charging, C_2 is in series with the a-c supply across the load and again the double voltage is maintained. It may help you to think of the a-c supply as charging one condenser, maintaining the double voltage and supplying part of the load current, during each alternation.

The circuits of Figure 11 show a conventional voltage doubler circuit and the electrical actions are exactly the same as explained for Figure 10. The only addition being in the heater circuit of the duo-diode tube which carries the necessary current to bring the temperature of the cathodes to the proper point to emit electrons. The resistance R is used only to provide a voltage drop so that the filament, or heater, will operate at its required value of voltage and current.

Tracing the circuit, when the upper wire of the source is positive, there will be current from P_1 to K_1, charging condenser C_1 the negative side of which connects back to the supply. On the next alternation of the a-c , the current will be from the lower lead to charge condenser C_2, the negative side of which connects to P_2, K_2 and back to the supply.

The output voltages given above are for no load con-

ditions and when a load is applied, they will drop to a value depending on the amount of current and the capacity of the condensers C_1 and C_2. You can easily understand this if you remember that the amount of electricity a condenser can store depends on its capacity.

For this reason, high capacity condensers, usually about 16 mfds., are used in voltage doublers, and to obtain satisfactory operation, the capacities of C_1 and C_2 should be equal.

FILTER SYSTEMS

The current which leaves the rectifiers can be shown by the curves of Figures 3-B and 3-C and, as we have explained, is a pulsating direct current. If this current is allowed in Radio equipment, it will produce a hum because it varies with or at twice the frequency of the a-c supply voltage.

To eliminate the hum, the variations of current must be smoothed out, therefore a filter, composed of choke coils and condensers, is connected to the rectifier output. To eliminate all hum, the filter must be carefully designed because, if the condensers are too small, they will not handle the load properly, while small choke coils will allow enough variation to cause hum.

Going back to the early Lessons on alternating current, you will remember that in an inductance, any variation of current induces an emf, which opposes the change. For a condenser, the amount of charge absorbed depends on its capacity and the voltage across it.

Looking at Figure 12-A, suppose the voltage from the rectifier is like the curve of Figure 3-C where, starting at the left at O, the voltage rises. This will cause an increasing current in coil L which, by self induction, will set up an opposing emf This induced emf will reduce the effective voltage and thus prevent the current from increasing as fast as the voltage. Also, it will tend to increase the voltage across condenser C-1 which will charge.

By the time the voltage reaches its maximum value, part of the current it caused will have passed through the choke coil and part will have charged the condenser C-1.

The voltage then starts to fall in value and the current starts to reduce, reversing the induced emf in the choke coil. Remember this induced emf does not oppose the current, but opposes the changes. Thus, it tries to prevent the current from increasing but now, that the current is decreasing, it tries to maintain it.

At the same time, the voltage is reducing across condenser C-1 allowing it to discharge. Thus we have the self induced emf of the choke and the discharge of the condenser both trying to hold up the value of current. As a result, when the rectifier voltage drops to zero, the condenser discharge and induced emf of the choke coil maintain a current in the circuit.

Looking at it in a different way, acting together, the choke and condenser hold the current back when the rectifier voltage is rising but release it when the rectifier voltage is falling.

Due to the fact that the condenser C_1 is directly across the output of the rectifier, the filter of Figure 12-A is known as "condenser input". It has been shown experimentally, that the input condenser C-1 has a marked effect on the voltage output of the filter but, with a reasonable value of capacity, seldom reduces the voltage variations or "ripple" much more than 10 per cant. For this reason, C_2 is necessary to reduce the ripple to the point where it will not be detremental in ordinary units. However, in some electronic devices having a very high gain, to further reduce the ripple, it is necessary to add on additional filter section, made up of chokes and condensers.

As mentioned above, condenser C-1 has an effect on the output voltage and, by increasing its capacity within certain limits, the voltage output can be increased. However, the rectifier tube must be of sufficient rating so that it will be capable of charging the condenser up to the required potential without overloading. If not, the high charging current, necessary for the condenser, will shorten the life of the tube.

The advantages of condenser input are high voltage output with a comparatively low hum level. However, it has the disadvantage of poor regulation. By poor regulation, we mean there is a comparatively large variation of output voltage with changes of load.

In Figure 12-B we show another type of filter which is similar to that shown in 12-A, the difference

being in the addition of the choke L1 ahead of condenser C1. The purpose of the choke coil L1 is to prevent current peaks from reaching a value high enough to damage the rectifier tube.

Due to the fact that this type of filter reduces the current peaks, it has the advantages of improved filter action, better voltage regulation and reduced heating of the secondary winding of the power transformer. However, it does have the disadvantage of a lower voltage output. Choke input filters are recommended for use with mercury vapor rectifiers where high peak currents cannot be tolerated. In appearance, a mercury vapor rectifier is similar to the types explained earlier in this Lesson. However, to reduce the internal resistance, a small amount of mercury, which is partially vaporized when the tube is in operation, is placed inside the bulb.

The mercury vapor consists of mercury atoms, permeating the inside of the bulb, which are bombarded by the electrons on their way to the plate. If the electrons are moving at a sufficiently high speed, the collisions will tear off electrons from the mercury atoms and, when this occurs, the mercury atoms become "ionized". That is, they lose one or more electrons and become positively charged.

In the case of mercury vapor, ionization is made evident by a bluish-green glow between the filament, or cathode, and plate. When ionization occurs, due to bombardment of mercury atoms by electrons leaving the filament, free electrons which would not reach the plate and tend to reduce the plate current, are absorbed by the positive mercury ions so that the plate current is increased.

A mercury vapor rectifier has a voltage drop, between the filament and plate, of about 15 volts. This drop is practically independent of current requirements up to the limit of emission of electrons from the filament but, is dependent to some degree on the bulb temperature.

You will find many arrangements of chokes and condensers in a filter, a very common type being like that of Figure 12-A with the choke connected in either the positive or negative side of the circuit. You must remember however that the filter is a complete unit and the condenser capacity must be determined by the inductance of the chokes in addition to the other

factors we have mentioned. When replacing any parts, the best plan is to duplicate the values of the originals as closely as possible.

As the voltages in the usual power supply are quite high, the condenser dielectric must be able to stand up under these high pressures. One important point that may be overlooked is the fact that a power supply does not provide a uniform output voltage.

Suppose it is designed to produce 250 volts at 100 milliamperes. If the load current is reduced to 15 or 20 milliamperes, the voltage will increase perhaps 40 or 50 volts. With no load current, the voltage might go up to 300 or 400 volts. This is what we call the regulation and the amount of variation will depend on the power supply design.

On account of their connections, the condensers have to withstand this high voltage and therefore it is not safe to operate any power supply unless it is properly connected to its load. The usual filter condenser is made to operate at 200, 300, 400, 600 volts or higher and, as a general rule, it is a good plan to install condensers designed for twice the normal voltage output of the rectifier. The voltage values listed above are considered as the "d-c" working voltage of the condensers and they should not be used in circuits operating at voltages above their rating.

Should any of the filter condensers break down and short, several things may happen. First, as the output varies inversely with the load, the shorted condenser forms such a heavy load that there is no voltage available at the regular output connections.

If the rectifier is allowed to operate under these conditions, the current will be above its rated maximum output and the plates will heat up, often becoming red hot. Even if it does not burn out, the life of the rectifier tube will be shortened. Should the rectifier tube hold up, high current will be present in the plate secondary of the transformer and may burn it out.

Whenever you find a power supply in which the rectifier seems to be working but furnishes no output voltage, shut off the main supply at once and locate the trouble before further damage is done.

VOLTAGE DIVIDER DESIGN

Back in an earlier Lesson, we gave you a detailed explanation of a voltage divider and told you how the various resistance values were calculated. In practice, the circuits of that former Lesson are connected across the output of the filters of Figure 12.

Perhaps the circuits of Figure 13, where we show a conventional power supply circuit, will give you a better idea of a voltage divider. For example suppose we are to find the resistances of R_1, R_2 and R_3 with 250 volts between B+ and B-, 90 volts across R_2 and a drop of 50 volts across R_3. Also, let us assume the coil L_1 has a resistance of 1000 ohms and requires 2.5 watts for proper operation. The current values are 30 milliamperes for the circuit connected across B+ and B- with 10 milliamperes for a circuit connected across R_2.

The first step in the design will be to find the amount of current necessary to give coil L_1 the required wattage. Using a power formula of an earlier Lesson, we have,

$$P = I^2R \text{ or } I = \sqrt{P/R}$$

Substituting the above numerical values,

$$I = \sqrt{\frac{2.5}{1000}} = \sqrt{.0025} = .05 \text{ ampere} = 50 \text{ milliamperes}$$

The total amount of current required for the other circuits is 30 + 10 or 40 milliamperes. Therefore, we must have an additional 50 - 40 or 10 milliamperes to properly excite the coil. This can be obtained by making the bleeder current 10 milliamperes.

To find the value of R_1, we must first find the voltage drop across it, which will be 250 - 90 or 160 volts. The total current through R_1 will be the bleeder current plus that drawn from the tap which will be 10 + 10 or 20 milliamperes. Knowing the voltage drop across R_1 and the current in it, we can find the resistance by Ohm's Law. Substituting numerical values,

$$R_1 = \frac{E}{I} = \frac{160}{.020} = 8000 \text{ ohms.}$$

As R_2 carries only the bleeder current of 10 ma, and there is a 90 volt drop across it, its resistance value in ohms must be,

$$R_2 = \frac{E}{I} = \frac{90}{.010} = 9000 \text{ ohms}$$

Because the currents approaching a junction of electrical conductors must equal those leaving it, there will be a total of 50 milliamperes to B- and on through R_3 to complete the circuit. As the voltage drop across R_3 is given as 50 volts, its ohmic value must be

$$R_3 = \frac{E}{I} = \frac{50}{.050} = 1000 \text{ ohms}$$

The power rating of the resistors can be found by one of the formulas where $P = IE = E^2/R$. For example, in R_1 we have a current of 20 ma and a drop of 160 volts. Using the first form above,

$$P_{R_1} = E_1 I_1 = 160 \times .02 = 3.2 \text{ watts}$$

For R_2,

$$P_{R_2} = E_2 I_2 = 90 \times .01 = .9 \text{ watt}$$

For R_3,

$$P_{R_3} = E_3 I_3 = 50 \times .05 = 2.5 \text{ watts}$$

Looking at the circuit again, the output voltage of the filters appears across condenser C_2 and here, the choke coil L_1 is in the positive side of the circuit. Resistances R_1, R_2 and R_3 are in series across C_2 with R_2 at the positive and R_3 at the negative side of the supply circuit.

The junction between resistors R_2 and R_3 is marked "B-" and is grounded therefore, with "B-" as a reference point, voltage drops across R_1 and R_2 will be positive while voltage drop across R_3 will be negative. This is a very common method of obtaining both positive and negative voltages from a single supply, voltages which, as you will soon learn, are required for the proper operation of many types of radio tubes.

Condenser C_3 and C_4, connected across resistances of the voltage divider, act as filters as explained for those of Figure 12. Here, variations of current in the resistors will cause corresponding changes of voltage across them and thus the condensers will charge and discharge to maintain a more uniform current. For example, referring to Figure 13, suppose the current in R_2 starts to increase. The voltage drop across R_2 and C_3 will also increase and the condenser will charge and absorb some of the increased current.

When there is a reduction of current in R_2, the action reverses and the condenser discharges, thus helping to maintain the current in the resistance. These precautions are necessary because any rapid variations of voltage, across any part of the voltage divider, will cause hum or noise in the speaker of a Radio Receiver.

Check over these circuits carefully because, in our next Lesson, we are going to use power supplies of this type to help explain the circuits and actions of other types of Radio Tubes.

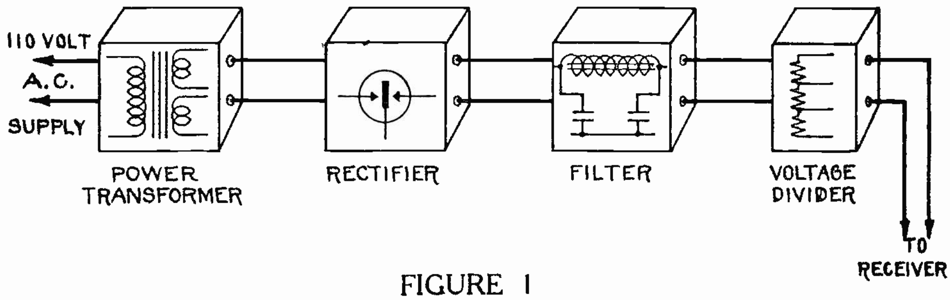


FIGURE 1

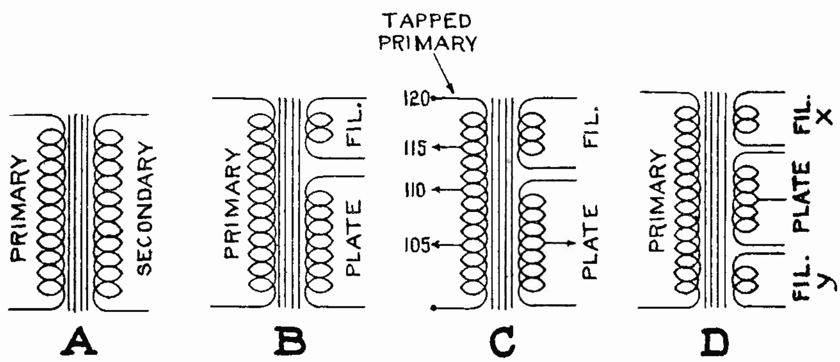


FIGURE 2

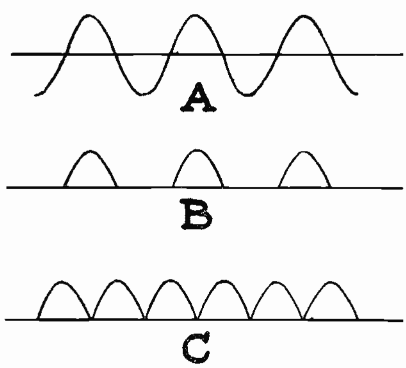


FIGURE 3

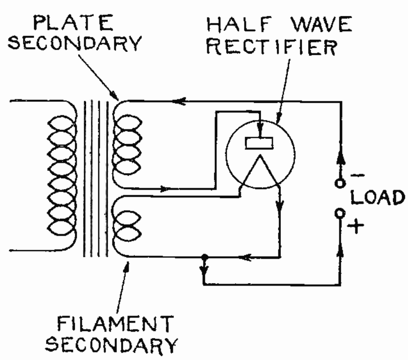


FIGURE 4

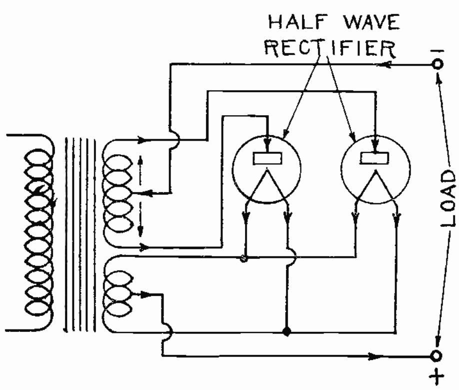


FIGURE 5

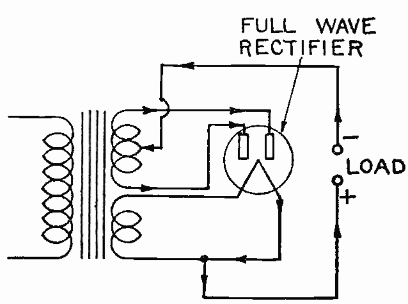


FIGURE 6

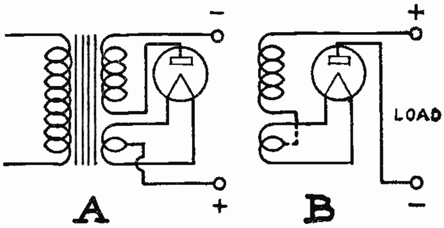


FIGURE 7

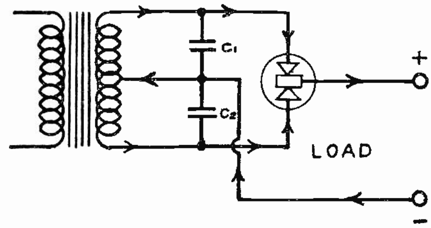


FIGURE 8

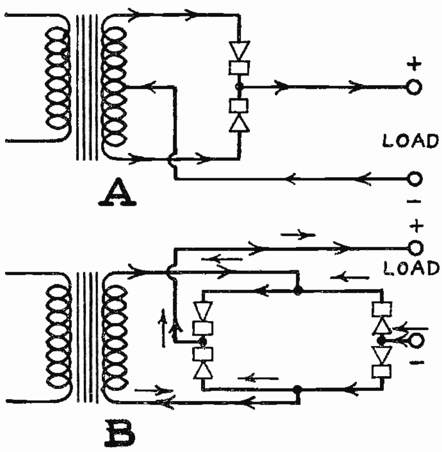


FIGURE 9

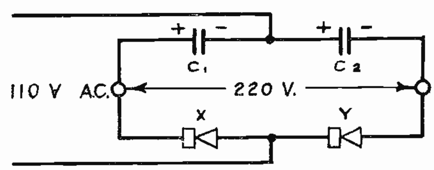


FIGURE 10

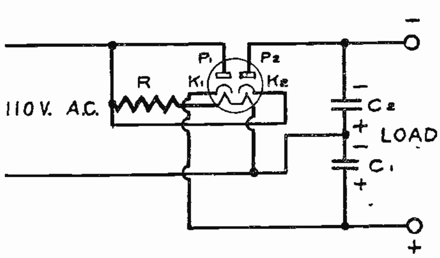


FIGURE 11

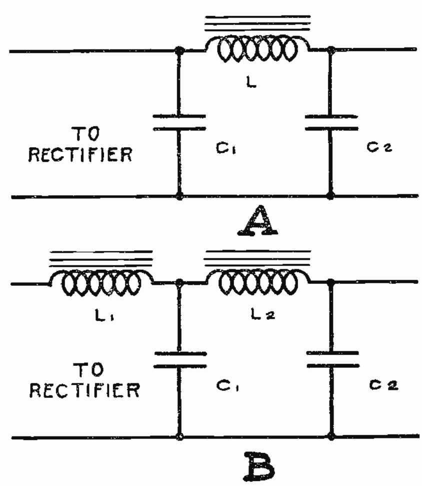


FIGURE 12

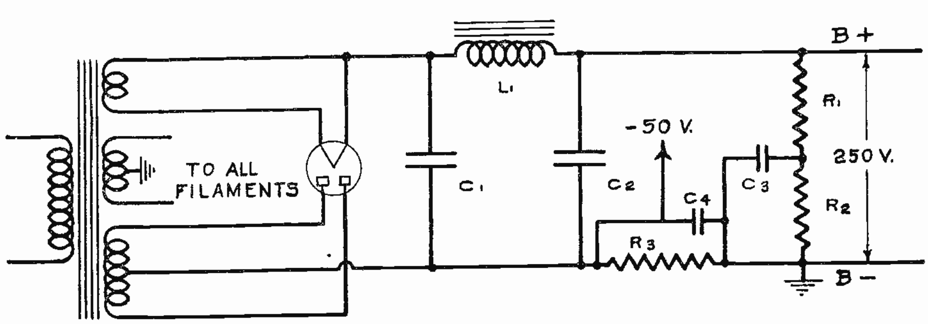


FIGURE 13

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ELECTRON TUBES

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LESSON TRA - 10

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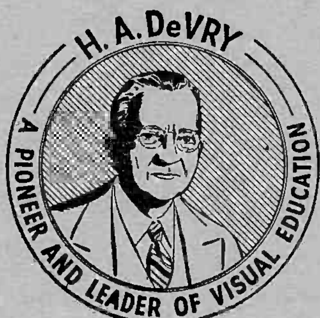


TUBES - RECEIVERS - AMPLIFIERS

Lesson 10

ELECTRON TUBES

* * * * *

The value of work depends upon the spirit that is put into it.

After all, we are nothing but human beings, whether at work, at play or asleep. Work is nothing but the forth-putting of the human spirit. It is the light that shines from the candle in the soul. It is the energy streaming out of the human mind.

—— Dr. Frank Crane

ELECTRON TUBES

As explained in the previous Lesson, the action of a two element, or diode type, tube is quite simple yet it took many years to discover and utilize its properties.

Some time before 1885, while Thomas Edison was perfecting the incandescent electric lamp, he noticed that, after being in use for a time, the inside of the glass bulb become blackened and eventually caused a serious reduction in the amount of available light.

Investigating this action, he mounted an electrode inside the bulb, but not connected to the filament. With this arrangement he found it possible to establish current from this electrode to the filament but not in the reverse direction. This is known as the "Edison Effect" but no further development was attempted at that time.

In the former Lesson on Radio Principles, we mentioned that Wireless Systems were in operation and much research was being done to improve their efficiency of operation. Dr. J. A. Fleming, a British scientist very active in Radio research, obtained a patent on a two element tube known as the Fleming Valve.

In effect, the Fleming Valve was merely an application of the Edison Effect and consisted of a plate surrounding the filament, both of which were mounted in an evacuated glass bulb. This was the original ancestor of our present diode tube but, designed to replace the crystal and other detectors used in the Radio Receiver of that day, it was not a great success.

It was soon found that the Fleming Valve was not as efficient as the older type of detectors, therefore it did not come into general use. However, it is of extreme importance as it started many experimenters to study its action.

The experiments culminated in the discovery, by Dr. Lee De Forest, that a third electrode, known as a "grid" could control the action when it was placed between the plate and the filament. It was in 1907 that Dr. De Forest obtained his original patent on the three element or "audion" tube, and this date is usually considered as the birth of our modern Radio Systems.

Like most important inventions, the value of the three element tube was not appreciated immediately

and later, Dr. De Forest was arrested for trying to sell stock in a company being organized to manufacture a "Worthless Glass Bottle". However, by continued research, the value of this tube gradually became apparent and its applications have completely dominated all of the later Radio developments.

THREE ELEMENT TUBES

Although the early models of tubes were comparatively crude, some of the modern versions have the general appearance of Figure 1, but before going into the electrical actions, we want to give you an idea of the mechanical construction.

Looking at Figure 1, you will find the complete tube consists of a base, the lower side of which carries a number of metal prongs that are used to complete the external electrical circuits through the inside parts.

Mounted inside the base is a glass stem which extends upward and contains a number of wires that are used both as mechanical supports and electrical connections. The upper ends of these wires carry the plate, grid and filament or what we call the "elements" of the tube.

Also mounted on the top of the base, you will notice a glass bulb which completely encloses the elements. The lower part of the bulb is sealed to the stem so that the elements are inside a tightly closed space from which the air is pumped.

The only element which can be seen in Figure 1 is the plate, made up of sheet metal in the form of flattened tube. It completely surrounds the other elements and thus produces the best action as it can intercept practically all of the electrons thrown off by the heated filament.

To show the inner construction, for Figure 2 we have removed the bulb and plate of Figure 1, leaving the grid exposed. Instead of solid metal like the plate, the grid is made of wire, wound in the form of a cage, or spiral coil, flattened to fit inside the plate.

The grid is supported by two of the wires extending upward from the stem and you will notice that one of these extends down through the base and prong to form an external connection.

In much the same way, the two outer wires which support the plate are mounted in the stem and one of them extends downward to another prong to form a connection for the plate circuit.

Going further, for Figure 3 we have removed the grid, leaving only the wire supports and the filament which has the general shape of an inverted "V", often called a "Hairpin". Three wires are used, the central one as a support only with the other two as supports and electrical connections which extend down through the two remaining prongs.

This three element or "triode" tube therefore requires four external connections and has four prongs on its base, a bottom view of which is shown in the upper sketch of Figure 4. This view is extremely important and you will notice the four prongs are equally spaced although those which are used for the filament connections have a larger diameter than the other.

Check this view carefully as many Radio circuit diagrams are shown in this way with the prongs marked, "F" for dilament, "G" for grid and "P" for plate. Other diagrams show a tube symbol, like that in the lower part of Figure 4, which we have lettered in the same way in order that you may compare all the views of Figures 1, 2, 3 and 4.

When in use, the tube prongs are pushed into a socket which has corresponding holes and metal springs which make contact with the prongs and to which the circuit wires connect. This arrangement permits the tubes to be removed and replaced without disturbing the wiring or permanent connections.

Like the two element tubes, when the filament of a triode is heated, there is a stream of electrons to the positively charged plate. With the grid placed between the filament and the plate, all of the electrons reaching the plate will have to pass close to the grid wires.

Should we give the grid a slight positive charge, by connecting it to the positive of a d-c supply, it will act like the plate and attract electrons. In other words, the positive charge of the grid will now attract many of those electrons which, after being thrown off, would be drawn back by the positive ions of the filament.

However, with a stronger positive charge than the grid, the plate attracts practically all of those electrons which have moved toward the grid and thus the number reaching the plate is increased. This means, of course, that the current in the plate circuit will be increased.

Should we give the grid a negative charge, be reversing its connections to the d-c Supply, it will repel the electrons, forcing them back toward the filament and allowing the positive ions there to attract them. In this way, the number of electrons reaching the plate will be cut down and the plate current will be reduced.

The voltage on the grid can thus control the current in the plate circuit and the main advantage of this type of tube is that a comparatively small change of grid voltage can cause a larger change of plate current.

TUBE CIRCUITS

Before going any further with these actions, we want to take up the practical side and show you how the circuits are arranged and of what they consist.

To begin with, in the left hand diagram of Figure 5, we have drawn the filament circuit connected to a source of supply. This source is known as the "A" supply and the main purpose of its current is to heat the filament and cause the emission of electrons. Unlike the other tube circuits, the filament will operate on either direct or alternating current but, for this Lesson, to simplify the explanations and emphasize some important points, we will assume a direct currént supply with the polarity as marked in Figure 5.

The filament is part of a simple circuit and the path of the current is from the supply positive through the filament and back to the supply negative. Near the negative "A" terminal we show a junction "O" and want you to keep this point in mind.

For the center diagram of Figure 5, we show the complete grid circuit which you can trace from the grid through coil "L1" through the "C" supply, through junction "O", through part of the filament and, across the space inside the tube, back to the grid.

The coil "L1" may be a choke coil, a transformer

winding or a resistance across which a signal or input voltage can be produced. For this reason, the unit in the position of the "L1" is often known as the input circuit of the tube.

The supply, often known as the "C", furnishes a d-c voltage and is connected so that its negative terminal is toward the grid and its positive terminal is toward the filament. This supply maintains the grid at some fixed value of voltage which is negative in respect to the filament and must not be confused with the signal voltages which appear across the input circuit.

To distinguish this fixed condition, the voltage developed by the C supply is known as the "grid voltage", "grid bias", "bias voltage" or "C voltage". All of these terms refer to the same action and, because the resistance of the space between the grid and filament is so high that practically no current is present, the "C" supply is considered as a source of voltage only.

Notice here, the complete grid circuit includes part of the filament circuit and the point "O", already mentioned, is where the two circuits join. For this reason, point O is commonly known as the "Grid Return".

At the right of Figure 5 we show the plate circuit which, you will notice, is about the same as the grid circuit. It consists of the plate, a coil "L2", a supply "B" and is completed through part of the filament.

Here, the coil "L_2" may be a choke coil, transformer winding or resistance and is thought of as the "Plate Load". Compared to coil "L_1" as the input circuit, coil "L2" is the output circuit. The "B" or plate supply furnishes direct current for the plate circuit and is always connected with its positive toward the plate and its negative toward the filament.

Our former explanation may have given you the impression that the plate current was made up of the electrons supplied by the filament. While this is true, you must remember that electrons move from negative to positive and therefore the negative of the plate supply will replace the electrons which pass from the filament to the plate. Regardless of the details, from a practical standpoint, the B supply maintains the plate at the desired positive potential, in re-

spect to the filament, and also supplies the plate current.

Checking the path of the plate current, it will leave the "B+", pass through "L2" to the plate, across the space between the plate and filament and return to "B-" through part of the filament and point "O".

For a tube operating as explained above, this junction marked "O" is called a "reference point" and all tube voltages are measured from it. For example, if you desire to measure the plate voltage in Figure 5, you place the positive terminal of a voltmeter on the plate connection at the tube and the negative on the reference point "O". When measuring grid voltage, a sensitive meter can be connected across the grid and "O" while for filament voltage, the meter will be from F+ to "O".

Spend enough time on these three circuits to get them firmly and clearly in mind because they are what we will have for any three element tube operating on direct current. Above all things, be sure you understand the purpose and circuits of the different supplies.

The filament, or A supply is connected across the F terminals of the tube socket. The B supply is always in the plate circuit with its positive connected toward the plate of the tube.

The C supply is placed anywhere in the grid circuit, usually at the filament end, with its negative toward the G terminal and its positive connected to the F-.

CHARACTERISTIC CURVES

As most technical articles on the action and operation of electronic tubes are written around their "Characteristic Curves", we will continue our explanations by showing you how curves of this kind are made. To being, we will make a curve which indicates the changes of plate current caused by variations of grid voltage.

Curves of this type represent actual operating values, therefore the circuits of Figure 5 are combined into an arrangement on the order of that shown in Figure 11. There, the filament circuit is controlled by the rheostat, R-1, and the voltmeter, "E_f", indicates the operating voltage.

The "B" supply is tapped, to provide different values of plate voltage, indicated by the voltmeter "Ep", while the milliameter "Ip", indicates the plate current. The potentiometer "R_2" provides a gradual adjustment of the grid voltage which is indicated by the voltmeter "Eg". The "Switch" reverses the polarity of the voltage applied to the grid circuit.

In Figure 6, we start with the usual arrangement of squares but, for clarity, have made them comparatively large. The plate current scale is at the left, with "0" at the bottom and, as we are interested only in the general action at this time, no numerical values are given. In the same way, the grid voltage scale is shown across the bottom with the "0" value off center toward the right.

With the curve scales laid out and the tube connected in the circuit of Figure 11, we adjust the grid voltage to zero and read the plate current as indicated on meter "Ip". To record this value on the curve, we start at "0" on the "grid volts" scale and go up the "0" line until we are opposite the indicated value of plate current on the plate current scale, where we plot the first point of the curve.

The grid voltage is then adjusted to some definite value of positive voltage, as indicated by voltmeter "Eg", and the value of plate current is read in milliameter "Ip". This value is plotted as previously explained, for the second point of the curve.

Following this same plan, we find that, as the positive grid voltage is increased, the plate current also increases quite rapidly at first but soon reaches a point where a further increase of positive grid voltage causes a smaller increase of plate current.

By plotting these various readings as points and then joining the points with a line, we have the upper part of "Curve 1" of Figure 6 and the smaller increase of plate current at higher values of positive grid voltage is shown by the way the curve "bends over" at the top.

The grid circuit connections are now changed by throwing the "Switch" of Figure 11 so that a negative voltage will be supplied and, starting with a small value, we find the plate current is less than with zero grid voltage. This value is plotted as before and, as the negative grid voltage is increased, the plate current decreases quite rapidly at first but again we

reach a point where a further increase of negative grid voltage causes a smaller decrease of plate current.

Here however, we continue increasing the negative grid voltage until the plate current drops to zero or what is known as the "Plate Current Cut Off". Then, joining the plotted points of plate current values with a line, we have the lower part of "Curve 1" of Figure 6.

Notice the shape of this curve carefully. Starting at the bottom, the plate current first increases gradually and then steadily, or in a straight line, for quite a distance, after which the increase is not so rapid. Keep this action well in mind because we are going to have more to say about it.

Curve 2 was made by repeating the steps explained for Curve 1 but, with a higher value of plate voltage, and you will notice it has the same general shape, but its current values are higher. Different values of plate voltage will cause different values of plate current, for the same values of grid voltage, but the general shape of the curves remain the same. The higher the plate voltage the higher the plate current.

Of course, there are limits to these values, depending on the size of the elements of the tube, the distance between them and so on but, for each particular type of tube, the manufactures specify how high the plate current can be raised with safety.

AMPLIFIER ACTION

The three element tubes we have been describing may be used as amplifiers, rectifiers or detectors, oscillators and modulators, with several methods of operation for each. For this Lesson, however, we will explain only the first two actions.

Starting with the amplifier action, we will assume that the grid of Figure 5 is supplied with a negative C voltage, or "biased", to a value such that when a straight line is drawn vertically from this value on the grid voltage scale of Figure 6, it crosses the plate current Curve 1 at the point we show as "O". This intersection is very important and is known as the "operating point" of the tube.

We want you to notice also that, for a comparatively large distance on either side of this operating point, the curve is almost a straight line. Thus, we say the tube is operating on the straight part

of its characteristic curve.

Suppose now that an a-c or signal voltage is induced in coil L_1 of Figure 5 which is in series with the d-c , "C" supply. For one alternation, the signal voltage will aid that of the "C" supply and increase the total negative grid voltage. For the next alternation, the signal voltage will oppose that of the "C" supply and reduce the total negative grid voltage.

Curve 1 of Figure 6 shows the changes of plate current caused by changes of grid voltage therefore we can use it to see the effect of the signal voltage. The C supply or bias voltage determines the operating point, which is shown as "O", therefore, directly below this point, we have drawn the "signal volts" curve to represent the a-c signal voltage.

It may help you to follow the action here by imagining that the signal voltage curve is moving upward and, the point at which it intersects the horizontal line of the grid voltage scale will indicate the total grid voltage at that instant.

For our explanation, we will imagine the signal curve has moved up until its maximum right hand or positive value crosses the grid voltage scale. This will cause a small positive grid voltage and, to find the corresponding value of plate current, we have extended the broken line up to Curve 1 and then over to the right.

By overcoming the negative grid voltage, this first half alternation of signal voltage has caused an increase of plate current which we have shown by the left hand quarter of curve Ip.

As the signal volts curve continues to move upward, the point at which it intersects the grid voltage line moves back toward the operating point "O" and therefore the value of plate current is reduced.

For the next alternation of signal voltage, the point of intersection will move toward the negative end of the grid voltage line and thus the plate current will be further reduced. Following the plan for the maximum value of the first alternation, we have drawn broken lines to show the value of plate current for the maximum voltage of the second alternation of signal voltage.

Curve Ip shows all the changes of plate current which take place during one cycle of signal voltage and of course, the action will be repeated for succeeding cycles. Notice here, curve Ipa has the same general shape as the signal volts curve but its amplitude is greater. It is by this action that small signal voltage, impressed on the grid circuit of a tube, are amplified and carried over to the plate or output circuit.

As a general definition of a tube action as an amplifier, we can say it is that action by which a small variation of grid voltage will cause a larger change in plate current.

DETECTOR ACTION

To continue our investigation of the action of this tube, for Figure 7 we have redrawn the lower part of curve 1, Figure 6, but have increased the C voltage, or negative grid bias, until the operating point is now at "O", Figure 7. The circuits have not been changed in any way except, but increasing the bias voltage, the operating point has been moved closer to the lower end of the curve.

Again we will assume an a-c signal voltage is induced in L_1 of Figure 5, and, for simplicity, will consider it to be the same as that of Figure 6.

Following the steps already explained, we imagine the signal volts curve as moving upward and, as shown by the broken lines, are able to draw the changes of plate current as curve Ipd. Check this curve carefully and you will find that the increase of plate current, above the value at the operating point, is greater than the decrease below this value.

This difference is due to the lower bend of Curve 1 and although both alternations of the signal volts curve are the same in shape and size, those of curve Ipd are different. In other words, like changes of grid voltage cause unlike changes of plate current.

As the increases and decreases of current, in curve Ipa, are equal, the average current remains at the same value as when no signal voltage is present. For the conditions of curve Ipd, the presence of the signal voltage causes an increase in the value of average plate current.

Although apparently causing distortion of the signal, the action of the tube, operating at point "O", Figure 7, is of importance because it is similar to that of a rectifier and allows the tube to be used as a "Detector". A tube operating under these conditions is generally referred to as a "Bias Detector".

As we will explain fully in a later Lesson, there are "Grid Leak" and "Diode" detectors which produce an action similar to that just explained for Bias Detectors. At this time however, we want you to remember only the general action of a detector, which is similar to that of a rectifier.

Now that we have explained the general idea, for Figure 8 we have drawn a more detailed graph of the lower parts of the curves of Figure 6 and include actual values of voltage and current. While the curves of Figure 6 are true for all triode tubes, curves like Figure 8 apply only to one particular type of tube. Tube manufacturers publish curves like this for each type of tube they make, by taking readings with a circuit on the general plan of Figure 11. That is why we want you to study these curves carefully.

Looking at Figure 8, you will find the plate current scale extends from 0 to 16 milliamperes while the grid voltage scale extends from "-16" to 0. As you will learn very soon, most tubes used in Radio Receivers have an operating point which prevents the grid voltage from becoming positive and therefore only negative values of grid voltage are required.

Checking the "E_p = 250 volts" curve, with -14 volts on the grid, the plate current has a value of slightly over 1 ma. As the negative grid voltage is reduced, the plate current increases, slowly at first and then at a nearly uniform rate until, at a value of -4 volts on the grid, it reaches a value of 16 ma.

The lower, "E_p = 150 volts" curve of Figure 8 has the same general shape as the upper one but, for any value of grid voltage, the plate current has a lower value. For example, with -8 volts on the grid, the upper curve shows a plate current of approximately 8 ma, while the lower curve indicates a value of but 1 ma.

PLATE CURRENT - PLATE VOLTAGE CURVES

In our explanation of Figure 6, we told you a tube is useful as an amplifier because a small change of

grid voltage causes a larger change of plate current. This can be seen in the curves of Figure 8 but, by comparing them as in the example above, you can see that a change of plate voltage will also have an important effect on the plate current.

To show all of these variations, it is common practice to adjust the grid voltage to different values and then check the plate current for different values of plate voltage. These are known as "plate current - plate voltage curves" and are made as shown in Figure 9.

Notice here, a separate curve is made for each value of grid voltage and the group is known as a "family". We want you to study Figure 9 very carefully because curves of this kind are published by most tube manufacturers and, as we will explain in this later Lesson, they give quite complete data on the characteristics of the particular type of tube from which they are made.

To illustrate one important use of these curves, in Figure 9 you will find the left hand or "Eg = 0" curve, shows that with 0 grid voltage, 100 volts on the plate causes a current of 7.75 ma. The "Eg = -2" curve shows that with -2 volts on the grid, the plate current is but 5 ma although the plate voltage remains at 100.

From these values we see that a change of 2 volts on the grid causes a change of 7.75 - 5 = 2.75 ma in the plate current and our next step is to find what change of plate voltage will cause the same change in plate current.

The "Eg = -2" curve shows 5 ma at 100 volts and for increase of 2.75 ma or a total of 7.75 ma, we follow it up and see its value is 7.75 when it crosses the 132 plate voltage line. In other words, it requires 132-100 or a 32 volt increase on the plate to cause a change of 2.75 ma in the plate current when the grid voltage is held constant at a value of -2.

Instead of following the curve until its value increases for the full change of current, a more accurate method is to start at the reference point, first read up for half the amount of change and then, going back to the reference point, read down for one half the current change. In this way, and variations in the slope of the curve will average between the two readings to provide greater accuracy.

In Figure 9, our readings were taken on a part of the curve which is approximately straight and therefore, the single reading should provide sufficient accuracy.

AMPLIFICATION FACTOR

From these values we can find the amplification factor of the tube. This is what we commonly called the "MU" of the tube and is often represented by the Greek Letter "μ".

The "mu" of a tube is a measure of the maximum voltage amplification available and is the ratio of the change of plate voltage to the change of grid voltage necessary to produce an equal change in plate current.

Going back to the curves of Figure 9, we found a change of 2 volts on the grid caused a change of 2.75 ma in the plate current. To cause a like change of 2.75 ma in the plate current, at a fixed value of grid voltage, there had to be a change of 32 volts on the plate. The "mu" of the tube then is 32/2 = 16.

To show you that the amplification factor remains about the same at different values of plate voltage, we can start at 300 on the plate voltage scale and follow the line up until it crosses the "Eg = 10" curve. Checking this point of intersection on the left hand scale, we find the plate current is 9.5 ma.

Starting at the 300 plate volt line again and going up to the "Eg = -14" line, we find the plate current is 4 ma. These two readings show that a change of 4 volts on the grid causes a change of 9.5 -4 or 5.5 ma of plate current.

To find the change of plate voltage necessary to cause this change of plate current we first divide the above value of 5.5 ma by 2 and have 2.75 ma. Following the former explanation for more accurate readings, we start at the intersection of the 300 plate volt line and "Eg = -10" curve and follow the curve up until we reach a point opposite a value of 9.5 + 2.75 or 12.25 ma on the left hand scale. From this point we follow straight down to the lower scale and read the value as 325 volts.

Starting once more at the intersection of the 300 plate volt line and "Eg = -10" curve we follow the curve down until we reach a point opposite a value of 9.5 - 2.75 or 6.75 ma. This point shows a plate voltage of 268.

Checking back, we see it requires a change of 325 - 268 or 57 volts on the plate to cause the same change of plate current as a change of 4 volts on the grid. The amplification factor therefore is equal to 57/4 or 14.25 which is approximately within 10% of our former example.

Using the values of our first readings from the curves of Figure 9, the tube has a mu of 16 and therefore each volt change on the grid will cause the same variation of plate current as a change of 16 volts on the plate. With these figures, you can see how the tube actually amplifies a signal because the grid is the input circuit and the plate the output circuit.

The curves of Figure 9 are not straight lines and therefore, under different voltage values, the mu will vary. However, this variation is so small under ordinary working conditions that you need not worry about it.

The amplification factor, or constant, is controlled largely by the mechanical construction of the elements of the tube. A fine mesh grid, placed close to the filament, produces a high mu, while a coarse mesh grid, placed further from the filament, produces a low mu.

INTERNAL RESISTANCE

Thinking of the plate circuit of a tube as a simple direct current circuit, at 0 grid voltage, the curves of Figure 9 show a current of 13.5 ma at 150 volts. Using Ohm's Law and remembering that 13.5 ma equals .0135 ampere, the d-c resistance is 150 volts divided by .0135 ampere or 11,111 ohms.

However, with 2 volts negative on the grid, and 150 volts on the plate, the plate current drops to approximately 9.5 ma. Notice that no change has been made in the plate circuit except the conditions in the space between the plate and the filament. Figuring as before, the d-c resistance is 150 divided by .0095 or 15,789 ohms.

We mention these figures only to show you that the internal d-c resistance of a tube varies with the grid and plate voltages and is not what is commonly called the "impedance" or plate resistance.

PLATE IMPEDANCE

The plate impedance is the resistance offered to al-

ternating current in the plate circuit and can be thought of as the ratio between the change of plate voltage and the change of plate current caused by the change in voltage.

Going back to the curves of Figure 9, we found that, with 0 grid voltage, the plate current was 7.75 ma at 100 volts and a change of 32 volts caused a change of 2.75 ma. The plate resistance, or plate impedance, in this case then, is equal to 32 volts divided by .00275 ampere, which is 11,636 ohms.

You may find this difference between the d-c resistance and impedance a little hard to follow but you must remember that, with constant grid and plate voltages, the plate current remains steady. In other words, under these conditions we have a direct current circuit.

When the tube is in operation however, an a-c voltage is impressed on the grid and, although the plate supply voltage remains constant, the plate current will vary because the actions already explained. These variations of plate current cause the same electrical actions as a-c and it is the resistance to them that we consider as the plate impedance.

SYMBOLS

Before going further we want to mention here that on most curves, or in technical descriptions, the letters E_g are used for grid voltage, E_p for plate voltage, I_p for plate current and R_p for plate impedance. Then to show a change in the values, the letter "d" is written before the other symbols. Instead of writing "change of plate current", the letters "dIp" are used.

Using these symbols, the general formula for the amplification factor or constant can be written as,

$$mu = \frac{dEp}{dEg}$$

and for the plate impedance,

$$Rp = \frac{dEp}{dIp}$$

MUTUAL CONDUCTANCE

The third important factor, or constant, of a tube is the Mutual Conductance, which is based on the amplification factor and the plate impedance. It is

usually defined as the ratio between the mu and R_p and shown by the symbol Gm. In other words, the mutual conductance of a tube tells us how much change in plate current is caused by a given change in grid voltage. This is very useful as it shows the efficiency of a tube as an amplifier.

Back in our early Lessons on parallel circuits, we gave an explanation of conductance and told you it was the reciprocal of resistance, For example, a circuit with a resistance of 4 ohms has a conductance of $\frac{1}{4}$ mho.

For the mutual conductance of the tubes, we follow the same plan but, because the values are small, use one millionth of a mho, called a micromho, as a unit of measure. Therefore, the mutual conductance is usually given in micromhos.

Using the symbols, the formula for mutual conductance can be written as,

$$Gm = \frac{mu}{Rp}$$

but we already found that

$$mu = \frac{dEp}{dEg} \text{ and } Rp = \frac{dEp}{dIp}$$

Substituting these values in the formula,

$$Gm = \frac{dEp}{dEg} \div \frac{dEp}{dIp}$$

To divide fractions, we simply invert the divisor and multiply which makes the equation,

$$Gm = \frac{dEp}{dEg} \times \frac{dIp}{dEp}$$

and cancelling the "dEp" terms, we have

$$Gm = \frac{dIp}{dEg}$$

which says that the mutual conductance is equal to the change in plate current divided by the change in grid voltage.

From the curves of Figure 9, we found an amplification constant or "mu" of 16 and a plate impedance of 11,636 ohms at 100 volts. Substituting these values in the

formula, we have

$$Gm = \frac{mu}{Rp} = \frac{16}{11,636} = .001375 \text{ mho.}$$

To have the answer in micromhos, we simply multiply by one million and find

$$Gm = .001375 \text{ mho} \times 1,000,000 = 1375 \text{ micromhos.}$$

To use the other form of the formula, the curves of Figure 9 show us, at 100 volts on the plate, a change of 2 volts on the grid causes a change of 2.75 ma, .00275 ampere, in the plate current. Using these values.

$$Gm = \frac{dIp}{dEg} = \frac{.00275}{2} = .001375 \text{ mhos} = 1375 \text{ micromhos.}$$

These three constants -- amplification factor, plate impedance, and mutual conductance -- will tell you the most important characteristics about the operation of any vacuum tube.

EMISSION

From our earlier explanations, you know the action of a vacuum tube depends on the emission, or stream of electrons thrown off by the heated filament therefore, in Figure 10, we show the fundamental circuit on which most emission type tube testers are based.

Unlike the circuit of Figure 11 which permits separate tests on the various elements, to make a test of the emission, we are not interested in the relative actions of the plate and grid therefore connect them together as shown in Figure 10. The filament, connected across the "A" supply has a control rheostat in series and a voltmeter to show the actual operating voltage.

A second voltmeter, "Ep" is connected across the plate circuit while the milliameter, "Ip" indicates the current which, as you know, is the useful emission. In commercial testers of this type, the milliameter scale is marked "Good - ? - Bad" and controls are provided to supply the proper voltages and connections for each type of tube in accordance with a prepared chart.

TUNGSTEN FILAMENTS

As we mentioned before, all substances are made up

of electrons and protons but, to be of use in a tube, the filament must be an electrical conductor and throw off electrons when heated. Tungsten has these qualities to such a degree that it is one of the three common materials in use at present.

At high temperatures, tungsten emits electrons quite freely and, while it will stand up well, requires a comparatively large amount of power to heat it. Although the filament operates in a high vacuum and will not oxidize or burn, the metal evaporates slowly and, in time, the diameter becomes smaller. As the diameter reduces, the electrical resistance of the filament increases and, if the voltage is kept constant, the current will decrease.

A decrease in current causes a drop in temperature and the flow of electrons is cut down. However, if the voltage is increased to bring the current up to normal, the filament usually burns out in a short time because, being of smaller diameter, its current carrying capacity is cut down. Therefore, you can see why a tube will have maximum life when the filament voltage is held constant.

THORIATED TUNSTEN FILAMENT

While there are a few tungsten filaments still in use, it has been found the action is greatly improved by adding a small amount of thorium. When heated, the thorium is thrown to the outside and forms a layer on the tunsten. Electrons are then emitted freely from the thorium at temperatures much lower than those required for pure tunsten.

As the thorium in the outer layer is exhausted, a new supply comes from the interior of the wire, renewing the outer layer and maintaining the emission. When the entire supply has been used, the emission is reduced but, unlike the older types of tubes, the filament still heats up and looks perfectly normal.

Should the tuoe be operated at a high voltage, the filament becomes overheated and the outside layer of thorium is exhausted before it can be replaced by that inside. To bring conditions back to normal, the grid and plate circuit are opened and a high voltage is applied to the filament for a short time. Under these conditions, a new outer layer of thorium is formed on the filament and the emission is restored to normal.

OXIDE COATED FILAMENTS

The third common type of filament is made of platinum or nicket wire coated with oxides of various elements such as barium, strontium, calcium or caesium.

The main advantage of the coated filament is the large number of electrons emitted at comparatively low temperatures. While the old tunsten filaments operate at a white heat, the oxide coated type give a greater emission when heated to a cherry red.

Another advantage lies in the fact that the platinum wire carries the current while the coating emits the electrons. Operating at a low temperature, the platinum will not evaporate and, as only the coating emits electrons, the resistance of the filament does not change with age. A filament of this type can be operated at either constant voltage or current for its entire useful life.

PLATE AND FILAMENT SATURATION

In our explanations so far, we have told you how the plate current was controlled by the plate and grid voltages but now you can s e that the filament must also be considered. Within certain limits, by increasing the temperature of any of the three types of filaments, the emission will be increased and to see just how far this action will go, we show the curves of Figure 12.

To draw these curves, the plate voltage was held at a constant value and the change of plate current plotted for each change of filament voltage. With 45 volts on the plate, the lower curve shows less then 1/2 ma, plate current at 1 volt, 1 ma at 2 volts and 2 1/2 ma at 5 volts. The point we want to bring out here is that a further increase of filament voltage causes but very little increase of plate current.

In fact, the way the curve flattens out, the tube would operate at 4 1/2 volts almost as well as at 7 volts. In other words, between 4 and 5 volts, the plate is attracting almost all the electrons it possibly can and a further increase of voltage, while heating the filament to a higher temperature, causes but a very slight increase in plate current.

The upper curve, made with 90 volts on the plate, has the same general shape and while the plate current increases

rapidly up to 4 1/2 volts, it then starts to flatten out. Above 5 volts, the increase is very slight, showing there is no advantage of operating the filament above this voltage.

Where the curves start to flatten out, we say a point of saturation has been reached and, in both curves of Figure 5, this occurs near the 5 volt line. However, we see that with 5 volts on the filament the plate current is 2.5 ma at 45 volts and 7.25 ma at 90 volts.

With 5 volts across the filament and 45 volts on the plate we decide therefore that the positive charge on the plate is not strong enough to attract any more electrons and we have a condition of filament saturation. As the plate voltage is increased, the plate current also increases, up to a certain point, and when a further increase of plate voltage causes no increase of plate current, we have a condition of plate saturation.

To fully understand these actions, there is one more condition we want to mention. Even though the plate is positive, in respect to the filament, and many of the electrons reach the plate, some are drawn back to the filament and others accumulate between the plate and the filament, making up what is known as the "Space Charge".

Being composed of electrons, the space charge is negative and its action will be to repel, or drive other electrons back towards the filament. In other words, a balance is reached between the positive charge of the plate and the negative space charge so that the plate current is definitely limited.

Then, when the voltage on the plate is increased, its positive charge is increased and thus there is a high plate current before a balance with the negative space charge is reached. Thinking along these lines, you can see how the grid, placed between the filament and plate, and given a positive charge, will tend to neutralize the negative space charge and allow a greater plate current for a given plate voltage. Keep this in mind because we will have more to say about it in the following Lessons.

FILAMENT CONSTRUCTION

Mechanically, all filaments are made in the form of a wire or ribbon and supported inside the tube as shown in Figure 13. At A, we have the common U-shaped filament supported at 3 points, making it fairly rigid, and exposing its entire surface to the surrounding grid and plate.

At B, the same idea is carried out a little further and the filament has two loops with 5 points of support. You will find this plan used in most of the filament type power tubes and will notice a glass bead at the top for holding the extra supports.

At C, the filament is straight, supported at the top and bottom. Remember in all of these, the grid is placed around the filament and the plate around the grid. We show only the filament in order that you may follow its shape and method of support.

A-C FILAMENTS

In the early days of Radio Broadcasting, the available tubes required 1 ampere at 5 volts to heat the filament properly and with several tubes in use, a 6 volt storage battery was the most common and economical source of supply. The higher voltages for the plate were obtained from batteries made up of larger numbers of dry cells or small storage cells. As a result, the owner of a Radio Receiver had an almost constant problem of battery replacement or recharging.

Because of this condition, much research was done to eliminate the batteries entirely and operate the tube filaments on a-c which usually could be obtained by a small inexpensive transformer operating on the house lighting circuit. This may seem a simple replacement job but the ordinary tube, with a filament designed for d-c will not operate satisfactorily on a-c

This is due to the fact that, with an a-c supply, the polarity of the filament changes at the frequency of the supply and the filament is part of the grid or input circuit of the tube. Thus, the variations of filament voltage cause corresponding changes of grid voltage which are amplified by the tubes and appear as a loud hum in the speaker.

This condition can be overcome to a large extent by connecting a potentiometer across the filament and

connecting the grid return to the variable contact. By this method, the grid circuit can be connected to the electrical center of the filament. Arrangements of this type were installed in many older model Radio Receivers and were known as "Hum Controls".

While an improvement, this method does not entirely eliminate the hum because alternating current is continually changing in value as well as direction. That means the filament will be heated as the current passes through maximum value, cool off as the current reduces and reverses, but be heated again as the current passes through maximum value in the opposite direction.

The effect is the same as if we were continually changing the filament voltage values of Figure 12 from 0 to maximum. Of course, with 60 cycles a-c, the changes take place so rapidly that the filament does not have time to cool entirely but there is enough change in temperature to vary the emission and cause the hum.

To overcome this trouble, filament type a-c tubes, are made to operate on low voltage and high current. Take a common filament type power tube for example. It requires an a-c filament supply of 2.5 volts and draws 2.5 amperes. That means the filament has a very low resistance and is of large cross section area. Being large, it takes longer for it to heat up and cool off therefore, the rapid changes of alternating current have but a small effect on its temperature. This same plan is carried out for all the later filament type a-c tubes as you can see by referring to a table of tube characteristics.

HEATER TYPE TUBES

As far as the useful operation of a tube is concerned, the filament is required only to furnish the supply of electrons. If it could be heated by some other means, there would be no need of the usual filament current.

Working along these lines, the majority of our modern tubes have been developed with the filament proper used only to supply the heat to a surrounding element that furnished the electrons and, used this way, the filament is called a heater. This arrangement makes it possible to keep the heater circuit entirely separate from the other tube circuits and thus reduce the a-c hum still further.

The element for supplying the electrons is made of metal, coated with an oxide and called a cathode. Its

general shape is in the form of a cylinder which is fitted closely around the heater, but insulated from it.

In Figure 14-A we show a cathode which was used in the early tubes of this type and we want you to notice that in this construction the cathode is placed around the filament of Figure 13-C. This arrangement was not satisfactory because the magnetic field, set up around the filament by the alternating current in it, induced a voltage in the other circuits and caused considerable hum.

To overcome this hum, the cathode of Figure 14-B was developed with a heater of the general shape of Figure 13-A. As the heater is in the form of an inverted "U", at any instant, the current in the sides of it will be in opposite directions. This will cause magnetic fields of opposite polarity and they will tend to neutralize, thus reducing the hum caused by the induced voltage. However, in this construction it was found that additional insulating material was necessary, between the cathode and heater, which made the tube slow heating.

A further improved type of cathode has been developed the general construction of which is shown in Figure 14-C. The heater is a comparatively long "hairpin" and is wound on an insulating dowel in the form of a double spiral. Due to its hairpin shape, the current in the sides will be in opposite directions, causing the fields set up to neutralize each other as explained for Figure 14-B. Also, due to the large amount of heating surface, the cathode is quickly brought to its normal operating temperature.

At the top of the cathode proper, you will notice an insulating washer through which the heater dowel extends, thus serving to keep the heater in its proper position. Extending upward, the dowel also serves as a top support of the entire cathode assembly. At the bottom, the ends of the heater are brought out through an insulating washer where they are spot welded to the leads in the stem which extend to the tube prongs. Also, there is an additional stem wire which connects the cathode to a prong in the tube base and also acts as a support.

You will find variations of this type of cathode, but the general construction will be the same. In all cathodes, manufacturers are constantly striving to design one which will heat more rapidly and keep the

a-c hum at the lowest possible value.

The complete construction of this type of tube is quite similar to that of the triode explained earlier in this Lesson. Here, the wire mesh grid is placed around the cathode and, to secure uniform spacing between the elements, the grid is also cylindrical in shape. The plate is placed around the grid and again, to secure uniform spacing, the active area is cylindrical in shape.

As shown in the left hand assembly view of Figure 15, the cylindrical plate is often extended to engage the supporting wires but the assembly proper is of comparatively small size and follows the shape of the cathode.

This arrangement provides four elements, — heater, cathode, grid and plate. However, the heater is not considered as an active element, therefore, the tube is known as a cathode type triode.

At the left of Figure 15, we show the completed tube and want you to notice that there are 5 prongs on this base instead of 4 as explained for the filament type triode. This is easily accounted for because of the additional connection to the cathode.

At the right of Figure 15 we have shown the bottom view of the base and the symbol which is used to represent the cathode type triode. We want you to compare this with the filament type triode tube of Figure 4 so that you can easily differentiate between the two. The action of both is very similar, the only difference being in the source of electrons. In the filament type, the filament is the source of electrons and for the heater type, the cathode is the source of electrons.

In the next Lesson we are going to take up multipurpose tubes but, at this time, we want you to be sure you fully understand the action of a triode. If there is any doubt in your mind concerning the action, throughly review the explanations of this Lesson before going ahead.

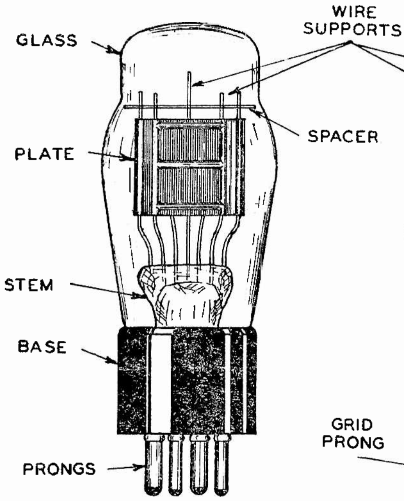


FIGURE 1

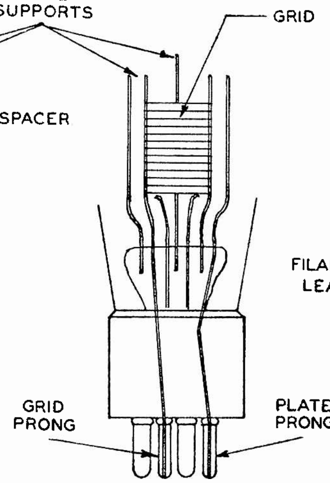


FIGURE 2

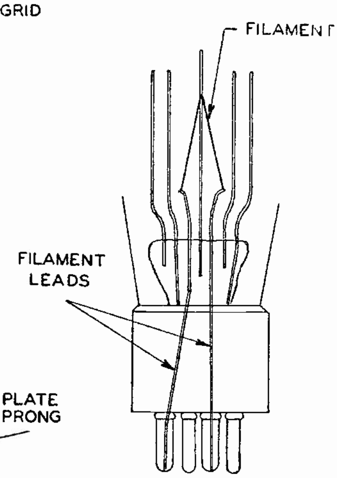


FIGURE 3

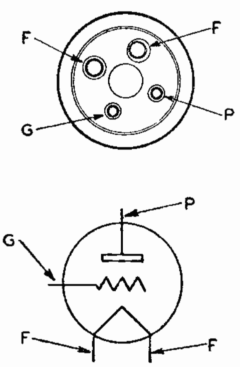


FIGURE 4

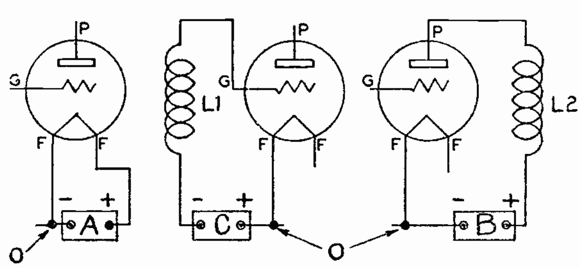
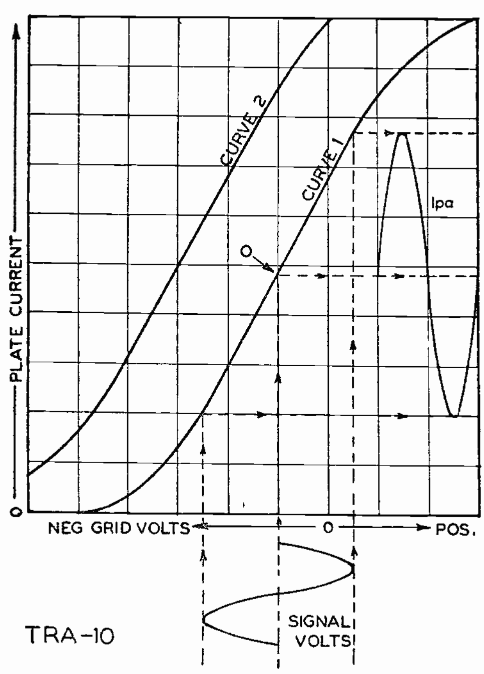


FIGURE 5



TRA-10

FIGURE 6

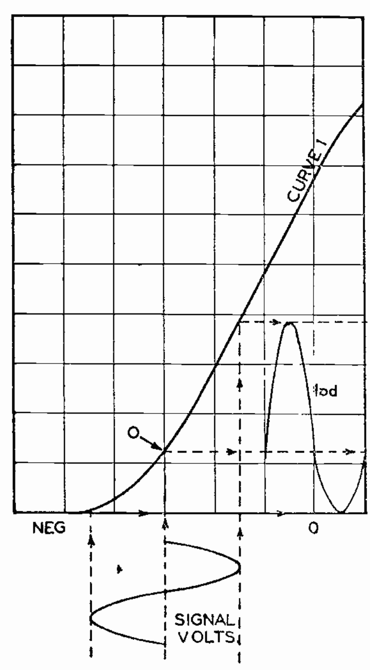


FIGURE 7

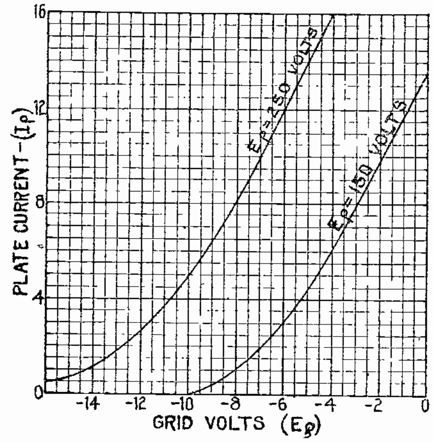


FIGURE 8

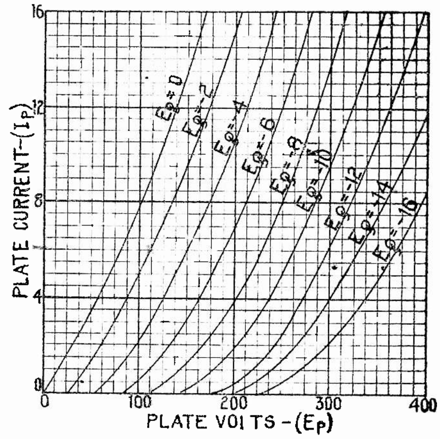


FIGURE 9

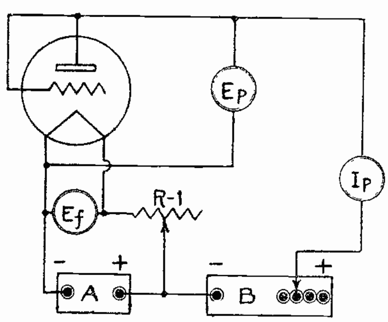


FIGURE 10

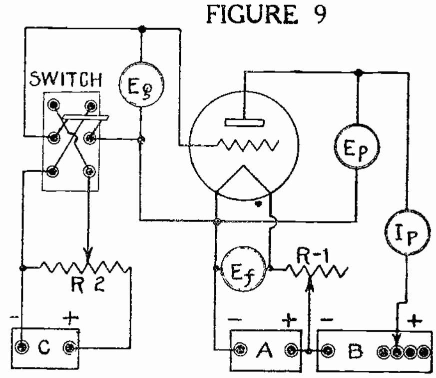


FIGURE 11

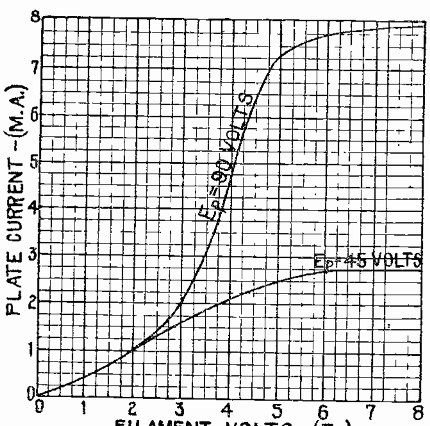


FIGURE 12

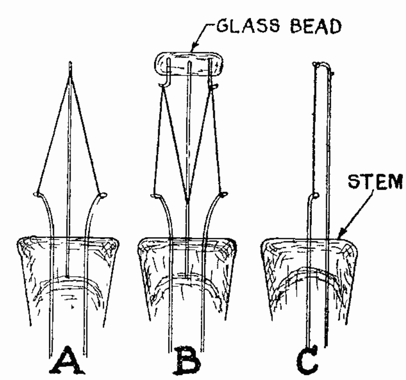
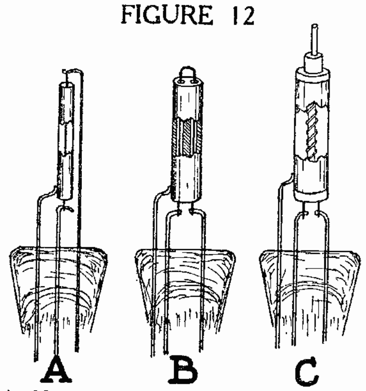


FIGURE 13



TRA-10

FIGURE 14

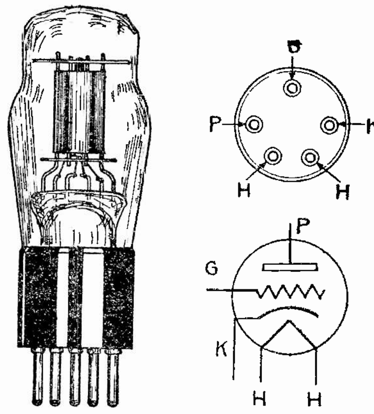


FIGURE 15

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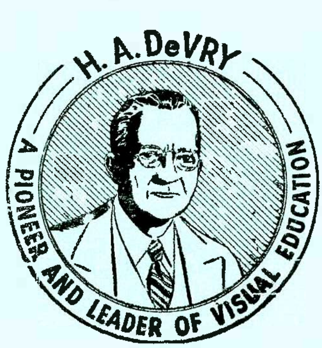
LESSON TRA - 11

MODERN TUBES

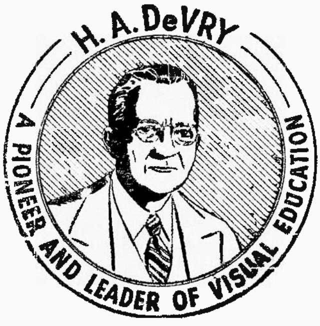
Founded 1931 by



DE FOREST'S
TRAINING, Inc.

LESSON TRA - 11
MODERN TUBES

Founded 1931 by



TUBES - RECEIVERS - AMPLIFIERS

Lesson 11

MODERN TUBES

* * * *

Shakespeare says, we are creatures that look before and after: The more surprising that we do not look around a little and see what is passing under our very eyes.

---- Carlyle

MODERN TUBES

In the former Lessons, we have explained the purpose and action of the three element radio tube which is really the foundation for all of the many types which are now on the market. Like most other developments, the trend in tube design has been to improve the efficiency, by increasing the number of elements, arranging them so that one tube will do the work which formerly required two or more.

Because of the many and rapid changes in tube design, it is almost impossible to remember the details of all the various types. However, as this detailed data is easily available in tables, similar to the one which follows this Lesson, we want to make a general explanation of the purpose and action of the additional elements found in the later and more complicated types.

A general explanation of this kind will not only give you a good understanding of the tubes now on the market but will make it easier for you to figure out the action of new types which may be developed in the future.

DESIRED CHARACTERISTICS

Contrary to a popular belief, tubes are not just put together and some use found for each completed type. Instead, the need for some particular type is carefully studied and the tube is designed and constructed to fit that particular need although additional uses have often been found for certain types of tubes after they appeared on the market. For example, the type 24 screen grid tube was originally designed for a high gain R.F. amplifier but later was often used as a detector and sometimes as an A.F. amplifier.

In respect to their application, all tubes can be divided into three general classes.
First: High Frequency Amplifiers, used at radio or intermediate frequencies where it is desired to have a large voltage gain with a low power output. This type has a high mu and high plate impedance with small power output.

Second: Low Frequency Amplifiers, used at audio frequencies. Here there is a sub-division because some tubes are designed for voltage amplifiers while others, used in the output stages, are re-

quired to deliver a comparatively large power output.

The low frequency, voltage amplifier tubes usually have a lower mu than similar high frequency types, making their operation more stable. Also, the plate impedance is lower to allow them to work properly into the lower impedance of the various types of A.F. coupling.

The output tubes are designed to operate the speaker, or other output device and, to deliver maximum power, have comparatively high plate current and low plate impedance. For the reasons mentioned above, the mu is low but, as we will explain later, for units which require maximum output with a minimum of tubes, there are some types with fairly high gain.

Third: Detector and Oscillator Tubes. Although the detector is primarily a rectifier and the oscillator an A.C. generator, we place them in one class because the same types of tubes are often used for either purpose. While many detectors are arranged to provide amplification, in addition to rectification, in general, tubes for this use are not amplifiers and therefore have a comparatively low mu and plate resistance.

Remember, these are general classes only and you will find many variations. However, we want you to appreciate the need for tubes of these three general divisions in order that you may better understand the more detailed explanations which follow.

CLASSIFICATION OF TUBES

In the early days of Radio, the different types of tubes were given numbers of two digits such as 01, 26, 27, 45 and the various manufacturers placed their own number first. Thus 226 was a type 26 manufactured by R.C.A., Radiotron, a 326 was the same type manufactured by E.T. Cunningham, and a 426 was again the same tube but manufactured by the DeForest Radio Company.

No definite system was used for the various types and it was necessary to memorize the various numbers. For example, type 43 is a 25 volt power output tube, type 44, a 6.3 volt R.F. amplifier and type 45 a 2.5 volt triode power amplifier. Types 43 and 44 have a cathode while type 45 uses the filament as a source of electrons.

This method was continued until most of the two number combinations had been used, making it necessary to adopt a more difinite system which employs both letters and numbers. Thus, we now have tube types such as 2A3, 6C7, 25Z5, and so on. In all of these you will notice there is a number, followed by a letter which, in turn,is followed by another number.

The first number indicates the filament or heater voltage in steps of 1 volt. Thus, for type 2-A-3 we know the filament voltage is between 2 and 2.9 volts. The exceptions of this rule are some 2 volt tubes, which are given a first number of 1.

The letter is arbitrarily chosen to represent the type of tube and is usually taken from the first part of the alphabet. However, as rectifier tubes serve an entirely different purpose. the first models are given the letter Z so that the 25-Z-5, mentioned above, is a rectifier with a 25 volt filament.

The last number shows the actual number of usable tube elements with external connections. Thus, the 2A3 is a 2.5 volt, three element or triode amplifier. By this method, a type 56 which is a 2.5 volt heater type triode would become a 2-A-4 because it has external connections for the heater, cathode, plate, and grid. A similar tube, built in a metal shell, is known as a 6-C-5 because of a connection to the shell.

The 6-C-7 has seven elements, the heater, cathode, plate, and four grids while the 25-Z-5 has five elements, the filament, two cathodes, and two plates.

To eliminate the comparatively long wire necessary to make a connection to the grid cap installed on top of some tubes, a series of "single ended" tubes is now in common use. The grid connection is made through a base prong as explained for the triode tube and, to identify this feature, the tube type includes the letter "S". For example, a type 6SF5 is a single ended tube with about the same characteristics as a type 6F5.

Because of the larger number of grids in some of the combination tubes, it has become rather difficult to name them all and therefore you will often find them numbered. All you need remember here is that the numbers start at the cathode, the grid closest to it being G-1. The next outer grid is G-2, and so on.

The size and shape of the glass envelopes have also been standardized and the letters indicate the general shape of the glass while the numbers show approximately the widest diameter in eighths of an inch. For example, an S-12 bulb is spherical with a diameter of about 12/8 or 1 $\frac{1}{2}$ inches.

The R.M.A. (Radio Manufacturers Association) have also adopted a numbering system for the prongs on the tube bases as shown in the tube table of the next Lesson. This system is used in many of the later type tube testers and analyzers as it simplifies their operation. The metal top cap of a tube is sometimes abbreviated "T.C." instead of being given a number.

MULTI - ELEMENT TUBES

As we mentioned at the beginning of this Lesson, the efficiency of many of the later types of tubes is due to the increase in the number of elements. This condition is taken into consideration by the present system of numbering and is also the basis for the names given to the various types.

From our earlier explanations, you know the positive terminal of a direct current source is often called the "anode" while the negative is the "cathode". As it is always connected to the positive of the supply, the plate of a tube is also known as an "Anode" and, as we have already told you, the electron emitting element, connected to the negative of the plate supply, is the "cathode".

A simple tube, consisting of but one anode and one cathode is called a "Diode", the prefix "Di" being a Greek word for two. The same plan is followed, when more elements are present, using the following Greek numerals as prefixes.

1 - Mono	5 - Penta
2 - Di	6 - Hexa
3 - Tri	7 - Hepta
4 - Tetra	8 - Octo

From this table you can readily see the reason for calling a three element tube a "Triode". Following the same plan, a four element tube will be a "Tetrode", and a five element tube a "Pentode", and so on.

To give you an idea of the general appearance of some of these combinations, for Figure 1 of this Lesson we show a tube with two plates and two cathodes, each

brought out to separate base prongs or pins. With the two heater connections, this makes a total of six pins in the base, the arrangement of which is shown below the outline view of the tube.

Below the bottom view of the base we have drawn the symbol which shows the assembly consists of two separate cathode type diodes having a common heater. Thus we have a double diode which is usually called a "Duo-Diode".

As we will explain later, tubes of this general type are used as rectifiers or detectors and may be of either the filament or cathode type with one or two plates. Notice the base view of Figure 1 because all tubes, with six base pins, have this same mechanical arrangement.

Another common type of tube is shown in Figure 2 and you will notice, in addition to the pins in the base, there is a grid cap on the top. Like the pins, the cap is used to complete an external circuit to a tube element.

In many tubes, you will find the glass is not transparent but has a coating on the inside. This is usually what is known as the "getter", a chemical which will absorb any small quantities of air or gas that may have been in the elements when the tube was evacuated.

Directly below the assembly view of the tube we show a bottom view of the base which has seven pins. You will find caps on tubes with four, five, or six pin bases and we show a seven pin base here merely to bring out one standard arrangement.

Looking at the symbol below the base, you will find that there are seven elements and thus a 6 volt model of this type might be numbered "6-A-7". However, following the general plan of naming according to the number of elements, it would be a "Heptode". Instead, the common plan is to call it a "Pentagrid" which means it has five grids and the presence of the plate, cathode, and heater are assumed.

There are many variations to the numbering and naming systems, but the general plans we have explained are sufficient to enable you to interpret almost any combination with which you may come in contact.

METAL TUBES

From our explanations, you can see that the glass envelope or "bottle" of a tube is used mainly to prevent the air from reaching the elements. Exactly the same results can be secured by using metal instead of glass but the problem has been to perfect a method of making an airtight joint to carry an insulated wire through a metal shell.

The solution of this problem was found in an alloy, known as "FERNICO" metal, which seals readily to certain kinds of glass. As shown in the cut away view of Figure 3, you will notice the connecting wires from the tube elements pass through a glass bead which, in turn, is sealed to an eyelet of Fernico metal.

This arrangement forms an airtight joint as well as an insulated support for the wires which complete the external circuits to the tube elements. The arrangement of the parts is similar to those explained for glass type tubes, a central cathode surrounded by one or more grids with a cylindrical plate on the outside.

This assembly is mounted on the metal header to which the steel shell is welded. The air is pumped out through a central glass tube which extends down into the base. As shown by the middle sketch, the base has eight equally spaced pins around a central "Aligning Plug".

This plug extends beyond the pins and has a raised "Key" which fits a corresponding "Keyway" in the socket. To place the tube in the socket it is necessary to enter the aligning plug in the central hole and turn until the key drops in the keyway.

Compared to the old glass tubes, the metal tubes eliminate the need of the glass stem and thus, for equal size elements, the assembly can be made shorter and more rigid, while the length of the connecting wires, between the elements and the pins, can be reduced.

The steel shell forms a good shield and to utilize this action, the shell is connected to one of the base pins in the same way as the other elements. Comparing the symbols of Figures 2 and 3, you will find the only difference is the shell or "S" connection.

Because the self aligning feature of the 8 prong or

octal base is a great convenience, you will find them in use on glass as well as metal tubes. In fact, some of the metal tube types are made with a glass envelope and given a type number ending in G.

For example, the symbol of Figure 3 corresponds to that of a 6-A-8 metal tube and, if the same elements were mounted on an octal base and enclosed in a glass bulb, the tube would be a "6-A-8-G".

Although some distinctive metal tube types have been developed, in general their action is the same as similar glass types, the difference being mainly in the mechanical construction.

RECTIFIER TUBES

To explain the action of the various types of tubes we have drawn a number of simplified circuits and will start in Figure 4 with a simple diode tube used as a rectifier. From the symbol, you will notice the tube has a plate, cathode, and heater and is therefore a "diode", as the heater is used merely to cause the emission of electrons.

For simple, yet practical conditions, we will assume the a-c supply is an ordinary 110 volt, 60 cycle house lighting circuit while the heater is designed to operate with .3 ampere at 12.6 volts. The series resistor "R" must be of the proper value to cause a drop of 110 - 12.6 or 97.4 volts with a current of .3 ampere. By Ohm's Law, the value of "R" must be,

$$R = \frac{E}{I} = \frac{97.4}{.3} = 324.6 = 325 \text{ ohms}$$

The current in this circuit will be alternating and because of resistance "R", the heater will carry the rated amount of current and its temperature will rise to the proper value to correctly heat the cathode.

Starting at the upper supply wire, you can trace another circuit through the plate, cathode and "d-c Load" resistance back to the supply. There are several points to keep in mind here.

First, the polarity of an a-c source reverses for each alternation therefore, for one alternation the plate will be positive, in respect to the cathode, and for the following alternation, the cathode will be positive in respect to the plate.

Second, as previously explained, there will be current in the plate circuit only when the plate is positive in respect to the cathode. This action, in combination with that of the a-c supply means there will be plate current only during every second alternation.

As shown by the arrows on Figure 4, there will be alternating current in the heater circuit but, because of the action between the tube elements, the plate current will be in but one direction. From our former explanations, as the direction is always the same, the plate circuit will carry pulsating direct current.

Although its value will vary and drop to zero during each second alternation, there is pulsating direct current in the plate circuit and thus we can show the "+" and "-" polarity of the d-c load. As but half of the supply alternations are used, we call this a "Half Wave" rectifier.

To utilize both alternations of the supply, we have "Full Wave" rectifiers built on the general plan of Figure 6 or with filament type tubes as shown by the symbol of Figure 5.

Although it can be operated by being connected directly to the supply on the plan of Figure 4, the tube of Figure 5 is usually connected to the secondary windings of a transformer, the primary winding of which is across the supply. One of these secondary windings has a comparatively small number of turns and thus develops the proper voltage for the tube filament while the other winding usually has a much larger number of turns and develops a high voltage for the plate circuit.

The action here is as explained for the tube of Figure 4 and the filament carries alternating current but there will be plate current only when the plate is positive in respect to the filament. To make use of both alternations of each a-c cycle, the d-c load connects back to a center tap of the plate winding.

Thus, as shown by arrows, when the a-c voltage is in one direction, one plate, which is positive in respect to the filament, will carry current. For the next alternation, when the a-c reverses polarity, the other plate, which is then positive in respect to the filament, will carry current.

In effect, the tube of Figure 5 consists of two of the tubes of Figure 4 connected so as to work alter-

nately. By following the arrows you will notice that, no matter which plate circuit of Figure 5 is in operation, the current in the d-c load resistance will always be in one and the same direction.

We will have more to say about rectifiers a little later. At this time we want you to think only about the action of the tube in changing a-c to d-c.

DIODE DETECTORS

While the circuits of Figure 5 are used as a part of the direct current supply for the plate circuits of amplifier, detector and oscillator tubes used in various Radio units, the action is often employed for the detection, or demodulation, of a modulated high frequency carrier.

To show this action, for the circuits of Figure 6, we have a tube with the elements of Figure 1 but, in practice, the assembly can be much smaller. The signal voltage in the input coil "L1" induces a similar voltage in the secondary "L2" which is tuned to resonance by condenser "C1".

Like the plate winding of the transformer in Figure 5, L2 of Figure 6 has each of its ends connected to a plate while the separate cathodes both connect to the "d-c Output" resistance which completes its circuit back to a center tap of the winding, L2.

Here again, we have a full wave rectifier and the current through the output resistance will always be in one and the same direction. The variations of this rectified current will cause the voltage drop across the output resistance to change in accordance with the signal frequencies impressed on the Radio carrier frequency.

Thus, the carrier frequency is demodulated or detected and the signal or modulation frequency appears across the output resistance. Condenser C2 forms a low reactance path or bypass for any high frequencies which may be present in the output circuit. By coupling the grid circuit of an amplifier tube across this output resistance, the signal frequencies are carried over to be properly amplified.

You will find diode detectors, both half wave and full wave, used in many circuits and, although they do not amplify, they do not distort the signal at high volume as readily as other types of vacuum tube detectors.

TRIODE TUBES

It is generally conceded that Dr. Lee DeForest's introduction of a third element, the grid, between the plate and cathode was responsible for the rapid growth of the Radio Industry. By means of this grid, it is possible for a small amount of energy to control a much larger amount and this simple idea is the foundation of all modern amplifiers which use electron tubes.

For a brief review of the action, in Figure 7 we show the complete circuits of a cathode or heater type triode tube used as a high frequency amplifier and want you to think of the modulated carrier voltage as appearing across the input coil L1.

By mutual induction, this voltage is carried over to the secondary coil L2 which is tuned by the variable condenser C1. When the resonant frequency of this circuit equals the carrier frequency, the voltage drop across the circuit will have its maximum value.

The grid circuit, from the upper end of L2 and C1 through the grid, cathode and C supply is completed to the lower end of L2-C1 and thus the voltage will be impressed on the grid circuit.

The plate circuit can be traced from the "+" of the B supply through coil "L3", through the plate and cathode back to "B-". The heater circuit consists of the A supply and heater only. Notice here, the heater has no connection to the other tube circuits and, as already explained, its only purpose is merely to heat the cathode.

Signal voltages in coil L2 cause like voltage changes on the grid which, in turn, causes similar but larger changes of plate current. The changes of plate current, in coil L3, cause changes of voltage drop across it and induce like voltages in coil L4. The ratio between the voltage across L4 and that across L2 is the "gain" of the tube and its circuits, which are known as a "stage".

For a following stage, coil L3 can act as coil L1 of Figure 7 and coil L4 can be tuned and connected across the grid the same as shown for coil L2. Connected on this plan, a number of stages are said to be in "Cascade" and most amplifiers are classified by the number of "stages" which they contain.

In general, triodes are general purpose tubes which

can be used in almost any stage of a complete unit. As amplifiers, the grid voltage, or bias, is of a value which allows the tube to operate on the straight part of its characteristic curve. As a detector, the grid bias is increased until the tube operates on the lower bend or knee of its grid voltage - plate current curve.

TETRODE TUBES

In a former explanation we mentioned that the "space charge" was a limiting factor of the plate current in a tube. To remedy this condition, an additional grid is placed between the control grid and plate and tubes of this type, with four active elements, are known as "Tetrodes". However, as the additional grid acts as a sort of screen, they are also called "Screen Grid" tubes.

For Figure 8 we show the circuits of a tetrode tube connected as a high frequency amplifier and you will notice the general arrangement is much like that of Figure 7 and, although the screen grid, "G2", is not a part of the signal circuits, it connects to a "+" terminal of the B supply but at a voltage lower than that of the plate. This positive voltage on the screen grid tends to neutralize the space charge and thus allows the voltage on the inner or control grid to have a greater control over the plate current. In effect, this gives the tube a higher "mu" or greater amplification factor.

Another advantage of the screen grid is somewhat more difficult to understand because it involved the action of capacity in a-c circuits. Back in the earlier Lessons, we told you a simple condenser was made up of two electrical conductors which were insulated from each other. Inside the tube, the grid and plate meet these conditions and, as they are in different circuits, there may be a difference of voltage between them. Thus, there is a "Grid-Plate" capacity which acts as a small condenser.

As we will explain later, when a tube is operated as a high frequency generator or "oscillator", some of the energy in the plate circuit is fed back into the grid circuit. In the case of a triode, the grid plate capacity acts as a path which allows the variations of the plate current to cause feed back to the grid.

As a result of this condition, it is difficult to operate a triode as a high frequency amplifier without causing it to oscillate. The screen grid,

placed between the control grid and the plate, reduces the "Grid-Plate" capacity to such an extent that the amplifier action of the tube is greatly improved, and the tendency to oscillate practically eliminated.

BIAS RESISTOR

You will notice also that the circuits of Figure 8 do not include a "C" supply but a resistance "R" is connected between the cathode and "B-". The circuits of the control grid, screen grid, and plate are all completed through this resistance.

Being positive in respect to the cathode, both the screen grid and plate will carry current which returns to the negative of the B supply through the resistance. From our earlier explanations of Ohm's Law, you know there will be a voltage drop across a resistance which carries current.

Thinking of the direction of current as being from positive to negative, it will pass from the cathode to the supply negative and the voltage drop across the resistance will be positive at the cathode and negative at the "B-" end.

The grid return is at the "B-" end of the resistance and thus, as the resistance is in the grid circuit also, the voltage drop across it will have its negative toward the grid. In other words, the voltage drop, caused by the plate and screen grid currents in this cathode or bias resistor, produces exactly the same effect as the voltage developed by a C supply.

For example, a tube chart shows one type of screen grid tube (24A) should have the following conditions.

Plate Voltage — 250	Plate Current — 4 ma
Screen Voltage - 90	Screen Current - 1.7 ma
Grid Voltage — -3	

Operating under these conditions the cathode current will be equal to the sum of the plate and screen currents for a total of 4 + 1.7 or 5.7 ma and to cause a drop of 3 volts, the bias resistor "R" must have a value of,

$$R = \frac{E}{I} = \frac{3}{.0057} = 526 \text{ ohms}$$

In practice, a 500 ohm resistor would be satisfactory and the voltage drop across it would bias the grid properly.

While developed mainly as high frequency voltage amplifiers, tetrode type tubes are also used for other purposes. Sometimes you will find the grid connections reversed with the screen grid used as the control grid while the inner grid is used as a screen. This arrangement is known as a "Space Charge Grid".

SECONDARY EMISSION

In all types of radio tubes, the electrons, attracted to the plate, may attain sufficient speed to dislodge other electrons when they strike. Thus, the stream of electrons, moving from the cathode to the plate, may cause an emission of electrons from the plate itself. The electrons driven off the plate in this way are known as "Secondary Emission" because they are the result of the original cathode emission.

For Diode and Triode types of tubes, secondary emission causes no trouble because the positive voltage on the plate eventually attracts all the free electrons inside the glass envelope. For tetrode types of tubes, the screen grid, with a comparatively high positive voltage, is placed close to the plate and thus attracts the electrons of the secondary emission. As a result, the plate current is reduced and the output of the tube is limited.

PENTODES

To overcome the bad effects of secondary emission, another grid is placed between the plate and screen grid as shown by "G-3" of Figure 9. Connected to the cathode, this grid is negative, with respect to the plate, and thus repels the electrons of the secondary emission, driving them back to the plate and preventing them from reaching the screen grid, "G-2".

Because its action is to suppress the secondary plate emission, this element "G-3" is called the "Suppressor Grid". Thus, in the tube of Figure 9, you will find a cathode, "K", a control grid, "G1", a screen grid, "G2", a suppressor grid, "G3", and a plate, "P". As this makes a total of five active elements the tube is known as a "Pentode".

To make a comparison easier, for Figure 9 we show the circuits of a high frequency pentode stage and you will see the connections are similar to those of Figures 7 and 8. Here however, instead of an extra terminal on the B supply, the lower screen voltage is

obtained by means of a voltage divider.

Resistors R2 and R3 are connected in series across the B supply and, as they form a complete circuit, they will carry current which, because it does not pass through any other circuit, is known as a "Bleeder". There will be a voltage drop across the resistances and, by connecting the screen grid to the point between them, the desired voltage can be secured.

To calculate the value of resistors used in an arrangement of this kind, it is customary to assume a value of bleeder current and, for this example, we will consider it to be 5 ma. Neglecting the voltage drop across the bias resistor R1, the voltage on the screen grid will be equal to the voltage drop across R2.

Using the values given for the tube of Figure 8, the B supply develops 250 volts and the screen requires 90 volts. For R2 therefore, the voltage "E" = 90 and the current "I" = 5 ma = .005 ampere. Substituting in Ohm's Law.

$$R2 = \frac{E}{I} = \frac{90}{.005} = 18{,}000 \text{ ohms}$$

Resistor R3 requires a drop of 250 - 90 or 160 volts but must carry the 1.7 ma screen current in addition to the 5 ma bleeder current. With a total current of 5+ 1.7 or 6.7 ma, for a drop of 160 volts,

$$R3 = \frac{E}{I} = \frac{160}{.0067} = 23{,}880 \text{ ohms}$$

Usually, the value of screen voltage is not critical and as ordinary commercial resistors are made with a tolerance of plus or minus 10%, in practice, R2 could be rated at 20,000 ohms and R3, at 25,000 ohms.

In addition to the high frequency voltage amplifier of Figure 9, other types of pentodes are used as power output tubes because the use of the suppressor grid makes it possible to secure comparatively high gain, or amplification, with high output.

As shown by the symbol of Figure 9, the suppressor grid G3, is brought out to separate connection or base pin. In fact, every element of the tube has a separate connection which allows considerable circuit variation. For example, if G2 and G3 of Figure 9 were connected externally to the plate, the tube would operate as a triode.

In other types of pentodes, the suppressor grid is internally connected to the cathode, reducing the number of external circuit connections but preventing the variations mentioned above. We mention these different arrangements because you will find them in commercial apparatus.

PENTAGRID CONVERTER

In our former explanations of Figure 2 and 3, we illustrated a tube with five grids and for Figure 10 we have drawn the circuits in which it is commonly used. With five grids, a plate, and a cathode, there are seven active elements and therefore a tube of this type may be classed as a "Heptode". The number and arrangement of these grids makes it possible for a single tube to perform the dual functions of first detector and oscillator which, as you will learn later, are required in superheterodyne circuits.

As we have mentioned before, when changes of energy in the plate circuit are fed back to the grid circuit, a tube will oscillate, or act as a high frequency generator. The frequency of these oscillations is controlled by the natural, or resonant frequency of a tuned circuit connected to the plate or grid of the tube.

Checking the connections of Figure 10, you will find a high frequency path is completed from G1 to ground through condenser C5 and the tuned circuit L5-C6. R2, between G1 and K, can be thought of as a grid load. The circuit of G2 is through L6 and the series or dropping resistor R4 to the B+ of the plate supply and, in action, G2 is really a plate, which is commonly referred to as the anode.

With coils L5 and L6 inductively coupled, changes of anode energy are fed back to the grid circuit and thus we have a triode oscillator with G1 as the control grid and G2 as the plate. Variable condenser C6 tunes the grid circuit to complete this common type of oscillator.

Going back to the tube, the electrons, emitted by the cathode and attracted toward G2 by its positive voltage, must pass through G1 and thus, changes of voltage on G1 will control the flow of electrons as explained for the simple triode tubes. With the arrangement of Figure 10, the number of electrons reaching G2 will vary at the frequency of the oscillator which is controlled by tuning condenser C6.

Forgetting G1 and G2 for a minute, the other elements of the tube form a tetrode with G4 the control grid, G3 and G5 the screen grid, and P the plate. The action of these elements is the same as explained for Figure 8.

In order to reach G3, G5, and the plate, electrons from the cathode must pass through G1, G2 and G4. With the plate at a higher positive potential than G2, many of the electrons passing through G1 will also pass through G2 because of their velocity and the attraction of G3, G5, and the plate.

However, being closest to the cathode, G1 has the greatest control over the electrons and its voltage determines the number of electrons which can reach any of the other grids or the plate. As we already explained, the number of electrons reaching G2 varies with the voltage on G1 and thus the tetrode section of the tube will have a supply of electrons which varies at the oscillation frequency.

As we will explain in detail in the later Lessons, a superheterodyne circuit is arranged so that the frequency of a local oscillator will be impressed on the modulated carrier frequency to produce a modulated beat, or intermediate frequency, which can be easily amplified. In the circuits of Figure 10, the modulated carrier frequency produces a voltage across the tuned circuit L2-C1-C2 which is part of the tetrode control grid circuit, G4. The action is like that previously explained, the changes of grid voltage producing changes of plate current.

However, the number of electrons reaching G4 is already varying at the oscillation frequency and thus the variations of plate current will carry the frequencies impressed on G1 as well as G4. This will give a total of four frequencies in the plate circuit, 1: the modulated signal carrier frequency, 2: the oscillator frequency, 3: modulated frequency equal to the sum of the carrier and oscillation frequencies, 4: modulated frequency equal to the difference of the carrier and oscillation frequencies.

Condenser C3, in parallel to coil L3, tunes the plate circuit to a frequency equal to the difference between the carrier and oscillator frequencies and thus the modulation is carried over to the following tubes at this lower or intermediate frequency.

The same action can be obtained by the use of separate tubes, one operating as an oscillator and the other as a first detector or mixer, but it is necessary there be some type of coupling between them. Here, the coupling is accomplished by means of the control of G1 on the electrons reaching the plate and thus we call it "Electron" coupled. The steady, or direct, plate and screen grid currents pass through R1 causing a voltage drop which is used as the d-c grid bias for the control grid, G4, of the tetrode section. Condenser C4 tends to keep the d-c voltage across R1 constant, when the voltage starts to change from a normal d-c value, by virtue of its property of absorbing and releasing electricity at the proper instant.

In the tuned input circuit, L2-C1-C2, the two condensers are in series across the coil L2. As the capacity of C2 is large compared to that of C1 the total capacity is approximately equal to that of C1. As far as the signal voltages are concerned, the presence of C2 has no practical effect. However, the presence of C2 prevents the lower end of L2 from being grounded, as far as the d-c or bias voltage is concerned.

Tracing the circuit of G4 you will find that it passes through coil L2 and down to the point marked "avc" which is the abbreviation for Automatic Volume Control. Keep this connection in mind as we will complete the circuit after we have explained the actions of the tube of Figure 11.

DUO-DIODE-PENTODE

In order to conserve space and reduce cost, without sacrificing performance, it is now common practice to combine the elements of two complete tubes in one envelope and mount the combination on a single standard base. In some of these combinations there is a common cathode while, in others, separate cathodes are provided.

A common example of this idea is shown in the circuits of Figure 11 where the tube has a heater and common cathode. Next to the catnode there are two small diode plates. "D.P.", each brought out to a separate base pin.

So far, the tube is similar to that of Figure 6 but, by externally connecting the diodes, the action is as explained for Figure 4. This connection is in common use because, other things being equal, with a given signal voltage across the tuned input circuit, L2-C1 of Figure 11, the voltage across "D.P.-K" will be twice as great as with the center tap arrangement of Figure 6.

Going back to Figure 11, the cathode is extended and, on the right you will find a control grid, G1, a screen grid, G2, and a suppressor grid which is not identified as G3 because it is internally connected to the cathode and thus has no separate connection or base pin.

As usual, the plate "P" is located on the outside of the other elements and thus we have a pentode similar to that shown in Figure 9. However, as the envelope also contains a diode, the assembly is known as a "Duo", meaning double, "Diode-Pentode."

The action here is much the same as explained for Figure 6 except, by connecting both diodes to a common point, the action is that of a half wave rectifier. The modulated carrier voltage, across the tuned circuit L2-C1 will alternately cause current between the diode plates and cathode, allowing a rectified or pulsating current in the circuit which is completed through ground, R3 and R2.

The current in this circuit causes the rectified signal voltage to appear across R3 which, with its moveable center contact, as a potentiometer. This moveable contact is coupled to the control grid, G1, through the condenser C5 and thus the signal voltage is carried over to the grid of the pentode. Resistor R4 acts as the grid load or grid resistance and for this circuit, the grid return is the "ground" or B negative. The condensers C4 and C6, in conjunction with R2, act as a filter to remove the carrier frequency and allow current at signal frequencies.

Notice here, the signal voltage across the control grid circuit will be the voltage drop across that part of R3 between the moveable contact and ground. The position of this contact, by regulating the amount of signal voltage on the grid, acts as a volume control.

The action of the pentode section is the same as already explained for Figure 9 but here the signal is at low or audio frequency and will appear across the plate load resistor R6 and be carried over to a following tube through the coupling condenser C2.

Going back to the diode circuits, you will notice an "avc" connection between R2 and R3 and we want you to imagine this circuit connects to the "avc" of Figure 10. Under these conditions, the circuit of G4, Figure 10, will be completed to ground through R3 of Figure 11 and from ground through R1, Figure 10 to the cathode "K".

From our former explanations, you know that in Figure 10, the direction of current in R1 is such that the polarity of the voltage drop across it makes the cathode end positive in respect to ground. For R3 of Figure 11, the direction of current in it makes the voltage drop across it, positive at the grounded end and negative at the "avc" or R2 end.

Tracing through the complete grid circuit of Figure 10, you will find the voltage drops across R1 of Figure 10 and R3 of Figure 11 are in series and thus, the total grid bias voltage on G4 of Figure 10, will be equal to their sum.

With no signal, there will be no current in R3, Figure 11 and no voltage drop across it. Therefore, the bias voltage in grid G4, Figure 10, will be the drop across R1 only. When a signal voltage is present, current in R3, Figure 11, will cause a voltage drop across it which as previously explained will be added to the drop across R1, Figure 10, and thus increase the negative bias voltage on grid G4.

In this way, an increase of signal voltage will cause an increase of grid bias voltage which, in turn, will reduce in amplification of the tube and thus reduce the signal voltage drop across R3 of Figure 11. Thus, the effect of the complete action is to tend to maintain a uniform signal voltage across R3 regardless of the strength of the signal impressed in the L2-C1 circuit of Figure 10. This action is known generally as Automatic Volume Control, "avc".

As we will explain later, there are many variations of this simplified circuit but, in every case, the signal strength reacts on the preceding tubes to automatically control the output level or volume.

DOUBLE TUBES

For the reasons already mentioned, it is sometimes desirable to have two similar or identical tubes in a single envelope. Here again, there are many combinations but for Figure 12, we show the circuits of a double triode with a single or common cathode.

In the circuits of Figure 7, the triode was used as a high frequency amplifier while for Figure 12, the circuits are those of a low or audio frequency, resistance coupled amplifier.

You can imagine here that condenser C1 is condenser C2 of Figure 11 and that the signal voltage will appear across R2 of Figure 12. The input grid, "IG", circuit is completed through R2 and R1 and, as already explained, R1 is the bias resistor.

Remember here, with no signal voltage , there will be no current in resistance R2 and therefore no voltage drop across it. However, there will be d-c plate current in R1, as already explained, and the resulting voltage drop across R1 provides the grid bias voltage.

Except for certain special circuits, in which there is grid current, the bias voltage is developed only across resistors which are common to both the grid and plate circuits. Thus, in the circuits of Figure 12, resistors R2 and R5, which complete the grid circuits to ground, carry no d-c, current and thus have no d-c voltage drop. Resistor R1, common to both grid and plate circuits, carries the d-c plate current and provides the voltage drop which is used as the grid bias.

Like the triode of Figure 7, the changes of signal voltage on the input grid will cause changes of current in the input plate, "IP", circuit and these will cause the amplified signal voltage to appear across the plate load resistor R4.

The input plate is coupled to the output grid, "OG" through condenser "C2, and this grid circuit is completed through R5 and R1 back to the cathode. The action of the output triode is the same as that of the input section and therefore the signal voltage, amplified again, will appear across the output plate resistor R3. Coupling condenser C3 will carry the signal over to the following tube.

BEAM POWER TUBES

In the earlier explanations of this Lesson we mentioned the advantages of a screen grid, placed between the control grid and plate to form a Tetrode tube and, to overcome the disadvantages of secondary emission from the plate, a suppressor grid was placed between the screen grid and plate to form a pentode.

As the plate circuits of output tubes must carry sufficient signal power to drive the speakers or other units, the variations of plate current are comparatively large. Variations of plate current

mean changes of voltage drop across the plate load which, with a constant voltage supply, will cause changes of voltage on the plate of the tube.

In the case of a tetrode, at times these changes cause the plate voltage to become lower than the screen voltage. The electrons of the secondary emission will therefore be drawn toward the screen, instead of returning to the plate, and the plate current will drop.

Under these conditions, the plate current will be controlled by the plate voltage, in addition to the control grid voltage, and the signal will be distorted. The suppressor grid of a pentode, connected to the cathode, is negative in respect to the plate, repels the secondary emission electrons and returns them to the plate. Because of this action, the plate current of a pentode is practically independent of the plate voltage.

Although an advantage in this respect, located between the screen and plate, the suppressor grid is an obstruction in the path of the electrons which reach the plate from the cathode. To reduce this effect, the suppressor grid is made of an open network of spiral wire and therefore, its repelling action on the secondary emission electrons is not uniform over the entire area of the plate. While these various actions may seem of little importance, their effect is to increase the distortion and limit the amount of usable power the tube can develop.

In the tube symbol of the circuits of Figure 13, we show the arrangement of a "Beam Power" type of tube in which the disadvantages, mentioned above, have been greatly reduced. As a result, power tubes of this type have greater efficiency, higher power output and sensitivity!

The electrons which are emitted by the cathode reach the plate by passing through the spaces between the beam forming plates which are connected to the cathode like a suppressor grid, and therefore repel the electrons causing them to be compressed into "beams".

The control and screen grids are made of wire, formed into a spiral like those shown in the cut away view of Figure 3.

The turns of the screen grid spiral are lined up with those of the control grid so that the electrons which pass through the grid will pass between the

turns of the screen grid also. In this way, the screen grid current is held at a comparatively low value.

As shown in Figure 13, there is no suppressor grid but the high density of the electrons in the beam tends to return the secondary emission electrons to the plate. Electrons which tend to reach the screen by returning from the plate on the outer edges of the beam are repelled by the beam forming plates.

Thus, although there is no actual suppressor grid to interfere with the electron stream from the cathode to the plate, the arrangement of the tube elements and the electrons themselves provide for the same action and prevent the secondary emission electrons from reaching the screen grid.

The circuits of Figure 13 are similar to those of Figure 8 except that the screen grid is operated from the same voltage supply terminal as the plate. Also, as the signal is at audio frequency, the input is made up of a resistance and coupling condenser like that of Figure 12. The coil L1 is the plate load and also the primary of a low frequency or audio transformer, the secondary of which, L2, connects to the speaker or other output device.

In this Lesson, we may have used some terms or given some explanations which are not entirely clear to you but the later Lessons will take them up in detail. At this time, therefore, we want you to go over the various circuits carefully and follow the actions as far as you are able because, a knowledge of the general principles given here will be of great help in your later work.

In the tube table of the next Lesson, you will find the manufacturers ratings on the different types of tubes. When using a table you need only remember that the filaments or heaters should be operated at the exact values shown in the "Filament Rating" column. The values of plate and screen voltages are either the maximum or average operating conditions and, in many cases, you will find tubes operating satisfactorily at voltages lower than those shown.

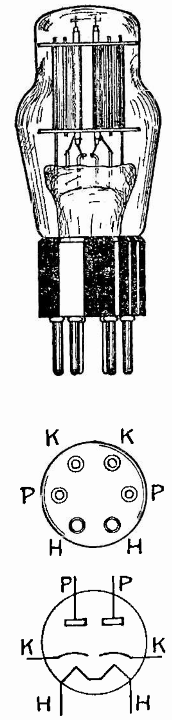


FIGURE 1

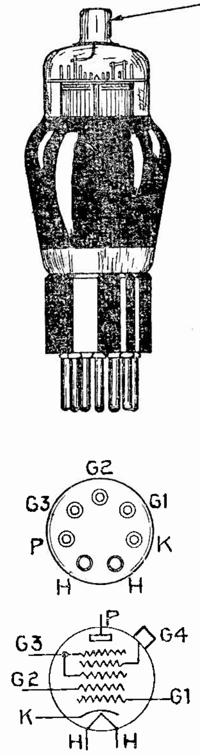


FIGURE 2

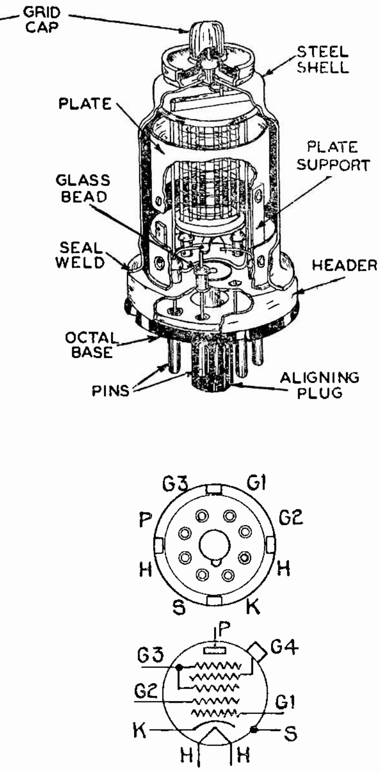


FIGURE 3

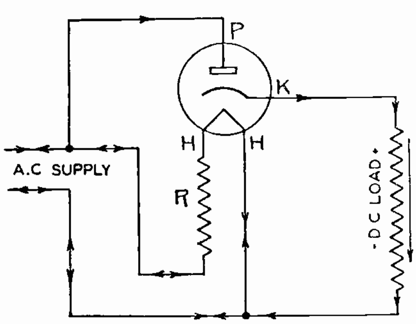


FIGURE 4

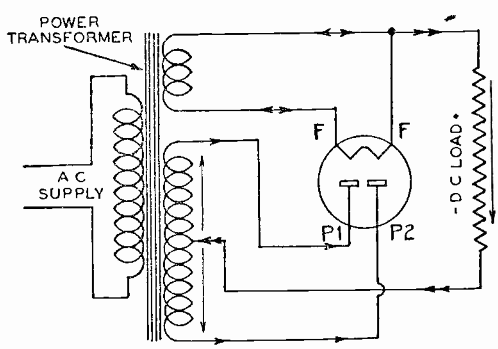
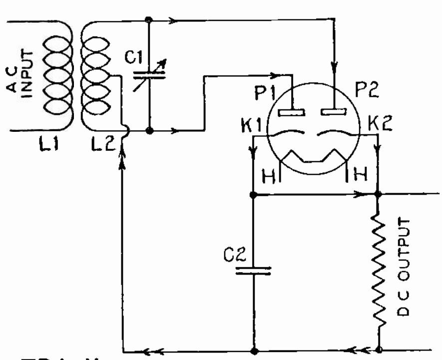


FIGURE 5



TRA-11

FIGURE 6

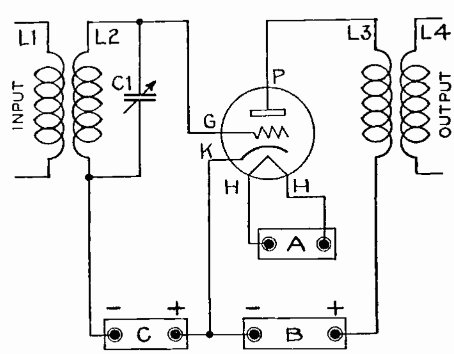


FIGURE 7

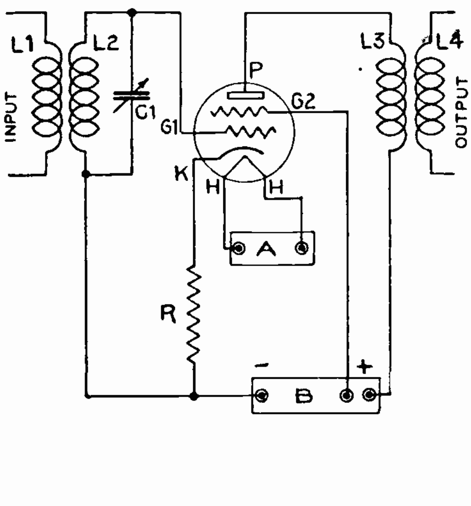


FIGURE 8

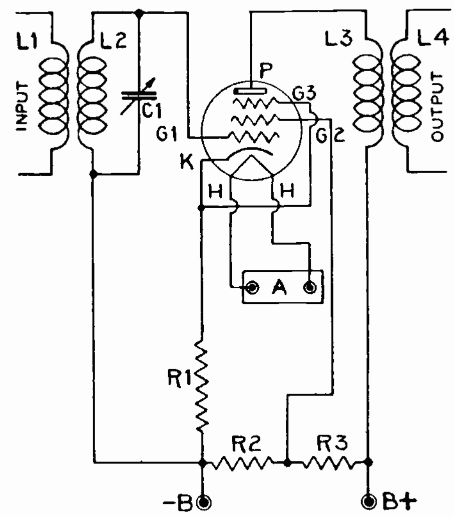


FIGURE 9

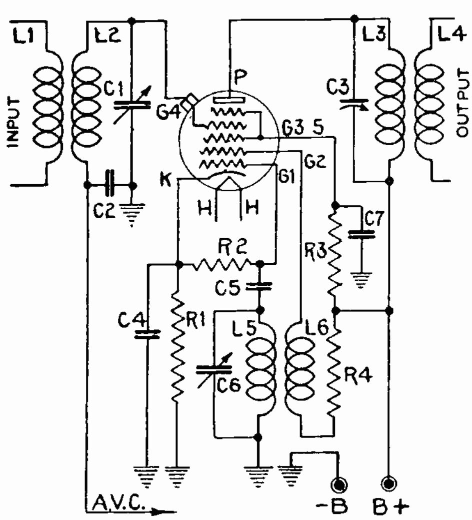


FIGURE 10

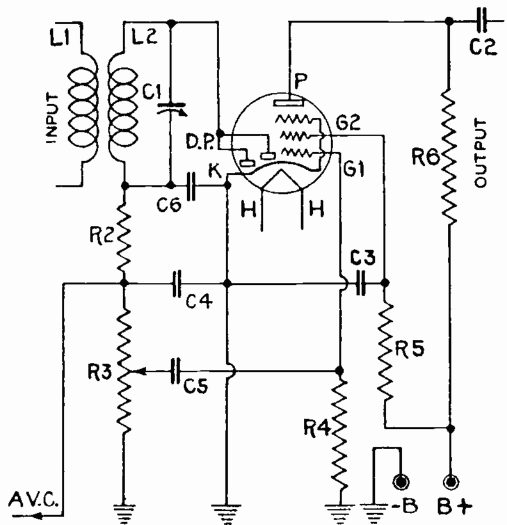
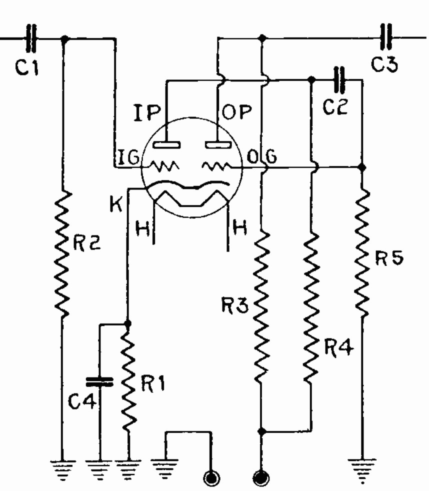


FIGURE 11



TRA-11

FIGURE 12

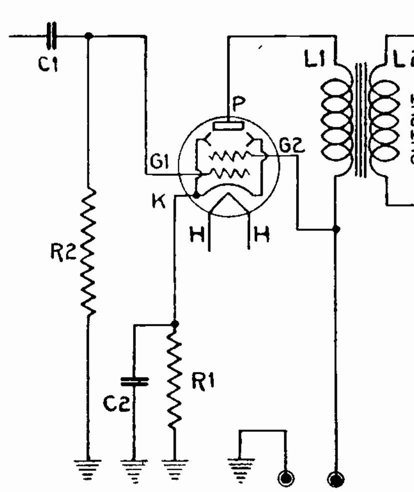


FIGURE 13

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LESSON TRA - 12
TUBE TABLES

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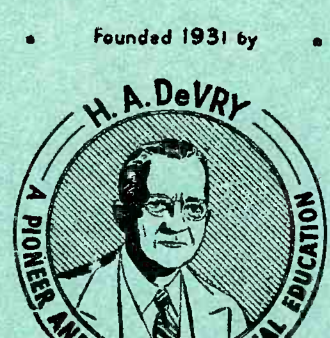

DE FOREST'S
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H. A. DeVRY
A PIONEER AND LEADER OF VISUAL EDUCATION

TUBES - RECEIVERS - AMPLIFIERS

LESSON 12

TUBE TABLES

. . . .

How much easier our work would be if we put forth as much effort trying to improve the quality of it as most of us do trying to find excuses for not properly attending to it.

-George W. Ballinger

GENERAL EXPLANATION OF TUBE TABLE

By courtesy of the Sylvania Electric Products, Inc., tube manufacturers at Emporium, Pa., the following pages contain the characteristics of the various types of tubes now in common use. You will find the various types listed according to number, starting with "OA4G" and continuing to "XXL". Several of the numbers are followed by the letter "G" which means it is the glass equivalent of a metal tube of the same type. For example, the "6F6" is a metal type pentode used as a Power Amplifier and "6F6G" is practically the same tube built into a glass envelope.

A smaller version of the "G" is the "GT" type of tube which is equipped with an octal base and has a tubular shaped bulb. Because of the similarity in characteristics between G tubes and the corresponding GT types, it is usually possible to inter-change GT tubes **for G tubes and visa versa** if space permits. Therefore a recent adoption of style GT/G indicates the tube will replace G or GT services.

Other types which contain the letter "S" usually refer to "single end" construction and the control grid connects to a base pin instead of a cap on the bulb. For example the "6SQ7" is designed for the same general service as the "6Q7" however, due to its single end construction, the 6SQ7 will not replace a CQ7 unless the proper connections are changed.

Recent engineering improvements have resulted in the addition of another group of single ended tubes such as a type 7B7. These are the "lock-in" or some times called "loctal" type of tubes. The tubes are small "all glass" types without the familiar bakelite base. The contact pins are sealed into the glass bottom of the bulb and the lower portion of the tube is fitted with a metal shell and guide pin. This unit acts as a shield and makes possible the lock-in feature of employing a groove around the bottom of the locating pin which fits into a catch on the socket.

The "loctal" tubes are not directly inter-changeable with other designs of receiving tubes because socket requirements differ. The important advantages of this type of tube are single ended operation, compactness, suitable shielding, and a special lock-in feature.

Pages 9, 10 and 11 contain diagrams of the base or socket connections, of the various tubes, when viewed from the bottom. The number and letter below each view corresponds to the data in the column with the heading "Base". The tube filaments should be operated as shown in the "Filament Rating" columns. The other values of voltage and current are either the maximum or average operating conditions and, in many cases, you will find tubes operating satisfactorily with different voltages and currents from those shown.

Type	Class	Base	Filament Rating Volts	Filament Rating Amps	Use	Plate Volts	Negative Grid Volts	Screen Volts	Plate Current Ma	Screen Current Ma.	Plate Resistance Ohms	Micromhos Mutual Conductance	* Amplification Factor	Ohms Load for Stated Power Output	Undistorted Power Output Milliwatts
0A4G	Triode	4-V			Relay Tube	Peak Cathode Ma = 100 D-C Cathode Ma = 25 Max Starter Anode Drop = 60 V Approx Anode Drop = 70 V Approx.									
0Z4, 0Z4G	Duodiode	4-R			F-W Rect	300 A-C Volts Per Plate, RMS, 75 Ma Max 30 Ma Min Output Current									
01A	Triode	4-D	5 0	0 25	Amplifier	90 135	4 5 9.0		2 5 3.0		11,000 10,000	725 800	8.0 8.0		
1A4P	Pentode	4-M	2 0	0 06	R-F Amp.	135 180	3 0 3 0	67 5 67 5	2 2 2 3	0 9 0 8	1 Meg 1 Meg	625 725			
1A4T	Tetrode	4-K	2 0	0 06	R-F Amp	135 180	3 0 3 0	67 5 67.5	2 2 2 2	0.7 0 7	350,000 600,000	625 650			
1A5GT/G	Pentode	6-X	1 4	0 05	Power Amp.	85 90	4.5 4 5	85 90	3 5 4 0	0 7 0 8	300,000 300,000	800 850		25,000 25,000	100 115
1A6	Heptode	6-L	2 0	0 06	Converter	135 180	3 0 3 0	67 5 67 5	1.8 1 5	2.1 2 0	400,000 500,000	275▲ 300▲	(G2 = 135 V □Max 2 0 Ma) (G2 = 180 V □Max 2 5 Ma)		
1A7G	Heptode	7-Z	1 4	0 05	Converter	90	0 0	45	0 55	0 60	600,000	250▲	(G2 = 90 V Max 1 2 Ma)		
1A7GT	Heptode	7-Z	1.4	0 05	Converter	Characteristics Same as Type 1A7G									
1B4P	Pentode	4-M	2 0	0 06	R-F Amp.	135 180	3 0 3.0	67 5 67 5	1.6 1 7	0 7 0 6	1 5 Meg ♦ 1 5 Meg ♦	560 650			
1B5/25S	Duodiode Tri	6-M	2 0	0.06	Detector	135	3.0		0 8		35,000	575	20		
1B7G	Heptode	7-Z	1 4	0.10	Converter	90	0 0	45	1 5	1 3	350,000	350▲	(G2 = 90 V, 1 6 Ma)		
1B7GT	Heptode	7-Z	1 4	0 10	Converter	Characteristics Same as Type 1B7G									
1C5GT/G	Pentode	6-X	1 4	0 10	Power Amp.	83 90	7 0 7 5	83 90	7.0 7 5	1.6 1 6	110,000 115,000	1,500 1,550	165 180	9,000 8,000	200 240
1C6	Heptode	6-L	2 0	0 12	Converter	135 180	3.0 3.0	67 5 67 5	1.3 1 5	2 5 2 0	600,000 700,000	300▲ 325▲	(G2 = 135 V □Max 3.1 Ma) (G2 = 180 V □Max 4 0 Ma)		
1C7G	Heptode	7-Z	2.0	0 12	Converter	135 180	3.0 3 0	67 5 67.5	1 3 1.5	2.5 2 0	600,000 700,000	300▲ 325▲	(G2 = 135 V □Max. 3.1 Ma) (G2 = 180 V □Max. 4 0 Ma)		
1D5GP	Pentode	5-Y	2 0	0.06	R-F Amp.	135 180	3 0 3 0	67 5 67.5	2 2 2 3	0.9 0 8	1 Meg. 1 Meg	625 725			
1D5GT	Tetrode	5-R	2 0	0 06	R-F Amp.	135 180	3.0 3.0	67 5 67 5	2 2 2.2	0.7 0 7	350,000 600,000	625 650			
1D7G	Heptode	7-Z	2.0	0 06	Converter	135 180	3 0 3.0	67 5 67 5	1 8 1 5	2 1 2.0	400,000 500,000	275▲ 300▲	(G2 = 135 V □Max, 2 0 Ma) (G2 = 180 V □Max, 2 5 Ma)		
1E4G	Triode	5-S	1.4	0 05	Amplifier	90 90	0 0 3 0		4 5 1.5		11,000 17,000	1,325 825	14.5 14		
1E5GP	Pentode	5-Y	2.0	0.06	R-F Amp.	135 180	3 0 3 0	67 5 67.5	1 6 1.7	0 7 0 6	1.5 Meg ♦ 1 5 Meg ♦	560 650			
1E7G	Duo Pentode	8-C	2.0	0.24	Power Amp.	135	7 5	135	7 0♦	2 0♦	220,000	1,600	350	24,000¶	575
1F4	Pentode	5-K	2 0	0 12	Power Amp.	135	4 5	135	8 0	2 4	200,000	1,700		16,000	310
1F5G	Pentode	6-X	2 0	0 12	Power Amp	135	4 5	135	8 0	2 4	200,000	1,700		16,000	310
1F6	Duodi Pent.	6-W	2 0	0 06	R-F or I-F A-F Amp	180 135*	1 5 2 0	67 5 (Screen Supply = 135 V. Thru 0 8 Meg. Rest Grid Rest = 1 0 Meg., Voltage Gain 46.)	2.2	0.7	1 Meg.	650			
1F7G	Duodi. Pent.	7-AD	2 0	0 06	R-F or I-F A-F Amp	180 135*	1 5 2 0	67 5 (Screen Supply = 135 V Thru 0 8 Meg Rest, Grid Rest = 1 0 Meg, Voltage Gain 46)	2 2	0.7	1 Meg.	650			
1G4GT/G	Triode	5-S	1 4	0 05	Amplifier	90	6 0		2 3		10,700	825	8 8		
1G5G	Pentode	6-X	2 0	0 12	Power Amp.	90	6 0	90	8 5	2 5	133,000♦	1,500		8,500	250
1G6GT/G	Duotriode	7-AB	1 4	0 10	Power Amp.	90 90	0 0 0 0		1 0# 1 0#		45,000	675	30	(Each Triode Class A) 12,000¶	675
1H4G	Triode	5-S	2 0	0.06	Det. Amp	90 135 180	4 5 9 0 13.5		2.5 3 0 3 1		11,000 10,300 10,300	850 900 900	9 3 9 3 9 3		
1H5G, GT	Diode-Triode	5-Z	1.4	0 05	Det, Amp.	90	0 0		0 15		240,000	275	65		
1H6G	Duodiode Tri.	7-AA	2 0	0.06	Det, Amp	135	3 0		0 8		35,000	575	20		
1J5G	Pentode	6-X	2.0	0 12	Power Amp	135	16 5	135	7 0	2 0	125,000	1,000	125	13 500	575
1J6G	Duotriode	7-AB	2.0	0 24	Power Amp	Characteristics Same as Type 19									
1LA4	Pentode	5-AD	1 4	0 05	Power Amp	85 90	4.5 4 5	85 90	3 5 4 0	0 7 0 8	300,000 300,000	800 850		25,000 25,000	100 115
1LA6	Heptode	7-AK	1.4	0.05	Converter	90	0 0	45	0 55	0 6	750,000	250▲	(G2 = 90V Max, 1 2 Ma.)		
1LB4	Pentode	5-AD	1.4	0.05	Power Amp.	45 67 5 90	4.5 6.0 9 0	45 67.5 90	1.6 3 8 5 0	0.3 0 8 1 0	300,000 200,000 200,000	650 875 925		20,000 16,000 12,000	35 100 200
1LC5	Pentode	7-AO	1.4	0.05	Amplifier	45 90	0.0 0 0	45 45	1.1 1 5	0.25 0.20	700,000 1 5 Meg	750 775			
1LC6	Heptode	7-AK	1.4	0.05	Converter	45 90	0 0 0 0	35 35	0 7 0 75	0.75 0.7	300,000 650,000	250▲ 275▲	(G2 = 45 V. Max., 1.4 Ma) (G2 = 45 V Max, 1 4 Ma.)		
1LD5	Diode Pent.	6-AX	1.4	0.05	Amplifier	45 90	0.0 0 0	45 45	0.55 0.6	0 12 0 1	900,000 750,000	550 575			
1LE3	Triode	4-AA	1.4	0.05	Amplifier	90 90	0 0 3.0		4.5 1 4		11,200 19,000	1,300 760	14 5 14 5		
1LH4	Diode-Tri.	5-AG	1.4	0.05	Amplifier	90	0 0		0 15		240,000	275	65		
1LN5	Pentode	7-AO	1.4	0.05	Amplifier	90	0 0	90	1.6	0.35	1.1 Meg	800			
1N5G, GT	Pentode	5-Y	1.4	0.05	R-F Amp.	90	0.0	90	1 2	0.3	1.5 Meg ♦	750			
1N6G	Diode Pent.	7-AM	1.4	0.05	Power Amp	90	4.5	90	3 4	0 7	300,000♦	800		25,000	100
1P5G, GT	Pentode	5-Y	1.4	0 05	Amplifier	90	0.0	90	2 3	0 7	800,000	750			
1Q5GT/G	Tetrode	6-AF	1 4	0.10	Power Amp.	90	4 5	90	9 5	1 3		2,200		8,000	270
1R5	Heptode	7-AT	1.4	0 05	Converter	45 90	0 0 0 0	45 67 5	0 7 1 7	1 9 3 0	600,000♦ 500,000♦	235▲ 300▲			
1S4	Pentode	7-AV	1.4	0.05	Power Amp	45 90	4.5 7 0	45 67 5	3 8# 7 4#	0.8# 1 4#	100,000♦ 100,000♦	1,250 1,575		8,000 8,000	65 270
1S5	Diode Pent	6-AU	1.4	0 05	Amplifier	67 5	0.0	67 5	1 6	0 4	600,000	625			
1T4	Pentode	6-AR	1 4	0.05	R-F Amp.	45 90	0 0 0 0	45 67 5	1 9 3 7	0 7 1 25	350,000 500,000	700 900			
1T5GT	Tetrode	6-AF	1 4	0 05	Power Amp	90	6 0	90	6.5	1.4		1,150		14,000	170
1V	Diode	4-G	6 3	0 30	H-W Rect	325 A-C Volts Per Plate, RMS, 45 Ma Output Current Condenser Input to Filter									
2A3	Triode	4-D	2 5	2 50	Power Amp Class AB1	250 300	45 0 62 0		60 0 40 0 per Tube, Push Pull, Fixed Bias		800	5,250	4 2	2,500 3,000¶	3,500 15,000

*Applied through 250,000 ohms. #Per Tube or Section—No Signal §Plate and Target Supply Voltage

**Triode Operation. ‡‡Applied through 200,000 ohms. §§With Average Power Input of 320 Mw. Grid to Grid

‡Pentode Operation ††For two tubes with 40 volts RMS applied to each grid

¶Plate to Plate. ♦Approximate. □Applied through 20,000 ohms.

▲Conversion Conductance †50 Volts RMS applied to two grids.

Type	Class	Base	Filament Rating Volts	Filament Rating Amps	Use	Plate Volts	Negative Grid Volts	Screen Volts	Plate Current Ma	Screen Current Ma	Plate Resistance Ohms	Micromhos Mutual Conductance	Amplification Factor	Ohms Load for Stated Power Output	Undistorted Power Output Milliwatts
2A4G	Triode	5-S	2 5	2 50	Relay Tube	Instantaneous Forward or Inverse Anode Volts = 200 Peak Anode Amps = 1 25 Average Anode Current = 0.1 Amp Max Averaging Time = 45 Seconds Cold Starting Time = 2 Seconds									
2A5	Pentode	6-B	2 5	1 75	Power Amp	Characteristics Same as Type 6F6G									
2A6	Duodiode Tri	6-G	2 5	0 80	Det Amp	250	2 0		0 9		91,000	1,100	100		
2A7, 2A7S	Heptode	7-C	2 5	0 80	Converter	Characteristics Same as Type 6A7									
2B7, 2B7S	Duodi Pent	7-D	2 5	0 80	R-F or I-F	Characteristics Same as Type 6B7									
2E5	Triode	6-R	2 5	0 80	Indicator	Characteristics Same as Type 6E5									
2S/4S	Duodiode	5-D	2 5	1 35	Detector	The Two Diode Plates each Draw Approximately 40 0 Ma with 50 Volts D C on the Plates									
2W3	Diode	4-X	2 5	1 50	H W Rect	350 A-C Volts Per Plate, RMS, 55 Ma Output Current. Condenser Input to Filter									
2X2/879	Diode	4-AB	2 5	1.75	H-W Rect	4,500 A-C Volts Per Plate, RMS, 7 5 Ma. Output Current Condenser Input to Filter									
2Z2/G84	Diode	4-B	2 5	1 50	H-W Rect	350 A-C Volts Per Plate, RMS, 50 Ma Output Current									
3A8GT	Diode Tri.-Pent	8-AS	1 4 2 8	0 10 0 05	Tri -Amp Pent -Amp.	90 90	0 0 0 0	 90	0 15 1 20	 0 3	240,000 600,000	275 750			
3LF4	Tetrode (Series Fil. Oper.)	6-BB	1 4 2 8	0 10 0 05	Power Amp. Power Amp	90 90	4 5 4 5	90 90	9.5 8 0	1 3 1.0	75,000 80,000	2,200 2,000		8,000 8,000	270 230
3Q5GT/G	Tetrode (Series Fil Oper)	7-AP	1 4 2 8	0 10 0 05	Power Amp Power Amp	Characteristics Same as Type 3LF4									
3S4	Tetrode (Series Fil Oper)	7-BA	1 4 2 8	0 10 0 05	Power Amp Power Amp	90 90	7 0 7 0	67 5 67 5	7.4 6 1	1 4 1 1	100,000 100,000	1,575 1,425		8,000 8,000	270 235
5U4G	Duodiode	5-T	5 0	3 00	F-W Rect	450 A-C Volts Per Plate, RMS, 225 Ma Output Current Condenser Input to Filter									
5V4G	Duodiode	5-L	5.0	2 00	F-W Rect	375 A-C Volts Per Plate, RMS, 175 Ma Output Current Condenser Input to Filter									
5W4GT/G	Duodiode	5-T	5 0	1 50	F-W Rect	350 A-C Volts Per Plate, RMS, 110 Ma Output Current, Condenser Input to Filter									
5X4G	Duodiode	5-Q	5 0	3 00	F-W Rect.	450 A-C Volts Per Plate, RMS, 225 Ma Output Current Condenser Input to Filter									
5Y3G	Duodiode	5-T	5 0	2 00	F-W Rect	350 A-C Volts Per Plate, RMS, 125 Ma Output Current Condenser Input to Filter 500 A-C Volts Per Plate, RMS 125 Ma. Output Current Choke Input to Filter									
5Y4G	Duodiode	5-Q	5 0	2 00	F-W Rect	Characteristics Same as Type 5Y3G									
5Z3	Duodiode	4-C	5 0	3 00	F-W Rect	450 A-C Volts Per Plate, RMS, 225 Ma Output Current Condenser Input to Filter									
5Z4	Duodiode	5-L	5 0	2.00	F-W Rect	350 A-C Volts Per Plate, RMS, 125 Ma Output Current Condenser Input to Filter									
6A3	Triode	4-D	6 3	1 00	Power Amp.	250 325 325	45 0 68 0		60 0 40 0# 40 0#	 (Push Pull, Fixed Bias) (Push Pull, Self Bias Resistor 850 Ohms)	800	5,250	4 2	2,500 3,000¶ 5,000¶	3,200 15,000 10,000
6A4/LA	Pentode	5-B	6.3	0 30	Power Amp.	135 180	9 0 12 0	135 180	13 0 22 0	2 8 3.9	52,600 60,000	2,100 2,500	150 150	9,500 8,000	700 1,500
6A5G	Triode	6-T	6 3	1.25	Power Amp. P P AB_1 Amp	250 325	45 0 68 0		60 0 40 0	 Per Tube, Push Pull, Fixed Bias	800	5,250	4 2	2,500 3,000¶	3,750 15,000
6A6	Duotriode	7-B	6 3	0 80	Power Amp Driver Driver	300 250 294	0 0 5 0 6 0		17 5 * 6 0 7 0	Per Plate, Class B Operation, Zero Signal	 11,300 11,000	 3,100 3,200	 35 35	10,000¶ (Class A Driver) (Class A Driver)	10,000
6A7, 6A7S	Heptode	7-C	6 3	0 30	Converter	Characteristics Same as Type 6A8G, Except Capacitances									
6A8	Heptode	8-A	6 3	0 30	Converter	Characteristics Same as Type 6A8G, Except Capacitances									
6A8G, GT	Heptode	8-A	6 3	0 30	Converter	100 250	1 5 3 0	50 100	1 1 3 5	1 3 2 7	600,000 360,000	360▲ 550▲	(G2 = 100 V, 2 0 Ma.) (G2 = 250 V□, Max., 4 0 Ma)		
6AB5/6N5	Triode	6-R	6.3	0 15	Indicator	135§	(Series Plate Resistor 0 25 Meg, Target Current 2 0 Ma, Grid Bias − 10 for 0° Shadow)								
6AB7/1853	Pentode	8-N	6 3	0 45	Amplifier	300	3 0	200	12 5	3 2	700,000♦	5,000	3,500♦		
6AC5GT/G	Triode	6-Q	6.3	0.40	Power Amp	250 250 250	+13 (Bias From 76 Driver) 0 0		32 0 32 0 2 5#	 (Class A_1, One Tube, Dynamic Coupled) (Class B, Two Tubes)	36,700	3,400	125	 7,000 10,000¶	 3,700 8,000
6AC7/1852	Pentode	8-N	6 3	0 45	Amplifier	300		150	10 0	2 5	750,000♦	9,000	6,750♦	Bias Res = 160 ohms	
6AD6G	Duodiode	7-AG	6 3	0 15	Indicator	100§ (Ray Control Volts = 45 Approx For 0° Shadow, Approx − 23 Volts for 135° Shadow) 150§ (Ray Control Volts = 75 Approx For 0° Shadow, Approx − 50 Volts for 135° Shadow)									
6AD7G	Tri. Pentode	8-AY	6.3	0 85	Triode Amp Pent Amp	250 250	25 0 16 5	 250	4 0 34 0	 6 5	19,000♦ 80,000♦	325 2,500	6	7,000	3,200
6AE5GT/G	Triode	6-Q	6 3	0 30	Amplifier	95	15		7 0		3,500	1,200	4 2		
6AE6G	Duo Plate Triode	7-AH	6 3	0 15	Remote Cut-Off Sharp Cut-Off	250 250 250 250	1.5 35 0 1 5 9 5		6 5 0 01 4 5 0 01		2,500 3,500	1,000 950	25 33		
6AE7GT	Duotriode	7-AX	6 3	0 50	Amplifier	250 (Driver for P P 6AC5GT = 250 V 10 Ma, 6AC5GT Plate Ma = 64 Output 9 5 Watts with 10,000 Ohms Load, Bias Developed in Circuit)	13 5		10 0		4,650	3,000	14		
6AF5G	Triode	6-Q	6 3	0 30	Amplifier	180	18 0		7 0		4 900	1,500	7 4		
6AF6G	Duodiode	7-AG	6 3	0 15	Indicator	100§ (Ray Control Volts = Approx 60 for 0° Shadow, Approx Zero Volt for 100° Shadow) 135§ (Ray Control Volts = Approx 81 for 0° Shadow, Approx Zero Volt for 100° Shadow)									
6AG7	Pentode	8-Y	6 3	0 65	Amplifier	300	10 5	300	25 0	6 5	100,000	7,700			
6B4G	Triode	5-S	6 3	1 00	Power Amp	Characteristics Same as Type 6A3									
6B5	Duotriode	6-AS	6 3	0 80	Power Amp	Characteristics Same as Type 6N6G									
6B7, 6B7S	Duodi Pent	7-D	6.3	0 30	R-F or I-F Amplifier A-F Amp	100 180 250 250	3 0 3 0 3 0 4 5	100 75 0 100 50 0	5 8 3 4 6 0 0 65	1 7 0 9 1 5	300,000 1 Meg 800,000	950 840 1,000			
6B8	Duodi Pent	8-E	6 3	0 30	R-F or I-F	250	3 0	125	10 0	2 3	600,000	1,325			
6B8G	Duodi Pent	8-E	6 3	0 30	R-F or I-F	Characteristics Same as Type 6B7									
6C5, G, GT	Triode	6-Q	6 3	0 30	Amplifier	250	8 0		8 0		10,000	2,000	20		
6C6	Pentode	6-F	6 3	0 30	Amplifier	100 250	3 0 3 0	100 100	2 0 2 0	0 5 0 5	1 Meg 1 Meg +	1,185 1,225			
6C7	Duodiode Tri	7-G	6 3	0 30	Det Amp	250	9 0		4 5		16,000	1,250	20		
6C8G	Duotriode	8-G	6 3	0 30	Amplifier Inverter	250 250	4 5 3 0	 Plate Load 100,000 Ohms, Self Bias Resistor 1500 Ohms, Voltage Amplification 48 Output Volts 80, RMS, for Inverter Service.	3 2		22,500	1,600	36	(One Section)	
6D6	Pentode	6-F	6 3	0 30	Amplifier	100 250	3 0 3 0	100 100	8 0 8 2	2 2 2 0	250,000 800,000	1,500 1,600			
6D7	Pentode	7-H	6 3	0 30	Amplifier	Characteristics Same as Type 6C6									
6D8G	Heptode	8-A	6 3	0 15	Converter	135 250	3 0 3 0	62 5 100	1 5 3 5	1 7 2 6	600,000 400,000	325▲ 550▲	(G2 = 135 V, 1 8 Ma) (G2 = 250 V □, 4 5 Ma)		
6E5	Triode	6-R	6 3	0 30	Indicator	100§ 250§	(Series Plate Resistor 0 5 Meg Target Current 1 0 Ma Grid Bias −3 3 for 0° Shadow) (Series Plate Resistor 1 0 Meg Target Current 4 0 Ma Grid Bias −8 0 for 0° Shadow)								

*Applied through 250,000 ohms
#Per Tube or Section—No Signal
§Plate and Target Supply Voltage
**Triode Operation
‡‡Applied through 200,000 ohms
§§With Average Power Input of 320 Mw
‡Pentode Operation
††For two tubes with 40 volts RMS applied to each grid
¶Plate to Plate Grid to Grid
♦Approximate
□Applied through 20,000 ohms
▲Conversion Conductance
†50 Volts RMS applied to two grids.

Type	Class	Base	Filament Rating Volts	Filament Rating Amps	Use	Plate Volts	Negative Grid Volts	Screen Volts	Plate Current Ma	Screen Current Ma	Plate Resistance Ohms	Micromhos Mutual Conductance	Amplification Factor	Ohms Load for Stated Power Output	Undistorted Power Output Milliwatts
6E6	Duotriode	7-B	6.3	0.60	Power Amp (1 Section)	180 250	20.0 27.5		11.5 18.0		4,300 3,500	1,400 1,700	6.0 6.0	15,000¶ 14,000¶	750 1,600
6E7	Pentode	7-H	6.3	0.30	Amplifier	Characteristics Same as Type 6D6									
6F5, G, GT	Triode	5-M	6.3	0.30	Amplifier	250	2.0		0.9		66,000	1,500	100		
6F6 6F6G	Pentode	7-S	6.3	0.70	Power Amp P P A_1 Amp P P AB_2 Amp	250 285 315 375	16.5 20.0 24.0 26.0	250 285 285 250	34.0 38.0 62.0 34.0	6.5 7.0 12.0 5.0	80,000 78,000 (Current & Output for Two Tubes) (Current & Output for Two Tubes)	2,500 2,550		7,000 7,000 10,000¶ 10,000¶	3,200 4,800 11,000 18,000
6F7, 6F7S	Pent.-Triode	7-E	6.3	0.30	Pent. Amp Pent. Amp Triode Amp	100 250 100	3.0 3.0 3.0	100 100	6.3 6.5 3.5	1.6 1.5	290,000 850,000 16,200	1,050 1,100 525	 8.5	Pentode Section Pentode Section Triode Section	
6F8G	Duotriode	8-G	6.3	0.60	Amplifier Inverter	250 250	8.0 5.5	 {Plate Load 50,000 Ohms Per Plate, Self Bias Resistor 1,150 Ohms, Voltage Amplification 29, Output Volts 65, RMS, for Inverter Service	9.0		7,700	2,600	20	(One Section)	
6G6G	Pentode	7-S	6.3	0.15	Power Amp	135 180	6.0 9.0	135 180	11.5 15.0	2.0 2.5	170,000 175,000	2,100 2,300		12,000 10,000	600 1,100
6H4GT	Diode	5-AF	6.3	0.15	Rectifier	100			4.0						
6H6, G, GT	Duodiode	7-Q	6.3	0.30	Rectifier	117 A-C Volts Per Plate, RMS, 4.0 Ma Output Current									
6J5GT/G	Triode	6-Q	6.3	0.30	Amplifier	250	8.0		9.0		7,700	2,600	20		
6J7	Pentode	7-R	6.3	0.30	Amplifier	250	3.0	100	2.0	0.5	1.0 Meg +	1,225			
6J7G GT	Pentode	7-R	6.3	0.30	Amplifier	Characteristics Same as Type 6J7, Except Capacitances									
6J8G	Tri.-Heptode	8-H	6.3	0.30	Mixer Oscillator	250 250	3.0 Plate Supply Thru 20,000 Res., Grid Resistor 50,000, Grid Current 0.4 Ma Plate Current 5.0 Ma (Triode Section)	100	1.3	2.9	4.0 Meg	290▲	(Heptode Section)		
6K5G	Triode	5-U	6.3	0.30	Amplifier	100 250	1.5 3.0		0.35 1.10		78,000 50,000	900 1,400	70 70		
6K5GT	Triode	5-U	6.3	0.30	Amplifier	Characteristics Same as Type 6K5G Except Capacitances									
6K6G, GT	Pentode	7-S	6.3	0.40	Power Amp	100 250 315	7.0 18.0 21.0	100 250 250	9.0 32.0 25.5	1.6 5.5 4.0	104,000 68,000 75,000	1,500 2,300 2,100		12,000 7,600 9,000	350 3,400 4,500
6K7	Pentode	7-R	6.3	0.30	Amplifier	90 180 250	3.0 3.0 3.0	90.0 75.0 100	5.4 4.0 7.0	1.3 1.0 1.7	300,000 1 Meg 800,000	1,275 1,100 1,450			
6K7G, GT	Pentode	7-R	6.3	0.30	Amplifier	Characteristics Same as Type 6K7, Except Capacitances									
6K8	Tri.-Hexode	8-K	6.3	0.30	Mixer Osc	Characteristics Same as Type 6K8G, Except Capacitances									
6K8G, GT	Tri.-Hexode	8-K	6.3	0.30	Mixer Oscillator	250 100	3.0 Grid Resistor 50,000 Plate Current 3.8 Ma, Conversion Conductance 3000 (Triode Section not Oscillating)	100	2.5	6.0	600,000	350▲	(Hexode Section)		
6L5G	Triode	6-Q	6.3	0.15	Amplifier	100 250	3.0 9.0		4.0 8.0		10,000 9,000	1,500 1,900	15 17		
6L6, 6L6G	Tetrode	7-AC	6.3	0.90	Power Amp P P A_1 Amp P P AB_1 Amp P P AB_2 Amp	250 350 270 360 360	14.0 18.0 17.5 22.5 22.5	250 250 250 270 270	72.0 54.0 134.0 88.0 88.0	5.0 2.5 11.0 5.0 5.0	22,500 33,000 23,500 Current & Output for two tubes Current & Output for two tubes	6,000 5,200 5,700		2,500 4,200 5,000¶ 6,600¶ 3,800¶	6,500 10,800 17,500 26,500 47,000
6L7	Heptode	7-T	6.3	0.30	Mixer Amplifier	250 250	6.0 3.0	150 100	3.3 5.3	9.2 6.5	1 Meg + 600,000	350▲ 1,100	(G3 = Neg. 15 Volts) (G3 = Neg 3.0 Volts)		
6L7G	Heptode	7-T	6.3	0.30	Mixer Amp	Characteristics Same as Type 6L7, Except Capacitances									
6N6G	Duotriode	7-AU	6.3	0.80	Power Amp	300 300	0.0 0.0	(Input Section) (Output Section)		8.0 45.0	 24,000♦	 2,400	 58	 7,000	 4,000
6N7, 6N7G	Duotriode	8-B	6.3	0.80	Power Amp Driver Driver	300 250 294	0.0 5.0 6.0		17.5 Per Plate, Class B Operation, Zero Signal 6.0 7.0		 11,300 11,000	 3,100 3,200	 35 35	8,000¶ (Class A (Class A	10,000 Driver) Driver)
6P5G, GT	Triode	6-Q	6.3	0.30	Amplifier Detector	250 250	13.5 20.0♦		5.0 (Plate Current to be adjusted to 0.2 Ma with no Input Signal)		9,500	1,450	13.8		
6P7G	Pent. Triode	7-U	6.3	0.30	Amplifier	Characteristics Same as Type 6F7, Except Capacitances									
6Q7	Duodiode Tri	7-V	6.3	0.30	Det.-Amp	100 250	1.5 3.0		0.35 1.1		88,000 58,000	800 1,200	70 70		
6Q7G GT	Duodiode Tri	7-V	6.3	0.30	Det.-Amp	Characteristics Same as Type 6Q7, Except Capacitances									
6R7	Duodiode Tri	7-V	6.3	0.30	Det.-Amp	250	9.0		9.5		8,500	1,900	16		
6R7G, GT	Duodiode Tri	7-V	6.3	0.30	Detector	Characteristics Same as Type 6R7, Except Capacitances									
6S7	Pentode	7-R	6.3	0.15	Amplifier	Characteristics Same as Type 6S7G, Except Capacitances									
6S7G	Pentode	7-R	6.3	0.15	Amplifier	135 250	3.0 3.0	67.5 100	3.7 8.5	0.9 2.0	1 Meg ♦ 1 Meg ♦	1,250 1,750	375 1,100		
6SA7	Heptode	8-R	6.3	0.30	Converter	100 250	2.0 2.0	100 100	3.3 3.5	8.5 8.5	500,000♦ 1.0 Meg ♦	425▲ 450▲			
6SA7GT G	Heptode	8-AD	6.3	0.30	Converter	Characteristics Same as Type 6SA7, Except Capacitances									
6SC7	Duotriode	8-S	6.3	0.30	Amplifier	250	2.0		2.0		53,000	1,325	70	(Each Triode)	
6SD7GT	Pentode	8-N	6.3	0.30	Amplifier	100 250	2.0 2.0	100 100	5.7 6.0	2.0 1.9	250,000♦ 1.0 Meg ♦	3,350 3,600			
6SF5	Triode	6-AB	6.3	0.30	Amplifier	250	2.0		0.9		66,000	1,500	100		
6SF5GT	Triode	6-AB	6.3	0.30	Amplifier	Characteristics Same as Type 6SF5, Except Capacitances									
6SJ7	Pentode	8-N	6.3	0.30	Amplifier	100 250	3.0 3.0	100 100	2.9 3.0	0.9 0.8	700,000♦ 1.5 Meg ♦	1,575 1,650			
6SJ7GT	Pentode	8-N	6.3	0.30	Amplifier	Characteristics Same as Type 6SJ7, Except Capacitances									
6SK7	Pentode	8-N	6.3	0.30	Amplifier	100 250	1.0 3.0	100 100	13.0 9.2	4.0 2.6	120,000♦ 800,000♦	2,350 2,000			
6SK7GT/G	Pentode	8-N	6.3	0.30	Amplifier	Characteristics Same as Type 6SK7, Except Capacitances									
6SQ7	Duodiode Tri	8-Q	6.3	0.30	Det.-Amp	250	2.0		0.9		91,000	1,100	100		
6SQ7GT G	Duodiode Tri	8-Q	6.3	0.30	Det.-Amp	Characteristics Same as Type 6SQ7, Except Capacitances									
6SR7	Duodiode Tri	8-Q	6.3	0.30	Det. Amp	250	9.0		9.5		8,500	1,900	16		
6T7G	Duodiode Tri	7-V	6.3	0.15	Det.-Amp	100 250	1.5 3.0		0.3 1.2		95,000 62,000	680 1,050	65 65		
6U5 6G5	Triode	6-R	6.3	0.30	Indicator	100§ 250§	(Series Plate Resistor 0.5 Meg., Target Current 1.0 Ma., Grid Bias −8.0 for 0° Shadow) (Series Plate Resistor 1.0 Meg Target Current 4.0 Ma., Grid Bias −22.0 for 0° Shadow)								
6U6GT	Tetrode	7-AC	6.3	0.75	Power Amp	110 200	10.5 14.0	110 135	44.0 55.0	4.0 3.0	10,000♦ 20,000♦	5,600 6,200		2,000 3,000	2,000 5,500
6U7G	Pentode	7-R	6.3	0.30	Amplifier	100 250	3.0 3.0	100 100	8.0 8.2	2.2 2.0	250,000 800,000	1,500 1,600			

*Applied through 250,000 ohms
#Per Tube or Section—No Signal
§Plate and Target Supply Voltage
**Triode Operation
‡‡Applied through 200,000 ohms
§§With Average Power Input of 320 Mw Grid to Grid
‡Pentode Operation
††For two tubes with 40 volts RMS applied to each grid
¶Plate to Plate
□Applied through 20,000 ohms
♦Approximate
▲Conversion Conductance
†50 Volts RMS applied to two grids

Type	Class	Base	Filament Rating Volts	Filament Rating Amps	Use	Plate Volts	Negative Grid Volts	Screen Volts	Plate Current Ma	Screen Current Ma.	Plate Resistance Ohms	Micromhos Mutual Conductance	Amplification Factor	Ohms Load for Stated Power Output	Undistorted Power Output Milliwatts
6V6GT G	Tetrode	7-AC	6.3	0.45	Power Amp	Characteristics Same as Type 7C5									
6V7G	Duodiode Tri	7-V	6.3	0.30	Det.-Amp.	135 180 250	10.5 13.5 20.0		3.7 6.0 8.0		11,000 8,500 7,500	750 975 1,100	8.3 8.3 8.3	25,000 20,000 20,000	75 160 350
6W7G	Pentode	7-R	6.3	0.15	Amplifier	250	3.0	100	2.0	0.5	1.5 Meg ♦	1,225			
6X5GT G	Duodiode	6-S	6.3	0.60	F-W Rect	325 A-C Volts per Plate, RMS, 70 Ma Output Current Condenser Input to Filter. 450 A-C Volts per Plate, RMS, 70 Ma Output Current Choke Input to Filter									
6Y5	Duodiode	6-J	6.3	0.80	F-W Rect	350 A-C Volts per Plate, RMS 50 Ma Output Current									
6Y6G	Tetrode	7-AC	6.3	1.25	Power Amp	135 200	13.5 14.0	135 135	58.0 61.0	3.5 2.2	9,300 18,300	7,000 7,100		2,000 2,600	3,600 6,000
6Y7G	Duotriode	8-B	6.3	0.60	Power Amp	180 250	0.0 0.0		7.5# 10.5#		(Class B Operation) (Class B Operation)			7,000¶ 14,000¶	5,500 8,000
6Z5	Duodiode	6 K	6.3 12.6	0.80 0.40	F-W Rect	230 A-C Volts per Plate, RMS, 60 Ma Output Current									
6ZY5G	Duodiode	6-S	6.3	0.30	F-W Rect	325 A-C Volts per Plate, RMS, 40 Ma Output Current Condenser Input to Filter									
6Z7G	Duotriode	8-B	6.3	0.30	Power Amp	135 180	0.0 0.0		3.0# 4.2#		(Class B Operation) (Class B Operation)			9,000¶ 12,000¶	2,500§§ 4,200§§
7A4	Triode	5-AC	6.3	0.30	Amplifier	90 250	0.0 8.0		10.0 9.0		6,700 7,700	3,000 2,600	20 20		
7A5	Tetrode	6-AA	6.3	0.75	Power Amp	110 125	7.5 9.0	110 125	40.0 44.0	3.0 3.3	14,000 17,000	5,800 6,000		2,500 2,700	1,500 2,200
7A6	Duodiode	7-AJ	6.3	0.15	Det.-Rect	150 A-C Volts per Plate, RMS, 8 Ma Output Current per Plate									
7A7	Pentode	8-V	6.3	0.30	Amplifier	100 250	1.0 3.0	100 100	13.0 9.2	4.0 2.6	120,000♦ 800,000♦	2,350 2,000			
7A8	Octode	8-U	6.3	0.15	Converter	100 250	3.0 3.0	75 100	1.8 3.0	2.7 3.2	650,000♦ 700,000♦	375▲ 550▲	(G2=100 V, 2.8 Ma) (G2=250 V □, 4.2 Ma)		
7B4	Triode	5-AC	6.3	0.30	Amplifier	100 250	1.0 2.0		0.4 0.9		85,000 66,000	1,150 1,500	100 100		
7B5	Pentode	6-AE	6.3	0.40	Power Amp	100 250 315	7.0 18.0 21.0	100 250 250	9.0 32.0 25.5	1.6 5.5 4.0	104,000 68,000 75,000	1,500 2,300 2,100		12,000 7,600 9,000	350 3,400 4,500
7B6	Duodiode Tri	8-W	6.3	0.30	Amplifier	100 250	1.0 2.0		0.4 0.9		110,000 91,000	900 1,100	100 100		
7B7	Pentode	8-V	6.3	0.15	Amplifier	100 250	3.0 3.0	100 100	8.2 8.5	1.8 1.7	300,000 750,000	1,675 1,750			
7B8	Heptode	8-X	6.3	0.30	Converter	100 250	1.5 3.0	50 100	1.1 3.5	1.3 2.7	600,000 360,000	360▲ 550▲	(G2=100 V, 2.0 Ma) (G2=250 V □, 4.0 Ma.)		
7C5	Tetrode	6-AA	6.3	0.45	Power Amp.	180 250 315	8.5 12.5 13.0	180 250 225	29.0 45.0 34.0	3.0 4.5 2.2	58,000 52,000 77,000	3,700 4,100 3,750		5,500 5,000 8,500	2,000 4,500 5,500
					Class AB_1	250 285	15.0 18.0	250 285	70.0 70.0	5.0 4.0	(Class AB_1 Two Tubes) (Class AB_1, Two Tubes)			10,000¶ 8,000¶	10,000 14,000
7C6	Duodiode Tri	8-W	6.3	0.15	Amplifier	100 250	0.0 1.0		1.0 1.3		100,000 100,000	850 1,000	85 100		
7C7	Pentode	8-V	6.3	0.15	Amplifier	100 250	3.0 3.0	100 100	1.8 2.0	0.4 0.5	1.2 Meg ♦ 2.0 Meg ♦	1,225 1,300			
7E6	Duodiode Tri	8-W	6.3	0.30	Amplifier	250	9.0		9.5		8,500	1,900	16		
7E7	Duodi Pent	8-AE	6.3	0.30	Amplifier	100 250	1.0 3.0	100 100	10.0 7.5	2.7 1.6	150,000♦ 700,000♦	1,600 1,300	36 42.5		
7F7	Duotriode	8-AC	6.3	0.30	Amplifier	100 250	1.0 2.0		0.65 2.3		62,000♦ 44,000♦	1,125 1,600	70 70		
7G7/1232	Pentode	8-V	6.3	0.45	Amplifier	250	2.0	100	6.0	2.0	800,000♦	4,500			
7H7	Pentode	8-V	6.3	0.30	Amplifier	100 250	1.0 2.5	100 150	8.2 9.5	3.3 3.5	250,000 800,000	3,800 3,800			
7J7	Tri.-Hexode	8-AR	6.3	0.30	Hex Mixer	100 250	3.0 3.0	100 100	1.1 1.3	3.1 2.9	300,000 1.5 Meg.	260▲ 300▲			
					Tri Osc	100 250♦	0.05 Meg. 0.05 Meg		3.7 5.4	(Triode Grid Current 0.3 Ma) (Triode Grid Current 0.4 Ma)					
7L7	Pentode	8-V	6.3	0.30	Amplifier	100 250	1.0 1.5	100 100	5.5 4.5	2.4 1.5	100,000♦ 1.0 Meg	3,000 3,100			
7N7	Duotriode	8-AC	6.3	0.60	Amplifier (One Unit)	90 250	0.0 8.0		10.0 9.0		6,700 7,700	3,000 2,600	20 20		
7Q7	Heptode	8-AL	6.3	0.30	Converter	100 250	2.0 2.0	100 100	3.3 3.5	8.5 8.5	500,000 1.0 Meg	525▲ {Osc Grid Resistor 20,000. 550▲ {Osc Grid Current 0.5 Ma.			
7R7	Diode-Pent	8-AE	6.3	0.30	Amplifier	100 250	1.0 1.0	100 100	5.5 5.7	2.2 2.1	350,000♦ 1.0 Meg ♦	3,000 3,200			
7S7	Tri.-Heptode	8-BL	6.3	0.30	Hep Mixer	100 250	2.0 2.0	100 100	1.9 1.8	3.0 3.0	500,000♦ 1.25 Meg ♦	500▲ 525▲			
					Tri. Osc	100 250♦	0.05 Meg 0.05 Meg		3.0 5.0	(Triode Grid Current 0.3 Ma) (Triode Grid Current 0.4 Ma)					
7V7	Pentode	8-V	6.3	0.45	Amplifier	300		150	10.0	3.9	300,000	5,800 (Cath Bias Resistor=160 Ohms)			
7W7	Pentode	8-BJ	6.3	0.45	Amplifier	Characteristics Same as Type 7V7, Except Capacitances									
7Y4	Duodiode	5-AB	6.3	0.50	F W Rect	325 A-C Volts per Plate, RMS, 60 Ma Output Current Condenser Input to Filter 450 A-C Volts per Plate, RMS, 60 Ma Output Current Choke Input to Filter									
7Z4	Duodiode	5-AB	6.3	0.90	F W Rect	325 A-C Volts per Plate, RMS, 100 Ma Output Current Condenser Input to Filter 450 A-C Volts per Plate, RMS, 100 Ma Output Current Choke Input to Filter									
10	Triode	4-D	7.5	1.25	Power Amp	250 350 425	23.5 32.0 40.0		10.0 16.0 18.0		6,000 5,150 5,000	1,330 1,550 1,600	8.0 8.0 8.0	13,000 11,000 10,200	400 900 1,600
12A	Triode	4-D	5.0	0.25	Det.-Amp	90 135 180	4.5 9.0 13.5		5.0 6.2 7.7		5,400 5,100 4,700	1,575 1,650 1,800	8.5 8.5 8.5	5,000 9,000 10,650	35 130 285
12A5	Pentode	7-F	12.6 6.3	0.30 0.60	Power Amp Power Amp	100 180	15.0 25.0	100 180	17.0 45.0	3.0 8.0	50,000♦ 35,000♦	1,700 2,400		4,500 3,300	800 3,400
12A7	Diode-Pent	7-K	12.6	0.30	Rectifier Amplifier	125 RMS 135	 13.5	 135	30.0 Max 9.0	 2.5	 102,000	 975	 100	 13,500	 550
12A8G, GT	Heptode	8-A	12.6	0.15	Converter	Characteristics Same as Type 6A8G									
12B8GT	Pentode Tri	8-T	12.6	0.30	Pent Amp Tri.-Amp	100 100	3.0 1.0	100	8.0 0.6	2.0	170,000 73,000	2,100	360 110	Pentode Section Triode Section	

*Applied through 250,000 ohms **Triode Operation ‡Pentode Operation ¶Plate to Plate ♦Approximate. ▲Conversion Conductance
#Per Tube or Section—No Signal ‡‡Applied through 200,000 ohms ††For two tubes with 40 volts RMS applied to each grid †50 Volts RMS applied to two grids.
§Plate and Target Supply Voltage. §§With Average Power Input of 320 Mw. Grid to Grid. □Applied through 20,000 ohms.

Type	Class	Base	Filament Rating		Use	Plate Volts	Negative Grid Volts	Screen Volts	Plate Current Ma	Screen Current Ma	Plate Resistance Ohms	Micromhos Mutual Conductance	Amplification Factor	Ohms Load for Stated Power Output	Undistorted Power Output Milliwatts
			Volts	Amps											
12C8	Pentode	8-E	12 6	0 15	R-F or I-F	Characteristics Same as Type 6B8									
12F5GT	Triode	5-M	12 6	0 15	Amplifier	Characteristics Same as Type 6F5G									
12J5GT	Triode	6-Q	12 6	0 15	Amplifier	Characteristics Same as Type 6J5GT/G									
12J7GT	Pentode	7-R	12 6	0 15	Amplifier	Characteristics Same as Type 6J7G									
12K7G, GT	Pentode	7-R	12 6	0 15	Amplifier	Characteristics Same as Type 6K7G									
12K8	Tri-Hexode	8-K	12 6	0 15	Converter	Characteristics Same as Type 6K8									
12Q7G, GT	Duodiode-Tri	7-V	12.6	0 15	Det-Amp	Characteristics Same as Type 6Q7G									
12SA7	Heptode	8-R	12 6	0 15	Converter	Characteristics Same as Type 6SA7									
12SA7GT G	Heptode	8-AD	12 6	0 15	Converter	Characteristics Same as Type 6SA7GT/G									
12SC7	Duotriode	8-S	12 6	0 15	Amplifier	Characteristics Same as Type 6SC7									
12SF5, GT	Triode	6-AB	12 6	0 15	Amplifier	Characteristics Same as Type 6SF5									
12SJ7	Pentode	8-N	12.6	0 15	Amplifier	Characteristics Same as Type 6SJ7									
12SJ7GT	Pentode	8-N	12 6	0 15	Amplifier	Characteristics Same as Type 6SJ7, Except Capacitances									
12SK7	Pentode	8-N	12 6	0 15	Amplifier	Characteristics Same as Type 6SK7									
12SK7GT/G	Pentode	8-N	12 6	0 15	Amplifier	Characteristics Same as Type 6SK7GT/G									
12SQ7	Duodiode Tri	8-Q	12 6	0 15	Det-Amp	Characteristics Same as Type 6SQ7									
12SQ7GT/G	Duodiode Tri	8-Q	12 6	0 15	Det-Amp	Characteristics Same as Type 6SQ7GT/G									
12SR7	Duodiode Tri	8-Q	12 6	0 15	Det-Amp	Characteristics Same as Type 6SR7									
12Z3	Diode	4-G	12 6	0 30	H-W Rect	235 A-C Volts per Plate, RMS, 55 Ma Output Current Condenser Input to Filter									
14A4	Triode	5-AC	12 6	0 15	Amplifier	90 250	0 0 8 0		10 0 9 0		6,700 7,700	3,000 2,600	20 20		
14A5	Tetrode	6-AA	12 6	0 15	Power Amp	250	12 5	250	30 0	3 5	70,000♦	3,000		7,500	2,800
14A7 12B7	Pentode	8-V	12 6	0 15	Amplifier	100 250	1 0 3 0	100 100	13 0 9 2	4 0 2 6	120,000♦ 800,000♦	2,350 2,000			
14B6	Duodiode Tri	8-W	12 6	0 15	Det-Amp	100 250	1 0 2 0		0 4 0 9		110,000 91,000	900 1,100	100 100		
14B8	Heptode	8-X	12 6	0 15	Converter	100 250	1 5 3 0	50 0 100	1 1 3 5	1 3 2 7	600,000 360,000	360▲ 550▲	(G2 = 100V, 2 0 Ma) (G2 = 250 V □, 4 0 Ma)		
14C5	Tetrode	6-AA	12 6	0.225	Power Amp	Characteristics Same as Type 7C5									
14C7	Pentode	8-V	12 6	0 15	Amplifier	100 250	1 0 3 0	100 100	5 7 2 2	1 8 0 7	325,000♦ 1 0 Meg ♦	2,275 1,575			
14E6	Duodiode Tri	8-W	12 6	0 15	Amplifier	250	9 0		9 5		8,500	1,900	16		
14F7	Duotriode	8-AC	12 6	0 15	Amplifier	100 250	1 0 2 0		0 65 2 3		62,000♦ 44,000♦	1,125 1,600	70 70		
14H7	Pentode	8-V	12 6	0 15	Amplifier	100 250	1 0 2 5	100 150	8 2 9 5	3 3 3 5	250,000♦ 800,000♦	3,800 3,800			
14J7	Tri Hexode	8-AR	12 6	0 15	Mixer Osc	Characteristics Same as Type 7J7									
14N7	Duotriode	8-AC	12 6	0 30	Amplifier (One Unit)	90 250	0 0 8 0		10 0 9 0		6,700 7,700	3,000 2,600	20 20		
14Q7	Heptode	8-AL	12 6	0 15	Converter	100 250	2 0 2 0	100 100	3 3 3 5	8 5 8 5	500,000 1 0 Meg	525▲ { Osc Grid Resistor 20,000 550▲ { Osc Grid Current 0 5 Ma			
14R7	Diode-Pent	8-AE	12 6	0 15	Amplifier	100 250	1 0 1 0	100 100	5 5 5 7	2 2 2 1	350,000♦ 1 0 Meg ♦	3,000 3,200			
14S7	Tri Heptode	8-BL	12 6	0 15	Mixer Osc	Characteristics Same as Type 7S7									
14W7	Pentode	8-BJ	12 6	0.225	Amplifier	Characteristics Same as Type 7V7, Except Capacitances									
14Y4	Duodiode	5-AB	12 6	0 30	F W. Rect.	325 A-C Volts per Plate, RMS, 70 Ma Output Current Condenser Input to Filter 450 A-C Volts per Plate, RMS, 70 Ma Output Current Choke Input to Filter									
15	Pentode	5-F	2 0	0 22	R-F Amp	67 5 135	1 5 1 5	67 5 67 5	1 85 1 85	0 3 0 3	630,000 800,000	710 750	450 600		
18	Pentode	6-B	14 0	0 30	Power Amp	Characteristics Same as Type 6F6G									
19	Duotriode	6-C	2.0	0 26	Power Amp	135 135 135	0 0 3 0 6 0		5 0 1 7 0 1		(Class B Operation) (Class B Operation) (Class B Operation)			10,000¶ 10,000¶ 10,000¶	2,100 1,900 1,600
20	Triode	4-D	3 3	0 132	Power Amp	90 135	16 5 22 5		2 8 6 0		7,800 5,850	450 600	3 5 3 5	9,600 6,500	50 130
22	Tetrode	4-K	3 3	0 132	R-F Amp	135	1 5	67 5	3 7	1 3	250,000	500	125		
24A, 24S	Tetrode	5-E	2 5	1 75	R-F Amp Detector	180 250 250*	3 0 3 0 5 0♦	90 0 90 0 20 to 45 (Plate Current to be adjusted to 0 1 Ma with no Input Signal)	4 0 4 0	1 7 1 7	400,000 600,000	1,000 1,050	400 630		
25A6GT/G	Pentode	7-S	25 0	0 30	Power Amp.	95 135 160	15 0 20 0 18 0	95 0 135 120	20 0 37 0 33 0	4 0 8 0 6 5	45,000 35,000 42,000	2,000 2,450 2,375		4,500 4,000 5,000	900 2,000 2,200
25A7GT/G	Diode-Pent	8-F	25.0	0 30	H-W Rect Power Amp	117 A-C Volts per Plate, RMS, 75 Ma Output Current 100	 15 0	 100	 20 5	 4 0	 50,000	 1,800		 4,500	 770
25AC5G,GT	Triode	6-Q	25 0	0 30	Power Amp Coupled Amp	110 165	+15 Bias from 6AE5GT G 46 0		45 0	 Dynamic Coupled with 6AE5GT/G Driver	15,200	3,800	58	 2,000	 2,000
25B6G	Pentode	7-S	25 0	0 30	Power Amp	105 200	16 0 23 0	105 135	48 0 62 0	2 0 1 8	15,500 18,000	4,800 5,000		1,700 2,500	2,400 7,100
25B8GT	Pentode Tri	8-T	25 0	0 15	Pent Amp Tri-Amp	100 100	3 0 1 0	100	7 6 0 6	2 0	185,000 75,000	2,000 1,500	370 Pentode Section 112 5 Triode Section		
25C6G	Tetrode	7-AC	25 0	0 30	Power Amp	Characteristics Same as Type 6Y6G									
25L6, G, GT	Tetrode	7-AC	25 0	0 30	Power Amp.	110 200	7 5 8 0	110 110	49 0 50 0	4 0 2 0	13,000 30,000	9,000 9,500		2,000 3,000	2,100 4,300
25Y5	Duodiode	6-E	25 0	0 30	H-W Rect	235 A-C Volts per Plate, RMS, 75 Ma Output Current per Plate									
25Z5	Duodiode	6-E	25 0	0 30	Doubler	Characteristics Same as Type 25Z6GT/G									
25Z6GT/G	Duodiode	7-Q	25 0	0 30	Doubler H-W Rect	117 A-C Volts per Plate, RMS, 75 Ma Output Current per Plate. 235 A-C Volts, RMS, 75 Ma Output Current per Plate									
26	Triode	4-D	1 5	1 05	Amplifier	90 135 180	7 0 10 0 14 5		2 9 5 5 6 2		8,900 7,600 7,300	935 1,100 1,150	8 3 8 3 8 3		
27, 27S	Triode	5-A	2 5	1 75	Amplifier Detector	90 135 180 250 250	6 0 9 0 13 5 21 0 30 0♦		3 0 4 7 5 0 5 2 (Plate Current to be adjusted to 0 2 Ma with no Input Signal)		10,000 9,000 9,000 9,250	900 1,000 1,000 975	9 0 9 0 9 0 9 0		

*Applied through 250,000 ohms.
#Per Tube or Section—No Signal
§Plate and Target Supply Voltage
**Triode Operation
‡‡Applied through 200,000 ohms
§§With Average Power Input of 320 Mw Grid to Grid
‡Pentode Operation
††For two tubes with 40 volts RMS applied to each grid
¶Plate to Plate
♦Approximate
□Applied through 20,000 ohms
▲Conversion Conductance
†50 Volts RMS applied to two grids

Type	Class	Base	Filament Rating Volts	Filament Rating Amps	Use	Plate Volts	Negative Grid Volts	Screen Volts	Plate Current Ma.	Screen Current Ma	Plate Resistance Ohms	Micromhos Mutual Conductance	Amplification Factor	Ohms Load for Stated Power Output	Undistorted Power Output Milliwatts
30	Triode	4-D	2 0	0 06	Det -Amp	90 135 180	4 5 9 0 13 5		2 5 3 0 3 1		11,000 10,300 10,300	850 900 900	9 3 9 3 9 3		
31	Triode	4-D	2 0	0 13	Power Amp	135 180	22 5 30 0		8 0 12 3		4,100 3,600	925 1,050	3 8 3 8	7,000 5,700	185 375
32	Tetrode	4-K	2 0	0 06	R-F Amp Detector	135 180 180	3 0 3 0 6 0♦	67 5 67 5 67 5	1 7 1 7 (Plate Current to be adjusted to 0 2 Ma with no Input Signal)	0 4 0 4	950,000 1 2 Meg	640 650	610 780		
32L7GT	Diode, Tet	8-Z	32 5	0 30	Rectifier Power Amp	125 RMS 110	 7 5	 110	60 40	 3 0	 15,000	 6,000	 81	 2,600	 1,000
33	Pentode	5-K	2 0	0 26	Power Amp	135 180	13 5 18 0	135 180	14 5 22 0	3 0 5 0	50,000 55,000	1,450 1,700	70 90	7,000 6,000	700 1,400
34	Pentode	4-M	2 0	0 06	R-F Amp	67 5 135 180	3 0 3 0 3 0	67 5 67 5 67 5	2 7 2 8 2 8	1 1 1 0 1 0	400 000 600 000 1 Meg	560 600 620	224 360 620		
35/51, 35S/51S	Tetrode	5-E	2 5	1 75	R-F Amp A-F Amp	180 250 250*	3 0 3 0 1 0	90 0 90 0 45 to 67 5	6 3 6 5 0 5	2 5 2 5	300,000 400,000 2 Meg	1,020 1,050	305 420		
35A5	Tetrode	6-AA	32 0	0 15	Power Amp	110 200	7 5 8 0	110 110	40 0 41 0	3 0 2 0	14,000♦ 40,000♦	5,800 5,900		2,500 4,500	1,500 3,300
35L6GT/G	Tetrode	7-AC	35 0	0.15	Power Amp	110 200	7 5 8 0	110 110	40 0 41 0	3 0 2 0	14,000♦ 40,000♦	5 800 5,900		2,500 4,500	1,500 3,300
35Y4	Diode	5-AL	32 0	0 15	H-W Rect	235 Max A-C Volts, RMS, 60 Ma Output Current with Panel Lamp 235 Max A-C Volts, RMS, 100 Ma Output Current without Panel Lamp									
35Z3	Diode	4-Z	35 0	0 15	H-W Rect	235 Max A-C Volts per Plate RMS, 100 Ma Output Current Condenser Input to Filter									
35Z4GT	Diode	5-AA	35 0	0 15	H W Rect	117 A-C Volts, RMS, 100 Ma Output Current Condenser Input to Filter									
35Z5GT/G	Diode	6-AD	35 0	0 15	H-W Rect	Characteristics Same as Type 40Z5 45Z5GT									
36	Tetrode	5-E	6 3	0 30	R-F Amp Detector	135 180 250 250	1.5 3 0 3 0 6 0♦	67 5 90 0 90 0 20 to 25 (Plate Current to be adjusted to 0 1 Ma with no Input Signal)	2 8 3 1 3 2	Not Over ⅓ of Plate Ma	575,000 500 000 550,000	1,000 1,050 1,080	475 525 595		
37	Triode	5-A	6 3	0 30	Amplifier	135 180 250	9 0 13 5 18 0		4 1 4 3 7 5		10,000 10,200 8,400	925 900 1,100	9 2 9 2 9 2		
38	Pentode	5-F	6 3	0 30	Power Amp	135 180 250	13 5 18 0 25 0	135 180 250	9 0 14 0 22 0	1 5 2 4 3 8	130,000 110,000 100,000	925 1,050 1,200	120 120 120	13,500 11,600 10,000	550 1,000 2 500
39/44	Pentode	5-F	6 3	0.30	R-F Amp A-F Amp	90 180 250 250*	3 0 3 0 3 0 1 0	90 0 90 0 90.0 67 5	5 6 5 8 5 8 0 5	1 6 1 4 1 4	375,000 750,000 1 Meg 2 Meg	960 1,000 1,050	360 750 1 050		
40Z5/ 45Z5GT	Diode	6-AD	45 0	0 15	H-W Rect	117 A-C Volts, RMS, 100 Ma Output Current without Panel Lamp Connected, or 60 Ma with Panel Lamp									
41	Pentode	6 B	6 3	0 40	Power Amp.	Characteristics Same as Type 6K6G									
42	Pentode	6-B	6 3	0 65	Power Amp	Characteristics Same as Type 6F6G									
43	Pentode	6-B	25 0	0 30	Power Amp	Characteristics Same as Type 25A6GT/G									
45	Triode	4-D	2 5	1 50	Power Amp	180 250 275	31 5 50 0 56 0		31 0 34 0 36 0		1,650 1,610 1,700	2,125 2,175 2,050	3.5 3 5 3 5	2,700 3,900 4,600	830 1,600 2 000
46	Tetrode	5-C	2 5	1 75	Power Amp	250 300 400	33 0 0 0 0 0	Tie Gs to P Tie Gs to G Tie Gs to G	22 0 4 0# 6 0#		2,380 (Class B Operation) (Class B Operation)	2,350	5 6	6,400 5,200¶ 5,800¶	1,250 16,000 20,000
47	Pentode	5-B	2 5	1 75	Power Amp	250	16 5	250	31 0	6 0	60,000	2,500	150	7,000	2,700
48	Tetrode	6-A	30 0	0 40	Power Amp	95 125	20 0 22 5	95 0 100	52 0 52 0	12 0 12 0	4,000 11 000	3,900 3 900	15 6 43	1,500 1,500	2,000 3,000
49	Tetrode	5-C	2 0	0 12	Power Amp	135 180	20 0 0 0	Tie Gs to P Tie Gs to G	6 0 2 0#		4,175 (Two Tubes Class B Operation)	1,125	4 7	11,000 12,000¶	170 3,500
50	Triode	4-D	7 5	1 25	Power Amp	300 350 400 450	54 0 63 0 70 0 84 0		35 0 45 0 55 0 55 0		2,000 1,900 1,800 1,800	1,900 2,000 2,100 2,100	3 8 3 8 3 8 3 8	4,600 4,100 3,670 4,350	1,600 2,400 3,400 4,600
50A5	Tetrode	6-AA	50.0	0 15	Power Amp.	110 200	7 5 8 0	110 110	49 0 50 0	4 0 1 5	10,000♦ 35,000♦	8,200 8,250		2,000 3,000	2,200 4,700
50C6G	Tetrode	7-AC	50 0	0 15	Power Amp	Characteristics Same as Type 25C6G									
50L6GT	Tetrode	7-AC	50 0	0 15	Power Amp	Characteristics Same as Type 25L6GT									
50Y6GT/G	Duodiode	7-Q	50 0	0 15	F-W Rect	Characteristics Same as Type 25Z6GT/G									
50Z7G	Duodiode	8-AN	50 0	0 15	Doubler H-W Rect	117 A-C Volts per Plate, RMS, 65 Ma Output Current per Plate With Current passing thru Panel Lamp Section 235 A-C Volts, RMS, 65 Ma Output Current									
53	Duotriode	7 B	2 5	2 00	Power Amp	Characteristics Same as Type 6A6									
55, 55S	Duodiode Tri	6-G	2 5	1 00	Det -Amp	Characteristics Same as Type 6V7G									
56, 56S	Triode	5-A	2 5	1 00	Amplifier Detector	250 250	13 5 20 0♦		5 0 (Plate Current to be adjusted to 0 2 Ma with no Input Signal)		9,500	1,450	13 8		
56AS	Triode	5-A	6 3	0 40	Amplifier	Characteristics Same as Type 56									
57, 57S	Pentode	6-F	2 5	1 00	Amplifier Detector	100 250 250*	3 0 3 0 4 3♦	100 100 100	2 0 2 0 (Plate Current to be adjusted to 0 1 Ma with no Input Signal)	0 5 0 5	1 Meg 1 Meg +	1,185 1,225			
57AS	Pentode	6-F	6 3	0 40	Amplifier	Characteristics Same as Type 57									
58, 58S	Pentode	6-F	2 5	1 00	Amplifier	100 250	3 0 3 0	100 100	8 0 8 2	2 2 2 0	250,000 800,000	1,500 1,600			
58AS	Pentode	6-F	6 3	0 40	Amplifier	Characteristics Same as Type 58									
59	Pentode	7-A	2 5	2 00	Power Amp	250** 250‡ 300 400	28 0 18 0 0 0 0 0	Tie Gs to P 250 Tie Gs to G and Su to P	26 0 35 0 20 0 26 0		2,300 40,000 (Class B Operation Two Tubes) (Class B Operation Two Tubes)	2,600 2,500	6 0 100	5,000 6,000 4,600¶ 6,000¶	1,250 3,000 15,000†† 20 000††
70L7GT	Diode-Triode	8-AA	70 0	0 15	Rectifier Amplifier	117 A-C Volts, RMS, 70 Ma Output Current Condenser Input to Filter 110	 7 5	 110	 40	 3 0	 15,000	 7,500		 2,000	 1,800
71A	Triode	4-D	5 0	0 25	Power Amp	90 135 180	16 5 27 0 40 5		10 0 17 3 20 0		2,170 1,820 1,750	1,400 1,650 1,700	3 0 3 0 3 0	3,000 3,000 4,800	125 400 790

*Applied through 250,000 ohms. **Triode Operation ‡Pentode Operation ¶Plate to Plate ♦Approximate ▲Conversion Conductance
#Per Tube or Section—No Signal ‡‡Applied through 200,000 ohms ††For two tubes with 40 volts RMS applied to each grid †50 Volts RMS applied to two grids
§Plate and Target Supply Voltage §§With Average Power Input of 320 Mw. Grid to Grid □ Applied through 20,000 ohms

Type	Class	Base	Filament Rating Volts	Filament Rating Amps	Use	Plate Volts	Negative Grid Volts	Screen Volts	Plate Current Ma	Screen Current Ma	Plate Resistance Ohms	Micromhos Mutual Conductance	Amplification Factor	Ohms Load for Stated Power Output	Undistorted Power Output Milliwatts
75, 75S	Duodiode Tri	6-G	6.3	0.30	Det.-Amp	250	2.0		0.9		91,000	1,100	100		
76	Triode	5-A	6.3	0.30	Amplifier Detector	250 250	13.5 20.0♦		5.0 (Plate Current to be adjusted to 0.2 Ma with no Input Signal)		9,500	1,450	13.8		
77	Pentode	6-F	6.3	0.30	Amplifier	100 250	1.5 3.0	60.0 100	1.7 2.3	0.4 0.5	600,000♦ 1.0 Meg.+	1,100 1,250			
78	Pentode	6-F	6.3	0.30	Amplifier	90 180 250	3.0 3.0 3.0	90.0 75.0 100	5.4 4.0 7.0	1.3 1.0 1.7	300,000♦ 1 Meg.♦ 800,000♦	1,275 1,100 1,450			
79	Duotriode	6-H	6.3	0.60	Power Amp.	180 250	0.0 0.0		7.5 10.5		(Class B Operation) (Class B Operation)			7,000¶ 14,000¶	5,500 8,000
80	Duodiode	4-C	5.0	2.00	F-W Rect.	350 A-C Volts per Plate, RMS 125 Ma. Output Current Condenser Input to Filter 500 A-C Volts per Plate, RMS, 125 Ma. Output Current Choke Input to Filter									
81	Diode	4-B	7.5	1.25	H-W Rect.	700 A-C Volts per Plate, RMS, 85 Ma. Output Current Condenser Input to Filter									
82	Duodiode	4-C	2.5	3.00	F-W Rect.	450 A-C Volts per Plate, RMS, 115 Ma. Output Current Condenser Input to Filter									
83	Duodiode	4-C	5.0	3.00	F-W Rect.	450 A-C Volts per Plate, RMS 225 Ma. Output Current Condenser Input to Filter									
83V	Duodiode	4-AD	5.0	2.00	F-W Rect.	375 A-C Volts per Plate, RMS, 175 Ma. Output Current Condenser Input to Filter									
84 6Z4	Duodiode	5-D	6.3	0.50	F-W Rect.	325 A-C Volts per Plate, RMS, 60 Ma. Output Current Condenser Input to Filter									
85	Duodiode Tri	6-G	6.3	0.30	Det.-Amp.	Characteristics Same as Type 6V7G									
85AS	Duodiode Tri	6-G	6.3	0.30	Det.-Amp.	250	9.0		4.5		16,000	1,250	20		
89	Pentode	6-F	6.3	0.40	Power Amp.	160** 180‡ 180	20.0 18.0 0.0	Gs & Su to P 180	17.0 20.0 3.0#	 3.0 Class B Opern. Tie Su to P & Gs to G (Two Tubes)	3,300 80,000	1,425 1,550	4.7 125	7,000 8,000 9,400¶	300 1,500 3,500
VR90-30	Diode	4-W	Voltage Regulator With Starting Voltage at 125 Operating Volts 90 Operating Current 10 Ma. Min., 30 Ma. Max.												
V99	Triode	4-E	3.3	0.063	Det.-Amp.	90	4.5		2.5		15,500	425	6.6		
X99	Triode	4-D	3.3	0.063	Det.-Amp.	90	4.5		2.5		15,500	425	6.6		
VR105-30	Diode	4-W	Voltage Regulator with Starting Voltage at 135, Operating Volts 105 Operating Current 5 Ma. Min., 30 Ma. Max.												
117L7/M7GT	Diode-Tet.	8-AO	117	0.09	H-W Rect. Power Amp.	117 A-C Volts, RMS, 75 Ma. Output Current Condenser Input to Filter 105	 5.2	 105	 43	 4.0	 17,000♦	 5,300		4,000	850
117N7GT	Diode-Tet.	8-AV	117	0.09	H-W Rect. Power Amp.	117 A-C Volts, RMS, 75 Ma. Output Current Condenser Input to Filter 100	 6.0	 100	 51	 5.0	 16,000♦	 7,000		3,000	1,200
117Z6GT/G	Duodiode	7-Q	117	0.075	Doubler	117 A-C Volts per Plate, RMS, 60 Ma. Output Current per Plate									
VR150-30	Diode	4-W	Voltage Regulator with Starting Voltage at 180 Operating Volts 150 Operating Current 5 Ma. Min. 30 Ma. Max.												
182B/482B	Triode	4-D	5.0	1.25	Power Amp.	250	35.0		20.0		2,500	2,000	5.0	4,500	1,350
183 483	Triode	4-D	5.0	1.25	Power Amp.	250	65.0		20.0		2,000	1,500	3.0	4,500	1,800
210-T	Triode	4-D	7.5	1.25	Power Amp.	(Standard Type 10 with Ceramic Base, See Type 10 Characteristics)									
485	Triode	5-A	3.0	1.25	Det.-Amp.	180	9.0		5.8		8,900	1,400	12.5		
864	Triode	4-D	1.1	0.25	Det.-Amp.	90 135	4.5 9.0		2.9 3.5		13,500 12,700	610 645	8.2 8.2		
950	Pentode	5-K	2.0	0.12	Power Amp.	135	16.5	135	7.0	2.0	125,000	1,000	125	13,500	575
1221	Pentode	6-F	6.3	0.30	Amplifier	Special Non-Microphonic Tube, Characteristics Same as Type 6C6									
1223	Pentode	7-R	6.3	0.30	Amplifier	"G" Equivalent of Type 1221 Above									
1231	Pentode	8-V	6.3	0.45	Pent.-Amp. Tet.-Amp.	300 300		150 150	10.0 12.0	2.5 0.5	700,000 540,000	5,500 6,500	3,850 Bias Rest. = 200 Ohms 3,500 Bias Rest. = 200 Ohms		
1612	Heptode	7-T	6.3	0.30	Mixer Amplifier	250 250	6.0 3.0	150 100	3.3 5.3	9.2 6.5	1 Meg.+ 600,000	350▲ 1,100	(G3 = Neg. 15 V.) (G3 = Neg. 3.0 V.)		
XXD	Duotriode	8-AC	12.6	0.15	Amplifier	250	10.0		9.0		7,600	2,100	16	(One Section)	
XXL	Triode	5-AC	6.3	0.30	Amplifier	250	8.0		8.0			2,300	20		

*Applied through 250,000 ohms. **Triode Operation. ‡Pentode Operation. ¶Plate to Plate. ♦Approximate. ▲Conversion Conductance.
#Per Tube or Section—No Signal. ‡‡Applied through 200,000 ohms. ††For two tubes with 40 volts RMS applied to each grid. †50 Volts RMS applied to two grids.
§Plate and Target Supply Voltage. §§With Average Power Input of 320 Mw. Grid to Grid. □Applied through 20,000 ohms.

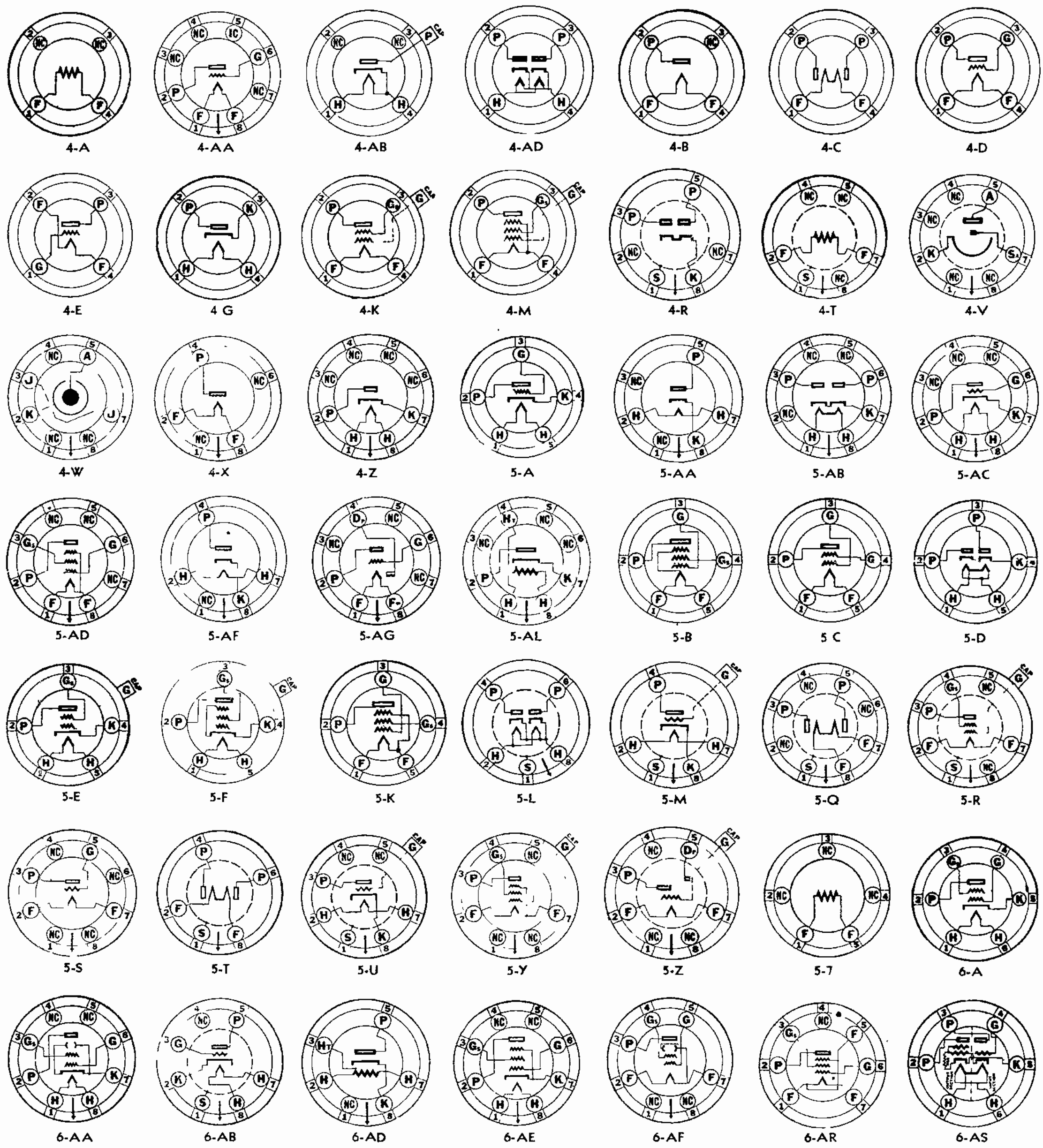
SYLVANIA PANEL LAMP CHARACTERISTICS

Type No.	Circuit Volts	Design Volts	Design Amp.	Bead Color	Bulb Style	Miniature Base	Usual Service	Type No.
S40	6-8	6.3	0.15	Brown	T-3¼	Screw	Radio Dials	S40
S41	2.5	2.5	0.50	White	T-3¼	Screw	Radio Dials	S41
S42	3.2	3.2	0.35	Green	T-3¼	Screw	Radio Dials	S42
S43	2.5	2.5	0.50	White	T-3¼	Bayonet	Radio Dials and Tuning Meters	S43
S44	6-8	6.3	0.25	Blue	T-3¼	Bayonet	Radio Dials and Tuning Meters	S44
S45	3.2	3.2	0.35	White	T-3¼	Bayonet	Radio Dials	S45
S46	6-8	6.3	0.25	Blue	T-3¼	Screw	Radio Dials and Tuning Meters	S46
*S47	6-9	6.3	0.15	Brown	T-3¼	Bayonet	Radio Dials	*S47
S48	2.0	2.0	0.06	Pink	T-3¼	Screw	Battery Set Dials	S48
*S49	2.0	2.0	0.06	Pink	T-3¼	Bayonet	Battery Set Dials	*S49
S50	6-8	7.5	0.20	White	G-3½	Screw	Auto Sets Flash Lights	S50
S51	6-8	7.5	0.20	White	G-3½	Bayonet	Auto Sets Auto Panels	S51
S55	6-8	6.5	0.40	White	G-4½	Bayonet	Auto Sets, Parking Lights	S55
S292	2.9	2.9	0.17	White	T-3¼	Screw	Radio Dials	S292
S292A	2.9	2.9	0.17	White	T-3¼	Bayonet	Radio Dials Coin Machines	S292A
S1455	18.0	18.0	0.25	Brown	G-5	Screw	Coin Machines	S1455
S1455A	18.0	18.0	0.25	Brown	G-5	Bayonet	Coin Machines	S1455A

*Sylvania Types S47 and S49 are interchangeable with Types 40A and 49A, respectively, in other brands.

TUBE AND BASE DIAGRAMS

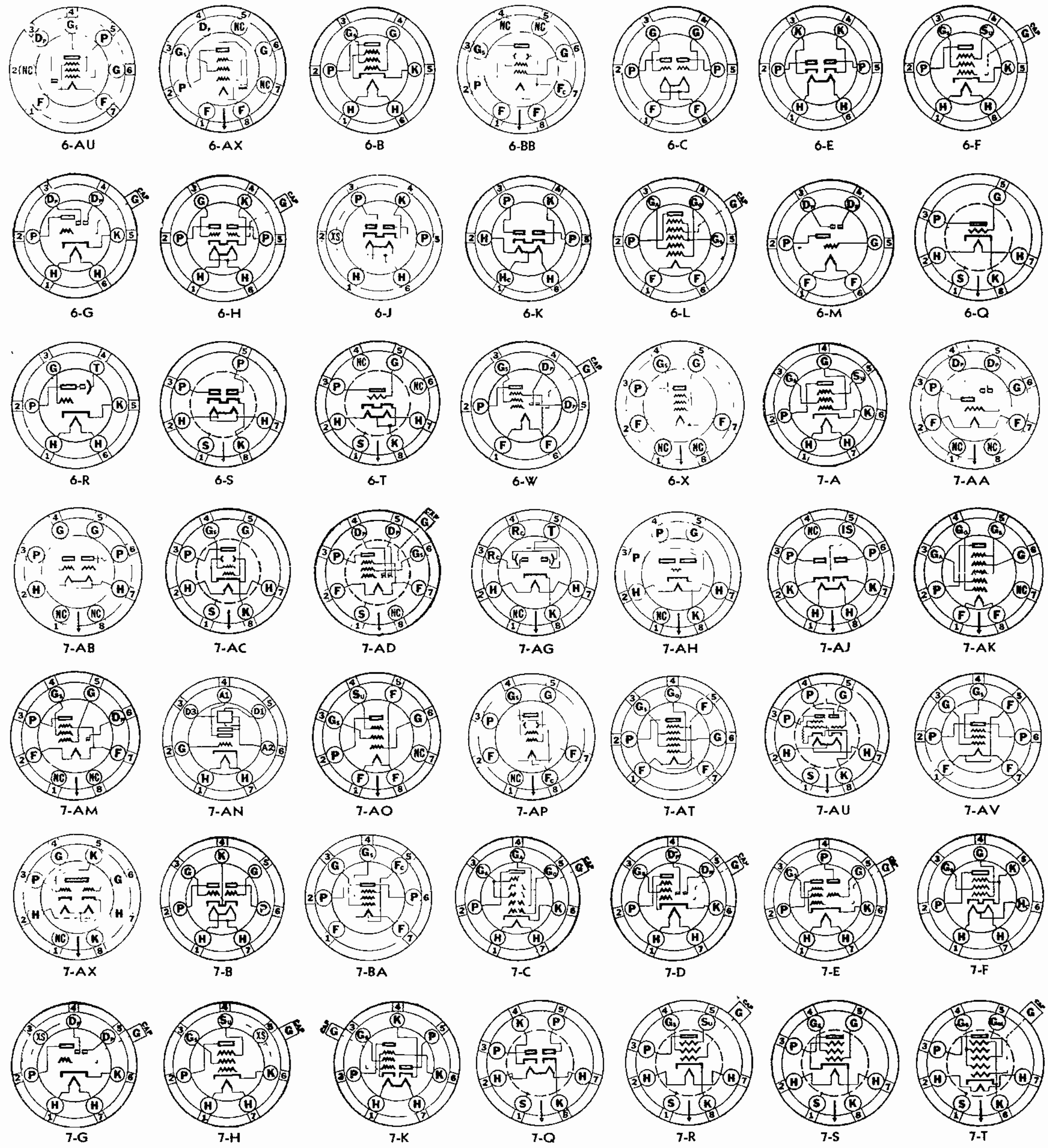
(Viewed From Bottom of Base—RMA Numbering System)



SYMBOLS A—Anode, A1—Anode 1, A2—Anode 2 D1—Deflector 1, D2—Deflector 2 D3—Deflector 3; D4—Deflector 4; D_P—Diode Plate; F—Filament; F_C—Filament Center, G—Control Grid, G_A—Anode Grid; G_M—Modulator Grid, G_O—Oscillator Grid, G_S—Screen Grid; H—Heater, H_C—Heater Center, H_T—Heater Tap, IC—Internal Connection, IS—Internal Shield, J—Jumper, K—Cathode NC—No Connection; P—Plate, R_C—Ray Control, S—Metal Shell, SA—Starter Anode, S_U—Suppressor Grid T—Target XS—External Shield, □—Top Cap, ——➤Locating Pin

TUBE AND BASE DIAGRAMS

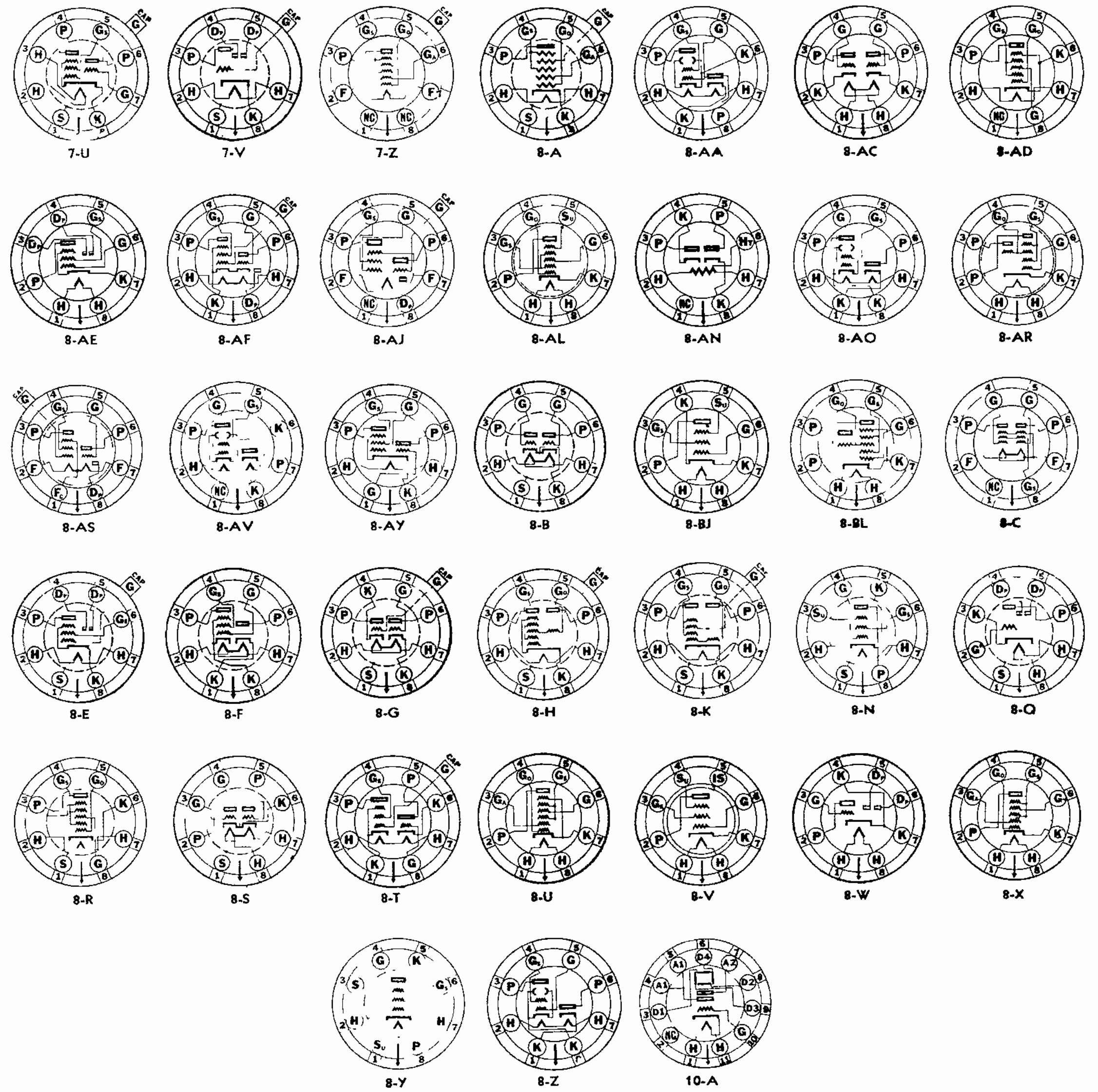
(Viewed From Bottom of Base—RMA Numbering System)—*Continued*



SYMBOLS A—Anode, A1—Anode 1; A2—Anode 2, D1—Deflector 1, D2—Deflector 2, D3—Deflector 3; D4—Deflector 4, Dp—Diode Plate, F—Filament, Fc—Filament Center, G—Control Grid, GA—Anode Grid, GM—Modulator Grid, Go—Oscillator Grid, Gs—Screen Grid, H—Heater, Hc—Heater Center; HT—Heater Tap, IC—Internal Connection; IS—Internal Shield, J—Jumper, K—Cathode, NC—No Connection, P—Plate; Rc—Ray Control; S—Metal Shell; SA—Starter Anode, Su—Suppressor Grid, T—Target; XS—External Shield, □—Top Cap, ——➤Locating Pin

TUBE AND BASE DIAGRAMS

(Viewed From Bottom of Base—RMA Numbering System)—*Continued*



SYMBOLS: A—Anode; A1—Anode 1, A2—Anode 2; D1—Deflector 1; D2—Deflector 2; D3—Deflector 3; D4—Deflector 4; Dp—Diode Plate; F—Filament; Fc—Filament Center, G—Control Grid, GA—Anode Grid; GM—Modulator Grid; Go—Oscillator Grid; Gs—Screen Grid; H—Heater; Hc—Heater Center; HT—Heater Tap, IC—Internal Connection, IS—Internal Shield; J—Jumper; K—Cathode; NC—No Connection; P—Plate; Rc—Ray Control; S—Metal Shell, SA—Starter Anode, Su—Suppressor Grid, T—Target; XS—External Shield; □—Top Cap; ——►Locating Pin

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LESSON TRA - 13
DETECTOR CIRCUITS

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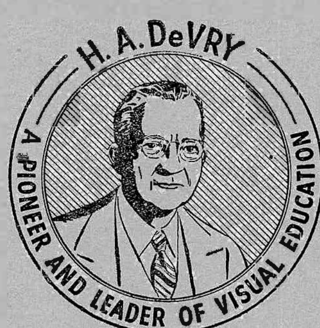

TUBES - RECEIVERS - AMPLIFIERS

Lesson 13

DETECTOR CIRCUITS

* * * *

Enthusiasm is hope, confidence in yourself, courage, determination to succeed, or at least to struggle on trying.

Enthusiasm includes courage in its meaning.

Enthusiasm lost, everything lost —— better you were never born.

——— Arthur Brisbane

In an earlier Lesson on Radio Principles, we explained a type of simple receiver which used no tubes but had a detector made of a crystalline metal such as Galena, Silicon or Carborundum. A fine wire point, known as a "Cat Whisker" was moved around the surface of the metal until a sensitive spot was found.

This arrangement operated as a rectifier or demodulator of high frequency Radio waves and was known as a "Crystal Detector". Due to its greater sensitivity, the triode type of vacuum tube rapidly replaced the crystal detector but, in later models of Radio Receivers, the triode has been largely replaced by the diode type of tube. None of these various types of detectors are obsolete and recently, a new, improved type of crystal has been placed on the market.

As all Radio Receivers, from the simplest to the most elaborate, require a detector, we are going to spend this Lesson in explaining them.

Their action can be shown quite simply by the arrangement of Figure 1 where we have a crystal detector in a circuit with a battery and sensitive milliammeter. Connected by the solid lines, the meter will register the current in the circuit but, with the crystal connections reversed, as indicated by the dotted lines, the meter will read little if any current.

This action of the meter tells us, with current in one direction, the crystal offers a low resistance but with current in the other direction, has an extremely high resistance. This principle holds for all types of detectors, or rectifiers, and can be thought of as the change in current when an equal voltage is applied to unequal resistances.

In Figure 1 for example, the battery voltage remains the same but the value of current is changed by reversing the connections to the crystal. The change of current is caused by the difference of resistance in the crystal.

VACUUM TUBE RECTIFIER

To make use of this principle, the earliest vacuum tubes were diodes and had but two elements, the filament or cathode and plate. A circuit with a tube of this type is shown in Figure 2 and, when the filament is heated, electrons are drawn to the positive plate. When the plate is negative, the electrons are repelled and driven back toward the filament.

Because a flow of electrons is considered as a current of electricity, there will be current in the plate circuit, only when the plate is positive. Connecting a diode tube as in Figure 2, during the alternation in which the upper wire is positive, there will be current in the direction of the arrows. During the next alternation, the plate will be negative, the electrons will be repelled and therefore there will be no plate current.

Although connected to an a-c supply, current in the supply circuit of Figure 2 will not be alternating. While changing in value with the changes of a-c voltage, the current will be in the direction of the arrows only and is called a pulsating direct current.

That is the action of modern rectifier tubes which are used in the power supplies of and Radio and other Electronic equipment. However, we are interested in detectors at this time and the diode tube of Figure 2 will produce a detector action like the crystal of Figure 1.

Perhaps the best way to see the entire action is by drawing a curve like that of Figure 3. Imagine we have the arrangement of Figure 2 but with an ammeter and voltmeter in the plate circuit. Instead of an a-c supply, this time we have d-c arranged so that we can make the plate either negative or positive, in respect to the filament, at any desired voltage.

Following the general plan used for three element tubes, we plot the plate current against the plate voltage. No actual values are shown because we are interested only in the general shape of the curve.

Starting over at the left, with negative plate voltage, the plate current is zero. As the negative voltage is reduced, the current still remains at zero. As soon as the plate voltage is positive, there is plate current and, as the positive voltage is increased, the plate current increases also. Notice however, the plate current does not increase in exact proportion to the voltage. It starts slowly but then increases at a faster rate to form the bend in the lower part of the curve.

Keep this in mind as we will have more to say about it later. Notice also, the similarity between this curve and the grid voltage-plate current curve previously explained for a three element radio tube.

MODULATION

To fully understand the detector action, you must have a clear idea of the form of radio wave reaching the receiver. In case you have forgotten, Figure 4 at A, represents the high frequency carrier wave produced by the oscillator at the Broadcasting Station and sent out from the transmitting antenna.

For the Broadcast band, the frequency of this wave will be somewhere between 550,000 and 1,600,000 cycles but, as we explained in the earlier Lessons, our ears will not respond to these high frequencies. Notice also, the carrier waves all have equal amplitude and will not produce any sound even if tuned in with a good receiver.

Audio frequency, or sound waves, having a lower frequency, change less rapidly and usually are of an irregular shape. The curve at B, Figure 4 is an example of a simple form of sound wave.

In order that the high frequency carrier waves will transmit signals, they are modulated and a modulated carrier wave is simply a combination of waves A and B, Figure 4, which can be shown by the form at C.

Notice here, the carrier wave of A is still used and has the same frequency but the amplitude of the waves is varied so that a dotted line, drawn along the wave crests, has the shape of the audio wave at B. The modulated carrier wave of Figure 4C is the form which reaches the detector which operates to change the wave back to the audio form of B.

As its name implies, the carrier wave is used to carry the audio frequencies from the transmitting to the receiving station and the detector, or demodulator, changes the modulated carrier waves back to the low frequency audio waves.

CHARACTERISTIC CURVES

To follow a modulated carrier wave through a three element radio tube we are going to use the characteristic curves explained in the earlier Lessons on tubes. In Figure 5, we show the usual grid voltage-plate current curve and you will see there is a plate current of 3 ma., with zero grid voltage. As the grid is made positive, the plate current increases but, with the grid negative, the plate current is reduced and drops to zero at about $5\frac{1}{2}$ volts. Notice here, the lower part

of the curve is about the same as the positive half of Figure 3.

To follow the action, in the upper center of Figure 5 we have drawn a sine wave to represent an alternating voltage which is applied to the grid. Reading down to the grid voltage scale, you will find this sine wave curve has a maximum value of 2 volts.

Starting at the top of this curve, with 0 grid voltage, there will be a plate current of 3 ma. Following the curve down, it goes to 2 volts negative which, as shown by the grid-voltage-plate current curve, reduces the plate current to $1\frac{1}{4}$ ma.

Then, as the voltage curve comes back to zero, the plate current increases to 3 ma. but, when the voltage curve reaches a value of 2 volts positive, the plate current has increased to $4\frac{3}{4}$ ma.

Plotting these values, we draw the curve at the right and find it has the same general shape as the voltage curve. Or saying it in another way, an alternating voltage applied to the grid will produce an alternating variation of current in the plate circuit.

The important point to notice here is that equal alternations of grid voltage produce equal changes of plate current.

Starting at zero grid voltage with a plate current of 3 ma. 2 volts negative reduces the plate current $1\frac{3}{4}$ ma. In the same way, when the grid is 2 volts positive, the plate current increases $1\frac{3}{4}$ ma., from the 3 ma. at zero grid voltage.

When the voltage wave of Figure 5 is like that of Figure 4-A, the changes of plate current take place so rapidly that no sound is heard in the speaker. From an electrical standpoint, as these rapid changes are equal, the average plate current will not change and therefore will not operate any sound producing device.

One trouble with conditions, as shown in Figure 5, is caused by the fact that the grid is positive part of the time. When the grid is positive it allows grid current which produces a voltage drop in the grid circuit and causes distortion of the wave.

To remedy this trouble, in Figure 6 we have placed a 3 volt negative bias on the grid but, to keep the values about the same as in Figure 5, have moved the curve so

that we still have a plate current of 3 ma. at zero grid voltage. The negative grid voltage is secured by the use of a C battery or bias resistor.

Now, comparing Figures 5 and 6, you can see that like values of grid voltage produce like changes of plate current, but in Figure 6, with the 3 volts negative grid bias, the average plate current is but $1\frac{3}{4}$ milliamperes.

With a maximum value of 2 volts, the a-c signal of Figure 5 causes the grid voltage to vary from 2 volts negative to 2 volts positive for a total change or "swing" of 4 volts. With the 3 volts negative grid bias of Figure 6, 4 volts swing of the signal varies the total grid voltage from 5 volts negative to 1 volt negative. Thus, although the signal voltage is the same in both cases, the bias voltage of Figure 6 prevents the signal from driving the grid positive.

As shown by the heavier lines, every change in grid voltage can be carried to the characteristic curve to find the corresponding value of plate current. Notice however, in both Figures 5 and 6, we are operating on the straight part of the characteristic curve, above the bend at the lower end. Increasing the plate voltage lengthens the straight part of the curve and therefore, the voltage swing of the grid can be increased without causing distortion.

IDEAL DETECTOR

If we could build a tube, or other device, having a perfect straight line for the entire length of its voltage-current characteristic curve, we would have a perfect rectifier. The curve of the diode tube, shown in Figure 3, comes close but the slope of the curve changes at the lower end. This change in slope is found in all present day detectors and, to a certain extent, determines the amount of distortion.

For Figure 7, we have drawn the grid voltage-plate current curve of an imaginary perfect rectifier. Here the curve is a straight line with the same degree of slope for its entire length. In order to make a comparison to Figure 6, we show zero plate current with 3 volts negative on the grid.

Here, with the grid held at negative 3 volts and the 2 volt a-c wave impressed as before, the negative values of the a-c voltage can not cause a reduction of plate current. When the a-c voltage is positive,

the plate current increases and, because the curve is a straight line, the amount of increase is in proportion to the change of voltage.

As shown in Figure 7, the a-c voltage is rectified and there is current in the plate circuit only during the positive alternation of each cycle of grid voltage. With the straight line curve, there is a true wave form without distortion.

Without the a-c voltage on the grid, the value of plate circuit current is zero but, when the a-c voltage is applied, there is plate current during the positive alternations. Therefore, the effect of the a-c grid voltage is to increase the plate current to an average value as shown by the dotted line just below .5 ma.

In the curves of Figure 5 and 6, an a-c voltage, like that of Figure 4-A, will not change the average value of plate current but, in Figure 7, will cause an increase of the average value of plate current.

In Figure 8, again we have the curve of Figure 7 but this time, are going to impress the modulated wave of Figure 4-C on the grid. Each positive alternation of voltage causes an increase of plate current the same as before but, as these positive alternations are of different strengths, or amplitudes, the changes of plate current will also vary. This time, the average plate current will also vary and its changes of value will follow the shape of the modulation voltage.

Remember, we show only a few of the high frequency waves because, in actual preactice, it requires several thousand carrier waves to make up the modulated wave of Figure 4-C. Keeping this in mind, you can easily understand that the separate peaks of plate current, shown in Figure 8, can not be followed but, the average plate current will vary like the lower shaded area.

In other words, the values of the average plate current vary so as to form a wave exactly like the original signal used to modulate the carrier wave. A speaker, or other sound producing unit, connected in the plate circuit now, will respond to these audio frequency changes of average plate current and reproduce signals the same as those which modulated the carrier waves.

The curves of Figures 7 and 8 show imaginary detectors with perfect action. In practice, we do not have these ideal conditions but approach them by three general methods.

DIODE DETECTOR

In present day receivers, the "Diode Detector" is perhaps the most common method of demodulation. This type of detector makes use of a two element, or diode, tube and for a simplified explanation of the action, we will refer you back to Figure 2.

For this explanation however, we want you to assume a resistor "R1" is used as a load and replaces the lower wire between the filament and the a-c supply. It will possibly help you to follow our explanation by actually drawing this load, R1, on Figure 2.

As R1 is in series with the tube, all the current in the plate circuit must pass through it and thus the voltage drop across it will be in proportion to the current and the ohmic value of the load. With an a-c supply, there will be current only in the direction of the arrows and the voltage drop across R1 will be in the form of pulsating d-c In other words, this voltage drop across R1 will be similar in shape to the positive alternations of the applied a-c as shown in the lower right of Figures 7 and 8.

Connected in parallel or across R1 a condenser of the proper value will charge on the peaks of these voltage pulses and discharge as the voltage decreases. This will tend to maintain a steady d-c voltage across R1 and it may help you to think of the charging and discharging action of the condenser as filling in the gaps between the positive alternations.

To establish the idea of this simplified explanation more firmly in your mind, we will use the same circuit again, but will assume the modulated carrier of Figure 4C is applied as the a-c source.

Analyzing the wave of Figure 4-C, you will notice that the peaks vary in amplitude. Thus, when applied to the plate of Figure 2, the peak values of current in the circuit will also vary and cause the peak values of voltage drop across R1 to vary in accordance with the input voltage. Without taking the condenser action into consideration, the wave form across R1 will be similar to the positive alternations of the carrier of Figure 4C, with varying degrees of amplitude, dropping to zero after each alternation.

However, by the charge and discharge action explained above, the condenser keeps the voltage from dropping to zero and tends to maintain the voltage drop across

R1 at the peak values. The result is a final waveform similar to the broken line shown across the tops of the positive alternations of Figure 4C.

This broken line conforms to the shape of the original sound wave of Figure 4B and thus the above circuit has achieved the purpose of a detector which is to separate the original sound from the carrier. You can see however, in order to accomplish this action, the condenser must be large enough to smooth out the high frequency variations yet small enough to have no appreciable effect on the audio variations.

In practical diode detectors, it is found necessary to provide a filter with the general arrangement shown in Figure 9. We want you to assume the combinations of C1-L1 and C2-L2 form the primary and secondary of the last **i-f** transformer in a superheterodyne receiver, resistors R1 and R2 form the load while condensers C3 and C4 give the needed condenser action and at the same time, in combination with R1, form a high frequency filter.

The action here is the same as previously explained for Figure 2 and assuming L2 of Figure 9 as the voltage source, when the plate is positive in respect to the cathode, the current will be from the plate, to cathode, to ground and, to complete the circuit, from ground up through R2 and R1 to the lower end of L2.

Therefore the rectified voltage appears across R1 and R2 but, as R1 is part of the filter, the audio voltage across it is lost and the useable A.F. is that which appears across R2. This signal is then applied, through a coupling condenser, to the grid of the first **a-f** amplifier tube. A filter like that in Figure 9, reduces the useful output voltage by the ratio $R1/(R_1 + R_2)$ as a result of the voltage drop in R1. Due to this ratio, it is common practice to make R2 several times the value of R1.

The diode method of demodulation has the advantage over other methods in that its characteristic more closely approaches that of the ideal detector and thus produces less distortion. It has the disadvantages that it does not amplify the signal and draws current from the input circuit thereby reducing its selectivity.

However, because the diode method of detection produces less distortion and, as we will explain in a later Lesson, permits the use of simple automatic

volume control circuits without the necessity of an additional voltage supply, it is most widely used in broadcast radio receivers.

GRID BIAS DETECTORS

A second method of demodulation uses a three element tube with a negative grid bias and is called, "Grid Bias Detector", "Plate Detector", or "Plate Rectification".

To understand the action, in Figure 10 we again have a grid voltage-plate current curve, similar to those already explained but, this time, have used values of plate and grid bias voltage which cause the tube to operate on the lower bend of the curve.

In our former explanations we told you that, to avoid distortion, like values of positive and negative grid voltage must produce equal changes of plate current and therefore the tubes are operated on the straight part of the curve. To make the tube operate as a detector, we adjust the voltage values and make it work on the bend of the curve because in effect, we want distortion.

Comparing the curves of Figure 6, 7 and 10, each has a negative grid bias of 3 volts but, for Figure 10, the plate voltage has been reduced until we have but 2 ma in the plate circuit at zero grid voltage.

As far as the a-c signal voltage is concerned, the 3 volts negative can be considered as zero, and again we have an a-c wave with a maximum of 2 volts. When the a-c grid voltage is zero, the 3 volt bias allows a plate current of but .45 ma. When the a-c is 2 volts negative, the grid is 5 volts negative and the plate current is reduced to .12 ma. Checking up, you will find an increase of 2 volts negative on the grid reduces the plate current by .33 ma.

With the a-c signal 2 volts positive, in combination with the 3 volt bias, the grid is 1 volt negative which, according to the curve, allows a current of 1.25 ma. Checking up here, an increase of 2 volts positive on the grid increases the plate current by .8 ma.

From these values, you can see that like changes of grid voltage cause unequal changes of plate current and the wave is distorted. The changes of plate current are plotted at the lower right of Figure 10 and show the distortion very clearly because the lower

loop is much shorter than the upper loop.

Notice also, without an a-c voltage on the grid, the value of plate current is at the dotted line A. When an a-c voltage is applied, the positive alternations cause an increase of plate current greater than the reduction caused by negative alternations of equal value. For that reason, the a-c grid voltage causes an increase of the average plate current. However, if the a-c voltage waves are at Radio frequency and all of equal amplitude, the average plate current will remain at a constant value and therefore will not operate a speaker.

Using the curve of Figure 10 and the Modulated wave of Figure 8, we have drawn the curves of Figure 11. Notice here, that while few of the negative a-c grid voltages reduce the plate current to zero, they cause but a small change in proportion to the positive a-c voltages.

The result is the wave at the lower right in which the average current has the same general wave form as that of Figure 6. While not a perfect rectifier, the detector of Figure 11 distorts the a-c grid voltage waves to such an extent that the changes of average plate current are at the same frequency as those which originally modulated the carrier wave.

GRID BIAS DETECTOR CIRCUIT

So far, we have done our explaining by means of characteristic curves but, in Figure 12, we have the circuits for producing the action of Figure 11. A signal, with a waveform like that of Figure 4-C, is connected to coil L1 and, by mutual induction, appears in the resonant circuit made up of coil L2 and the variable condenser C.

The negative grid bias is secured by means of resistor R1 and its by-pass condenser C1, connected in series with the cathode circuit. In order that the tube act as a detector, values of grid bias and plate voltage are used to make it operate on the lower bend of the curve as explained for Figure 10.

As we explained for Figures 5 and 6, the grid should never become positive in respect to the cathode therefore, it is necessary to have the bias voltage of a value equal to, or a little greater than, the maximum signal voltage on the grid. The number of amplifier stages ahead of the detector will, in a great measure,

control the signal voltage. Then, with the proper value of grid bias, the plate voltage is adjusted until the tube operates at the proper point of its curve.

Earlier in the training, we gave you a table of tube characteristics, in which you will find the correct values of voltage on the different elements of a tube in order for it to operate as a bias detector or amplifier. By applying these voltages, the tube will operate on the desired portion of the characteristic curve.

Looking at the plate current curve of Figure 11, you will find that the variations appear in the form of pulses which occur at the carrier frequency applied to the grid circuit. Therefore we think of the detector plate circuit as carrying some Radio or Carrier frequency as well as signal or audio frequencies.

As explained for Figure 9, the action is improved by a filter which "smooths out" these high frequency variations and, in many cases, a condenser connected in the position of C2, Figure 12, is sufficient. Because of its action, it is known commonly as a "By-Pass" condenser and thought of as forming a low reactance path to "ground" the high frequencies.

The modulation, or sound signal, is developed across the load resistance R2 from which it is applied to the grid of the first a-f amplifier through a coupling condenser and grid load which form a resistance coupled stage.

GRID LEAK DETECTORS

The third method of demodulation is accomplished by means of a grid leak and condenser, the circuits of which are shown in Figure 14. It is more sensitive than the grid bias detector because it acts as an amplifier as well as a detector and its action can be shown best by means of the curve of Figure 13 where we have plotted the grid current against the grid voltage.

In our former explanations we told you that, with a negative grid voltage, there was no grid current. However, by using a sufficiently sensitive meter and measuring in "Microamperes", we find an extremely small current and can plot the curve. A microampere is equal to one millionth of an ampere and as the curve of Figure 13 shown but 2 microamperes at zero grid

voltage and zero grid current at 6 volts negative, for most explanations this extremely small current need not be considered.

While not exactly correct, we have drawn the curve of Figure 13 like that of Figure 10 to show that like changes of grid voltage cause unequal changes of grid current.

Looking at the circuits of Figure 14, the radio frequency voltage, induced in the tuned circuit L2-C is impressed on the grid circuit which includes resistance R1, with condenser C1 across it, in series with the grid. Condenser C2 and resistor R2 have the same action as explained for C2 and R2 of Figure 12.

The grid current, shown by the curve of Figure 13, will travel from the grid, to the cathode inside the tube and, to complete the circuit, back through L2 and the grid resistor R1 of Figure 14. As we have told you many times, current in a resistance causes a voltage drop and here, with the direction of current toward the grid, the voltage drop across R1 will make the grid negative in respect to the cathode.

In the arrangement of Figure 12, the grid circuit includes input coil L2, tuned by condenser C, the grid, the cathode and bias resistor R1 with its by pass condenser C1. The voltage drop across R1, caused by the plate current in it, provides the negative grid bias voltage of the proper value.

In the arrangement of Figure 14, the grid circuit includes the same components but resistor R1, with its by pass condenser C1, have been taken out of the plate circuit and placed in series with the grid. While this general action is the same as explained for Figure 12, here, R1 will carry grid current only but, as before, the voltage drop across it provides the negative grid bias. Looking at the curve of Figure 13, there is a grid current of less than $\frac{1}{2}$ microampere at the operating point "A" of 3 volts negative on the grid. Assuming the current to be $\frac{1}{2}$ microampere, it will require a resistance of 6,000,000 ohms, or 6 megohms to cause a drop of 3 volts. Therefore, if R1 of Figure 14 has a value of 6 megohms, conditions in the grid circuit will be as shown by the curve of Figure 13.

As we mentioned before, the curve of Figure 13 was drawn to compare with those of Figures 10 and 11 and does not represent actual values of any particular

type of tube. Although the action is the same, in actual circuits, the resistor in the position of R1 Figure 14, has a value of 1 megohm to 2 megohms and its known as a "Grid Leak". Remember, the value of the grid leak determines the operating point of the tube as shown at "A", Figure 13.

GRID CONDENSER VALUES

So far, the action in the grid circuit of Figure 14 compares closely to that shown by the curves of Figure 11 if we substitute grid current for plate current. Then, if you will imagine R1 and R2 of Figure 9 are replaced by a single resistor, with C3 and C4 replaced by single condenser, the diode circuit has components identical to those of the grid circuit of Figure 14. The only difference is that the condenser-resistor combination of Figure 9 is in the "low" or grounded side of the circuit, while in Figure 14, it is in the "high" or grid side of the circuit. However, the action will be the same in both cases therefore, the variations of voltage across R1, Figure 14 will compare with those across the load resistor R2, Figure 9.

As previously explained, these variations of current occur as high frequency pulsations and it is customary to provide a condenser to "smooth them out". Grid condenser C1, Figure 14, is used for this purpose and, operates on the general plan explained for the circuit of Figure 9.

To provide the proper filtering action and yet have no appreciable effect on the signal or audio frequencies, in most circuits of this type, the grid condenser capacity is usually .0001 mfd .00025 mfd or .0005 mfd.

DETECTOR ACTION

In effect therefore, the grid circuit of Figure 14 acts as a diode detector, the output or signal voltage appearing across the grid cathode of the tube. As previously explained, this grid voltage controls the plate circuit to cause corresponding changes of plate current. Therefore the tube acts as an amplifier as well as a detector or demodulator.

Keeping all of the actions in mind, when a signal voltage is impressed on the grid, it causes changes of grid current as shown by the curves of Figure 13, Like the action explained for Figure 11, the average value of grid current will vary in accordance to the signal frequency of the modulated carrier wave.

As the grid current increases, there is a greater voltage drop across the grid leak and thus a greater negative grid bias. This increase of negative grid voltage causes a decrease in plate current. Therefore the plate current will have the same signal frequency as the grid current but will reduce as the grid current increases.

For the grid bias detector of Figure 12, the signal voltage on the grid causes an increase of plate current. For the grid leak detector, the signal voltage on the grid causes a decrease of plate current. For the grid leak detector however, the changes of grid voltage cause corresponding changes of plate current the same as explained for the amplifier tubes.

You will find the action of the grid leak detector is often explained by means of the Electron Theory without any mention of grid current. For example, if the grid leak of Figure 14 is omitted, condenser C1 will prevent any direct current in the grid circuit. As the signal voltage is impressed on it, the grid is first positive and then negative in respect to the cathode. While positive, it attracts electrons, but when negative there is little if any attraction.

These electrons cause the grid to become negatively charged and each time the signal voltage makes the grid positive, more electrons are attracted and the charge is increased. As condenser C1 prevents the electrons from escaping, the negative charge on the grid increases. The usual tube action takes place and the negative grid reduces the plate current.

If allowed to continue, the negative grid charge would increase and reduce the plate current to such a low value the tube would not operate. Connected across the grid condenser, the high resistance grid leak forms a leakage path for the electrons, allowing them to escape and thus the grid loses its negative charge and returns to normal, or zero potential.

Being used as a leakage path for the electrons, the grid leak can be connected across the condenser, as shown in Figure 14, or connected from the grid to the cathode.

SENSITIVITY

Due to its amplifying action, the grid leak detector is more sensitive than the grid bias, or plate detector, and in general, the steepness, or slope of the grid

voltage-plate current curve determines the amplification. Therefore, the steeper the slope, the greater the sensitivity.

While not as sensitive, the bias and diode detectors have the advantage of being able to handle stronger signals without distortion. In general, you will find grid leak detectors used for weaker signal voltages but, where the signal is built up with several stages of high frequency amplification, the bias and diode detectors are employed.

POWER DETECTORS

Although there has been a great deal of advertising, electrically there is no exact meaning for the term, "Power Detector". A power detector uses the same type of tubes and circuits we have explained in this Lesson. To improve the tone quality and reduce noises of receivers, many designers decided that but one stage of audio amplification should be used therefore the detector output has to be increased to secure sufficient volume.

The so called "power detector" is designed to handle an input signal of several volts without distortion and the only difference between ordinary and power detectors is in the strength of the signals that can be handled. While both the grid leak and grid bias types types are used as power detectors, the diode type is perhaps the more common. It has the natural ability to handle stronger signals and, with a high gain, high frequency amplifier between it and the antenna, this lack of sensitivity does not affect the sensitivity of the receiver.

LINEAR DETECTION

A linear detector resembles the ideal detector of Figure 7. It is operated on the straight part of its curve and produces changes in output current which are proportional to the changes of input voltage.

There are no perfect linear detectors because all have a certain amount of bend in their characteristic curves. For weak signals, the detection is as we have explained but, for strong signals, the action approaches that of Figure 7 and gives "straight line" or linear detection.

The advantages of power detectors are important enough to make their use worth while. By applying a stronger signal, linear detection is obtained and distortion reduced. Using but one stage of audio amplification, distortion is further reduced and because most of the amplification in a Receiver is at high frequency, hum, tube noises and other interference is reduced.

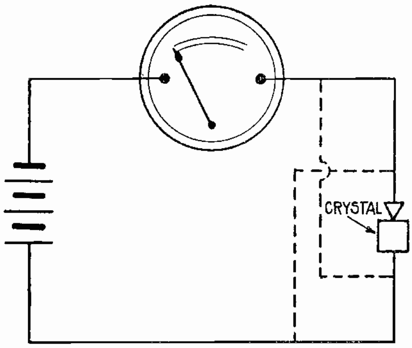

FIGURE 1

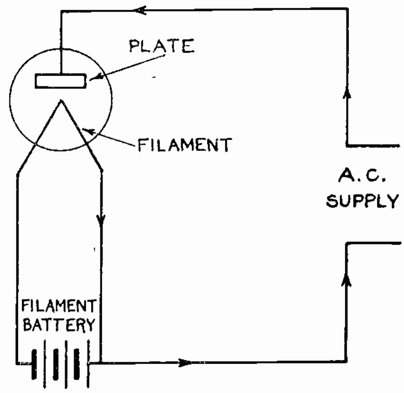

FIGURE 2

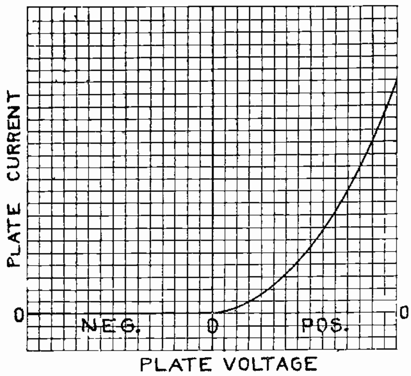

FIGURE 3

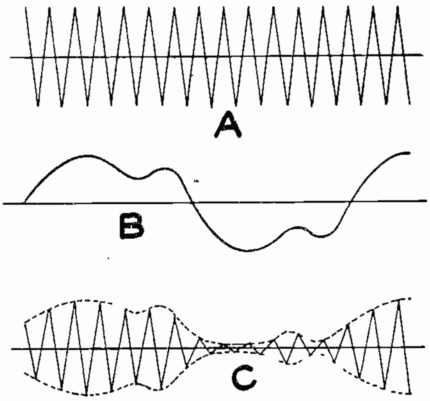

FIGURE 4

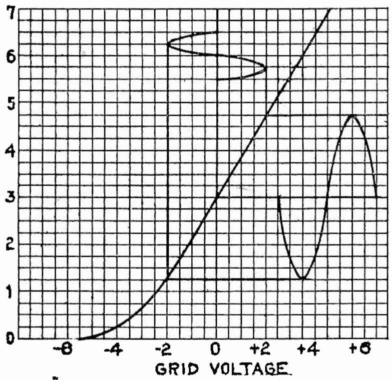

FIGURE 5

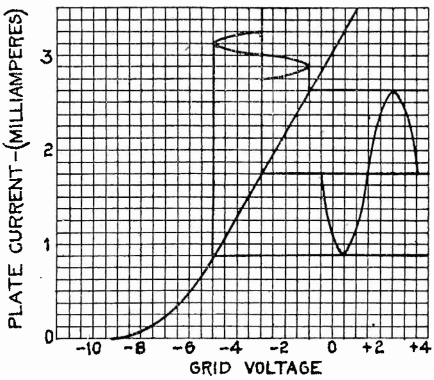

FIGURE 6

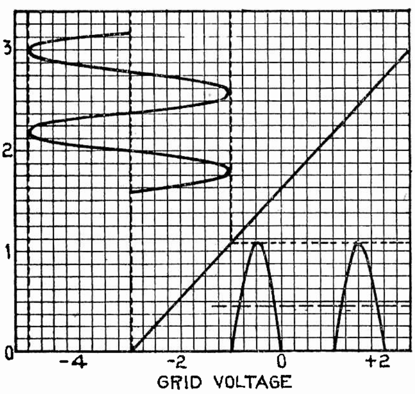

FIGURE 7

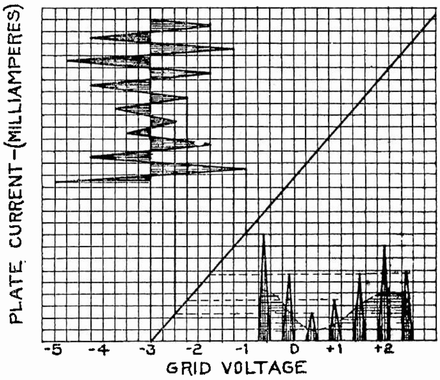

FIGURE 8

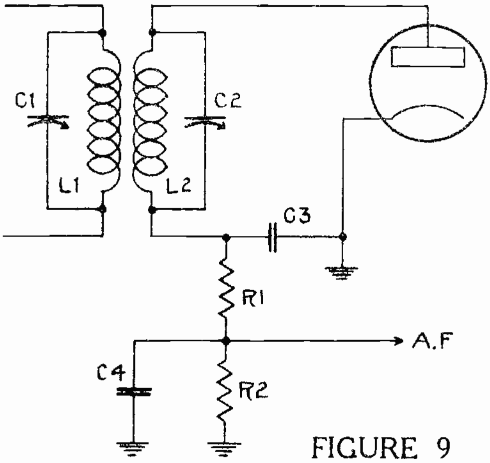

FIGURE 9

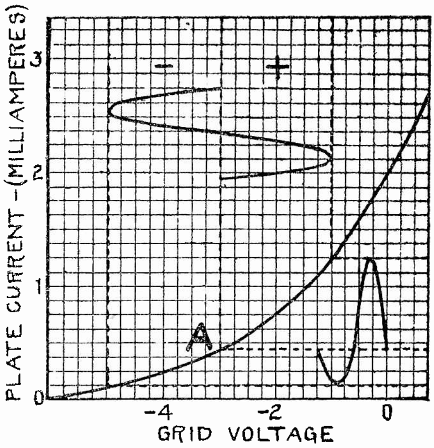

FIGURE 10

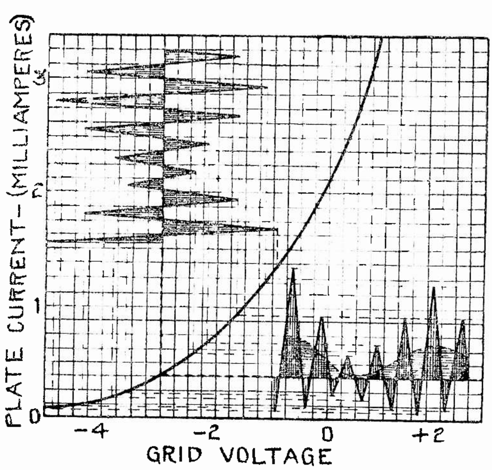

FIGURE 11

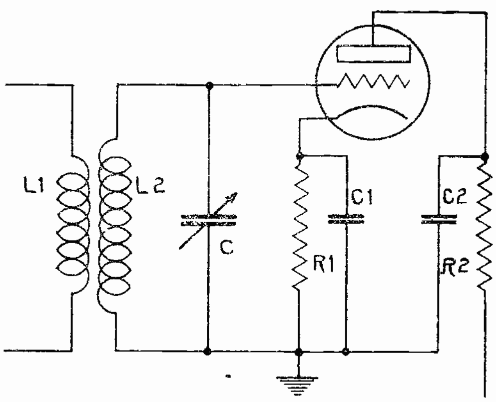

FIGURE 12

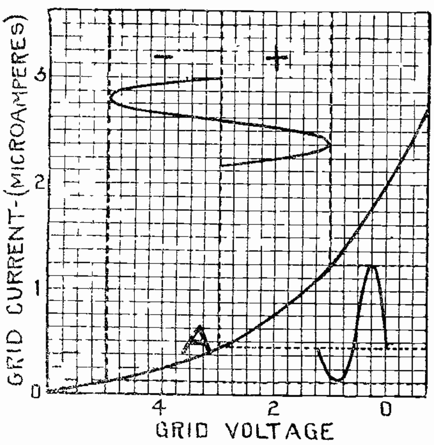

FIGURE 13

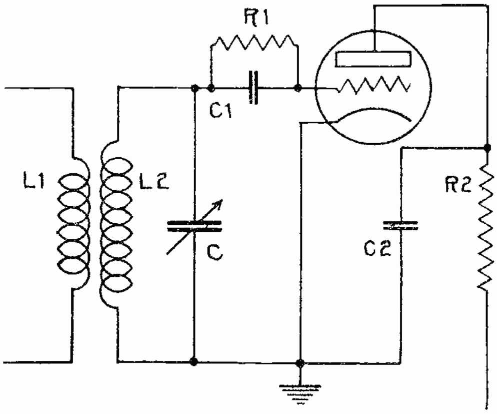

FIGURE 14

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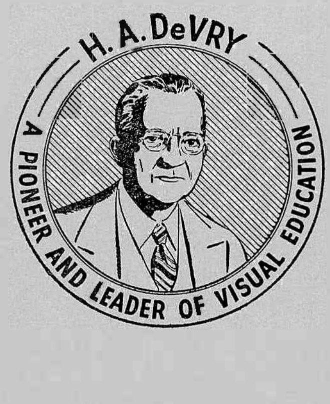


TUBES- RECEIVERS - AMPLIFIERS

LESSON TRA-14

ANTENNAS

* * * * *

I love the man that can smile in trouble, that can gather strength from distress, and grow brave by reflection. 'Tis the business of little minds to shrink but he whose heart is firm, and whose conscience approves his conduct, will pursue his principles unto death.

—— Thomas Paine

ANTENNAS

In the early days of Radio Broadcasting, the sensitivity of the Receivers and the power of the Transmitters were so low that, for satisfactory reception, most Radio Receiver owners found it necessary to erect an outdoor antenna. Since that time, the sensitivity of the Receivers has been increased to a point that, with the high power Broadcasting Stations now in operation, outdoor antennas have almost disappeared.

The adoption of "CHAIN" Broadcasting has also been a factor because today, most desirable programs are put on the air by stations in all parts of the country, making it possible to tune them in most anywhere even with a comparatively insensitive Receiver. Therefore, as far as broadcast reception is concerned, the subject of antennas has been given but minor consideration.

However, the present trend of development is toward the use of higher carrier frequencies which in most cases, require some special form of antenna to provide satisfactory reception. Today, the general public appreciates that an outdoor antenna is needed to bring in the distant Short Wave Stations while many advertisements of Frequency Modulation and Television Receivers emphasize this same need for those services.

For this Lesson, therefore, we want to expand our former simple explanation of Radio Energy radiated in space and give you a few details in regard to its behavior.

WAVE PROPAGATION

Reviewing our former explanations, when a varying voltage is applied across an ordinary wired circuit, the current varies in proportion to the voltage and sets up a magnetic flux which varies in proportion to the current. In turn, the varying magnetic flux induces an E.M.F. which can be thought of as an electric field.

Thus, if the voltage variations are thought of as waves moving along a wire, the action produces a moving electric field, corresponding to the current changes, and a moving magnetic field, produced by the variations of current. In one of papers written nearly 100 years ago, James Clark Maxwell pointed out that a changing electric field is equivalent to a current and therefore can produce a magnetic field directly, without any intermediate steps. By the same reasoning, a changing magnetic field can produce an electric field.

In the former Lesson on Radio Principles, we told you how the presence of a high frequency antenna current sort of pushed the electric and magnetic fields out into space and their action, combined with that given above, will explain the radiation of energy through space without wires or conductors.

Used in this respect, the word space usually refers to regions, like those between the earth and sun which, with the exception of meteors and other widely separated bodies, are considered as a vacuum. From this standpoint, instead of living on the surface of the earth, we are located at the bottom of an ocean of air, which completely surrounds the more solid center, and is estimated to have a depth of several hundred miles.

The recent tests of receiving Radio waves reflected by the moon prove that Radio energy can penetrate this ocean of air and travel through interspace. However, practically all of the Radio energy in use today travels only in this ocean of air.

In the level at which we live, the air is under comparatively high pressure, 14.7 lbs per square inch at sea level, and rates as one of the best electrical insulators. At higher levels, the air pressure is greatly reduced, making it possible for the ultra violet, and other radiations from the sun, to ionize a large proportion of the atoms which make up the air.

As explained in the earlier Lessons, when an electron is knocked off, an atom becomes an ion, has a positive charge and, to regain its balance, will recapture an electron as soon as possible. In the lower levels of the atmosphere, the pressure forces the particles of air together so closely that an ion collides almost immediately with an electron and thus becomes an atom or molecule again.

Due to this action, and also because most of the ultra violet radiations are absorbed in the upper atmosphere, there is very little ionization in the layer of air between sea level and an altitude of about 30 miles. However, at higher levels, where the molecules of air are more widely separated, the collisions between them occur less frequently and thus an ion may retain its charge for comparatively long periods of time.

As a result, the upper regions of the air contain ionized layers which, unlike ordinary air, act as electrical conductors and change the direction of Radio waves which strike them. We speak of these as layers because the different gasses, which make up the atmosphere, ionize at different altitudes because of the different pressures.

Then, due to the variation of radiation from the sun, the number of these layers, as well as their height, vary from hour to hour, day to day, week to week, and year to year.

THE IONOSPHERE

Due to their bending or refraction of Radio waves, it is possible to measure the height of the various layers and, in general the region in which they occur is known as the "IONOSPHERE". The layers are identified by letter and, in general, are as shown in Figure 1, with the following characteristics:

B layer - A rather small and scattering layer, about 6 to 18 miles high, assumed to be due to the pressure of water vapor or ice in the upper atmosphere.

C layer - A reflecting or scattering layer, 22 to 44 miles high which is assumed in order to explain the action of some radio signals.

D layer - A region of absorbing ionization, 30 to 55 miles high, thought to be formed by hydrogen, bursts from the sun. It may cause complete absorption of short waves but result in improved long wave transmission.

E layer - The Kennely-Heaviside layer, the most regular of the ionized regions in the ionosphere, extending from about 55 miles to 85 miles in height. Its density increases from zero before dawn to maximum at noon and decreases to zero after sunset.

F layer - The upper ionized layer of the ionosphere, extending at night from about 110 miles to 250 miles, is caused by the ultra-violet radiation from the sun. In the day time, it divides into two parts, the lower, or F_1 layer extending from 90 miles to 155 miles while the upper, or F_2 layer extends from 155 miles to 248 miles. In winter its range is from about 90 miles to 190 miles.

Layers B, C, and D, existing only at comparatively low levels, are of relatively small importance compared to the effects of the E and F layers.

WAVES IN SPACE

It has been determined that the waves, radiated from the antenna of a Broadcast Station, divide into two main parts. One part, which travels comparatively close to the earth's surface, is known as the "ground-wave", while the other part, radiated

upward, travels through the ionosphere and is called the "sky-wave".

The ground wave is absorbed, or attenuated quite rapidly, as it travels away from the antenna and dies out after a comparatively short distance. This attenuation varies with the frequency of the carrier, therefore the higher the frequency, the shorter the distance of ground wave travel. In general, only those receivers located at comparatively short distances from the Transmitting Station can pick up the ground wave, and thus it is useful mainly for short distance communication.

Our present day distance transmission of Radio energy is possible because the sky waves are refracted by the ionized layers in the upper regions of the atmosphere. Although refraction is the proper word, the explanations can be simplified by thinking of waves as being reflected by the ionized layers.

To illustrate the action, at the lower left of Figure 1, we show a Broadcast Station antenna and by lines "a", "b", and "c" have indicated sky waves radiated upward at different angles. The high angle of wave "a" permits it to penetrate the lower layers but, at the higher layers its direction is changed. However, before the change of direction has become very great, the wave passes the center of the refracting layer where the bending action reverses and changes the direction back toward the original angle. As a result, the wave passes on upward and is lost.

Wave "b", with a lower angle, has its direction changed at a lower level than wave "a" and, due to the difference of angle, it does not penetrate the refracting layer but is reflected back to the earth which it reaches at point "2". Wave "c", with a still lower angle, is reflected by a lower layer and returns to earth at point "3". As indicated in the drawing, these waves may be reflected by the earth and travel back up into the ionosphere to be reflected back to earth again.

Following the surface of the earth, and starting from the Broadcast Station, the ground wave extends to point "1" and receivers in this area would receive the signals. Assuming wave "b" to represent the highest angle which will reflect back to earth, a receiver at point "2" could receive the signals, but no signals could be heard between points 1 and 2. As shown by wave "c", lower angle waves also return to earth and thus waves at all angles, between "b" and "c" return to earth between points 2 and 3. Therefore, receivers in this area could hear the signals.

The space between points 1 and 2 is called the "Skip Zone" because no signals are heard in this area. Neglecting the effect of the ground wave, the space such as that between the Station and point 2 is called the "Skip Distance".

We have already mentioned that the ionized layers vary in both height and density therefore, looking at Figure 1, you can see that any such change may vary the skip distance. Those variations cause the common types of fading which are common in short wave reception.

Another cause of fading is due to the fact that a signal may reach a receiver by two different paths. Following waves "b" and "c" of Figure 1 for a number of reflections between the earth and the ionosphere, you can see they may reach the earth at the same point but one path would include more "jumps" than the other. Or, a change in the ionized layer might cause wave "b" to be reflected back to earth at point 1, so that a receiver at that location would receive signals by both the sky wave and the ground wave. As the waves travel at the same speed and the two paths are of different lengths, the signals may arrive out of phase, to cause a reduction of signal or arrive in phase to cause an increase of signal.

It has also been found that the length of the waves, or frequency of the signal, has an important effect on the angle of reflection of the sky waves. As the frequency is increased, the angle of reflection also increases until finally, due to the curvature of the earth, the waves do not return and are lost.

Thus, for the higher frequencies, above 30 mc, the sky waves are not reflected back to the earth. In addition, the ground wave is shorted out by the earth and therefore the transmission of signals depends almost entirely upon waves which travel in straight lines from the antenna of the Transmitting Station to that of the Receiver. This is known commonly as direct "line of sight" transmission.

To illustrate this action, for Figure 2 we show the curved surface of the earth with the transmitting antenna at the left and three receiving antennas at different distances from it. The waves are indicated by the straight lines "a" and "b".

Wave "a" intercepts the antenna of Receiver 1 but, travelling in a straight line, is far above the antennas of Receivers 2 and 3. Wave "b", which just clears the surface of the earth, intercepts the antenna of Receiver 2, but the antenna of Receiver 3 must be considerably higher to reach the path of the wave. Thus, the actual distance that the signal can be transmitted and received depends upon the height of the antenna.

Wave "b" touches the surface of the earth at the Horizon because, looking from the top of the transmitting antenna, this point is a part of the line on which the earth and sky appear to meet. Therefore, the usual service area of the transmitter of this type is often said to extend only to the horizon. Actually, redeption can be obtained a distance beyond the horizon because the waves are bent slightly by the conditions of the atmosphere with a result similar to that of the ionized layers of the upper regions. Also, the high frequency waves are slightly bent or "Diffracted" by obstacles in their path.

Neglecting these variations and assuming the surface of the earth to be smooth or flat, the distance from the top of the transmitting antenna to the horizon can be calculated by the following formula.

$$\text{Distance (in miles)} = 1.224\sqrt{\text{Antenna height in feet}}$$

ANTENNA WAVELENGTH

Now that we have given you a general idea of what happens to the transmitted waves in space, we want to explain what takes place when these waves cut through a conductor which can be considered as an antenna. Reviewing briefly, all energy of this type travels at the rate of 300,000,000 meters or 186,000 miles per second and the relationship between frequency and wavelength is stated usually by the equation

$$\text{Wavelength (meters)} = \frac{300,000,000}{\text{Frequency (cycles)}}$$

To make a comparison with the explanations of the earlier Lessons, we will assume the common commercial frequency of 60 cycles and, substituting in the equation above, find the wavelength is

$$\text{Meters} = \frac{300,000,000}{60} = 5,000,000$$

Now, as 1609 meters equal one mile,

$$5,000,000 \text{ Meters} = \frac{5,000,000}{1609} = 3107 \text{ miles}$$

As shown in Figure 3, you can think of the wave as traveling around a circuit but, for a length of 100 miles, as indicated by the vertical parallel lines, the amplitude will vary according to the curve but, at any instant, the amplitude will be about uniform for the 100 mile section. That is why we consider uniform conditions of current and voltage in our circuit explanations.

In contrast, we will assume a frequency of 30,000,000 cycles or 30 megacycles and, proceeding as before,

$$\text{Meters} = \frac{300,000,000}{30,000,000} = 10$$

Then, as one meter equals 3.28 feet,

$$10 \text{ Meters} = 10 \times 3.28 = 32.8 \text{ feet}$$

As shown in Figure 4, if a voltage of this frequency is applied to a circuit 100 feet long, it will contain a trifle more than three complete waves. This means that the voltage will not be only of different value but of opposite polarity at different points of the circuit. Therefore, it becomes necessary to modify our ideas of voltage and current as applied to **d-c** and low frequency **a-c** circuits.

We know that high frequency energy will travel through space, without the aid of wires or conductors, by means of the electric and magnetic fields. Therefore we consider the action to be much the same in the case of a circuit except that the fields center around the wire which acts as a sort of a guide to carry the energy from the source to the load. For a **d-c** circuit, we think of current in but one direction and here, in comparison, we can think of the energy as traveling with the waves.

Suppose we have a wire suspended in space, with both ends completely insulated, and that it is cut by the passing waves of energy radiated from a transmitting antenna. Thinking of these as voltage waves, they can be represented by the "Incident" curve of Figure 5 which is similar to one cycle of the curves of Figures 3 and 4.

When it reaches the end of the insulated wire, the voltage wave acts much like a water wave which strikes a solid obstacle and backs up as a reflected wave. At the start, the amplitude of the reflected wave is the same as that of the incident wave at the stopping point and therefore it can be represented by the "Reflected" curve of Figure 5. Thus, while the incident and reflected waves travel in opposite directions, at the ends of the wire, their polarity and amplitude is the same.

Traveling at the same speed, but in opposite directions, these waves will aid each other at some points and oppose at other points, therefore the action can be shown by algebraically adding the instantaneous amplitudes to find the "total" curve of Figure 5 which thus represents the total voltage.

As in any other circuit, the voltage of Figure 5 will cause a current and, to see what happens, we have drawn the curves of Figure 6. Here you will find the "Incident" wave is the same as that of Figure 5 and the current varies with the voltage. However, at the end of the circuit, the current path stops therefore, at this point, the current must have a zero value.

Compared to a water wave, we think of the current as traveling to the end and then reversing in polarity as well as direction of wave travel. Looking at the right hand side of Figure 5, the incident wave is rising from its lowest, or most negative value and, although reversing the direction of travel, the reflected wave continues to rise from the lower value.

At the right side of Figure 6, the incident current wave is also rising from its lowest, or most negative value but, as current cannot pass this point, the reflected wave must neutralize the incident wave. To show this action in the form of curves, the reflected wave is given a value equal to that of the incident wave, but of opposite polarity.

Following the plan of Figure 5, the incident and reflected waves were added to find the value of the total curve of Figure 6 which, you will notice, is 90° out of phase with the total curve of Figure 5.

Should you plot curves, like those of Figures 5 and 6, for incident curves of different phase angles, you would find the values of the total curves vary from maximum positive to maximum negative but, in respect to the length of the wire, the position of these values does not change.

Thus, the total wave varies in amplitude but does not travel along the wire and therefore is known as a "Standing" wave.

In order to cause this action, the length of the wire must have a definite relation to the wave length of the transmitted energy. For Figures 5 and 6, the wire is equal to one wavelength and the action can be compared to that in a resonant circuit. Notice also, in both Figures 5 and 6, if the wires were cut in half, the curves would remain as shown.

Following the explanations of the earlier Lessons, it is possible to describe the constants of circuits in terms of inductance and capacity but, for the conditions we have been explaining, it is more convenient to think of them in terms of fundamental frequency or wavelength. In the case of a straight wire, such as an antenna, its length is inversely proportional to its lowest resonant frequency, which is known as its fundamental wavelength or frequency.

To illustrate this action, for Figure 7 we have combined the curves of Figures 5 and 6 to show the standing waves of current and voltage as they occur on a wire which is one wavelength long. In comparison, Figure 8 shows the same curves for a wire which is a "half wave" often called a Hertz, and one known as a Marconi which is a "quarter wave" in length. As the half wave is a very common condition, we want you to notice carefully that the current has zero value at the ends, with maximum amplitude at the center while the voltage has maximum amplitude at the ends with zero value at the center. The points of maximum amplitude are known commonly as "Nodes" while those of zero value are "Anti-nodes".

Should the frequency of the curves of Figure 8 be doubled, the standing wave would appear as shown in Figure 7. Thus, if the wire of Figure 8 were resonant as a half wave antenna at 2000 kc, it would also resonate as a full wave antenna at 4000 kc, and a two wavelength antenna at 8000 kc.

You are no doubt wondering why it is necessary to take the resonant frequency of an antenna into consideration but you must remember that any circuit which will resonate, is most efficient at its resonant frequency and the same holds true for antenna systems. In other words, an antenna system which resonates at 2000 kc will receive signals at that frequency much better than signals at 500 kc.

Under these conditions, a large number of separate antennas would be necessary to receive signals from the various broadcasting stations with the greatest amount of efficiency. However, as this is impractical, a compromise must be made as to the actual length of wire used. We will show you how this is accomplished in the following explanations of the two fundamental types known as the "Marconi" and "Hertz", named after the men who first applied them to Radio communication.

MARCONI ANTENNA

The Marconi is the common type of antenna which used to be erected on almost every housetop and, for the entire system, it is completed to ground through the antenna coil of the receiver. In other words, the ground is an integral part of the system and it is therefore quite often referred to as a grounded type antenna.

There has never been much attention paid to this type of antenna, except to have it up in the air, with connections made so that various stations could be heard. There are, however, three important points to remember about the Marconi system -- its length, height and ground.

To be most effective, the antenna should be as high as possible and the ground connection should have low resistance to radio frequency currents. The ground should preferably be one with conductors buried deep enough in the earth to reach natural moisture. However, in most localities, good grounds can be made to cold water pipes where they enter the house. To make the connection, the pipe should be scraped clean and a low resistance connection made with a tightly fastened ground clamp. If no water mains are available, a metal rod or pipe, 6 to 8 feet long may be driven in the earth and connections made as explained above.

This brings us up to the length but, before going into that subject, we want to tell you that the horizontal section of an antenna is called the "flat-top" while the wire connecting the antenna proper to the receiver is called the "lead-in" or "transmission line". "Lead-in" is the term most commonly used with the Marconi system and both it and the flat top are designated in Figure 9.

The flat top is separated from its supports by suitable insulators and the lead-in is connected to it so as to form an inverted "L". Thus, we have one continuous length of wire from the open end of the flat top to the receiver. When calculating the length for resonant frequency you must take into consideration the total length from the far end of the flat top to the ground connection.

Earlier in this Lesson, we gave you the following formula,

$$\text{Wavelength in Meters} = \frac{300{,}000{,}000}{\text{Frequency in cycles}}$$

and also told you the length of an antenna is specified in terms of the wavelength corresponding to the lowest frequency at which it will be resonant. This is known as the fundamental frequency or wavelength and for the Marconi antenna, this length is approximately a quarter wavelength.

Under these conditions then, and assuming a quarter wavelength, to find the actual length of the antenna in meters, for any desired frequency, it will be necessary only to use the formula above and divide the answer by 4. However, to be more correct, due to closeness of objects, the natural wavelength is approximately 4.2 times the actual length. Substituting this value in the formula, we have,

$$\text{Length in Meters} \times 4.2 = \frac{300{,}000{,}000}{\text{Frequency in cycles}}$$

or letting kc represent 1000 cycles, the formula becomes,

$$\text{Length in Meters} = \frac{300{,}000}{4.2 \times \text{Frequency in kc}}$$

To find the actual length in feet, we know that meters are equal to feet divided by 3.28 and therefore we can write

$$\frac{\text{Length in feet}}{3.28} = \frac{300{,}000}{4.2 \times \text{Frequency in kc}} \quad \text{or}$$

$$\text{Length in feet} = \frac{3.28 \times 300{,}000}{4.2 \times \text{Frequency in kc}}$$

Multiplying through and dividing by 4.2

$$\text{Length in feet} = \frac{234{,}000}{\text{Frequency in kc}} \qquad (1)$$

Just to show you how this works out, we will assume that we want to design a Marconi type antenna which will be resonant at 2000 kc. Substituting in equation (1)

$$\text{Length in feet} = \frac{234{,}000}{\text{Frequency in kc}} = \frac{234{,}000}{2{,}000}$$

Length = 117 feet.

Therefore, if an antenna of the Marconi type were erected, reasonably far from obstruction, and with a complete length, from far end of flat top to ground, of 117 feet, it would be resonant at 2000 kilocycles. Remember, the above formulas are for a quarter wavelength antenna, the minimum length that can be used with a Marconi type for the frequency desired.

By substituting the frequencies of the regular Radio broadcast band into equation (1) you will find that the results will be long lengths of wire which, in most localities, would be impractical. However, present day standard broadcast stations have such comparatively high power that little attention is required regarding the resonant frequency of the antenna at these wavelengths.

For all-wave receivers, the antenna is designed to resonate somewhere around the 49 meter band and, by operating on its harmonics, will also resonate at higher frequencies. The reason the antenna is resonated at the higher frequencies is due to the fact that, as a general rule, transmitters operating on the shorter wavelengths have less power than those on the regular broadcast band and are therefore favored.

Therefore, we can give credit to the advent of the all wave receiver for the present interest in antenna systems and without some good type, in "noisy" communities, the reception of long distance signals, with clarity and volume, is almost impossible.

Under these conditions then, if you are called upon to design an antenna system for a receiver capable of operating on the higher frequencies, be sure that the length is such that it will resonate in the desired frequency spectrum. It has been determined that most of the "noise", interference from motors, neon signs, etc., in a receiver is picked up by the vertical section, most generally the lead-in of an antenna system and considerable research has been made to neutralize these effects.

One of the easiest methods, and perhaps the simplest to understand, is to replace the single lead-in wire of Figure 9 with a pair of twisted wires. One end of the twisted pair is connected to the flat-top of the antenna while the other is left open. At the receiver end of the line, the ends of the twisted pair are connected across the primary of the antenna coil.

Under these conditions, any voltage induced in the wires of the transmission line will be equal in magnitude and phase. Therefore, the opposite ends of the antenna coil primary will be at the same potential and polarity and cause these voltages to cancel. This action will minimize, or eliminate, any noise voltages, picked up by the lead-in, from entering the receiver.

Another simple method of noise reduction is to completely shield the lead-in with some metallic material. The material most generally used is copper, so interwoven that it is cylindrical in shape, with an opening through the center to enclose different sizes of wire. Of course, when this copper shielding is used, the lead-in wire must be insulated from it to prevent a short circuit which would eliminate the noise reducing feature.

The actual lead-in wire is run direct from the flat top to the receiver terminal while the shield is connected to ground. The effect is that the shield, completely covering the lead-in, prevents the noise from reaching the receiver by providing a low resistance path for it to ground. A bad feature of this method is that the shield, lead-in wire and the insulation between them form a condenser which will tend to attenuate the signals. The percentage of this attenuation increases with the frequency and thus this method is not very practical for short wave work although it will give quite satisfactory results, with considerable noise reduction, on the broadcast band.

The above two methods of noise reduction are two of the simplest types but, under ordinary conditions, give good results in the elimination of "man-made static".

HERTZ ANTENNA

The ungrounded, or Hertz, antenna as applied to receiver systems, is comparatively new to the ordinary radio listener, although it has been in use for many years in the transmitting field. Fundamentally, it consists of two quarter-wave flat-top sections, insulated from each other, with a lead-in from each.

In Figure 10, we show a simple Hertz system, commonly called a "Doublet", and you will notice that if you were to take two quarter wave Marconi antennas like Figure 9, and place them end to end, the Hertz system of Figure 10 would result.

The natural wavelength of the Hertz antenna depends on its length and such factors that may operate to change the distributed constants from those it would have in space. That is, the closeness to other objects such as trees, buildings, antenna posts, etc.

In practice, the natural wavelength of the wire will be approximately 2.1 times the physical length. Keeping this constant in mind and following the earlier derivation of this Lesson, we can arrive at the following formula.

$$\text{Length in Feet} = \frac{468{,}000}{\text{Frequency in kc}} \qquad (2)$$

The above formula gives the total length of the flat-top, in feet, and the result is for half wavelength antennas, the minimum length that can be used for a Hertz antenna at any desired frequency. In designing an antenna of this type, the lead-in should not be figured in the total length because it maintains its functions independent of flat-top.

You can easily understand this because the lead-in is transposed, crossed over at regular intervals, or twisted so as to neutralize any signal pick-up in it. Thus, it acts merely as a conductor to transmit the signal energy in the flat-top to the receiver proper.

To show you how formula (2) is employed in the design of a simple doublet type antenna, we will assume that we are called upon to construct a system to resonate at 6000 kc, which is 6 megacycles. In using the prefix "mega" it simply means million, like "kilo" means thousand. In other words,

6,000,000 cycles = 6,000 kilocycles = 6 megacycles

Getting back to our design, we will first substitute 6,000 kc in formula (2) and have

$$\text{Length in feet} = \frac{468,000}{\text{Frequency in kc}} = \frac{468,000}{6,000}$$

$$\text{Length} = \frac{468}{6} = 78 \text{ feet}$$

The above length is the total amount of wire in the flat-top to resonate at the desired frequency but, as this system is fundamentally two quarter wave length antennas, we cut the wire at the exact center and separate the sections with an insulator as shown in Figure 10. This will give us a length of 39 feet on each side of the center insulator and each outer end is also connected to an insulator so that the flat-top can be suspended in the air. However, before stringing the antenna, the transmission line should be properly connected as indicated.

After the above connections are made, the antenna is suspended, by suitable masts or supports and, to complete the job, the other ends of the transmission line are connected to the receiver. Of course, the efficiency of the entire system can be improved by the use of proper antenna coupling transformers, to match the impedance of the transmission line, and also to make the antenna resonant at different frequencies. These units, however, will be explained later in this Lesson.

Although we have not mentioned it before, the simple doublet antenna we have been explaining is quite highly directional and receives best from right angles to the direction in which the flat-top is stretched. Therefore, in erecting a system of this type, the location should be taken into consideration and the wire run in such a direction as to give the best possible reception of the stations desired.

In general, there are three outstanding characteristics of this simple doublet antenna which you should remember. Because of their importance, we will list them here.

1. Resonance at fundamental and harmonic frequencies.

2. High directivity.

3. Pick-up or flat-top, and lead-in sections maintain their functions independently of each other.

The above explanations have all been based on the simplest form of Hertz antenna but they can be used as a basis to understand the more complicated arrays, such as the double doublet, "V" doublet and web type. These systems are on the market and are completely assembled with their rather involved matching transformers. To be placed in operation, they need only be "strung" between supports, as directed in the instructions included with each system.

Due to the many and complicated details which must be taken into consideration, in the complete design of such systems, we do not think it advisable to go into them at this time. We can tell you however, that their entire purpose is to increase the overall efficiency so as to allow the best signal to noise ratio.

This is accomplished by combining two or more simple doublet antennas, together with matching transformers, to make the system resonant at different frequencies and, in some cases, to give the effect of a common Marconi system at the lower frequencies, particularly on the regular Broadcast Band.

COUPLING TRANSFORMERS

The main considerations involved in the design of a receiving antenna are, the amount of energy it can deliver to the Receiver, its directivity, and the freedom from undesired noises in the signal. To improve the overall efficiency of receiving antenna operations, considerable research has been done in respect to the transmission of energy from the flat-top to the Receiver itself.

This research has led to many types of ingenious coupling devices which, for "All Wave" types of antennas, often are made up of a rather involved network of capacity, inductance and resistance. Usually, there are two units, one for coupling the flat-top to the lead-in, or transmission line, and one for matching the impedance of the transmission line and serving to couple it with good efficiency, to the Receiver.

When of the proper length, an antenna has the characteristics of a resonant circuit, therefore its resonant frequency can be altered by changing its value of inductance and capacity. Also, for any given value of capacity and inductance, the capacity reactance reduces while the inductive reactance increases as the frequency is increased.

Thus, in an antenna like that of Figure 7, the effective or electrical length can be reduced by adding a series capacity and increased by adding a series inductance. By utilizing all

of these factors, a coupling transformer can alter the characteristics of an antenna system to provide efficient reception over a wide band of frequencies.

LOOP ANTENNAS

As we have mentioned before, the high sensitivity of modern Receivers plus the high power of standard Broadcast stations has practically eliminated the need for an efficient antenna, therefore it has become common practice to install a loop antenna inside the Receiver cabinet.

As far as the circuits are concerned, these loops are merely an enlarged coil of the input circuit tuned by the variable condenser of the tuning control. Mechanically, the loop is a flat, or "pancake" type of winding with dimensions which permit it to fit inside the cabinet. A typical arrangement is shown in Figure 11 with the flat oval coil held in shape by bands of tape and clamped in a central support. As an antenna, the loop is but a fraction of a wavelength in size, therefore the voltages induced in each end will be in the same direction and tend to oppose each other. However, the time required for the radiated energy to travel from one end of the loop to the other causes the induced voltages to be sufficiently out of phase to **generate** current in the loop.

Because of this action, the received signal will be maximum when one end of the loop is pointed toward the Broadcast Station and minimum when turned broadside to the station. To provide greater pickup, most loops include a few turns, brought out to terminals, which can be connected to a more efficient type of antenna.

INSTALLATION

Due to the fact that it is becoming more and more common practice to purchase an antenna system completely fabricated, the proper installation is all that is necessary to allow it to operate at its maximum efficiency.

Practically all antenna systems, now on the market, contain complete instructions as to the proper installation methods and we want to impress on you the fact that they should be followed to the smallest detail. Each system has been completely engineered and every detail worked out to give the maximum efficiency. Should some detail, which in your opinion is trivial, be omitted, the result may be a system which operates poorly. Therefore, follow directions exactly and completely and the results will be satisfactory.

Should no instructions be included with the system, or you are constructing one of your own, the following explanation will be of benefit.

When locating a place to erect the flat-top, it should be removed as far as possible from sources of interference. This is important because the strength of a Broadcast signal, received from a considerable distance, varies almost directly as the distance, while the signal strength of local interference varies as the square of the distance.

Also, keep the flat-top away from trees, wires, buildings, etc., as such objects absorb signal strength. A good example of this absorption is when passing under a viaduct in an automobile which has a radio receiver. Almost invariably, the signal strength will be reduced to the point where it will be noticed by listeners. In some cases, the stations will fade out entirely.

The next important fact is the height. Always place the flat-top as high as possible because this means getting further away from interference and the desired signal pick-up will be greater.

We cannot over-emphasize the importance of a good ground connection. We told you how this is made for a Marconi system and can add that it is also important for a receiver employing a Hertz antenna.

This may seem contradictory to the explanations of the doublet systems designed to operate with no ground but, in such cases, the purposes of a ground is to prevent chassis pick-up and possible pick-up from the power line which would introduce noise in the receiver. The ground, as used with a Hertz antenna, has no function in the signal pick-up.

When making connections, both at the ground and antenna, first make a mechanical joint and then a low resistance electrical connection by soldering. Remember, a single high resistance joint can cause the complete system to be inoperative or to operate poorly.

LINE FILTERS

We mentioned above that considerable noise pick-up may be experienced from the power-line and now we will show you how, to a great extent, this can be minimized or entirely eliminated. Noise of this type is generally caused by electric sparking machines, such as motors, vibrators, electrical sign flashers, etc.

To determine whether receiver noise is being picked up by the antenna or is transmitted through the power line, disconnect the antenna from the receiver and short the "ant", and "gnd" terminals. If the noise persists, you can be reasonably sure it is coming through the power line. However, if it is reduced, then it is being picked up by the antenna.

If the noise is found to be entering the receiver through the power line, the next step is to find where it is originating. The simplest way of doing this is to turn off the various electrical devices in the immediate vicinity until the one causing interference is found. The common causes, in the ordinary home, are vacuum cleaners, oil burners, electric razors, and the various electrical toys.

Once the source is determined, a very simple and usually effective method of elimination, is by the use of capacity connected as shown in Figure 12A. The principle of operation is that the sparks, produced by the machine, cause waves of a fairly high frequency and the capacity forms a low reactance path to ground thus preventing them from being sent back to the power line.

When installing the capacity, the condensers should, if possible, be placed directly on the noise making machine, with the ground being made to its chassis. Any long length of wire will be a source of radiated energy which may be picked up by the antenna system.

For fractional horsepower motors, vibrators, flashers, etc., the capacity of the condensers need not be over .1 mfd. For larger motors, which draw considerable current, the capacity of the condensers must be increased in proportion.

No doubt the question has come in your mind concerning the fact that, in our former explanations, we told you that a condenser will allow current in an a-c circuit yet, we connect them directly across the a-c power line. That is true and, as previously explained here, is the principle by which this filter operates. Although the power loss across the capacities is negligible, as a safety precaution it is a good practice to connect them so that, when the unit is turned off, the condensers will also be out of the circuit.

In cases where the interference is very bad, it is sometimes necessary to make up a filter composed of both inductance and capacity. A common form of connection is shown in Figure 12B. Checking the circuit, you will notice that we have simply added two inductances and two condensers to the circuit of Figure 12A.

As you will remember, an inductance has a high reactance with an increase of frequency and, connected as shown, will tend to stop, or prevent the "noise" from going back in the power line while the capacities provide a low reactance path to ground.

Compared to the circuit of Figure 12A, this circuit gives us approximately three times the protection against unwanted frequencies entering the power line and causing disturbances in the radio receiver.

In our explanations, we have assumed that you were able to locate the source of interference but, in cases where this is impossible, it is necessary to make all connections at the receiver itself. If such is the case, it is generally the best plan to use the circuit of Figure 12B. Even then, it is sometimes quite a task to completely eliminate the interference, although in most cases it can be minimized.

Should you desire to construct the circuit of Figure 12B, the coils are of approximately 60 turns of wire on a form with a diameter of 2 inches. Enamel copper wire should be used, the size depending on the current it is to carry. As a conservative rule, you can consider 1 ampere per 1500 circular mils. The condensers are the same size as explained for Figure 12A.

There are many different makes of line filters on the commercial market and all are made up of capacity, inductance or a combination of both. Remember, however, as explained for the antenna systems, if you are called upon to make an installation, for the best results, completely follow the directions.

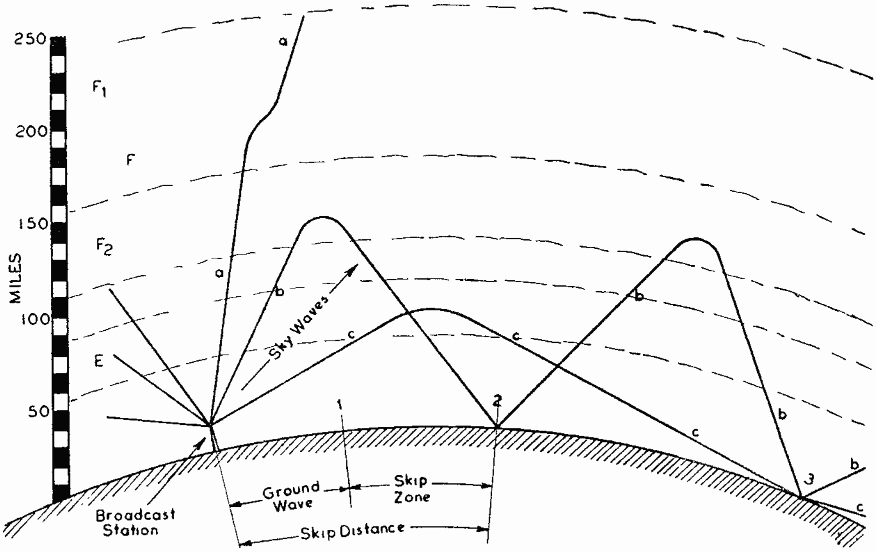


FIGURE 1

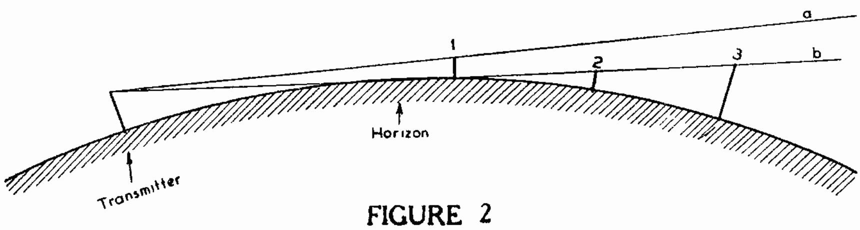


FIGURE 2

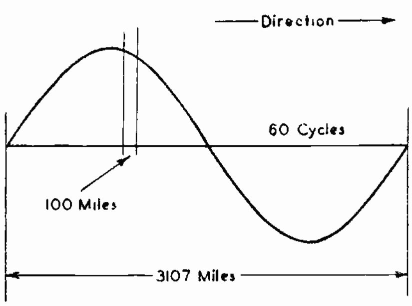


FIGURE 3

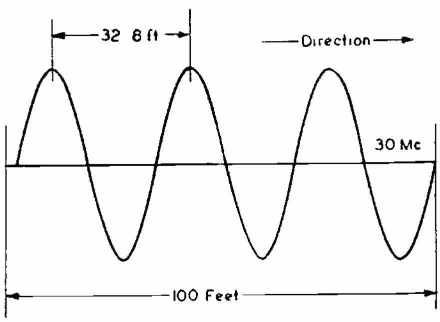
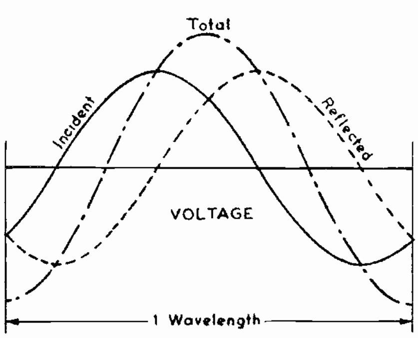


FIGURE 4



TRA-14

FIGURE 5

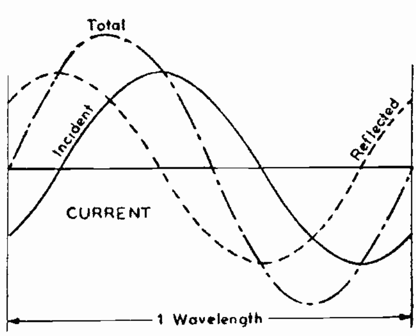


FIGURE 6

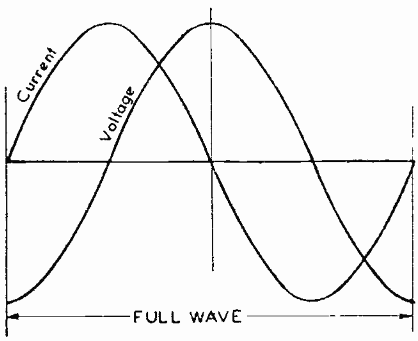


FIGURE 7

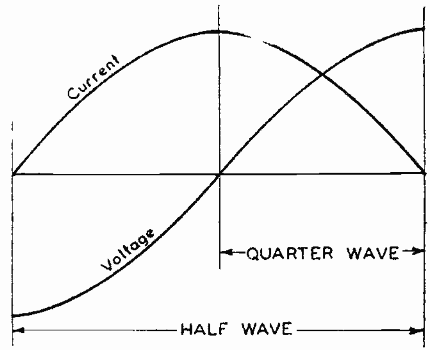


FIGURE 8

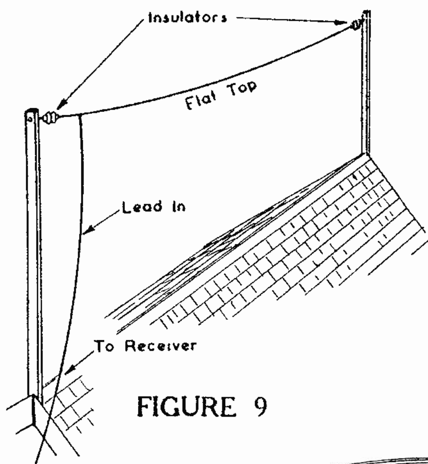


FIGURE 9

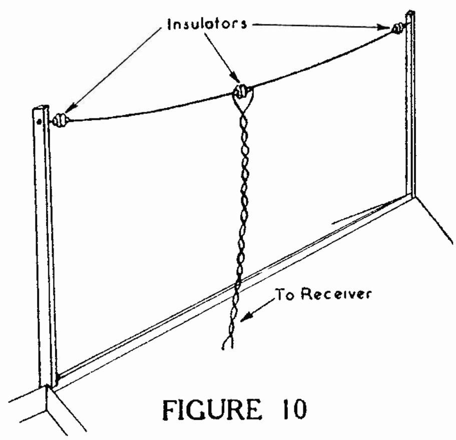


FIGURE 10

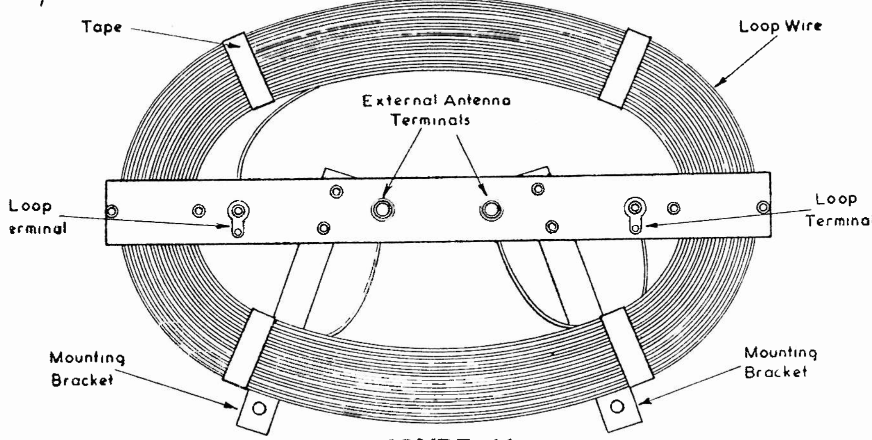


FIGURE 11

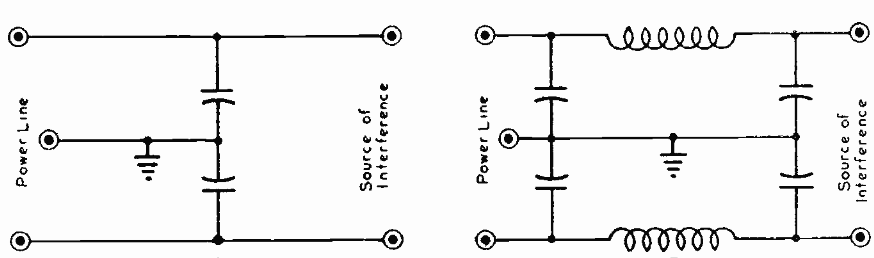


FIGURE 12

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LESSON TRA - 15
SIMPLE RECEIVERS

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DE FOREST'S

TRAINING, Inc.

LESSON TRA - 15

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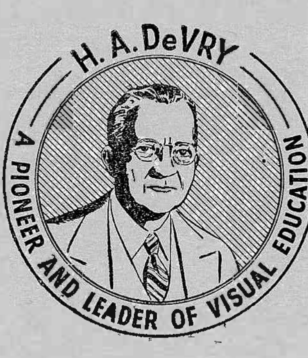


TUBES - RECEIVERS - AMPLIFIERS

LESSON TRA-15

SIMPLE RADIO RECEIVERS

* * * * * * * * *

Earnestness is the devotion of all the faculties. It is the cause of patience, gives endurance, overcomes pain, strengthens weakness, braves danger, sustains hope, makes light of difficulties and lessens the sense of weariness in overcoming them.

— C. W. Bovee

SIMPLE RADIO RECEIVERS

In the last few Lessons, we have explained the Principles of Radio Communication, Power Supply Tubes, Detector Circuits, and Antennas, all of which must be combined to permit the operation of a simple Radio Receiver. The Radio Principles Lesson included a description of a "Crystal" receiver but now, with the later explanations in mind, we are going to take up the operation of a simple receiver which incorporates a vacuum tube.

Reviewing briefly, the energy from a Broadcast or Transmitting station is radiated through space in the form of pulses or waves which are varied, or modulated so as to carry the voice and music "signals". The carrier energy is of comparatively high frequency while the signals are of low or audio frequency.

This energy, considered as a "Modulated Carrier", cuts the receiver antenna and induces a voltage of a frequency the same as that of the carrier. Under present conditions, every receiving antenna will be cut by a number of modulated carriers, each transmitted by a different station, and have a corresponding number of frequencies in it.

Thus, the receiver has three necessary functions. First, it must be able to select any one of the frequencies induced in the receiving antenna, second, it must separate the carrier and signal frequencies and third, it must convert the signal frequencies into corresponding sound waves.

No matter how complex, all Radio Receivers must perform these three main functions and, while additional tubes are used for amplification, a single tube, operating as a detector, or demodulator, makes possible the reception of Radio Signals. For this Lesson, therefore, we want to explain the circuits and operation of simple, single tube receivers.

TUBE CIRCUITS

First of all, we want to remind you that as far as the signals are concerned, for most circuits, the control grid circuit of the tube is the "Input" and the plate circuit is the "Output". This does not apply to diode tubes which are employed as detectors or as power supply rectifiers because they do not contain a control grid.

With the exception of the heater or filament circuits, the various power supplies provide direct current to maintain the

desired operating points of the tubes. They also provide the power which is necessary to change the amplitude of the signal as it passes through from the input to the output circuits.

Following the signal through the receiver, it appears as a-c or as variations in the values of d-c in what are known as the "Signal Circuits". In other circuits, conditions remain essentially the same, whether or not a signal is present, and these are known as the "Supply Circuits".

To show the application of these terms, for Figure 1 we have drawn the circuits of a simple one tube receiver employing a triode tube which, for proper operation, required one supply to heat the filament and another supply for the plate circuit.

Following conventional terminology the "A" supply connects to the filament while the "B" supply connects to the plate to provide the two supply circuits. The signals, picked up by the antenna, appear as high frequency across the grid circuit and as variations of d-c in the plate, or output circuit, therefore these can be considered as the signal circuits.

For the tube there are three separate and distinct circuits, the filament, the plate and the grid. The "A" supply provides the current to heat the filament while the path of the plate circuit is from the "B+" through the "phones" to the plate and across the space between the plate and filament inside the tube. Here, it unites with the filament circuit and returns to "B-" through the "A" supply.

INPUT CIRCUITS

For the grid, or signal input circuits, there is a radio frequency transformer made up of a primary winding, "L1" and a secondary"L2". Both windings are placed in fixed positions on a single coil form and the primary winding is connected between the antenna and ground wile the secondary winding connects across the grid circuit.

When carrier frequencies cut across the antenna, they induce voltages of like frequency which, in turn cause currents, also of like frequency, in the primary coil L1. These currents in coil L1 set up a magnetic flux which cuts the turns of the secondary coil "L2" and induces an emf in it.

As explained in the former Lesson on antennas, the strength of the voltage induced in the antenna, will depend on the strength of the carrier and the dimensions of the antenna. With the primary coil grounded, as in Figure 1, the antenna

is of the Marconi type and the complete circuit extends from the outer end of the antenna wire to ground.

Cut to the proper length, the antenna will be resonant and carry higher induced voltages at some particular frequency but, for several practical reasons, this action is seldom utilized for ordinary Broadcast reception.

The Broadcast Band extends from 550 kc to 1600 kc and, using the formula of the antenna Lesson, for a Marconi type,

$$\text{Length in feet} = \frac{234{,}000}{\text{Frequency in kc}}$$

and substituting the above values of frequency, for 550 kc

$$\text{Length} = \frac{234{,}000}{550} = 425 \text{ Ft.}$$

and for 1600 kc

$$\text{Length} = \frac{234{,}000}{1600} = 146 \text{ Ft.}$$

Thus, no one length would approach resonance for the entire band and even the shortest length is too great for construction by the average listener. As the ratio between the highest and lowest frequencies of the band is approximately 3 to 1, it is not possible for any one length of antenna to be resonant over even a part of the band.

In any resonant circuit, the important changes of voltage, current and impedance occur at frequencies with values comparatively near that of resonance while, for values far removed from resonance, changes of frequency have but a negligible effect. Therefore, by means of a coil in the position of L1, Figure 1, the resonant frequency of the antenna circuit is of a value far removed from those of the Broadcast Band. As a result, the response of the circuit is reduced but remains about the same for all frequencies of the band.

This condition may be obtained by making the antenna circuit resonant at a frequency either above or below the frequencies of the band and, as the average antenna is about 50 feet in length, its resonant frequency is above those of the Broadcast Band. However, in an arrangement like that of Figure 1, the primary coil L1 is a part of the antenna circuit, therefore its value of inductance will effect the resonant frequency.

By making coil L1 with but a few turns of wire, its value of inductance will be small and the resonant frequency of the circuit may be close to those of the Broadcast Band. When this is done, the antenna transformer coil, made up of L1 and L2 is said to have a low impedance primary.

By making coil L1 with a large number of turns, its inductance will be comparatively large, thereby increasing the electrical length of the antenna to such an extent that the resonant frequency of the circuit is lower than the Broadcast band. With this arrangement, the antenna coil is said to have a high impedance primary.

TUNING

As mentioned before, the small currents in L1 set up magnetic flux which cuts the turns of the secondary L2 and induces an emf in it. For each current frequency in the primary, there will be an emf of corresponding frequency induced in the secondary. Under ordinary conditions, there will be a number of carrier frequencies induced in the secondary, therefore it is necessary to provide some method by which but one of these frequencies will be built up while the others are reduced.

This process is known as "Tuning" and, in a circuit like that of Figure 1, it is accomplished by connecting a variable condenser across the secondary coil L2. The coil is wound so that its value of inductance in conjunction with the variations of capacity in the tuning condenser C1, will make it possible to resonate the circuit, made up of L2-C1, at all frequencies of the Broadcast Band.

Thinking of L2-C1 as a series resonant circuit, from the explanations of the earlier Lessons you will remember that, at resonance, it will have minimum impedance and maximum current. Thus, by adjusting the capacity of the variable condenser C1, the circuit can be tuned until its resonant frequency is the same as that of one primary current. For that particular frequency, the circuit will provide minimum impedance. Therefore, the emf, induced in the secondary, will cause maximum current which, in turn, will cause maximum voltage drop across the coil and condenser.

For other frequencies, the circuit will offer a higher impedance, therefore the induced emf will cause a lower current and the voltage across the coil and condenser will be reduced. Thus, by tuning this circuit, it is possible to obtain maximum voltage at the resonant frequency with reduced voltages at other frequencies. It is this action which allows the listener to "Tune" the particular carrier which is modulated by the signals he wants to hear.

As the resonant frequency of the circuit is controlled by the variable condenser, C1 of Figure 1, it is known as a "Tuning Condenser".

DETECTOR ACTION

So far, the receiver of Figure 1 permits the selection of separate carriers and its next function is to restore the signal frequencies to their original form which requires the removal of the carrier frequency. This process is known generally as "Detection" or "Demodulation". In an earlier Lesson on "Detectors" we explained this action in detail, therefore you should recognize the arrangement of Figure 1 as a "Grid Leak" type of detector.

Reviewing briefly, the action of the tube permits current in the grid circuit only when the grid is positive in respect to the filament and thus it acts as a rectifier or diode detector. To help you follow the action, for Figure 2A, we have drawn a curve to represent a modulated carrier but, for simplicity, have shown a carrier frequency much lower than those in common use. You can think of this curve as representing the wave form of the voltage across the tuned circuit L2-C1.

Because of the rectifying action in the grid circuit this voltage will cause a pulsating current which, in resistor R1, will have a wave form as represented in Figure 2B. The current pulses will cause corresponding voltage drops across R1 and thus condenser C2 will charge and discharge in accordance with the changes of voltage. As explained previously, the action of the condenser tends to reduce the variations of current in the resistor making its actual value vary more like the dotted line of Figure 2B.

The direction of current is such that the grid end of R1 will be negative and the voltage drop across it can be thought of as a sort of negative grid bias.

Notice however, in this case, the voltage across R1 will vary with the signal frequency which modulates the carrier and therefore, the action is about the same as that of a diode detector.

Going back to the earlier explanations on tube action, you will remember that the grid voltage controls the plate current therefore, the voltage drop across R1, which is in series with the grid circuit, will cause corresponding changes of plate current.

Thinking of voltage, condenser C2 of Figure 1 will allow the modulated carrier to be impressed on the grid, therefore th

total grid voltage will be a combination of the modulated carrier and the drop across R1. In the form of a curve it would have the general shape of Figure 2C and, with the tube operating as an amplifier, the variations of plate current will follow the changes of grid voltage.

As the overall function of the receiver is to reproduce the original signals, it is necessary to remove the carrier frequency variations of plate current, therefore condenser C3 is connected from plate to ground. The "B-" connects to ground also, therefore C3 is connected across the B supply and the phones where its action is similar to that explained for C2 in respect to R1.

The result of these combined actions is shown by the curve of Figure 2-D which contains no variations at the carrier frequency but changes in accordance with the frequency of the signal which modulated the carrier.

OUTPUT CIRCUIT

So far, this simple receiver circuit of Figure 1 has the ability to select individual carrier frequencies by means of the action in the tuned circuit, L2, C1. It can separate the signal and carrier frequencies, or demodulate the carrier by means of the detector tube action and, to complete its functions, must convert the signal frequencies into sound waves of corresponding frequencies.

The simplest method of obtaining this last result is to connect a pair of headphones in series with he plate of the tube, as shown in the circuit of Figure 1. As you will learn later, a headphone contains a combination permanent and electromagnet with a thin steel diaphragm placed close to but not touching the magnet poles. Variations of current in the coils of the electromagnet cause corresponding changes of pull on the diaphragm and cause it to vibrate at the frequency of the current variations. The movement of the diaphragm produces the changes of air pressure which we call "Sound Waves" and which we can hear.

Thus, if current with a waveform like that of Figure 2-D is carried by the electromagnet coils in the phones of Figure 1, the diaphragm will vibrate in step with the variations of current and produce sound waves which reproduce the original signal.

As we mentioned in the earlier explanations on tubes, the grid circuit is the "Input" and the plate circuit is the "Output" therefore, in the circuit of Figure 1, the "Phones" are connected in the output or output circuit.

We want you to follow the circuits and actions of Figure 1 very carefully and thoroughly. Although the arrangement is one of the simplest receiving circuits, a complete understanding of its functions and operation will make it much easier for you to follow our explanations of more complicated receivers of this and the later Lessons.

POWER SUPPLIES

To maintain the simplicity of the circuit of Figure 1, we show but three terminals for power supply connections and assume the receiver is to be operated by dry batteries. The "B-A+" terminal is common to both batteries with separate terminals for "A-" and "B+".

In most cases of battery operated tubes the "A-" is the common reference point for the supply voltages but, for a single tube, operating as a grid leak detector, it has been common practice to make the connections as shown. The "A" supply must provide a voltage specified for the filament of the particular type of tube which is used while the "B" battery is usually a 45 volt unit.

The point we want to emphasize here is that the power supplies are used mainly to keep the tube in operating condition by furnishing the proper values of filament and plate current. The actual operation of the receiver depends upon the changes of plate current caused by the voltages induced in the antenna.

Thus, any type of Power Supply which will provide the proper type and values of voltage and current may be connected to terminals like those shown in Figure 1. As we will explain later, most Receivers obtain their power from batteries or the common home lighting circuits but additional tubes and parts are needed to convert the home lighting power to values suitable for the tube circuits. Some of those circuits have been explained in the earlier "Power Supply" Lesson and others will be taken up later.

REGENERATION

In our former explanations of Tubes, we told you that as amplifiers, they had the ability to allow small changes of grid voltage to control larger changes of energy in the plate circuit. Thinking in terms of power, a small amount in the grid circuit can control a much larger amount, provided by the plate supply. Also, as Radio Carriers and Signals are a-c, the action depends on the changes of voltage and current rather than on any fixed value.

For example, a steady d-c voltage on the grid of the tube of Figure 1 would cause a uniform and unchanging plate current. Regardless of its actual value, this steady plate current in the phones would hold the diaphragm in a stationary position and prevent it from producing any sound waves. However, as explained for Figures 1 and 2, changes of grid voltage cause changes of plate current which, in turn, cause the diaphragm to vibrate, and produce sound waves.

As the grid is the input, or controlling circuit, the variations of plate current will vary with those of the grid voltage. Also, as there is a larger amount of power in the plate circuit, the variations could be increased if, in some way, they could be fed back into the grid circuit. For example, if the high frequency variations of Figure 2-C could be added to the modulated carrier of Figure 2A, its amplitude would be increased.

The later explanations will tell you how this is done but now we want you to remember only that, when the changes of plate energy are fed back in phase, so as to increase the changes of grid voltage, the action is known as "Regeneration".

When the changes of plate energy are fed back out of phase, or so as to oppose the changes of grid voltage, the action is known as "Degeneration".

REGENERATIVE DETECTOR

By making use of the regenerative action, the detector tube of Figure 1 will become much more sensitive and produce louder signals. Therefore, in Figure 3, we have added coil L3 to the circuits of Figure 1 and changed C3 from a fixed to a variable type of condenser.

As explained for Figure 1, signal currents in the primary L1, induce voltages in the secondary L2, and these act on the grid of the tube to cause corresponding changes of plate current. In Figure 3, plate current with a waveform similar to that of Figure 2C is carried by L3, because it is connected in series with the plate, and therefore the changes of plate current will cause a varying flux to be set up around this coil.

Like the primary L1, coil L3 is placed quite close to the secondary L2 and, carrying current with changes at the same frequency as that in L1, it acts as an additional primary, causing a higher induced **emf** in L2. Thus, the plate coil L3, often called a "Tickler", feeds some of the plate circuit energy back to the grid circuit and causes an increase in the changes of grid voltage.

As explained for Figure 1, condenser C3 of Figure 3, still acts to by-pass any high frequency around the phones, but has another important action which makes it necessary for us to trace its circuits for you. As we have already explained, the changes of plate current cause coil L3 to set up a varying flux and act as a primary, as far as L2 is concerned.

For this explanation therefore, we can think of L3 as a source of high frequency and find it connects to the plate at one end, with a path completed to ground through the tube and the "B-A+" leg of the filament. The other end of the coil connects to one side of C3 and also to one side of the phones. The other side of C3 connects directly to the ground and the other side of the phones connects to ground through the B supply to B-.

The high frequency circuit of coil L3 can therefore be completed by the path through the phones or the path through C3. As the headphones are made up of many turns of wire, wound on an iron core, they can be thought of as an inductance with a large inductive reactance at the high carrier frequency.

As C3 is a condenser, it can be thought of as a capacity reactance, the value of which reduces as the frequency increases. Thus, as the reactance of C3 will be much less than that of the phones, it acts as a by-pass for the high frequency.

Going back to the earlier Lessons, you will remember that capacity reactance, in ohms, is equal to one divided by $2\pi fC$, when C represents the capacity in farads. Therefore, at any given frequency, as the value of C is increased, the reactance is reduced and, as the value of C is reduced, the value of the reactance is increased.

By using a variable type of condenser for C3, we can change the capacity which, in turn, varies the reactance. As in any other a-c circuit, assuming a constant voltage, the current is controlled by the impedance and here the effective impedance consists almost entirely of the capacity reactance of C3.

The adjustment of C3 therefore controls the high frequency current in L3 and thus controls the amount of feedback or "Regeneration". In effect, it acts as a volume control for the sound in the headphones. For simplicity, we did not show a volume control in Figure 1 because a one tube receiver of this type seldom requires it.

The circuit of Figure 2 is a great improvement over that of Figure 1, as far as signal strength, sensitivity and sharpness

of tuning are concerned, but it has some bad faults.

While the regenerative action will increase the strength of the signal, if too much energy is fed back from the plate circuit, the high frequency variations will continue without the presence of a carrier. When this occurs we say the tube is "oscillating" because it is actually generating a-c at a frequency determined by the resonant frequency of the tuned circuit, made up of coil L2 and tuning condenser C1.

With frequencies generated by the tube, it no longer can act as an efficient detector, therefore, as far as the reception of signals is concerned, best results are obtained when the adjustment of C3 is such that the tube is just below the oscillating point.

To provide the desired performance, the selected values of inductance and capacity are such that the tube can be made to oscillate and when it does, a high frequency current is set up in the primary coil, causing the antenna to send out waves like a transmitter or broadcasting station.

While not very powerful, these waves travel for quite a distance and may cause trouble for the other receivers in the neighborhood. Like any radio wave, they cut the antennas near them and induce a voltage but, being straight high frequency c-w, (Continuous Waves), by themselves, will not cause any sound in a receiver phone or speaker.

But suppose they have a frequency of 825 kc, and some neighbor is trying to tune in an 830 kc station. These two frequencies, acting together, set up a third wave with a frequency equal to their difference, which in this case would be 830 minus 825 or 5 kc.

We call this action Heterodyning and use it in some cases, which we will explain later, but here the 5 kc wave would cause a howl or squeal in your neighbor's receiver. Perhaps you have used, or heard, a receiver which starts to squeal for no apparent reason, and the tone may run up and down the scale. The above action is one explanation of this condition and the change in tone is caused by the user of the oscillating set who, when changing his tuning, changes the frequency of the wave he is sending out.

The same action is present in the set itself and, with the tube oscillating, by changing the tuning, the difference in the frequency of the oscillations and the incoming wave produce a frequency that causes a squeal in your phones.

This we call a beat note and it is heard on both sides of the proper tuning point of a station. Going back to the figures we used a minute ago, suppose you are tuning for a frequency of 830 kc.

By changing your adjustments until the oscillations have a frequency of 825 kc, there is a difference of 5 kc, which makes the note. Should you keep on moving your adjustments until the oscillations had a frequency of 835 kc, the difference would once more be 5 kc, and you would hear the same note again.

This is a very easy method of tuning because, for the proper setting, all you have to do is tune midway between the squeals.

However, while you are doing this, your neighbors will hear a variety of squeals and howls in their receivers. As these will not be appreciated, especially when they interrupt a program, it is much better to operate a regenerative detector by reducing the feed back until the tube stops oscillating and then do your tuning without any beat notes.

TICKLER COIL

In the early days of Radio, coils L1, L2, and L3 of Figure 3 were built usually in the form of a Vario-Coupler, described in the earlier Lessons. The primary L1 and secondary L2 were wound on the outer, stationary tube while the tickler L3 was wound on the inner, movable form. With this arrangement, the amount of regeneration could be controlled by changing the position of coil L3 in respect to coils L1 and L2, therefore, condenser C3 was of the fixed type, as shown in Figure 1.

For the arrangement of Figure 3, coils L1, L2 and L3 are all wound on a single coil form, with the proper spacing between them and the regeneration is controlled by the variable condenser C3. Because of the smoother action, the arrangement of Figure 3 has made the older Vario-Couplers almost obsolete.

To obtain Regeneration, instead of Degeneration, the ends of the tickler coil must be properly connected. Assuming an arrangement like that of Figure 3, with all three coils wound in the same direction and on the same form, the plate and grid must be connected to opposite ends of their respective coils. As shown in Figure 3, the plate connects to the lower end of L3 while the grid connects to the upper end of L2.

Should you ever assembly a receiver of this type and find the regeneration does not produce the desired results, always reverse the connections to the tickler coil before looking further for trouble.

SCREEN GRID VOLTAGE CONTROL

There are a great many varieties of regenerative circuits and in Figure 4 we show a common form using an r-f pentode as the detector, the advantage of this type of tube being its low inter-electrode capacities and high amplification factor.

The only changes we have made in the circuits of Figure 3 are in the grid leak "R1" which now connects from grid to ground instead of across the grid condenser C2. However, this changes only its position and not the electrical action. The condenser C3 is of the fixed type and provides a by-pass for the high frequency current.

To obtain voltage for the screen grid, we have the potentiometer, R2, across from B+ to B-, with the movable arm connected to the screen. By changing the position of this movable contact, the voltage on the screen can be varied from zero to the full potential of the B supply.

The path of the signal is the same as in Figure 3 and, when a voltage is induced in L2, with the grid circuit L2-C1 resonated at this frequency, the changes of voltage are impressed on the control grid and cause variations of plate current at the same frequency as the modulation. The current variations produce a changing magnetic field around L3 which induces a voltage in L2 and thus we have the regenerative action.

In a former Lesson, we told you that changing the voltage on the screen grid caused a variation in the amount of electrons reaching the plate and thus, to a certain extent, controlled the plate current.

From an earlier explanation, you will remember that the strength of the magnetic field, set up around a coil, is determined by the number of turns and the current in it. Also, among other factors, the amount of emf induced in another coil, depends on the strength of this magnetic field.

Keeping these actions in mind, coil L3 is in series with the plate circuit and will carry the total plate current. Now, if changing the screen grid voltage varies the plate current, it will also vary the strength of the magnetic field and control the amount of induced emf in the coil L2. In other words, we can control the amount of feedback by varying the voltage on the screen-grid, by means of the potentiometer R2, which therefore acts as a volume control.

This method of controlling regeneration, by varying the voltage on the screen grid, has been found more satisfactory than that explained for Figure 3, due to the fact that it has a smoother action over a wider range of frequencies.

There is one other thing you have no doubt noticed in Figure 4 and that is the use of a cathode type tube instead of the filament type. In this type of tube, you know the cathode is the reference point and that the only purpose of the heater is to bring the temperature of the cathode to the proper operating point. For this reason, we did not indicate a supply but, before the receiver can operate, the correct voltage must be applied to the heater.

TAPPED INPUT COIL

Another common variation of a regenerative detector circuit is shown in Figure 5 where we have coils L1 and L2 of Figure 1, the grid leak R1 and condenser C2 of Figures 1 and 3 with the tube of Figure 4. The tickler coil, L3, is omitted but instead, the cathode connects to a tap near the grounded end of coil L2.

In this arrangement, regeneration is obtained because the plate current path is from the cathode to the tap on coil L2 and through a number of turns of the coil to B−. Here then, instead of a separate tickler coil, a part of coil L2 carries the plate current, acts as the primary of a transformer and induces a voltage in the entire winding of L2. As explained for the circuit of Figure 4, regeneration is controlled by varying the screen grid voltage by means of the potentiometer, R2, connected between B+ and B−.

The output circuit of Figure 5 is different from those explained previously because the plate current is carried by the choke instead of the phones. Connected in series with the plate, the choke current will be as shown in Figure 2-D. As the choke contains resistance and reactance, it is considered as an impedance and variations of current in it will cause corresponding changes of voltage drop across it.

The changes of voltage drop will cause condenser C4 to charge and discharge and, due to the circuit connections, these charge and discharge currents will be carried by the phones. Thus, the phones will reproduce the signals in much the same way as explained for Figures 1, 3, and 4.

This arrangement has several advantages from a practical as well as an electrical standpoint. First, C4, known as a

coupling condenser, insulates the phones from the d-c voltage of the "B" supply and thus reduces the possibility of shock to the person wearing them. Second, the headphones will carry only the changes of current, or the a-c signal, which reduces the total current in its windings. Third, the choke coil can be made with values of resistance and inductance which will more nearly match the pentode tubes which require a high impedance plate load.

As you will learn later, this is the method by which the signal can be coupled from one tube to another in order to increase its amplitude or volume.

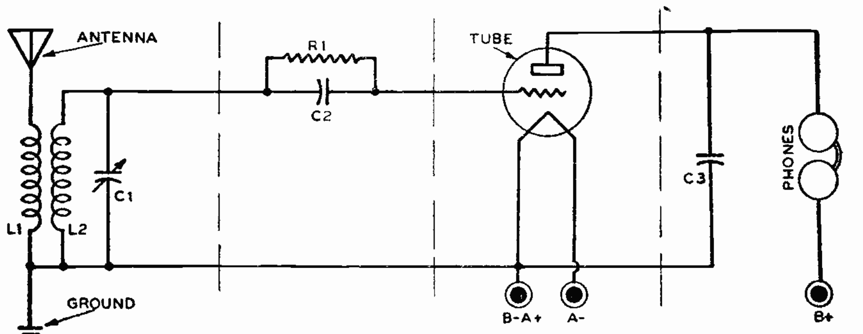


FIGURE 1

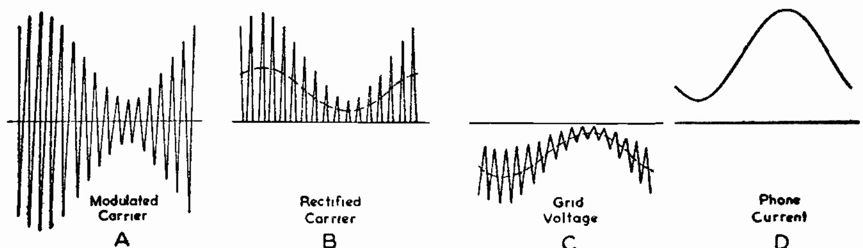


FIGURE 2

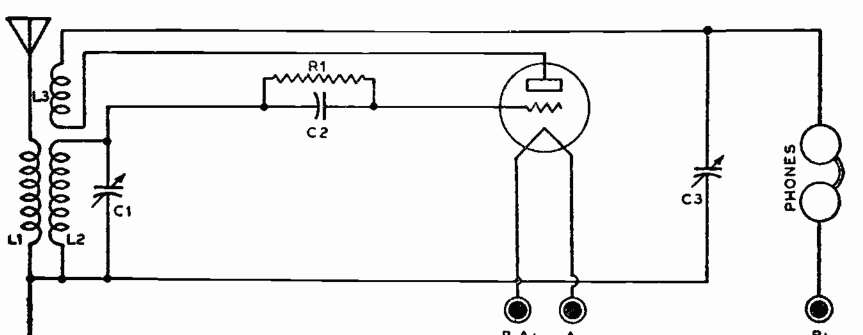
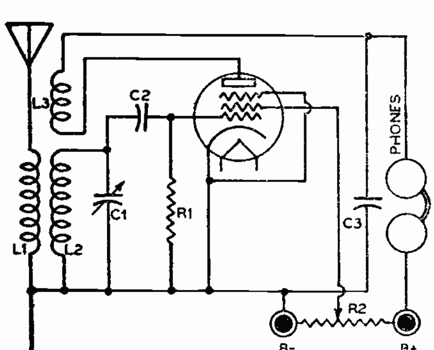


FIGURE 3



TRA-15 FIGURE 4

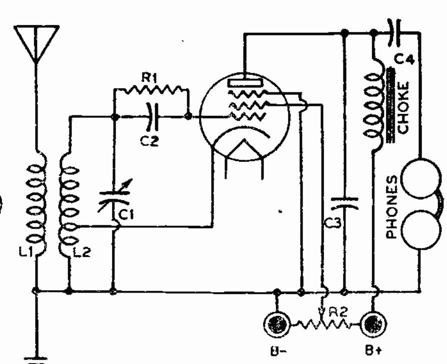


FIGURE 5

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TUBES - RECEIVERS - AMPLIFIERS

LESSON 16

AUDIO FREQUENCY AMPLIFIERS

* * * * * *

The gay high road of human welfare lies along the old highway of steadfast well being and well doing, and they who are the most persistent, and work with a true spirit will invariably be the most successful; success treads the heels of every right effort.

---- Samuel Smiles

AUDIO FREQUENCY AMPLIFIERS

In our explanation of a simple Radio Receiver, we told you its three necessary functions are (1) to select one of the frequencies induced in the antenna, (2) to separate the carrier and signal frequencies, and (3) to convert the signal frequencies into corresponding sound waves. The circuit is arranged so that, after the first two functions have been completed, the signal frequencies appear as variations of output voltage or current.

To perform the third function it is customary to convert the electrical changes of output into corresponding changes of magnetism which cause corresponding motion of a diaphragm. The motion or vibration of the diaphragm sets up the sound waves which strike our ears and permit us to hear the signals.

In the later Lessons we will give you complete details on the construction and operation of the various types of phones and speakers which convert electrical variations into sound waves of corresponding frequencies, but now we are interested in the electrical actions.

In the early days of Radio, when nothing but crystal and simple one tube Receivers were available, we were satisfied to wear a pair of headphones while listening to Radio Programs. Even then, the room had to be quiet or the weak sounds could not be heard. As Radio programs increased in popularity, the public demanded signals which were not only louder but could be heard without the inconvenience of wearing headphones.

To appreciate how well the demands have been met it is necessary only to listen to a modern Radio Receiver yet, in spite of the enormous improvements, the general principles of operation have not changed. Therefore, in this Lesson, we will follow the development and show the method by which the strength, or amplitude of the signal voltage is increased.

It may be well to mention here that, by signal frequencies, we mean those of speech and music or those frequencies to which our ears respond. Because they are audible, we call them "Audio Frequencies" but, due to the variation of human ears, it is difficult to establish exact values for the upper and lower limits. However, the complete range extends from about 20 cycles per second up to 20,000 cycles per second but, for most cases, it is not necessary to reach these limits.

The ordinary telephone systems operate on frequencies from 250 cycles per second to about 3000 cycles per second. However records and Broadcast programs consist of frequencies from

about 50 cycles per second to 5000 cycles per second while high fidelity production may extend up to 15,000 cycles per second. Although 10,000 cycles per second has been commonly considered as the dividing line between audio and radio frequencies, there is some overlap and the higher frequencies are necessary for more life like reproductions of sound.

As explained for a simple Receiver, the audio frequencies appear in the output of the detector as electrical variations and, as such, can be amplified by means of tubes in an arrangement known as an "Audio Frequency Amplifier" or, more commonly, an "Audio Amplifier".

CASCADE AMPLIFIERS

From an electrical standpoint, the audio amplifier must contain a device by which the variations of signal current, like in the output circuit of a detector tube in a Radio Receiver, can be made to produce a change of voltage. Going back to earlier Lessons, you will remember a change of current in a resistance causes a change of voltage drop across the resistance. Then, in the Lessons on a-c, we explained how a similar change of voltage was produced by a change of current in an inductance.

These changes of voltage, caused by the changes of plate current in a resistance or inductance, can be impressed on the grid of a following tube and, due to the amplifying action of the tube, the changes of grid voltage cause like, but greater changes of current in its plate circuit.

These greater changes of plate current are made to cause voltage changes on the next tube and the process is continued throughout the amplifier. Following the path of the signal, it is carried over from the detector output circuit through the following tubes in order. Electrically, it passes through the tubes in series and a device of this type is called a "Cascade Amplifier"'

Each tube, with its associated circuits, is known as a 'Stage" and, whenever there are several stages of audio amplification, the purpose of the first stages is to amplify the voltage. The last stage, however, must furnish the power to operate the speaker.

TYPES OF AMPLIFIERS

As we mentioned briefly in the early Lessons, according to the method of coupling the stages, there are three main types of audio amplifiers. Using the names of the coupling methods, they are,

1. Resistance
2. Impedance
3. Transformer

In this Lesson, we want to tell you the general operating principles and advantages of each type. Although you will find a great many variations and combinations used in present day units, built according to the ideas of different designers, in every case the general principles remain the same.

RESISTANCE COUPLING

Starting with Figure 1, we have the circuits of a simple resistance coupled stage of audio amplification. In the plate circuit of the first tube is the resistance, R_o, and because the action starts in the plate circuit, we will begin our explanation there.

Imagine the left tube is operating as the detector of a Radio Receiver and resistance R_o, in series with the plate circuit, carries the entire plate current. Therefore, every change of plate current will cause a change of voltage drop across the resistance.

With a constant d-c voltage from the B supply, the changes of voltage drop across R_o will cause a changing voltage at the plate. As the plate current increases, the drop across R_o will increase also, therefore, in respect to "B-", the plate voltage will decrease. Because the changes of plate current are caused by the changes of grid voltage, the action of R_o will cause the plate voltage to vary at the same audio frequency as the grid voltage.

Looking at Figure 1 again, you will find condenser "C" connected between the plate of the left tube and the grid of the right hand or following tube. As a condenser will not pass d-c , the grid of this tube is insulated from the d-c voltage of the B supply for this left hand tube. However, from the plate end of this condenser there is a path through the plate circuit of the tube to ground, while from the grid end there is a path through resistor "Rg" to ground.

Reviewing the action, a change in the value of voltage across a condenser causes a displacement current to enter one plate and leave the other. The direction of this current will be in one direction when the voltage increases and the condenser changes, but reverse when the voltage decreases and the condenser discharges.

Connected as in Figure 1, the voltage across the circuit made up of condenser "C" and resistor "Rg" is the same as that across the plate of the left hand tube, therefore variations of plate current in R_o will cause changes of voltage across the circuit.

For example, when the plate current increases, the increased voltage drop across R_o will cause a reduction of plate voltage and allow the condenser to discharge to a certain extent. The path of this discharge, or displacement current will be from the condenser to the plate of the left tube, through the tube to ground and back up through Rg to the other side of the condenser. Carried by Rg, this current will cause a voltage drop which will be impressed on the grid circuit of the right hand tube.

When the plate current decreases, the reduced voltage drop across R_o will cause an increase of plate voltage and condenser "C" will charge accordingly. The path of this displacement current will be from the grid end of the condenser, through R_g to "B-", through the supply to "B+", and through "R_o" to the plate side of condenser "C".

Checking back, with a steady value of current in R_o, the condenser will neither charge or discharge, therefore there will be no current in "Rg" out variations of current in "R_o" cause reversals of current in Rg and thus, in effect, variations of d-c in R_o are changed to a-c in R_g.

As explained for R_o, the changes of current in R_g cause corresponding changes of voltage drop across it and these voltages are impressed in the grid of the tube which operates as an amplifier. To obtain the desired operating point, resistor Rc, with its bypass condenser Cc, is connected between cathode and ground to provide the proper grid bias.

PLATE RESISTOR

For the proper operation of this circuit, the value of the plate resistor is of great importance, because it is in series with the plate circuit of the tube. Current in the circuit will cause a voltage drop across each of these, in proportion to their relative values of resistance. Remembering that it is the changes of voltage drop caused by the changes of plate current, which cause condenser C to charge and discharge, for maximum results, the ohmic value of R_o should be as high as possible.

However, for proper tube operation, it is necessary to maintain a definite value of plate voltage, therefore, as the

value of R_o is increased, the plate supply voltage must be increased also. This condition imposes a limit on the value of the plate load resistor, R_o, and, in practice, a compromise is made. For triode voltage amplifier tubes, the value of R_o is usually somewhere from 1 to 10 times the plate impedance, depending on the characteristics of the tube.

THE CONDENSER

Condenser C, Figure 1, is a capacity coupling between the plate circuit of one tube and the grid circuit of another and, therefore, is called a "Coupling Condenser". However, as it prevents the d-c voltage of the plate supply from reaching the grid, it is sometimes referred to as a "Blocking Condenser".

To be effective, the condenser must have a high d-c resistance to prevent direct current from the upper end of the plate resistor, through the condenser and grid resistance, R_g, back to the B negative.

Any coupling condenser leakage current in R_g will cause a voltage drop but, as the grid connects to the positive end, it will tend to make the grid positive in respect to the cathode, in spite of the negative bias produced by the resistor R_c. Should the grid become positive, it may increase the plate current to the point of saturation and the tube will no longer operate as an amplifier.

With the condenser C in perfect condition, it will charge and discharge at the same frequency as the voltage drop across R_o. The charge and discharge current caused by this action will be through R_g and thus cause a voltage drop across it in accordance with the signal frequency. For normal operation, the drop across R_g will always be less than that across R_c, therefore the plate current will vary in proportion to the signal voltage.

Considering R_o as the source of signal voltage, condenser C and resistance R_g are in series and, as only the voltage drop across R_g is applied to the grid of the tube, the drop across C is lost. Going back to the early a-c Lessons, you will remember the reactance of a condenser depends on the frequency. At low frequencies, the reactance is high but, as the frequency increases, the reactance becomes lower.

The circuit of Figure 1, used as an audio amplifier, impresses audio frequency on condenser C and therefore a small capacity produces a high reactance. This high reactance will cause a loss of the energy which we want to supply to the grid of the following tube and the grid load R_g.

The voltage changes across R_o are divided between the reactance of the condenser C and the resistance of the grid load R_g. The percentage of signal voltage across the grid circuit of the right hand tube in Figure 1, will depend on the relative values of C and R_g.

GRID RESISTANCE

Still looking at Figure 1, resistance R_g is in parallel to the grid circuit of its tube. Thinking of the grid as the input circuit, its impedance is in parallel with the resistance R_g. The higher the resistance of R_g, the greater the signal energy on the grid.

When electrons accumulate on the grid, it becomes more negative and, if the action continues, the negative charge increases to a value high enough to prevent plate current. This action is known as "blocking" and, for best results, the capacity of the coupling condenser must have the proper relation to the resistance of the grid load. While you will find variations of these values, for a grid load of 470,000 Ohms, it is customary to use a .01 mfd condenser.

Because changes of frequency have but little effect on the voltage drop across a resistance, the general arrangement of Figure 1 provides fairly uniform action for the ordinary band of audio frequencies while the efficiency of modern tubes permits satisfactory operation at comparatively low plate voltages. These conditions, plus the relatively low cost of the resistors and coupling condenser, have made resistance coupling the most popular and widely used type.

IMPEDANCE COUPLING

The main objections to the resistance coupling of Figure 1 are the need of high plate supply voltage and the loss of power in the plate resistance. However, it is only the changes of plate current we want to amplify and these can be considered as alternating current. If you will think back, you will remember that whenever these changes of plate current were used to produce a voltage, the voltage was alternating.

Suppose now, instead of a resistance, an inductance is placed in the plate circuit in the position of L_o, Figure 2. It is made of a large number of turns of wire wound on an iron core but has a fairly low resistance to direct current. Due to self induction, the inductance provides a high impedance to the variations of current without changing the direct current resistance values. By using an iron core and with the proper number of turns, the coil is made to have a high reactance value at the audio frequencies.

In general, the action of the amplifier of Figure 2 is much like that of Figure 1. The low d-c resistance of L_o causes but a small voltage drop, therefore the loss is less than that of the resistance coupling. At audio frequencies, the high impedance of the coil causes a voltage drop which is carried over to the grid of the following tube. As the value of the voltage drop varies with the changes of plate current, the signal voltage is impressed on the following grid by coupling condenser C.

Replacing the grid load resistance, R_g of Figure 1, we have the inductance L_g of Figure 2. The action is similar to that already explained except the lower d-c resistance of the choke coil prevents blocking. The reactance at audio frequencies produces a high impedance which causes a strong signal voltage on the grid.

Another point we want to mention here is that the coupling condenser, "C", and choke, L_g, make a circuit with capacity and inductance in series. This circuit will be resonant at some frequency determined by the values of inductance and capacity.

Back in the earlier Lessons, you learned that, at resonance, a series circuit had maximum current and minimum impedance. Here, however, the grid is connected across the choke only and at resonance, the maximum current in the choke causes it to have a voltage drop higher than that across the complete circuit. By this action, the signal voltage is amplified although the turn ratio between chokes L_o and L_g may be 1 to 1.

Another advantage of this action is that certain audio frequencies can be amplified more than others. For example, suppose we want to emphasize the lower or bass notes. The circuit can be made resonant at about 75 cycles and frequencies from 50 to 100 cycles will then cause a higher voltage across the grid than those frequencies above 100. Thus the lower frequencies will be overemphasized to make up for possible losses in the speaker.

To offset these advantages, the reactance of the choke coils will vary with the frequency of the signal, and therefore, for equal signal input voltages, the drop across them will vary with the frequency. Because of this action, the response of the circuit will not be uniform for the ordinary audio band.

In order to provide the required value of reactance at low audio frequencies, the choke coil must contain a comparatively large number of turns of wire which, together with its luminated iron core, make it a relatively expensive and heavy unit.

Therefore, in the common types of Broadcast Radio Receivers, but few impedance coupled audio amplifiers are used.

RESISTANCE - IMPEDANCE COUPLING

Because there are two chokes in Figure 2, this method is known as "Double Impedance" coupling. Many designers prefer some of the features of Resistance Coupling and combine the circuits of Figures 1 and 2. For example, some audio stages have the plate resistor R_o of Figure 1 but use the choke L_g of Figure 2. Others do the opposite, using the plate choke L_o of Figure 2 but with the grid circuit of Figure 1.

With several audio stages, you may sometimes find both these combinations* used in the same receiver. The first stage may have resistance in the plate and impedance in the grid circuit. The second stage then will have impedance in the plate and resistance in the grid and so on alternately for all stages. This alternate arrangement reduces the possibility of feed back between the various circuits and tends to prevent oscillation or motor boating.

AUTO TRANSFORMER

A different combination of Figures 1 and 2 is shown in Figure 3. Here we have the plate resistance of Figure 1 and the grid impedance of Figure 2. The coupling condenser is connected from the plate to a tap on the impedance winding. Signal voltages will then be across the condenser and lower part of Impedance L_g.

The entire winding of L_g connects across the grid circuit and acts as an auto transformer. As shown in Figure 3, the lower part of L_g is the primary and the entire winding the secondary. Because the secondary has more turns than the primary, the signal voltages across the primary are "stepped up" in the grid circuit and greater amplification is secured.

TRANSFORMER COUPLING

The third type of audio amplifier uses transformer coupling with the circuits of Figure 4. The transformer primary, L_o, is in series with the plate circuit of the first tube while the secondary, L_g, is in series with the grid of the following tube. Notice here the circuits of Figures 2 and 4 are quite similar but Figure 4 has no coupling condenser because the coils are inductively coupled by being wound on the same core.

The main advantage of transformer coupling is that, in addition to the amplifying action of the tubes, the transformer

also amplifies the signal voltages in proportion to the turn ratio of the windings. This does not mean, however, that a transformer with a 100 to 1 ratio would amplify the signal voltage 100 times. The secondary voltage depends on the voltage drop across the primary and, to keep the transformer down to a practical size, its step up ratio is limited.

As we explained for the circuits of Figure 1, to make full use of the signals, or variations of plate current, the plate load, R_o, must have a value several times that of the plate impedance. In Figure 4, transformer primary L_o is the plate load and therefore its value of reactance should approximate the value of the plate load resistor R_o of Figure 1.

As explained for the choke coils of Figure 2, the transformer primary winding is an inductance and its reactance will vary with frequency. Therefore, to provide the necessary value of reactance, at low audio frequencies, the primary winding requires a comparatively large number of turns.

For a step up ratio in the transformer, the secondary winding requires more turns than the primary and, as turns are added, the distributed capacity of the winding is increased. By definition, any two conductors, separated by insulation, form a capacity, therefore adjacent turns and layers of the insulated wire of the winding provide what is known as "distributed capacity". As capacity reactance varies inversely as frequency, the impedance of the winding will decrease as the frequency increases.

Thus, the primary turns must be sufficient to provide proper reactance at low frequencies while the secondary turns must be limited to a value which will provide sufficient impedance at high frequencies. To satisfy both of these conditions, the turn ratio of a good audio transformer seldom exceeds 3 to 1.

In the older models of Radio Receivers, employing low mu triode tubes, transformer coupling was employed to increase the overall gaid of the stages but, with the development of high gain pentode tubes, resistance-capacity coupling is now used in most cases. However, as we will explain later, in some types of power amplifiers and for coupling the plate circuit of an output tube to a speaker, transformers are in common use.

POWER AMPLIFIERS

All of the circuits explained so far in this Lesson are designed to provide maximum signal voltage across the grid circuit of the output tube and are, therefore, classed generally

as "Voltage Amplifiers". Their purpose is to increase the amplitude of the signal voltage so that louder or higher level signals may be obtained. However, to convert these electrical signals into corresponding sound waves, the last, or output tube of an audio amplifier must be able to deliver sufficient power to operate the headphones, or speaker at the desired level or volume.

To illustrate this difference, we will assume the circuit of Figure 1 is in operation and provides a drop of 5 volts across the 250,000 ohm grid resistor R_g. This signal may be several times greater than the signal on the grid of the preceding tube and be sufficient to drive its tube to capacity. From a power standpoint, with 5 volts across a 250,000 Ohm resistor we find,

$$\text{Watts} = \frac{E^2}{R} = \frac{25}{250{,}000} = .0001$$

which is one ten thousandth of one watt or one tenth of 1 milliwatt. Also, with 5 volts across 250,000 Ohms, the current

$$I = \frac{E}{R} = \frac{5}{250{,}000} = .00002 \text{ ampere}$$

which equals two hundred thousandths of an ampere or 2 hundredths of one milliampere. With these small values of voltage and current we consider the arrangement as a voltage operated circuit.

In contrast, many speakers have voice coils of 4 ohms impedance and, following the plan above, with 5 volts across the circuit,

$$\text{Watts} = \frac{E^2}{R} = \frac{25}{4} = 6\text{-}1/4$$

$$I = \frac{E}{R} = \frac{5}{4} = 1\text{-}1/4 \text{ amps}$$

This is considered as a power circuit and, compared to a voltage circuit, its value of impedance is lower while its current is higher.

In order to provide appreciable power output, power amplifier tubes have a lower plate impedance than corresponding amplifier tubes and are operated at higher values of plate voltage. Preceding stages of voltage amplification build up the signal to apply the required value on the grid of the power tube. This value of grid voltage produces comparatively large changes of plate current to provide the required power.

PUSH PULL AMPLIFIERS

None of these amplifiers work perfectly, therefore the output signal voltage is not of exactly the same wave form as the input signal. Using a power tube, the signals may reach a strength which overloads the tube or transformer and causes distortion. To overcome this trouble most amplifiers, which have a high power output, use the circuits of Figure 5 for the last audio stage.

Starting at the left, we have a plate circuit like that of Figure 4, but the secondary winding of the transformer is tapped at its center. Each end connects to the grid of a tube while the center tap acts as a grid return for both tubes through the bias resistor R_c.

Notice carefully, the grid circuit of each tube is from the center tap to its end of the winding. When a change of plate current occurs in the primary, a voltage is induced in the secondary. As explained for Figure 4, this voltage makes one end of the secondary positive and the other negative. The same is true in Figure 5, but here we have to consider the center tap.

What really happens is that the voltage across the entire winding is divided, one grid is negative to the center tap and the other is positive. For example, suppose the induced E.M.F. in the secondary was 20 volts with the positive at the top. There would be a difference of 10 volts between the upper positive end and the center tap. There would also be a difference of 10 volts between the lower negative end and the center tap.

As the center tap connects to the cathodes through R_c, the upper grid is 10 volts positive while the lower grid is 10 volts negative. This action takes place under all conditions and, regardless of the value or direction of induced emf in the secondary, the grids will always have equal voltage of opposite polarity. In other words, the signal voltage on the grids is 180° out of phase.

Of course, the negative C bias prevents either grid from actually being positive in respect to the cathode but, at the positive voltage from the transformer reduces the negative bias on one grid, the negative voltage from the transformer increases the negative bias on the other grid.

Following this action through the tubes, as the change of voltage on one grid causes its plate current to increase, the change of voltage on the other grid causes its plate current to decrease.

Tracing the plate circuits, we see an arrangement similar to that of the grid circuits. Each plate connects to one end of a transformer winding with a center tap connected to the B supply. Starting at B positive, there is a circuit up to the center tap, through the upper half of the winding to the plate of the upper tube. Also, there is a circuit from the center tap through the lower half of the winding to the plate of the lower tube.

With no signal voltage, both grids have the same bias and, therefore, the plate currents of both tubes should be equal. With equal current of opposite direction in each half of the winding, the magnetic fields will neutralize each other. As far as the core is concerned, it is the same as if there were zero current in the winding.

Looking at it in a different way, with the center tap as the point of high potential, equal current through equal turns of each half of the winding will cause an equal drop of voltage. Therefore, the outer ends of the winding will be at equal potentials with no difference in voltage, or voltage drop between them. As far as the transformer is concerned, the direct current in the plate circuit has no effect, and there will be no induced voltage in the secondary winding "Ls". It is only the changes of plate current which cause the transformer action.

Now, suppose a change of plate current in the input transformer primary "L_o" induces an emf in the center tapped secondary "L_g". As previously explained, one grid will become more positive and the other grid more negative to cause the current in one plate circuit to increase while the current in the other plate circuit will decrease.

Going back to the laws of induction, the induced emf is always in a direction to oppose a change. Thus, in that half of winding L_o, in which the current is increasing, there will be a self induced emf in a direction to oppose the increase.

For the other half of the winding, in which the current is decreasing, there will be an induced emf in a direction to oppose the decrease. Following these actions for the entire coil, you will find the self induced emf in both halves of the winding is in the same direction and the difference is voltage across the entire winding will be equal to the sum of that induced in both halves of the winding.

Going back to an earlier explanation of transformer action, you will remember that the self induced emf in the primary

is caused by changes of magnetic flux which cuts the secondary also. Thus, the action explained for the primary of the output transformer will induce an **emf** in the secondary winding "L_S".

Because the induced primary voltage pushes away from the plate of one tube and pulls toward the other, circuits like that of Figure 5 are known as "Push Pull". Due to the double action, other things being equal, the total voltage induced in the secondary will be twice as great as with a single tube.

The push-pull amplifier has several important advantages we want to mention at this time. Changes of voltage caused by variations of the plate supply or by the use of a-c in the tube filaments tend to balance out the same as the d-c plate current, and thus hum is reduced in the output transformer secondary. However, hum which originates in preceding stages will be carried over and amplified with the signal. The balancing action also tends to reduce distortion and thus the push pull stage can deliver more than twice the undistorted power output of a single tube.

No bypass condenser is shown for bias resistor R_C of Figure 5 because, with the tubes properly balanced, the total plate current of both will remain the same although the separate plate currents will vary. Thus, with a steady current in the resistor, the bypass condenser is not needed but, for protection against unbalanced conditions, a condenser is installed in some circuits.

OUTPUT CONNECTIONS

In our explanation of a simple one tube receiver, we connected a pair of headphones in series with the plate of the tube and thus the variations of plate current caused the diaphragm to vibrate and produce the sound waves. The two main disadvantages of this arrangement are, first, the reactance of the coils in the phone may not be of proper value to match the plate impedance of the tube and, second, the phones are connected directly to the high voltage plate supply, exposing the user to the possibility of shock.

This latter disadvantage may be overcome by using an arrangement similar to that of Figure 2 and substituting the phones for the coil shown as "L_g". Coupling condenser "C" blocks the high d-c voltage of the plate supply but permits the variations of plate voltage to be carried over to the phones. However, as most modern Receivers are equipped with a speaker, the common arrangements for the output connections are shown in Figures 5 and 6.

In Figure 6 you will see a pentode type tube with the screen grid connected directly to the "B+" and the transformer primary "L_O" in series with the plate. Bias resistor "R_C", with its bypass condenser "C_C", is connected between cathode and ground while the signal voltages are impressed on the grid as shown for the output tubes of Figures 1 to 4. The speaker, or headphones, connect across the transformer secondary "L_S" and are isolated from the high d-c voltage of the plate supply.

The transformer is useful also in "matching" the required plate load of the tube to the impedance of the speaker or other output device. For example, we will assume the tube of Figure 6 will provide an output of 2 watts with a plate load of 2000 ohms but we want to use a speaker which has an impedance of but 5 ohms.

As explained in the earlier Lessons, a transformer does not produce any energy and the power in the secondary will always be less than that in the primary but it can alter the values of voltage and current. This is done by changing the ratio of primary to secondary turns but, in every case, the product of voltage and current in the secondary is less than the product of the voltage and current in the primary.

For Figure 6, to simplify our explanation, we will neglect the plate current, which causes no action in the secondary, and assume the secondary power equals the primary power. From the earlier Lessons we know the relationship between power, voltage and resistance is stated as,

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

and, transposing the terms,

$$E = \sqrt{WR}$$

Here then, with 2 watts in a 2000 ohms plate load,

$$E = \sqrt{WR} = \sqrt{2 \times 2000} = \sqrt{4000} = 63.24 \text{ volts}$$

Thus, with 2 watts in the primary L_O, there should be a drop of 63.24 volts across it.

For the secondary, which is to connect to a 5 ohm speaker, for a power of 2 watts,

$$E = \sqrt{WR} = \sqrt{2x5} = \sqrt{10} = 3.162 \text{ volts}$$

Thinking of the transformer only, with 63.24 volts across the primary, there should be but 3.162 volts across the secondary

for a ratio of 63.24 divided by 3.162 which is 20. As the turn ratio of the winding is approximately equal to the voltage ratio, in this case the primary will require 20 times as many turns as the secondary.

Notice here, the ratio between the 2000 ohms of the primary and the 5 ohms of the secondary is 2000 divided by 5, or 400 and the square root of 400 is 20, the same value as the turns ratio. As this relationship holds true in all cases, as a general rule we can state the turns ratio squared is equal to the ratio of the impedances between which the transformer works.

From the primary side, the transformer looks like the load impedance multiplied by the turns ratio squared and thus, in the example just given, the 5 ohm speaker is equivalent to $5 \times 20^2 = 5 \times 400 =$ a 2000 ohm plate load. This action is often referred to as a "reflected load".

For the push pull circuits of Figure 5, the arrangement is about the same as that of Figure 6 except that the primary has a center tap and thus each half of the winding acts as the load for one tube.

TYPICAL AUDIO AMPLIFIER

To show the common combination of these various circuits, for Figure 7 we have the arrangement of a typical audio amplifier used in the popular table model Radio receivers. Tube T1 is a "Diode-Triode" in which the diode acts as a rectifier or detector for the modulated radio carrier.

The signal voltages appear across resistor R1, and are coupled to the grid of the triode section of the tube through condenser C2. Resistor R1 is in the form of a potentiometer and acts as a volume control but, with that exception, the circuits are similar to those of Figure 1 with R1 in place of R_o, C2 in place of C and R2 in place of R_g.

The triode section of T1, operating as an amplifier, is resistance coupled to the output tube, T2, on the general plan of Figure 1. Here, R3 replaces R_o, C4 replaces C, R4 replaces R_g, and R5 replaces R_c. Condenser C3 acts to remove any carrier frequencies which may be present in the plate circuit.

The circuits of the output tube, T2, are similar to those of Figure 6 except the tube is of the beam power type. The bypass condenser, corresponding to "C_c" of Figure 6, is omitted to reduce distortion by inverse feed back, an action which will be explained later.

Condenser C5, connected between the plate and screen grid, prevents the generation of unwanted frequencies, known as "Parasitics". Its action is to provide a low reactance path for high frequencies and thus prevent high r-f voltages between the plate and screen. This same action reduces the higher frequency audio signals somewhat and thus C5 acts also to limit the high frequency response.

While values will vary in different models, assuming T1 to be a 12SQ7 and T2 a 50L6 type of tube, the following are representative values of resistance and capacity.

R1 - 1 Megohm control	C1 - .0001 mfd
R2 - 2 to 10 Megohms	C2 - .01 mfd
R3 - 470,000 Ohms	C3 - .0005 mfd
R4 - 470,000 Ohms	C4 - .01 mfd
R5 - 150 Ohms	C5 - .01 mfd

In addition to amplifying the signal of a detector, these circuits will amplify any audio frequency signals such as those produced by a microphone or phonograph pickup. To make use of this action, some models of Radio Receivers are equipped with a "phono" terminal as indicated by the broken lines of Figure 7.

Any audio frequency voltage, applied between the phono terminal and ground, will appear across resistor P1 and be amplified the same as the detector output. In practice, some sort of a switching arrangement is installed to cut off the radio signals while the "phono" circuit is in use.

Audio amplifiers have many applications in Electronics such as the "Phono" arrangement mentioned above, as Public Address Systems, Intercommunication Systems, Sound Movies, and so on. The basic circuits of these specialized audio amplifiers are the same as explained in this Lesson, therefore the details will be taken up later in the study of their applications.

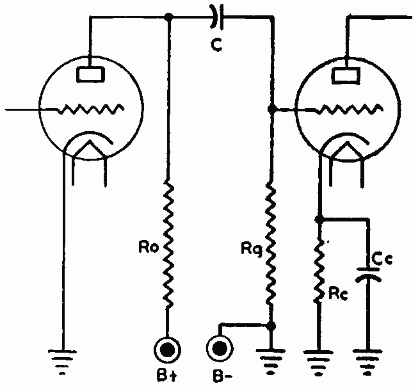


FIGURE 1

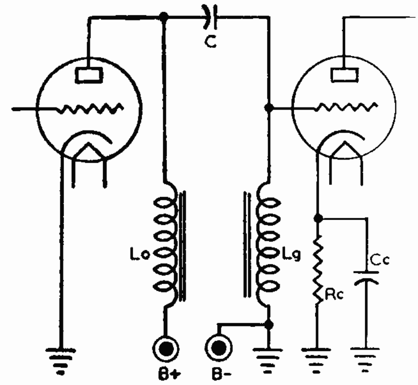


FIGURE 2

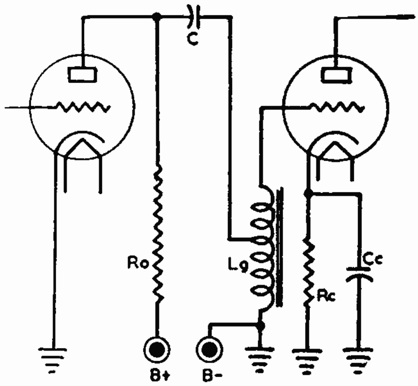


FIGURE 3

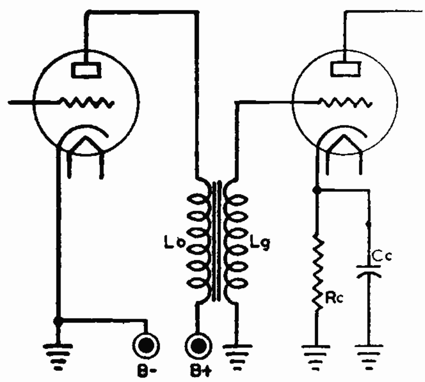


FIGURE 4

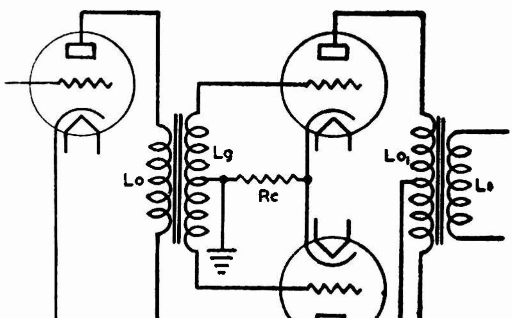


FIGURE 5

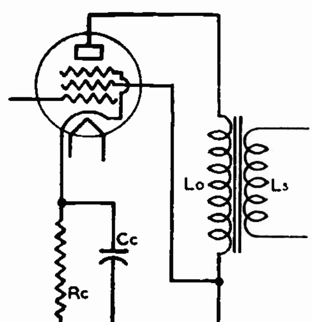
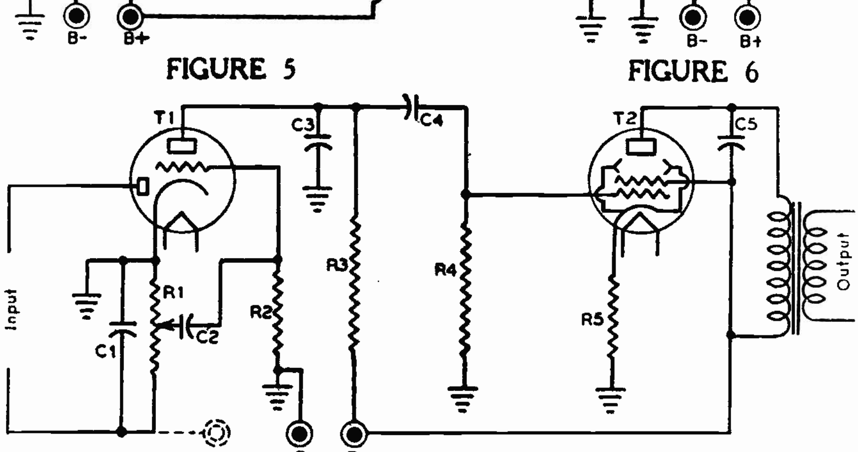


FIGURE 6



TRA-16

FIGURE 7

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LESSON TRA - 17

HIGH FREQUENCY AMPLIFIERS

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LESSON TRA - 17

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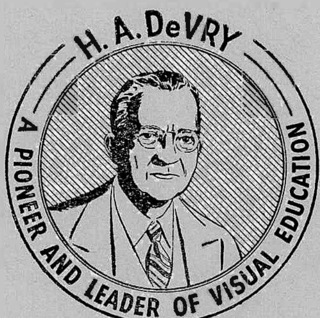

TUBES - RECEIVERS - AMPLIFIERS

LESSON 17

HIGH FREQUENCY AMPLIFIERS

* * * * *

The heights by great men, reached and kept
Were not attained by sudden flight,
But they, while their companions slept,
Were toiling upward in the night.

--- Longfellow

HIGH FREQUENCY AMPLIFIERS

In our explanation of a simple Radio Receiver, we described the action of the antenna coil or transformer and, reviewing briefly, the primary winding connects between the antenna and ground to form a path for the current caused by the voltages induced in the antenna.

The secondary winding is tuned to resonance by a variable condenser to provide selectivity by amplifying the resonant frequency and attenuating other frequencies. For Figure 1 of this Lesson, we show a similar circuit with L1 as the primary and L2 as the secondary, tuned by the variable condenser C1, and connected across the grid-cathode circuit of the tube.

In the simple Receiver circuit a grid leak and grid condenser, connected in series with the grid of the tube, caused a demodulating or detector action, but here the grid connects directly to one side of the coil and condenser. Therefore, the modulated carrier voltage, developed in the tuned circuit, is applied directly to the grid.

Acting as an amplifier, the tube will cause the variations of grid voltage to control the changes of plate current and thus, the modulated carrier frequencies will appear across the plate coil L3. As an amplifier, the tube does not cause a change of frequency but, due to its action, the signal voltage drop across L3 will be greater than the voltage of the tuned circuit L2-C1.

Thus, the arrangement of Figure 1 is known as a Radio Frequency amplifier or, more commonly, an **r-f** stage. The term "stage" is used quite loosely but, in general, you can think of a tube and its associated circuits as a "stage". On this basis, the simple one tube Receiver contained a Detector stage, while the audio amplifiers of the preceding Lesson included Input or First stages, Output stages, Push-Pull stages and so on.

In modern multi-tube Radio Receivers, it is customary to use one or more stages of high frequency amplification between the antenna and detector. As we will explain later, the common type of Receiver circuit reduces the carrier to a lower or intermediate frequency to provide more efficient operation but, at this time, we will consider all of these as "high frequency amplifiers".

These high frequency stages form an important part of a complete Receiver as they determine its selectivity, sensitivity

and fidelity or tone. The following definitions will help to clarify the similarities and differences of these actions.

Selectivity is the ability of a Receiver to accept and reproduce the signals of the desired Broadcast or other Transmitter without interference or the reproduction of signals from other stations.

Sensitivity is the ability of a receiver to accept weak signals and reproduce them at the desired level or volume.

Both of these Receiver characteristics are controlled by the high frequency amplifier stages which must be balanced to provide the best results. For example, a highly sensitive receiver will pick up a greater number of signals and thus reduce the apparent selectivity. Then, a Receiver which is extremely selective may tune so sharply that it is difficult to operate and, even when tuned properly, will pass a band of frequencies too narrow for good tone.

COUPLING

Going back to the Audio Frequency Amplifier Lesson, you will remember there are three distinct types of coupling.

1. Resistance
2. Impedance
3. Transformer

While all these are used for audio amplifiers, practically all high frequency amplifiers are built with transformers. Resistance coupling requires higher plate voltages and does not produce good amplification at the higher frequencies. Impedance coupling has similar faults because the windings have a high distributed capacity and, at high frequencies, the impulses pass through the capacity, instead of the winding. This, in effect, really shorts the winding.

Transformer coupling has several advantages which make it the most popular system in common use. Greater amplification can be obtained by means of transformers than by any other method. The ohmic resistance of the winding is low, permitting the use of lower supply voltages.

The losses in high frequency air core transformers are lower than in the usual iron core types, thus producing a more uniform amplification over a wide band of frequencies. Also, the transformer secondary may be tuned with a variable condenser, connected as in Figure 1. Because of their common use, we will explain only the transformer type of coupling in this Lesson.

RADIO FREQUENCY SYSTEMS

As we have previously explained, the purpose of the high frequency amplifier is to increase the strength or amplitude of the signal before it reaches the detector. In Figure 1, we have the circuits of one stage of the simplest type of tuned Radio Frequency Amplifier. Coil L1 is the primary and L2 the secondary winding of an air core transformer with a variable condenser, C1, connected across the secondary L2. Since the inductance of the coil is of fixed value, the circuit L2-C1 is tuned to resonance by varying the capacity of the condenser.

If the various actions, explained in the Lessons on Resonant Circuits and Electron Tubes, are not clear in your mind, we suggest that you review those Lessons before going ahead.

With a varying, or alternating, current in the primary L1, a voltage of like frequency will be induced in the secondary L2. Coil L2, therefore, really is the source of voltage as far as its circuit is concerned.

With condenser C1 connected across the coil, the circuit is completed and is considered as containing inductance and capacity in series. When tuned to resonance, the impedance of this circuit will be at minimum to allow maximum current with maximum voltage drop across the coil and also across the condenser.

Tracing further, you will find the grid of the tube connects to one end of the coil and condenser while the cathode connects to the other ends. This means that the voltage drop across the condenser will be impressed on the grid circuit of the tube.

Because of the action in the tube, the changes of grid voltage cause similar but greater changes of current in the plate circuit. Following the action through, the current changes in coil L1 are amplified and reproduced in coil L3. As coil L3 may be the primary of another transformer, like L1-L2, you can see the action will be repeated in the next stage if L3 replaces L1 of Figure 1.

OSCILLATION

Although the later Lessons contain detailed explanations of vacuum tube oscillators and their circuits, the following brief description should enable you to understand the action as it applies to the operation of high frequency amplifiers.

The inductance L1 and condenser C1, of Figure 1, are often called an oscillating circuit because of their action when

tuned to resonance. However, the term "oscillation" is used in so many different ways that we will start by giving you a little explanation regarding it.

The word, Oscillate, means to reverse or move back and forth. Thus, if the condenser C1 of Figure 1 were charged, by some external source of voltage, when the source was removed, it would discharge around the circuit first one way and then the other. The frequency of these reversals or oscillations, would depend on the values of inductance and capacity.

By utilizing this action, the common types of Radio tubes will generate high frequency current and, in Figure 2, we have two arrangements of tube oscillator circuits. At A, coils L1 and L2 are similar to those of Figure 1. By being placed close to each other, or coupled, any change of plate current in coil L2 induces an emf in coil L1 which, in turn, causes a change of grid voltage.

When connected so that an increase of plate current causes a more positive voltage on the grid, there will be an oscillating current in the coil L1 and the condenser across it. The frequency of this oscillating current is controlled by the inductance and capacity in the circuits but, as in Figure 1, the frequency can be varied by changing the capacity of the variable condenser.

In Figure 2-A, the condenser is across the grid coil, L1, and thus we call the circuit a "tuned grid". In Figure 2-B, the same results are obtained but the condenser is across the plate coil L2 and we call it a "tuned plate" circuit. Because of the electro magnetic coupling between the coils, some of the energy in the plate circuit is carried over to the grid circuit causing what we call "feed back".

In Figure 3, we have coils L1 and L2 so far apart that there is practically no coupling between them. However, the condenser, connected between the grid and plate, provides a low reactance path for high frequency current and therefore allows feed back.

Even though we do not install the condenser shown in Figure 3, there will be a certain amount of capacity between the connecting wires to the grid and plate and also between the grid and plate inside the tube.

With all the connecting wires and units carefully placed to avoid feed back, there will still be a certain amount of capacity as shown by the dotted lines of Figure 3. As long

as the grid and plate are at different potentials, there will be a capacity current between them. Then, the grid being a part of the input circuit, and the plate a part of the output circuit, there is an action in one which affects the other.

Now notice, in Figure 1 we have circuits similar to those of Figure 3 and, although the tube is supposed to be an amplifier, it may also act as an oscillator. We want the circuit L2-C1 of Figure 1 to resonate at the frequency of the signal carrier but, with enough feed back, the tube will act as an oscillator and produce oscillations of a different frequency. These oscillations may build up and prevent the signal from passing through or may combine with it and produce squeals and howls.

FACTORS INCREASING OSCILLATION

In general, when we say a tube, or receiver, is oscillating, we mean the tubes are acting as oscillators and producing frequencies which spoil the reception of the desired signals.

The methods used in building amplifiers are very apt to increase feed fack. Increasing the amplification of each stage or adding stages will have a tendency to cause oscillation. Using tubes with a higher mu, increasing the plate voltage or doing anything which might increase the gain of an amplifier, also increases the tendency of the tub s to oscillate.

Another point we want to mention here is that the tendency to oscillate increases with the frequency. This fact explains the reason that many of the early model Receivers worked fairly well on the lower frequencies but gave trouble on the higher frequencies.

REGENERATION

In most cases, a feed back of energy from the plate to the grid of an amplifier tube is not wanted but, when controlled properly, can be used to advantage. As explained in the Simple Receiver Lesson, the first models had but one tube, operating as a Detector and Regeneration was employed to improve their selectivity and sensitivity.

The circuits were similar to Figure 4 of this Lesson with the tickler coil L3 mounted so that the coupling, between it and coil L2, could be varied. Notice here, coils L1 and L2 compare to those of Figure 1 while L2 and L3 of Figure 4 compare to L1 and L2 of Figure 2. As explained for Figure 3, when no feed back is provided intentionally, a certain amount will be present at all times.

To follow the action, suppose a constant carrier voltage is applied across coil L1 of Figure 4. The current in the coil will then be controlled by its impedance which, for this explanation, we will think of as Resistance. Changes of current in L1 will induce corresponding voltage in L2 which, in turn, will cause changes of grid potential.

This change of grid potential will cause changes of the plate current, carried by the tickler coil L3 and, due to the coupling between them, will induce voltages in coil L2. With the tickler coil connected properly in its circuit, the voltages it induces in coil L2 will be in phase with those induced by coil L1 and the total induced voltage in L2 will be equal to the sum of the voltages induced by coils L1 and L3.

As a result of the action of the tickler coil, L3, the increased induction in L2 is the same as if the changes of current in coil L1 were increased. However, thinking of coil L1 and L2 only, as we assumed a constant voltage across L1, an increase of current could be caused only by a decrease of reactance. Therefore, the addition of coil L3 has caused a decrease of effective resistance.

In mathematics, it is necessary to add a negative quantity to obtain a reduced sum, therefore the action of the tickler is often considered as "Negative Resistance". For a circuit of this kind, when sufficient negative resistance is added to overcome the losses, continuous oscillations can be produced. Then, if the negative resistance is increased, the circuit can supply energy to other coupled circuits. Such a conditioh can occur by the feed back of voltage through the tickler coupling.

While regeneration may be desired, difficulties often arise, due to the grid plate capacity, by which the voltage, fed back in the right phase and amount, causes not only regeneration but oscillation, as already explained earlier in the Lesson.

As we told you in the first part of this Lesson, when a receiver starts to howl or squeal, it shows a tube is no longer operating in step with the incoming signals but, is generating a frequency of its own. To use regeneration, yet prevent oscillation, some method of control must be provided.

In the circuits of Figure 4, the tickler coupling is controlled by the position of the rotor. Regeneration is at radio frequency and when the tube is used as a detector, the plate coil L4 has a high impedance to radio frequency current. To reduce the high frequency impedance of the plate circuit, condenser C2 is connected, either across the coil as shown, or with one side connected to the cathode as

indicated by the broken line. In either case, the condenser forms a low reactance circuit around the coil. That is why, when used for this purpose, we call it a "By-pass" condenser.

NEUTRODYNE

When several stages of high frequency amplification are used in a radio receiver, unwanted coupling and feed back are very likely to occur. Sufficient feed back, or regeneration, will cause a tube to oscillate and, even when it does not cause a howl, may make the music or speech sound "mushy".

In the older type of receivers, using triode tubes, the greatest cause of excessive feed back was due to the grid plate capacity of the tube. This is shown in Figure 3 and the action was explained earlier in this Lesson.

In order to overcome oscillation in these early high frequency amplifiers, the "Neutrodyne" principle, developed by Prof. Hazeltine, was employed. This method and others of similar design are also often called "Bridge" or "Balanced" systems. In principle, the Neutrodyne simply makes use of a voltage, outside the tube, to offset the feed back voltage.

For Figure 5, we show a "Neutrodyne" circuit which is commonly referred to as the Rice System. The input coil L2 is tapped at its exact center and while one end of this coil connects to the grid in the usual way, the other connects to the plate through the neutralizing condenser C2. The condenser C3 is simply a by-pass to allow Radio frequency current in the plate circuit but not in the plate supply.

With the tap at the exact center of L2 and the capacity of C2 equal to the grid plate capacity of the tube, the circuit is neutralized. Feed back voltage from the plate to the grid will be balanced by an equal and opposite voltage, fed from the grid to the plate, through the neutralizing condenser C2.

This is often explained as a bridge circuit and laid out as in Figure 6. The heavy solid lines are the actual parts and the dotted lines indicate the capacities between the tube elements. Checking up, you will find grid plate, grid cathode and plate cathode capacities.

If it were possible to have the grid cathode and plate cathode capacities exactly equal and the coupling between the two parts of L2 in proper relation, the circuit would be balanced at any frequency. Since such a condition rarely exists, regeneration takes place and must be eliminated by the methods described.

R.F. AND I.F. AMPLIFIERS

In the high frequency amplifiers of our present day radio receivers, pentode type tubes are used almost universally. As explained in earlier Lessons, the additional grids and construction of modern tubes have resulted in a very high amplification factor and low inter-electrode capacities.

The inter-electrode capacities are so low that, for the ordinary frequencies, the feed back voltage caused by them is not large enough to make the former methods of neutralization necessary.

The modern R.F., or Radio Frequency, amplifier is fundamentally the same as explained for Figure 1. However, the other elements of the tube must be supplied with their proper voltages in order to secure satisfactory operation. Remember, as far as the signal is concerned, the control grid is the input, the plate the output and the extra elements are employed only to increase the overall efficiency of the stage.

Checking back on the circuits of Figure 1, and 5, the tubes operate as amplifiers but, for simplicity, we have omitted the cathode resistor or other arrangements used to provide the proper grid bias voltage. However, the action of the tube is such that the variations of plate current will occur at the same frequency as that of the voltage across the grid circuit. Thus, the a-c voltage drop across the plate coil L3 will have a greater amplitude but its frequency will be the same as that across the grid coil L2.

Amplifiers of this general type are employed between the antenna and detector of a Radio Receiver in order to increase its sensitivity and selectivity. The weak signal voltages, induced in the antenna, are built up by the amplifying action of the tubes to increase the sensitivity while the tuned circuits, like L2-C1 increase the selectivity by causing an increase at the resonant frequency with a reduction of other frequencies.

Although complete details will not be given until a later Lesson, we can tell you now that the common types of Superheterodyne Receivers combine or mix the modulated carrier of the Broadcast stations with the frequency of an oscillator to obtain a lower or intermediate frequency.

The tuning circuits are arranged so that, for the full tuning range, the intermediate frequency remains at the same value, thereby making it possible to employ semi-fixed condensers for tuning the transformer windings. Once the

condensers are set, or aligned, they require only an occasional check to see that they remain tuned to the proper intermediate frequency.

In Figure 7, we show a common i-f stage and you will notice it is very similar to Figure 1, with the exception of additional condensers C1, C3 and the bias resistor R with its bypass condenser C. The action is the same as explained for Figure 1 and, with the coils L1 and L2 inductively coupled, we have the transformer action. With signal current in L1, a voltage of like frequency will be induced in L2. The control grid, being connected across L2-C2, will thus have this voltage applied on it.

In some radio receiver, you may find that only the secondary of the i-f transformer is tuned, however, the common practice is to tune both the primary and secondary. To a large extent, the i-f amplifier controls the sensitivity and selectivity of a superheterodyne receiver and with the primary and secondary both tuned, the maximum voltage drop will be obtained and the selectivity will be improved.

Practically all of the smaller superheterodyne receivers, and some of the larger ones, do not have an r-f amplifier, the signal from the antenna being applied, through an antenna coil, direct to the grid of the first detector. Therefore, practically all the high frequency amplification is obtained in the i-f stages. However, due to the high voltage amplification and selectivity in the i-f amplifier, it is seldom necessary to use more than one or two stages in order to drive the second detector.

SELECTIVITY

As we explained earlier in this Lesson, selectivity was the ability of a tuned circuit to receive a certain signal without interference from others. However, we did not say how selective a receiver must be in order to provide satisfactory reception.

To fully understand this requirement, it will be necessary to have a general knowledge of what happens at the transmitting station. The energy, radiated from the antenna of a broadcast station, is a rather involved wave motion and, when the microphone is idle, it may be considered as a single frequency called the carrier wave. In other words, if a station is transmitting on 1000 kc, its carrier wave has a frequency of 1000 kc.

Let us assume such a carrier and that an audio frequency of 2000 cycles, or 2 kc, is put into the microphone. The antenna then has frequencies of 1000 kc + 2 kc = 1002 kc and 1000 kc - 2 kc = 998 kc. When music is broadcast, the audio frequencies may vary between zero and 5000 cycles, above and below the carrier, from instant to instant. These frequencies, on either side of the carrier, are called "side bands".

The design of the transmitter should be such that each of these audio frequencies is given equal power, compared to the others. To do this, the resonance curve of the antenna should have a flat-top response, 5 kc each side of the carrier, with steep sides showing a sharp cut-off.

The ideal curve is shown in figure 8 and you will notice that it is rectangular in shape and meets the requirements listed above. However, such a response is seldom obtained in practice and Figure 9 will give you a better idea of what to expect.

If audio frequencies up to 5000 cycles are transmitted, each station requires a channel, or band width, of 10 kc for its transmission. The regular broadcast band is from 550 to 1600 kc which means there are 1050 kc available . With 10 kc for each station, there are 105 channels or space for 105 simultaneous transmissions.

At the listening station, the receiver should be able to pick out any one of these stations and receive it without interference from signals on other channels. This means a receiver, with a good degree of selectivity, is one which, for example, will receive and amplify on a band from 995 to 1005 kc, but not reproduce a signal in the adjacent channels. That is, to cope with conditions in the broadcast band, the receiver should have ten kilocycles selectivity.

To obtain this condition, the high frequency amplifier of the receiver should have a square top, steep sided response curve like the "ideal curve" shown in Figure 8. As previously mentioned, this is very difficult, if not impossible, to obtain and most receivers will have a curve which resembles Figure 9.

In some receivers, the response curve is so broad that stations on an adjacent band, or even two or three channels away, will be audible during weaker passages of the desired signals. Then again, other receivers may be so selective that the higher audio notes are lost, due to side-band cutting. This simply means that the high frequency waves, corresponding to the carrier frequency plus or minus 5000 cycles, are cut off in the high frequency amplifier.

A receiver which has such a steep selectivity curve that the higher audio frequencies are reduced or cut off, cannot possibly deliver a high quality loud speaker output even though the audio amplifier is perfect.

Considerable research has been done to improve the overall response curve of radio receivers. Some of the developments involve very complicated circuit design and therefore are not used in general practice.

One of the most common types of unit, employed to obtain a reasonably flat-topped response curve, is the triple tuned I.F. transformer. Its input and output circuit are very similar to the double tuned transformer of Figure 7, however, between L1 and L2 of Figure 7, and inductively coupled to them, is another coil with its semi-fixed condenser.

This tuned circuit, which we will call LX-CX, has no electrical connections to other circuits and operates only by the induced voltage from L1. The plan here is to tune L1-C1 slightly below resonance, L2-C2 slightly above resonance, and LX-CX exactly to resonance. By adding the response curves of all three tuned circuits, the result is a curve with a fairly flat top and straight sides.

OVER COUPLED AMPLIFIERS

It has been definitely determined, by laboratory experiments, that the amount of magnetic coupling is a big factor in the sharpness of the resonance curve of a high frequency amplifier.

The effect of coupling upon selectivity might be utilized if a system were provided so that, as the receiver is tuned to the lower frequencies, the coupling between the coils could be increased automatically. In an i-f transformer, where a single band of frequencies is to be handled, this variable coupling may be utilized.

With minimum coupling, between the primary and secondary of an i-f transformer, the response curve is very sharp. If the primary and secondary windings are placed closer together, the selectivity decreases, which means that a wider band of frequencies will be passed. An amplifier, arranged to provide this change of coupling, will have variable selectivity making it possible to pass a band of only a few hundred cycles, at the most selective position, and as wide as 10,000 cycles or more when the coupling is increased.

As we will explain in the later Lessons, over-coupling two coils, tuned to the same frequency, results in a response

curve which has two peaks separated by a dip, as shown in Figure 10. The frequency characteristic of such a transformer, when its coils are closely coupled, will not be very good because the center of the response curve will have less amplification than the outer bands.

Under these conditions, the higher audio frequencies will receive greater amplification while the low notes may be decreased materially. However, a clever way of overcoming this difficulty and of producing a response curve with steep sides and an almost flat top, has been developed.

To show you how this accomplished, we will assume an i-f amplifier with three stages like that of Figure 7, the final one feeding into a diode-detector. We will also assume that the first two transformers are arranged mechanically so that the coupling between their coils can be increased or decreased. The third one, however, is loosely coupled or under-coupled, so that its response curve is fairly sharp. This curve is also shown in Figure 10.

When the coupling of the first two transformers is increased so that a dip occurs in the curve, the third transformer still has a sharp response exactly on the carrier frequency and on the lower audio frequencies.

Now, if the overall response of such an amplifier is measured, it will be found that the overcoupled transformers produce amplification at the higher audio frequencies, filling in the portion of the range not covered by the third transformer.

Furthermore, the final transformer, having a good response at low frequencies, fills up the gap in the characteristic produced by overcoupling the earlier transformers. A general idea of what the overall characteristic of such an amplifier would be is shown in Figure 11 and you will notice that it tends to approach the ideal curve shown in Figure 8.

The above described feature is incorporated in some of the larger modern radio receivers, making it possible to vary the selectivity. This is generally accomplished by means of a control knob placed at the front of the cabinet.

IRON CORE HIGH FREQUENCY TRANSFORMERS

As we explained in the earlier Lessons, the usefulness of magnetic materials at high frequencies is limited by the eddy-current losses. It has been found, however, that by suitably subdividing the core material, the eddy current losses can be reduced to low values even at high frequencies.

The required degree of subdivision is obtained by producing the magnetic material as a fine dust that is mixed with an insulating binder and then formed under pressure to the desired shape. Coils employing such cores have reasonably low losses in the broadcast band frequencies from 550 to 1600 kc and are used to a great extent at frequencies, below 500 kc, which fall into the general i-f bands.

Air core coils are wound on a core having a permeability of one or unity. From your earlier Lessons, you know that if the permeability of the core of a coil is increased, the inductance, per length of wire and per unit of space, will also increase. Using an iron core, as described above, the permeability of the material may be as high as 12. Therefore, with a given length of wire, of a given high frequency resistance, a greater inductance may be wound.

Although we have not mentioned it before, the losses in a coil are commonly expressed in the convenient terms of the ratio of the reactance to the effective resistance and called the "Q" of the coil. Written as an equation,

$$Q = \frac{\text{Coil reactance}}{\text{Coil resistance}} = \frac{2\pi f L}{R} \qquad (1)$$

When: L = inductance of the coil in henrys
π = 3.1416
f = frequency in cycles
R = effective resistance of the coil

To show you how this works out, we will assume a coil with an inductance of 185 microhenrys, an effective resistance of 6 ohms and find its Q at a frequency of 1000 kc. Substituting in equation (1),

$$Q = \frac{2\pi f L}{R} = \frac{2 \times 3.1416 \times 1000000 \times .000185}{6}$$

$$Q = 193.7 = 194$$

From the earlier Lessons, you know that resistance in an a-c circuit introduces losses and, in a coil, this would mean a reduction in amplification. Looking at equation (1), you can see that as the resistance increases, the Q reduces, therefore, the Q of a coil is really the reciprocal of the losses. In other words, the higher the Q, the less the losses and the greater the amplification.

Getting back to the iron core coils, we told you above that with a given length of wire, of a given high frequency resistance, a greater inductance could be wound on an iron core

than on an air core. This, of course, means there will be a higher ratio of inductance to resistance than is obtainable with an air core. Because the ratio is higher, the Q of the coil will be increased and result in greater amplification.

Due to this greater amplification, iron core high frequency coils are being used in both **r-f** and **i-f** amplifiers of radio receivers. These transformers are now on the market under various trade names, such as "Ferrocart" coils.

FILTERING

So far, we have explained only the feed-back caused by the grid plate capacity on the inside of the tube and told you how it could be neutralized. However, oscillation is also caused by other "feed-backs".

Unless special care is taken, the transformer following a tube will couple its field with that of the transformer ahead of the tube and thus produce an inductive feed-back. This can be remedied by properly placing the coils or by shielding the transformers and tubes.

Then, between the turns of the coils, or between connecting wires which run parallel and close to each other, there is capacity. At the higher frequencies, the reduced reactance of these various capacities allow feed-back, often of sufficient strength to produce oscillation.

In many of the older battery type receivers, run down B batteries produced oscillation and caused a howl by another form of feed-back. As a dry cell discharges, its internal resistance increases and forms a resistance coupling of the battery circuits. With the radio frequency amplifier stages all connected to the same B battery, the resistance coupling is common to all, producing feed-back which causes oscillation.

To overcome these troubles, and keep the high frequency currents in their proper circuits, various forms of filters are used, a good example of which is shown in the Radio Frequency stage of Figure 12.

The grid bias voltage is represented by "E1" and the plate voltage by "E2". The grid circuit is from the grid, through coil L1, resistance R, supply E1 and back to the cathode of the tube. However, high frequency current in this circuit has a low reactance path from the lower end of L1 to the cathode through the condenser C1.

In other words, the resistance R makes it more difficult for radio frequency current to enter the supply while condenser C1 offers a low reactance bypass.

The same general plan is followed in the plate circuit but, instead of a resistance, there is an inductance or choke, L3. The choke offers a fairly low resistance to direct, or low frequency current but has a high impedance at radio frequency.

Here, condenser C2 offers a low reactance bypass for the radio frequency, allowing it to complete its circuit to the cathode without passing through the plate supply E-2.

By the proper use of resistance, inductance and capacity, filters may be made to confine the various currents to their proper circuits and thus reduce the unwanted coupling between stages.

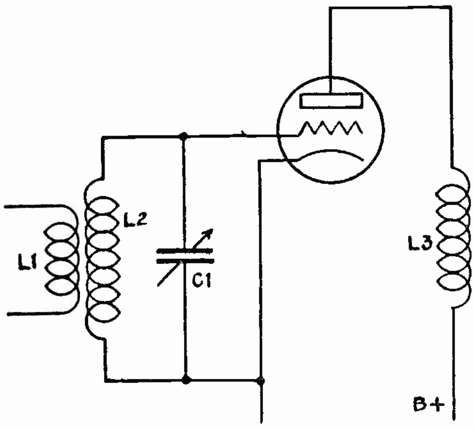

FIGURE 1

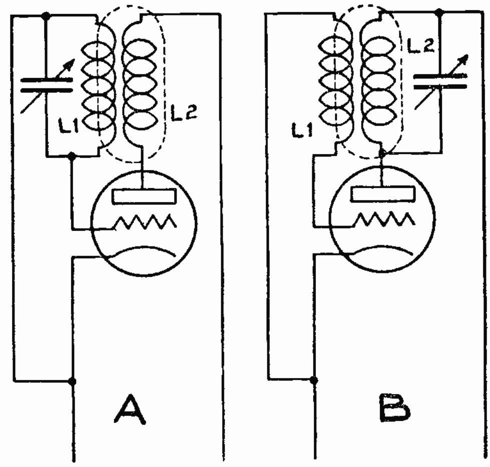

FIGURE 2

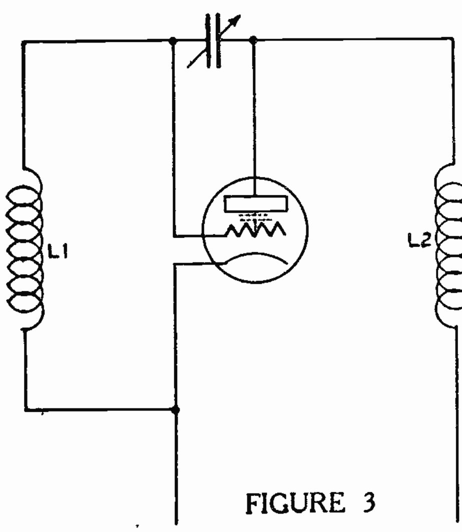

FIGURE 3

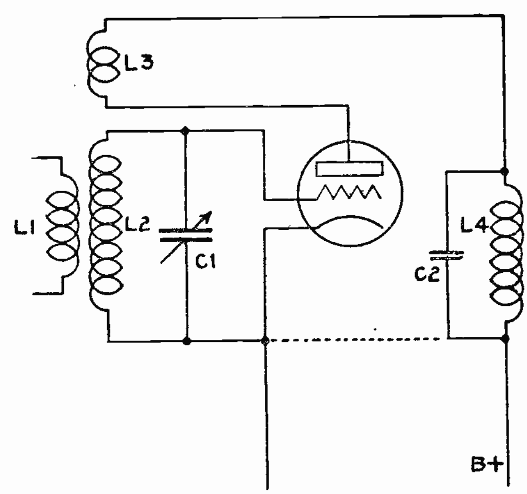

FIGURE 4

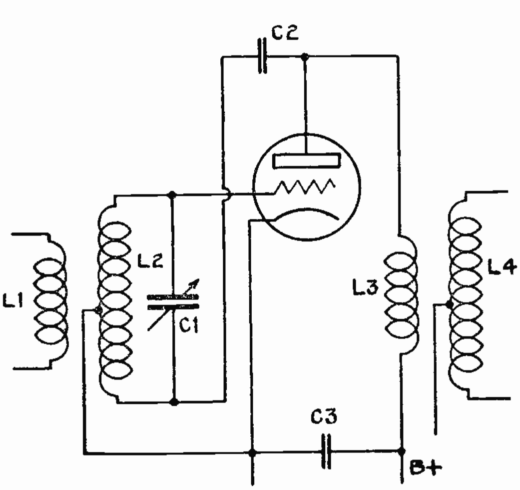

FIGURE 5

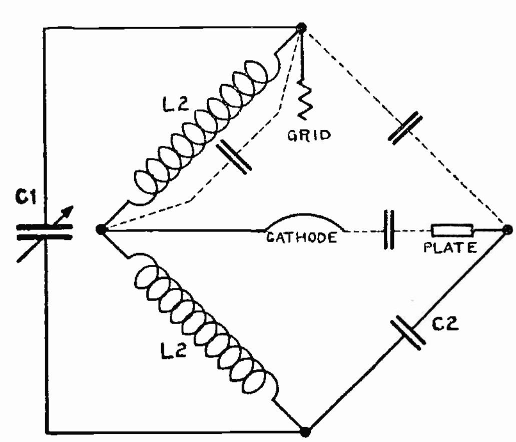

FIGURE 6

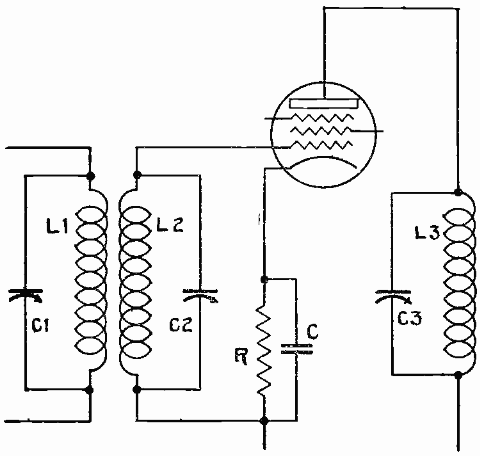

FIGURE 7

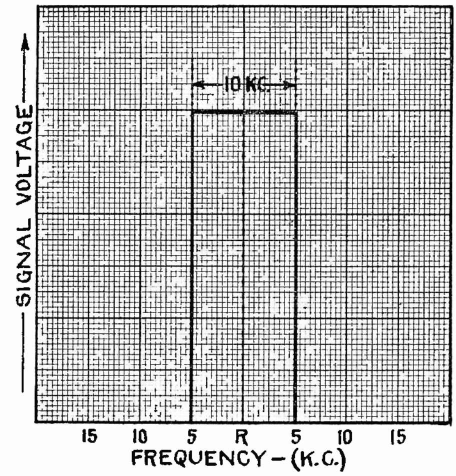

FIGURE 8

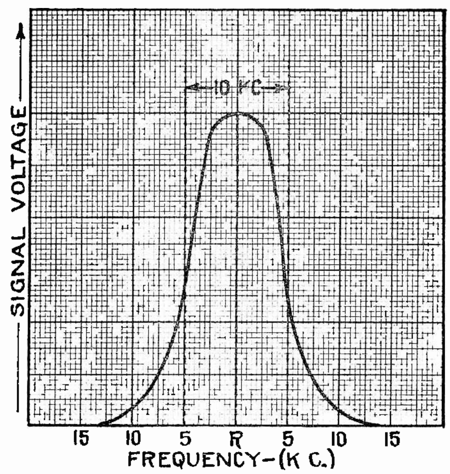

FIGURE 9

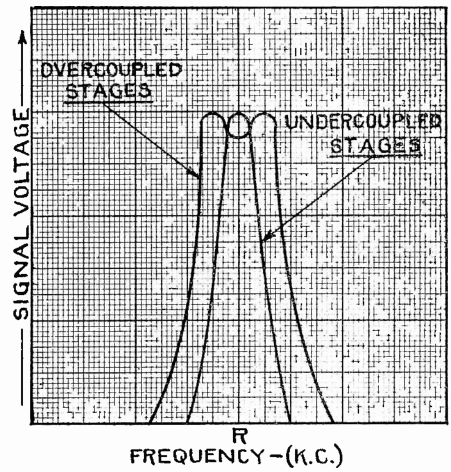

FIGURE 10

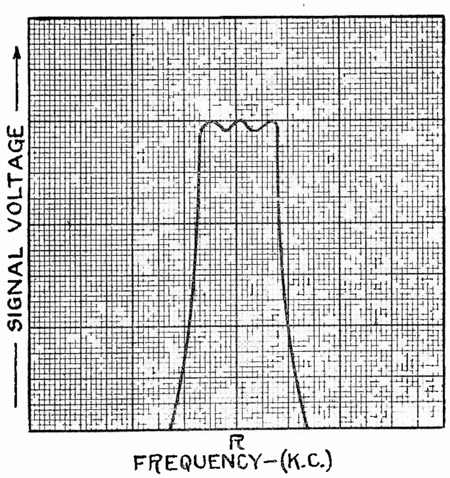

FIGURE 11

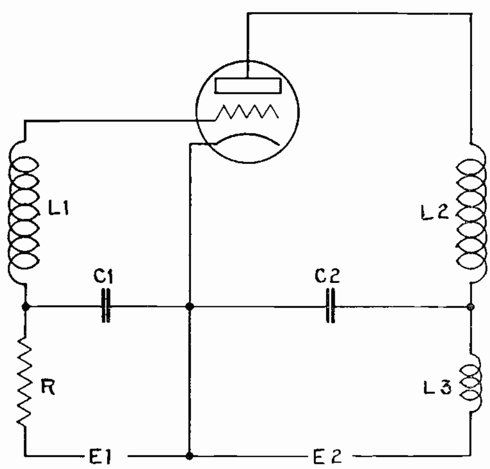

FIGURE 12

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LESSON TRA - 18
BAND PASS FILTERS

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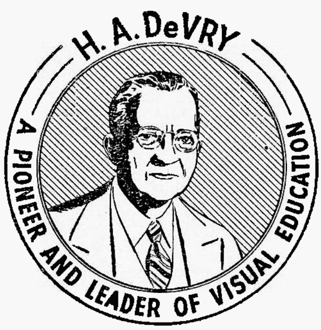


TUBES - RECEIVERS - AMPLIFIERS

LESSON TRA-18

BAND PASS FILTERS

* * * * * * *

Keep your head clear with regular sleep, hard thinking, wise living, constant observation. Start now, ahead of the others, and they will never catch up if you will stick with it. It is not special brilliancy that makes success but persistency.

—— Arthur Brisbane

BAND PASS FILTERS

One method of increasing the selectivity of Radio Receivers is by the use of a Band Pass Filter or what is often called a "Pre-Selector". The operation of this type of circuit is not clearly understood by the average man because it is made up of two tuned circuits which are coupled by either a small inductance or comparatively large capacity. There is nothing new about these circuits but, because the coupling is common to both tuned circuits, the action becomes a little more complicated.

Starting with Figure 1-A, we have an input coil "L" coupled to coil "L1" which, in turn, is tuned by the variable condenser C1. The circuit is completed through the smaller inductance "M".

The coil "L1" and condenser "C1" are of standard size and do not differ from those explained for the usual forms of radio frequency amplifier circuits while the small inductance "M" has a value of but several microhenrys. So far, we have the usual tuned circuit except that a few turns of "L1" are placed at M and, for this part of our explanation, we will think of M as a connection instead of an inductance.

If coil "L" is in an antenna circuit, the energy in it will be carried over to coil L1 in the usual way. The circuit L1 - C1 - M will be resonant at the frequency to which it is tuned by condenser C1.

It might be well to mention here that, in band pass filter circuits, the energy must be fed in at one point only with no inductive coupling between any of the inductances in the different circuits. For this reason, coils M and L2 must be completely and separately shielded from coils L1 and L. Because coils L and L1 carry the input or pick up energy, it is not absolutely necessary that they be shielded.

Looking along the circuits further, you will see that coil L2 is tuned by the condenser C2 to form a second resonant circuit L2 - C2 - M. Coil L2 has the same inductance as L1 and condenser C2 has the same capacity as L1, therefore the circuit L2 - C2 - M can be tuned to resonance at the same frequency as L1 - C1 - M.

The point we want to bring out here is that inductance M is in series with two resonant circuits, both of which are tuned to the same frequency. Therefore, current in circuit C1 - L1 - M will cause a voltage drop across M and, because of the circuit arrangement, this voltage will be impressed on the

tuned circuit consisting of L2 - C2 - M. Thus, coil M acts as the coupling between the two tuned circuits.

Looking at Figure 1-A again, and neglecting coil M, that part of the circuit, made up of L2 - C2 is connected across L1 - C1. Thus, energy in L1 - C1 can be transferred directly to L2 - C2 to provide a total of three tuned circuits.

Circuit 1 - L1-C1-M
Circuit 2 - L2-C2-M
Circuit 3 - L1-C1-C2-L2

in which L1 is equal to L2 and C1 is equal to C2. To check further, the general formula for resonance is

$$f = \frac{1}{2\pi\sqrt{LC}}$$

therefore, the frequency will be inversely proportional to the square root of the product of L and C. For circuit 1 above, the total "L" is equal to L1 + M and, because L1 is equal to L2, the same is true for circuit 2. Then, as C1 is equal to C2, the resonant frequency will be the same for both circuits.

For circuit 3, the total "L" is equal to L1 + L2 and, as they are equal and connected in series, their sum is equal to twice the value of either one. However, C1 and C2, also of equal value, are connected in series, therefore, their sum is equal to 1/2 the value of either one. For the complete circuit there will be twice the inductance and 1/2 the capacity, therefore the produce "LC" will be the same as for circuits 1 and 2 without "M".

With all the units connected as shown, there will be two circuits, resonant at different frequencies, one for the circuits including M, and one for the circuit without M. Connected across condenser C2, the grid circuit of the tube will have these resonant frequency voltages impressed on it.

REACTANCE

In the earlier Lesson on Impedance, we told you the inductive reactance of a coil, indicated by the symbol "XL", is calculated by the formula,

$$X_L = 2\pi fL$$

when "L" is the value of inductance in henrys, "f" is the frequency in cycles per second and "2π" is equal to 6.28.

In much the same way, we told you the capacity reactance of a condenser, indicated by the symbol "X_C", is calculated by the formula,

$$X_c = \frac{1}{2\pi fC}$$

with the symbols the same as for inductive reactance except that "C" represents the value of capacity in Farads.

To follow the action of the tuned circuits of Figure 1-A, we have made use of these formulas to draw the curves of Figure 1-B. As the curves are shown only to explain the action, and are not intended for actual design, to obtain a resonant frequency of approximately 1000 kc, we assume coils L1 or L2 to have an inductance of 80 microhenrys.

Substituting this value of "L", together with the frequencies shown by the scale across the bottom, in the formula for inductive reactance, we calculated the values for the curve "X_L". Notice, this curve is a straight line and the value of inductive reactance, as shown by the scale at the left, increases directly with the frequency.

Following the same general plan, and assuming C1 and C2 to have a value of 316 mmfd, we substituted the various frequency values in the formula for capacity reactance to calculate the value for the curve X_C. Because inductive and capacity reactance are opposite in effect, the reactance scale at the left has a center zero with X_L values above and X_c values below.

The X_c curve is not a straight line, but the capacity reactance increases as the frequency decreases and at zero frequency we say there is infinite reactance. Of course, this is not actually true in practice as the condenser dielectric will have less than infinite resistance and allow some loss.

With both capacity and inductance in the circuit, the total reactance is equal to their algebraic sum but, as one is above and the other below the zero line, we seem to subtract.

For example, at a frequency of 600 kc, curve XC has a value of 840 below the zero line while XL has a value of 300 above. Adding the 840 below as minus 840 to the 300 above as plus 300, the result is minus 540, or 540 below the zero line.

Adding these curves at different values of frequency, you will find they are equal and opposite at 1000 kc, and thus the total reactance of the circuit is zero. This is really

nothing but a different way of explaining the action of a resonant circuit and it may help you here to go back and review the earlier Lesson on the subject.

Adding the curves X_L and X_C of Figure 1-B, we locate the values for curve X which represents the total reactance of the tuned circuit. Notice the slope of this curve and see how, at frequencies below 1000 kc, there is an increase of capacity reactance while at frequencies above 1000 kc there is an increase of inductive reactance.

Following the same general plan, and assuming "M" to have a value of 10 microhenrys, we added this value to the 80 microhenrys of coils L1 or L2 and plotted the curve "XL+M". This curve is similar to that of X_L but, with a higher value of inductance, its reactance values are greater. Notice here, the difference between curves "XL" and "XL+M" increases with frequency.

Adding the values of curve "XL+M" to those of curve "XC", we plotted curve "XM" to represent the reactance of those circuits of Figure 1-A which include inductance "M". Checking the values here, the reactance is zero at a frequency lower than that of curve X while the values of both become more nearly equal at the lower frequencies, but separate at the higher frequencies.

Thinking of "M" as the coupling between two tuned circuits, the higher its value, the greater the difference between the values of reactance as shown by curves "X" and "XM".

CAPACITY COUPLING

Looking at Figure 1-C, you will find the circuits like those of Figure 1-A except that inductance "M" is replaced by capacity "MC". As explained for Figure 1-A, there are three circuits but here, they contain the following units.

Circuit 1 - L1-C1-MC
Circuit 2 - L2-C2-MC
Circuit 3 - L1-C1-C2-L2

For the first two circuits, capacity MC is in series with the tuning condensers, C1 and C2, therefore the total capacity in the circuit will be less than for the tuning condensers alone. In the earlier Lessons we told you the total capacity of two series connected condensers was calculated by the formula,

$$C \text{ total} = \frac{C1 \times C2}{C1 + C2}$$

For Figure 1-C, we assume condensers C1 and C2 are the same as those of Figure 1-A, each with a capacity of 316 mmfd. Giving MC a value of .002 mfd, which is 2000 mmfd, and substituting in the above equation

$$C\ total = \frac{316 \times 2000}{316 + 2000} = 273\ mmfd\ (approx.)$$

With this value of total capacity, for Figure 1-D we have plotted curves for the circuit of Figure 1-C to correspond to the curves of Figure 1-B, drawn for the circuit of Figure 1-A. Assuming L1, L2, C1 and C2 have the same values in both circuits, curves XL, X, and XC are the same for both.

The reactance of the smaller total capacity, equal to the sum of C1 and MC in series, is shown by curve "XC + MC" in Figure 1-D and, adding the values of this curve to those of XL, we have reactance curve"XMC". Compared to curve "X", curve "XMC" indicates zero reactance at a higher frequency and its values approach those of "X" at the higher frequencies.

In the circuit of Figure 1-A, the higher the value of "M" the greater the difference in frequency at which curves "X" and "XM" indicate zero reactance, while in the curves of Figure 1-D, the smaller the value "MC", the greater the difference in frequency at which curves "X" and "XMC" indicate zero reactance.

RESISTANCE

The curves of Figures 1-B and 1-D show the changes of reactance over a rather wide band of frequencies but, in the usual type of receiver, we are interested in the action for a narrow band of frequencies and therefore, for Figure 2-A have enlarged a small section of curve X. Checking here you will find values of -22 ohms at 980 kc, zero ohms at 1000 kc and +18 ohms at 1020 kc.

Reviewing the earlier Lesson on Impedance, you will remember that even when the inductive and capacity reactance neutralize each other and a circuit is resonant, it still has resistance. Therefore the response of the circuit depends largely on the value of resistance.

Thinking of curve "X" of Figure 2-A as representing the reactance of a series circuit, we assumed different values of resistance to calculate the impedance at the frequencies shown. Then, applying agiven value of voltage, we calculated the circuit current.

The results of these calculations are shown in the curves of Figure 2-B with resistance values of 2 ohms, 5 ohms and 10 ohms. At the high and low frequency ends of the scale, the resistance has little effect on the response but, as resonance is approached, it becomes the controlling factor. At resonance, the response is inversely proportional to the resistance.

In most circuits of this type, the coil contains all appreciable resistance and the ratio of inductive reactance to resistance is known as the "Q" of the circuit. As an equation

$$Q = \frac{XL}{R}$$

Thinking along these lines, the curves of Figure 2-B show the response of a circuit with different values of Q. As curves "XL" of Figures 1-B and 1-D show a reactance of 500 ohms at the resonant frequency of 1000 kc, the values of "Q", for the curves of Figure 2-B, are as follows,

When $R = 2$, $Q = \frac{500}{2} = 250$

When $R = 5$, $Q = \frac{500}{5} = 100$

When $R = 10$, $Q = \frac{500}{10} = 50$

As the Q is reduced, the peak response is reduced also and the curve tends to broaden, which means a more uniform response for a wider band of frequencies. As the Q is increased, the response increases also and the curve becomes sharper, which means it will pass a narrower band of frequencies.

IDEAL RECEIVER

If it were possible to build a perfect Broadcast Receiver, the tuned circuits would have a response as indicated by the dotted line of Figure 2-B. Checking the values of this curve, and starting at the low frequency end, the response is zero up to 995 kc where it goes straight up to maximum. The maximum value is held uniformly up to 1005 kc where it drops straight down to zero.

With a response like this, a Receiver would respond only to a 10 kc band of frequencies and, as present Broadcast carriers are separated by 10 kc, it would be possible to tune each one with no interference from any other.

SIDE BANDS

Going back to the earlier Lessons again, you will remember the carrier wave of the Broadcast station is modulated by the signal or audio frequency. These audio frequencies are usually from about 50 cycles up to 5000 cycles and form what we call "Side Bands".

The carrier wave is a-c therefore the side band will be present on both sides and we have to add 5000 cycles to, and subtract 5000 cycles from, the frequency of the carrier wave. With a carrier wave frequency of 1000 kc, the receiver must respond to frequencies from 995 kc to 1005 kc in order to take care of the modulation or audio frequencies.

The broken line curve of Figure 2-B has a flat top which indicates it will have equal response to all frequencies between 995 kc and 1005 kc, and therefore all side band frequencies will be amplified equally. Thus, this straight side, flat top curve is the ideal type of response for a Broadcast Receiver.

In contrast, curve "R = 2 ohms" has a maximum response nearly equal to that of the ideal curve but, at 995 kc and again at 1005 kc, the response is but 40% of the maximum. This means that the higher signal frequencies appearing at the upper and lower edges of the side bands will be amplified and reproduced at lower levels than the lower signal frequencies. For the "R = 5 ohms" and "R = 10 ohms" curves, the difference in response at different frequencies is much less but, the maximum response has been reduced.

As far as the performance of a Receiver is concerned, the height of the response curves, like those of Figure 2-B, represents the relative sensitivity while the width represents the relative selectivity. The main purpose of a band pass filter is to provide the desired degree of selectivity.

EFFECTS OF FREQUENCY AND COUPLING

Going back to Figures 1-A and 1-C, the circuits provide for two resonant frequencies, the difference in their values being controlled by the coupling and the frequency. If these factors are not chosen properly, the circuits will not tune within the desired limits and will not fulfill their original purpose.

Take the circuits and curves of Figure 1 for example, Tuning is done by changing the capacity of condensers C1 and C2 which merely raises or lowers the values of the "XC" curves.

This results in a change of the "XM" curves to provide zero reactance at a higher or lower frequency.

Should we change the value of the inductive coupling "M" or the capacity coupling "MC" then curves "XM" and "XMC" would be raised or lowered to provide zero reactance at different frequencies.

As the value of "M", Figure 1-A, is increased, there is more inductance in the circuits of which it is a part, their resonant frequency is reduced and we think of the coupling as having been increased. In contrast, as the value of "MC", Figure 1-C is reduced, the total capacity in the circuits of which it is a part is reduced also, causing an increase of resonant frequency and again we think of the coupling as being increased.

To show the effect of coupling, for Figure 2-C we have two curves, similar to "R = 2 ohms" of Figure 2-B, with a difference of 10 kc between their resonant frequencies. Assuming these to represent the relative values of voltage across C2 of Figures 1-A and 1-C, their combined effect is as indicated by the broken line curve.

Compared to either of the original curves, the combined action provides a response which, with the exception of the dip in the center, approaches the shape of the ideal response curve.

By reducing the coupling, the difference between the resonant frequencies is decreased, indicated by the curves of Figure 2-D, while with an increase of coupling, which separates the resonant frequencies, the resulting response is shown by the curves of Figure 2-E.

A study of these three curves will indicate the effect of coupling and let you see how, with the proper degree of coupling, the response of a band pass circuit can be made to more nearly approach that of the ideal, shown by the broken line of Figure 2-B.

While these explanations have been based on the common type of Broadcast Receivers, which require a band pass of 10 kc, for Television and Frequency Modulation, much wider bands are required. Details of these circuits will be included in the later Lessons but, at this time, we want to assure you that they are nothing but special applications of the principles explained in this Lesson.

So far, we have assumed the value of the coupling unit did not change but, as shown by the curves of Figure 1, the coupling reactance varies at different frequencies. To check

This effect, we want you to examine the "XM" and "X" curves of Figure 1-B.

The frequency scale covers the Broadcast Band and, as condensers C1 and C2 are tuned to provide resonance at various points of the band, in effect, curves "XM" and "X" are moved up or down until they have zero reactance at the desired frequency. Thus, the horizontal distance between these curves is proportional to the difference of the two resonant frequencies.

For example, reading across the XC-450 line, curve XM corresponds to a frequency of 600 kc while curve X corresponds to a frequency of 650 kc for a difference of 50 kc. Reading across the zero reactance line, XM corresponds to a frequency of 930 kc and curve X to a frequency of 1000 kc for a difference of 70 kc. Reading across the XL-450 line, curve XM corresponds to a frequency of 1400 kc and curve X to a frequency of 1540 kc for a difference of 140 kc.

Thus, when tuning the circuits of Figure 1-A, across the Broadcast Band, the resonance peaks will be closer at the lower frequencies and further apart at the higher frequencies because the effective value of the coupling changes with the result as shown by the curves of Figure 2-C, 2-D and 2-E.

Similar effects occur in the capacity coupled circuit of Figure 1-C but the action is such that the resonant peaks separate at the lower frequencies and become closer at the higher frequencies.

CIRCUIT COUPLING

For Figure 3, we show a common type of circuit which is a good example of electro-magnetic or "inductive" coupling between stages. Coil L1 is a transformer primary connected in the plate circuit of a preceding tube and tuned by condenser C1. The transformer secondary, tuned by condenser C2 is connected across the grid circuit of the following tube.

Checking the connections here, by omitting condenser C1, the circuit is that of an r-f stage, explained in an earlier Lesson. Also, the circuit is identical to Figure 1-A of this Lesson, with the exception of the coupling shown as "M".

However, as coil L2 of Figure 3 is located in the magnetic field of coil L1, the mutual inductance provides an effect similar to coil "M" of Figure 1-A. For circuits of this type, the amount of coupling is controlled by the relative positions of the primary and secondary coils.

When the coils are coupled loosely, the pass band is narrow and, when coupled tightly, the pass band is wider. In some cases, this coupling is adjustable to provide variable selectivity. In other cases, when a wide band is required, you will find a capacity connected from the plate end of the primary to the grid end of the secondary.

LINK CIRCUITS

Another form of electromagnetic coupling is shown by the simplified circuits of Figure 4. Here we have two transformers and the secondary "L3" of one is connected to primary "L4" of the other.

In other words, we really have the circuits of Figure 3 but have moved coils L1 and L2 apart, coupling them by means of coils L3 and L4. The circuits L3-L4 is called a "Link" because it couples, or links the tuned circuits. One advantage of the link circuit is that it allows us to adjust the coupling.

For example, the coupling between coils L1 and L3 can be fixed and that between coils L2 and L4 can be made variable. Thus, a small adjustment between coils L2 and L4 will vary the coupling but have little effect on the tuned circuits.

You will find many variations of this simple link circuit are now in use and very often the link is grounded to reduce any capacity coupling between the tuned circuits.

TYPES OF COUPLING

From our explanation so far, you can see that in all band pass filters, the type and amount of coupling between the tuned circuits is important.

In Figure 1-A, the tuned circuits are coupled by the small inductance "M", which is common to both, and you can think of this as "Inductance Coupling".

In Figure 1-C, the tuned circuits are coupled by the condenser MC, which is common to both, and you can think of this as "Capacity Coupling".

In Figure 3, the tuned circuits are coupled by the mutual induction between the coils of the tuned circuits. There is a magnetic field common to both coils and you can think of this type as "Inductive Coupling". However, the action is similar to that of Figure 1-A which is also called an Inductive or Direct Coupling.

SHIELDING

We have already mentioned that energy must enter the band pass filter circuits at one point only and therefore some of the units must be shielded. For the circuits of Figure 1, coils L and L1 are inductively coupled and, while it is not neccssary, if shielded they must be both be inside the same shield. There must be no mutual induction between coils L1, M or L2 therefore both M and L2 should be placed in separate shields.

These same general rules hold for the circuit of Figure 3 also but in Figure 1-C, it is not necessary to shield the coupling condenser MC or the tuning condensers.

No matter what the actual arrangement of the circuits or shields may be, their purpose is to prevent any form of coupling between coils except that for which the circuit is designed.

NUMBER OF STAGES

So far, all our circuits have consisted of a single stage filter. While one stage greatly improves the performance of a receiver, it may not provide enough selectivity unless the following stages are well tuned.

In a complete Band Pass filter receiver, particularly the older models, you will often find two or more filter stages, between the antenna and first tube, which are followed by several stages of untuned radio frequency amplification.

Another plan is to use a one stage filter, between the antenna and first tube, followed by several stages of tuned high frequency amplification. Still other receivers combine both these plans and in the following figures of the Lesson, we have some of the typical circuits.

PRE-SELECTOR

In Figure 5, we show the circuits of a two section filter between the antenna and first tube and, in this position, the filter is generally called a "Pre-Selector".

In each section, coils L1 and L2 are inductively coupled like those of Figure 3. Coupling between the sections is like that of Figure 1, the common inductance coil here being L3. Checking through, in section 1 you will find two tuned circuits, L1-C1 and L2-C2-L3 and for section 2, circuits C1-L1-L3 and C2-L2. Also, the output circuit of section 1 and input

circuit of section 2, Figure 5, duplicate the arrangement of Figure 1-A to provide the tuned circuit L1-L2-C2-C1. In addition, coils L1 and L2 of Figure 5 are coupled as explained for the circuit of Figure 3.

You will notice all condensers of Figure 5, except the one in the antenna circuit, are shown in two parts. The larger is the main condenser while the smaller represents a trimmer. These trimmers can be adjusted so that all the main condensers will tune properly with a single dial.

For Figure 6, we have the circuits of another filter with a combination of inductive and capacity coupling. Capacity C1 is an antenna compensating condenser which is adjusted and set according to the length and type of antenna. In effect, this condenser really tunes the antenna circuit to a frequency which provides efficient operation over the tuning range of the pre-selector.

Coil L1 is inductively coupled to L2 which is part of the resonant circuit L2-C2-C6. Condenser C6 is also in the resonant circuit C3-L3-C6 and thus couples the two tuned circuits like MC of Figure 1-C. The third tuned circuit consists of L2-C2-C3-L3.

Coil L3 is inductively coupled to L4 which is part of the resonant circuit L4-C4-C7. Here, C7 is also part of the resonant circuit C5-L5-C7 and, like C6, is the capacity coupling. Here, the third tuned circuit consists of L4-C4-C5-L5.

Here we have a common ground connection but, in tracing, be sure to follow only the circuits mentioned above. Notice also, tuning condensers C3, C4 and C5 are provided with trimmers so that they can be adjusted to tune with C2 from a single control.

INDUCTANCE AND CAPACITY COUPLING

In the circuits of Figure 7 we have still another arrangement of a multi-stage Band Pass filter. As in Figure 6, the antenna circuit is tuned to the proper value by condenser C1.

The first resonant circuit is made up of L1-L2-C2-C6 and is tuned by condenser C2. The second resonant circuit consists of C3-L3-L6-C6 and is tuned by condenser C3. Condenser C6 is common to both these circuits and therefore we have capacity coupling. With the exception of C6, these units also make up the resonant circuit, L1-L2-C2-C3-L3-L6.

The third resonant circuit is made up of C4-L4-L6-C7 and tuned by condenser C4. Coil L6 is common to both the second and third circuits, therefore, we have a common inductance like that of Figure 1-A.

The fourth resonant circuit is made up of C5-L5-L7-C7 and tuned by condenser C5. Condenser C7 is common to the third and fourth circuits and, therefore, we again have a capacity coupling.

Coils L1 and L7 are not used for coupling but, being made with values equal to L6, allow coils L2, L3, L4 and L5 and their tuning condensers to be of equal value.

Another good example of a band selector input to the first radio frequency tube is shown in Figure 8 where we have a partial circuit of a complete receiver.

The antenna circuit is tuned broadly by condenser C1 and coil L1 is inductively coupled to L2 in the usual way. The first resonant circuit is made up of L2, C2-L4 and tuned by condenser C2. The second resonant circuit, L3-C3-L4-C4 is tuned by condenser C3. Coil L4, being common to both tuned circuits, is the coupling.

The fixed condenser, C4, is not common to both circuits and must not be considered as a capacity coupling. Instead, it really is a part of a filter circuit and forms part of a high frequency path from the upper end of R to ground.

We do not want to explain the rest of the circuit in detail but you will notice there is a double impedance coupling between the tubes while each grid, screen grid and plate lead has a filter made up of a resistance and condenser.

INDUCTIVE PRE-SELECTOR

For Figure 9, we have a circuit used with some superheterodyne receivers. The antenna circuit has a high inductance winding, L1, which is inductively coupled to L2. Coil L2 is part of the tuned circuit L2-C2 which is coupled inductively to L3. Coil L3, in turn, is part of the tuned circuit L3-C3 which is connected across the grid circuit of the first r-f amplifier tube.

While it may be a little hard to follow, the circuits here are similar to those of Figure 1-A. Instead of the common inductance "M", in Figure 9 coils L2 and L3 are wound on the same form and the coupling is by mutual induction. To have the small coupling required, the coils are wound the proper distances from each other. The output of the r-f tube is then fed

through the next r-f transformer to the input grid of the following tube.

MODIFIED LINK CIRCUIT

In the circuits of Figure 10, we show another arrangement of a pre-selector and here again, we have the circuits of Figure 1-A but the coupling is by mutual induction between coils L4 and L5.

Coils L1, L2 and L3 are shielded, as shown by the dotted lines, and thus the value of the coupling is controlled by coils L4 and L5.

Pre-selectors of this type are followed by two or three stages of tuned High Frequency amplification to make an extremely selective receiver.

There are many variations and types of band pass filter circuits and, like those we have shown here, all are based on the simple circuits of Figures 1 and 3.

Before leaving this Lesson, be sure you understand the connections and general actions of both capacity and inductive coupling. These circuits are in common use and, in order to do intelligent work, you must know what the various units are supposed to do.

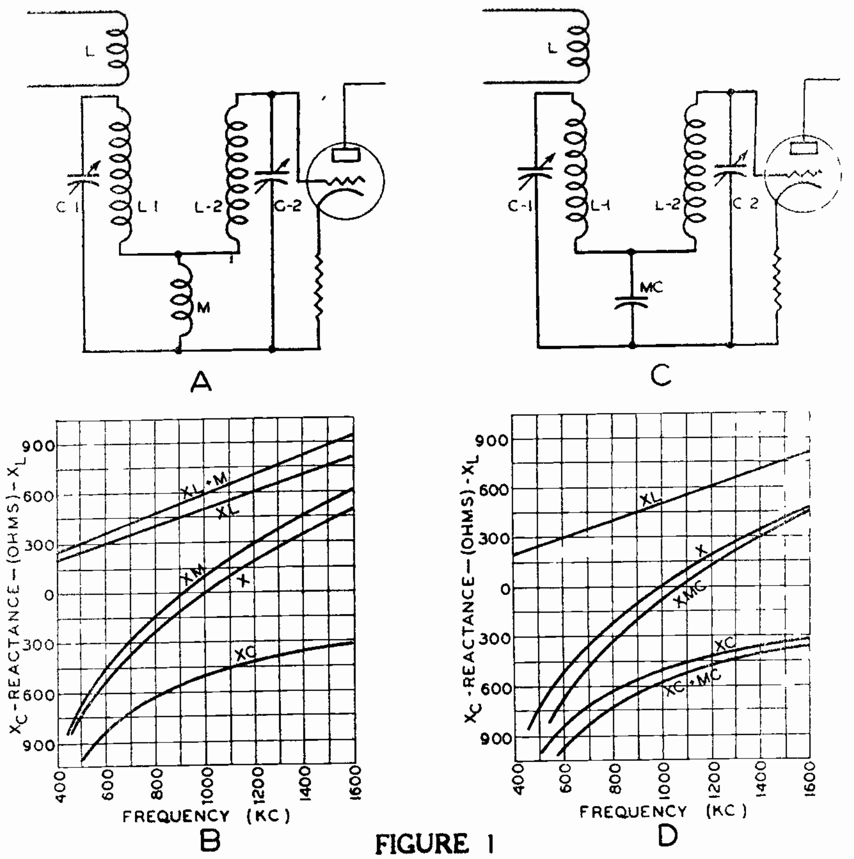
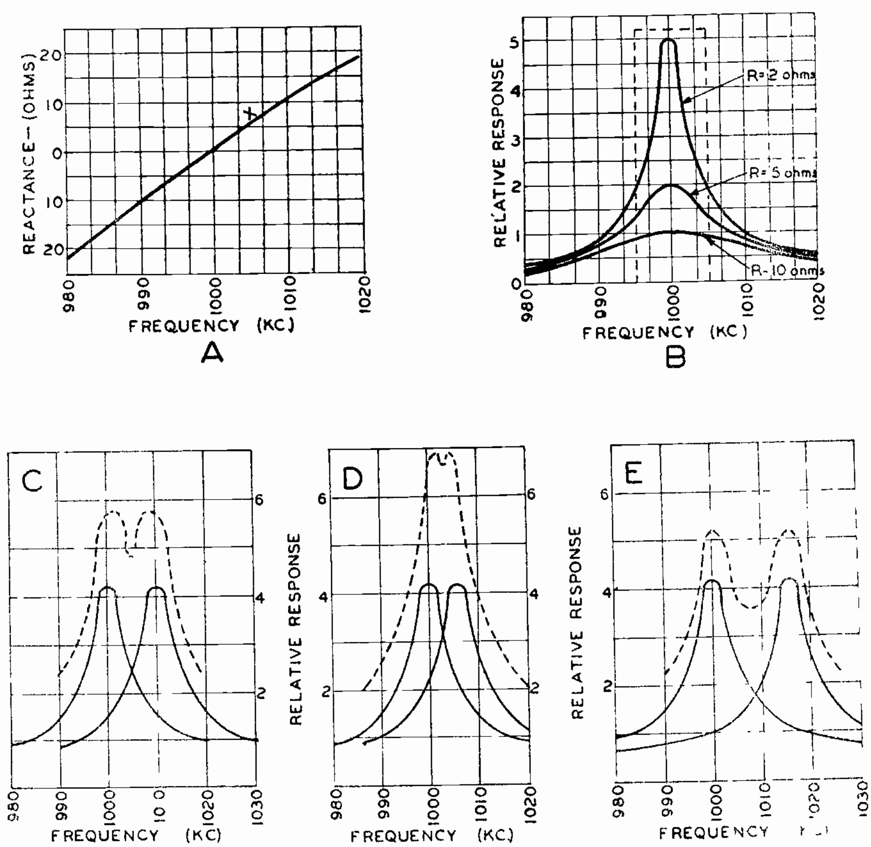


FIGURE 1



TRA-18

FIGURE 2

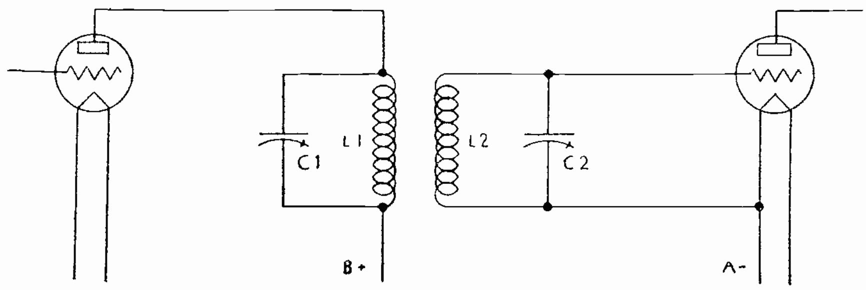


FIGURE 3

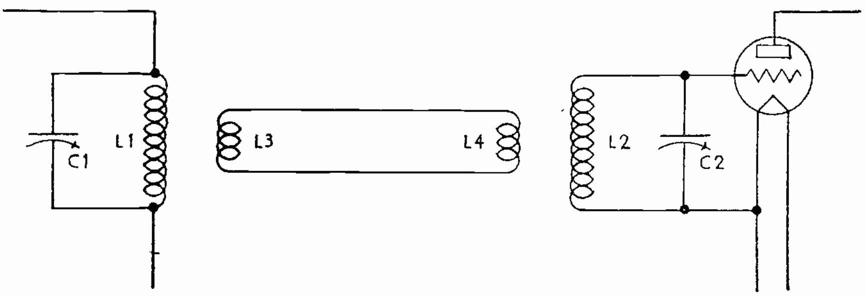


FIGURE 4

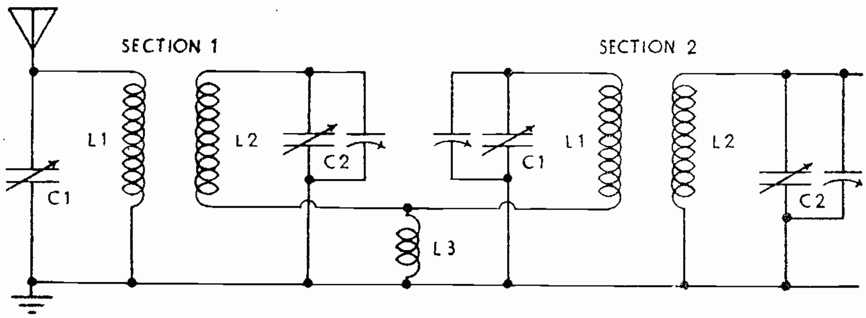


FIGURE 5

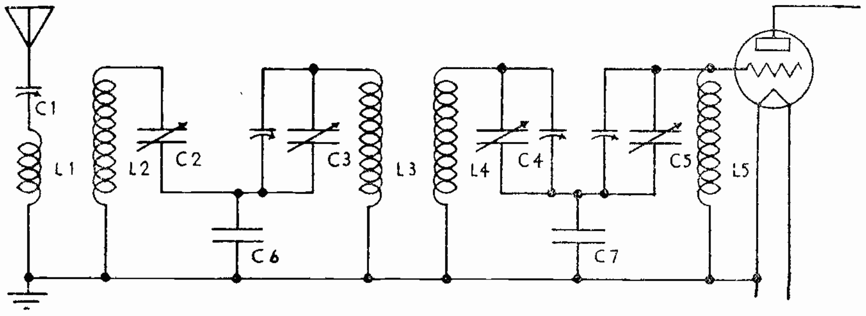


FIGURE 6

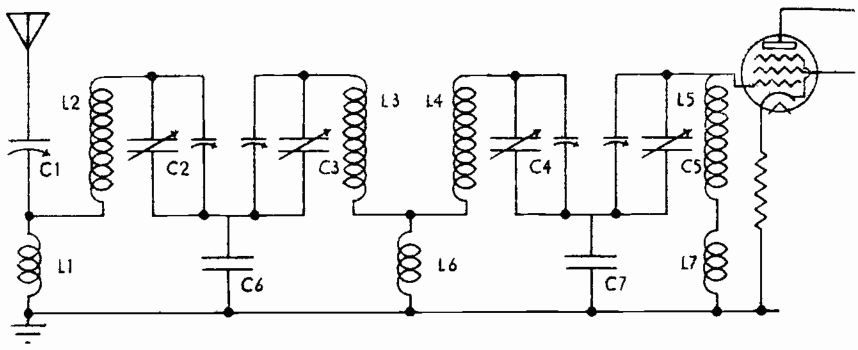


FIGURE 7

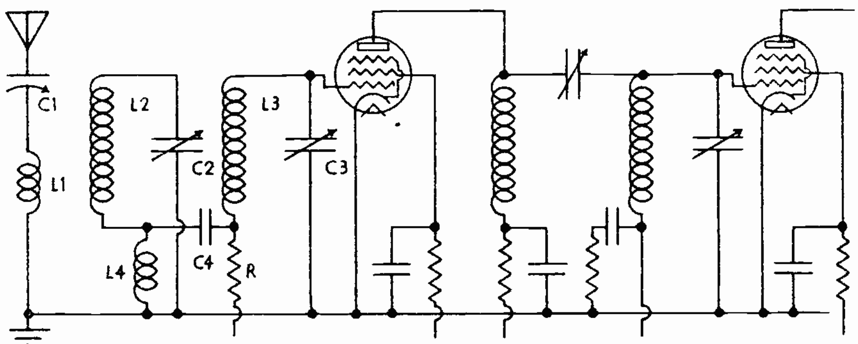


FIGURE 8

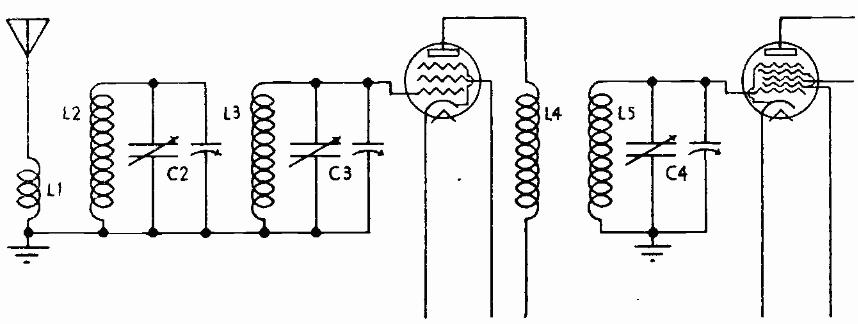


FIGURE 9

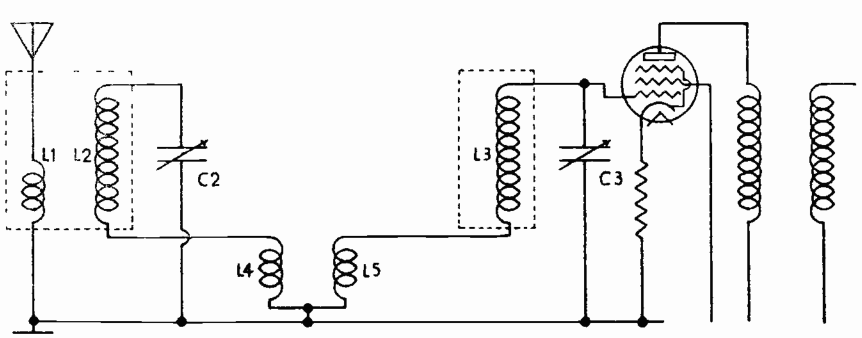


FIGURE 10

DE FOREST'S
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LESSON TRA - 19

COIL DESIGN

• • Founded 1931 by • •

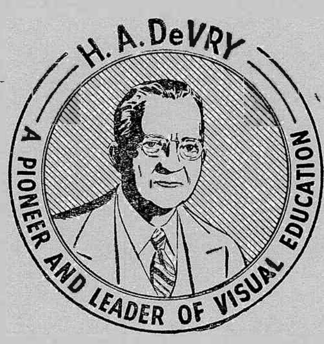
DE FOREST'S

TRAINING, Inc.

LESSON TRA - 19

COIL DESIGN

Founded 1931 by



TUBES - RECEIVERS - AMPLIFIERS

LESSON TRA-19

COIL DESIGN

* * * * * *

The idle do not know that it is to enjoy rest. Hard work, moreover, not only tends to give us rest for the body but what is even more important, peace to the mind.

--- Sir John Lubbock

COIL DESIGN

Modern Broadcast Receivers are made up of three main parts or sections. 1 - A high frequency amplifier, 2 - a detector or modulator and 3 - an audio frequency amplifier.

That part of the receiver between the antenna and detector, amplifies the modulated high frequency, increasing its strength or amplitude before it is demodulated by the detector. Because of the comparatively high carrier frequencies, many of the coils used in these circuits have no iron in their cores and are made with a comparatively small number of turns.

These are known generally as radio frequency, (r-f) coils, and for this Lesson we want to give you details of their design. Although powdered iron cores are employed in some types of r-f coils, our explanations will be based on the air core types.

TYPES OF WINDINGS

There have been a wide variety of coil designs, in regard to size, shape and method of winding but practically all of them can be placed in one of the four general types shown in Figures 1 to 4.

However, before taking up the details of these main types, we want to give you an idea of their general appearance and therefore, in Figure 5, we have shown a few of the many forms which have been, or still are in use.

At A, the coil ends are connected to a row of plugs, which fit into a terminal strip, making it a simple matter to remove or replace the coil assembly. Those shown at D and M are similar but with ridges holding the wire away from the main part of the form. The windings are connected to prongs like those of a tube base.

This particular type is still quite popular, for home made short wave receivers, where it is necessary to use several coils to cover the desired wave bands. An ordinary tube socket can be connected in the receiver and the various coils plugged in, when required, as easily as a tube.

All of these contain primary and secondary windings, placed a certain distance apart, to allow a definite magnetic "coupling" between them. Because neither of the windings are movable on the form, we call it "fixed coupling".

While these coils show the windings placed along side of each other, both wound on the outside of the form, there are other styles. Some coils have the primary wound over, or on top of, a part of the secondary with a layer or two of insulation in between. Others place one winding, usually the primary, on a smaller form which is slipped inside and fastened to the larger one.

For some circuits which require a change of coupling between the windings, the arrangement of Figure 5-B has been in common use. This is similar to the vario-couplers, explained in an earlier Lesson and, by turning the rotor, the coupling can be varied from maximum to minimum.

The same idea will be found in other types, like the one shown at H. Here, the primary is wound on a separate form and supported on an adjustable bracket. The coupling can be changed to secure the best operating conditions but, is not adjustable from the panel like the one at B. For that reason, the form at H is called a "Semi-Fixed" type of coupling.

As we will explain later, the coil form causes electrical actions which increase the losses in the winding. Air is one of the best known insulators and therefore many attempts have been made to reduce the amount of solid material in the coil form.

For example, at C, Figure 5, the cylindrical form is made up of a ring at each end with thin strips in between. While the strips support the wire, it is insulated mostly by air. At E, the same idea is carried still further and the coil is wound in the shape of a figure 8 to reduce the size of its magnetic field. Here, there is but one piece of supporting material placed at the point the turns cross. Still another type is shown at F where the winding is bent around in the shape of a doughnut, supported only at the center.

As we explained in the earlier Lessons, a coil has inductance but between the turns there is a condenser action, which produces a capacity. One reason for the various types we have mentioned, is to reduce what is known as the "Distributed Capacity" of the winding.

Coils A, B, C, D and M of Figure 5 are of the general type of Figure 1 and consist of a coil, wound as a single layer of wire on a cylindrical form of insulating material, such as fibre, bakelite or other plastics. This is a basic type, known as a single layer solenoid, and is made in a wide variety of lengths and diameters.

Figure 1 is a sectional view in which dimension line "b" represents the length of the winding, line "d" represents the diameter and line "a" the radius which is equal to 1/2 the diameter. Keep these dimensions in mind as we will have more to say about them.

BANK WOUND COILS

There are some circuits which require more inductance than can be had with the single layer coil of Figure 1, unless it is made too large for practical use. To permit more turns in a smaller space, the wire can be wound in layers as shown in Figure 4. Starting at the left end of the inner layer, the turns go to the right, then out to the second layer and back to the left. While a winding of this type has far more inductance than the single layer winding of similar dimensions it also has a greater distributed capacity.

Going back to the earlier Lessons, you will remember there is a voltage drop across a coil whenever there is current in it and this drop, or difference in potential, is spread evenly all the way along the wire. Following the numbers on the upper part of Figure 4, the voltage drop between turns "1" and "2" will be that caused by the length of wire in one turn. However, "22" is also next to "1" and the voltage drop, or difference in potential here, will be equal to that caused by 21 turns of wire.

In the earlier Lesson on Condensers we told you the amount of charge was expressed by the formula --

$$Q = CE$$

When Q = quantity of charge in coulombs
C = capacity in farads
E = voltage across the condenser

The effect of the distributed capacity will be proportional to the amount of charge therefore, although the actual value of capacity is the same, with 21 times the voltage between turns 1 and 22, there will be 21 times the capacity effect as between turns 1 and 2.

To cut down the losses produced by this action, the Bank Winding of Figure 3 is often used. The turns are wound in the order of the numbers and you will see there are never more than 4 turns between any two wires which lie next to each other. In this way, the distributed capacity is cut down to a value low enough to make the coil more efficient.

A good example of this type of winding is shown in Figure 5-H where we have a cut away form, the winding being made in several banks with a space between each.

HONEYCOMB COILS

One of the first forms of windings for Radio circuits was the Honeycomb Coil. It is layer wound, but the turns of each layer are at an angle to those of the layers above and below. By this method, the turns close to each other are not parallel and thus the capacity is reduced.

Figure 5-K will give you a good idea of the appearance of a honeycomb coil in its mounting. The coils were made in a standard width but with from 50 to 1500 or more turns, providing almost any value of inductance. Being wound in layers, the diameter increases as turns are added.

Many modern circuits employ coils which are similar to the "Honeycomb" but are known as "Universal Wound" or "Lattice Wound". Here again, the winding is made on the general plan of Figure 4 but the turns of each layer are placed at an angle to those above and below.

Instead of the large diameter shown in Figure 5-K, these later models are wound on a dowel of wood or other insulating material from 1/4" to 1/2" in diameter. In Figure 5-G, we show two of them mounted in a glass tube and while the dimensions of the complete coils are quite small, values of inductance may be comparatively high.

Another type of winding, shown in Figure 2, is a combination of Figures 1 and 4. The wire is wound in layers but with only one turn to each layer. This we call a "Disk" or "Pancake Winding" and, like the bank winding of Figure 3, the difference in voltage between adjacent turns is quite low.

A good example of this type is the "Paddlewheel" inductance of Figure 5-L, which is made up of a number of disks or "pies" electrically connected in series. Here, the capacity of each disk is low and the spacing between the disks reduces the distributed capacity of the entire winding.

SPIDERWEB COILS

Another type of winding, made somewhat on the same plan, is the spiderweb coil of Figure 5-N. A form of sheet fibre, cardboard or bakelite, has an odd number of slots cut in it and the wire is wound around, down through one slot and up through the next.

There are many varieties of this type of winding and, when wooden pegs are used in place of the flat form, it is often called a basket-weave. Imagine the form of Figure 5-N made up of a wooden hub with an odd number of pegs, arranged like the spokes in a wheel. The wire can be wound under one peg and over the next, or under one, over the next two, under the next two, and so on.

After the winding is finished and tied together, the pegs can be removed, leaving coils like those of Figure 5-J. Here, there is practically no form material and the capacity is further reduced because adjacent turns are kept as far apart as possible.

Other types of basket-weave coils are made by placing a circle of pegs at right angles to a wooden base. The wire is then wound around the pegs as explained above.

We mention these various types of windings to give you an idea of the different forms of coils which have been, or are, in common use for the inductance units of the resonant circuits of a High or Radio Frequency Amplifier. In every case, the object is to produce the correct value of inductance with the least amount of distributed capacity or other actions that will cause a loss of energy.

In modern Broadcast Receivers the various coils have been fairly well standardized and, in most cases, the assembly includes a metal shield. The general arrangement and appearance can be seen in Figures 6 and 7 where we show several models of Meissner coils with the shield cut away to expose the windings.

Figure 6-A illustrates an antenna or r-f coil with a secondary, bank wound on the general plan of Figure 3 and a primary, wound on the general plan of Figure 5-G. The coil assembly is mounted over an opening in the metal chassis and circuit connections are made on the underside of the chassis to lugs riveted on the lower end of the coil form.

The coil of Figure 6-B is of the same general type but is mounted in a square shield can and the illustration shows the spade lugs which are riveted to the lower part of the shield to provide a method of mounting. The secondary coil is made of "Litz" wire, to reduce losses, and is wound by a special arrangement known as "Universal Progressive". This is a combination of the bank and universal methods of winding and improves the efficiency of the coil.

For Figure 7 we show the popular type of intermediate frequency transformer used in Superheterodyne Receivers.

Although the details of the action and purpose of these units will be explained in a later Lesson, at this time we want you to notice there are two universal wound coils, wound on a common form with adjustable trimmer condenser mounted at the top. Holes in the shield permit adjustments to be made.

While the windings of Figure 7-A are clearly visible, to exclude moisture, many coil assemblies are dipped in hot wax, or similar compounds, to give them the general appearance of Figure 7-B. Unlike some of the older types of Figure 5, the coils of Figures 6 and 7 are completely enclosed and therefore only the shield cans are seem by a visible inspection of the receiver chassis.

INDUCTANCE

From the earlier Lessons, you know a tuned, or resonant, circuit must have certain values of inductance and capacity. While various plans have been worked out, the common method is to use a coil, or inductance, of fixed value and, by means of a variable condenser, change the value of capacity in order to tune the circuit until it is resonant at the carrier frequency of the desired signal.

The alternate method, often called "Permeability" tuning, is accomplished by a mechanically movable core, usually made of powdered iron, and arranged to slide inside the coil. By changing the position of this movable core, the permeability of the magnetic circuit is changed and thus, the inductance of the coil can be altered. This arrangement employs a fixed condenser is conjunction with the coil and the circuit is tuned by changing the position of the movable core.

FACTORS CONTROLLING INDUCTANCE

Thinking of a common type of coil, wound on the general plan of Figure 1, the value of its inductance will depend on four main factors.

1. The size of diameter of the form.
2. Total length of winding.
3. The number of turns.
4. Material used for the core.

Before going ahead, we want to remind you here that inductance is due to electromagnetic induction. If the action is not clear in your mind, review the earlier Lessons on Electro-Magnets, Induction and Inductive Reactance.

To illustrate factor No. 1 above, suppose we have two simple coils, both wound with the same size wire and the same number of turns. While both use the same material for the form, one is 1 inch in diameter, while the other is 2 inches in diameter. Without going into all the electrical details, you can understand that here, other things being equal, the larger coil will have the greater inductance because its greater length of wire will cause greater induction.

Factor 2, "The total length of winding" can be easily followed in Figure 8. Here we have two coils, both wound on forms of the same material and diameter, each having the same number of turns. Instead of being wound close together, the coil at the left has the turns separated so that it requires a total length of 2 inches for the entire winding.

The coil on the right is exactly like that on the left except the turns are closer and the total length is but 1-1/2 inches. Because the turns are closer, the induction between them is greater and thus the shorter winding, on the right, has the greater inductance.

Factor 3, "The number of turns", is shown in Figure 9 where again we have two coils wound on forms of the same size and material with the same size of wire. Here however, the left coil has but 25 turns while the other has 35 turns. In both cases, the turns are close together making the 35 turn winding longer. Because of the larger number of turns, the coil on the right will have a greater inductance than the one of the left.

Should smaller wire be used, so that the 35 turns of the right hand coil make a winding of the same length as the left hand 25 turn coil, the larger number of turns will cause the coil on the right to have a greater inductance than the one on the left.

For factor 4, "Material used for core", in Figure 10 we show two coils having equal dimensions and an equal number of turns. Here, the right hand coil has a laminated iron core and, because of the magnetic quality of iron, will have a much greater inductance than the one on the left.

VARIABLE CONDENSERS

We have already told you that most radio frequency circuits contain a variable condenser for tuning. The condenser adjustment is mechanical and, as they are easily secured in many forms, we will not take time here to explain them.

Electrically however, the variable condenser will have a certain maximum capacity, or rating, when the rotor plates are meshed all the way into the stator plates. It is this capacity which determines the size of a condenser.

When the rotor plates are turned all the way out, there is still some capacity, which we call "Minimum". While there is quite a variation in the minimum capacity of various types having equal maximum capacity, most of those on the market will give satisfactory results.

OSCILLATION CONSTANT

In the Lesson on "Resonant Circuits", we gave you the formulas

$$kc = \frac{159,160}{\sqrt{LC}}$$

$$\text{Wavelength} = 1.884\sqrt{LC}$$

in which "L" was the inductance in microhenrys and "C" the capacity in micro-microfarads. For your work here, "L" represents the inductance of the coil and "C" the capacity of the variable condenser.

Suppose we have a variable condenser, with a maximum capacity of 350 mmfd, and want to wind a coil which, when connected across the condenser, will form a tuned circuit that will be resonant at a frequency of 545 kc, equivalent to a wavelength of 550 meters. Thus we have definite values of frequency, wavelength and capacity for calculating the required value of inductance, "L".

To simplify the work, we can transpose the terms of the formulas to make them read —

$$L = \frac{(159160)^2}{(kc)^2 C}$$

$$L = \frac{(\text{Wavelength})^2}{(1.884)^2 C}$$

Substituting the values given for this example,

$$L = \frac{(159160)^2}{(545)^2 \times 350} = \frac{25331905600}{297025 \times 350}$$

$$L = \frac{25331905600}{103958750} = 243 + \text{microhenrys}$$

Substituting in the Wavelength equation,

$$L = \frac{(550)^2}{(1.884)^2 \times 350} = \frac{302500}{3.55 \times 350}$$

$$L = \frac{302500}{1242} = 243+ \text{ microhenrys}$$

Therefore, the coil requires an inductance of 243 microhenrys in order to tune the circuit to 545 kc or the equivalent wavelength of 550 meters. If the circuit is to be used in a Broadcast Receiver, it must tune to 1600 kc or 187.5 meters when the variable condenser is set at its position of minimum capacity.

To calculate the required value of capacity, with known values of frequency, wavelength and inductance, we can transpose the formulas to read,

$$C = \frac{(159160)^2}{(kc)^2 \times L}$$

$$C = \frac{(\text{Wavelength})^2}{(1.884)^2 \times L}$$

and substituting the known values of frequency and inductance,

$$C = \frac{(159160)^2}{(1600)^2 \times 243.5} = \frac{25331905600}{2560000 \times 243.5}$$

$$C = \frac{25331905600}{623360000} = 40.6 \text{ mmfd}$$

Substituting the known values of Wavelength and Inductance in the Wavelength equation,

$$C = \frac{(187.5)^2}{(1.884)^2 \times 243.5} = \frac{35156}{3.55 \times 243.5}$$

$$C = \frac{35156}{864} = 40.6 \text{ mmfd}$$

Which tells us the minimum capacity of the condenser must be 40.6 mmfd. We give you this figure simply to show how the formula is used because the ratio between maximum and minimum capacity is fixed by the mechanical construction of the variable condenser and is usually about 10 to 1.

What with the square root sign, decimals and fairly large figures for frequency or wavelength, it is quite a job to work out the values for each particular circuit. However,

as the values of L and C are the only variables and are always multiplied, we call their product the oscillation constant.

Like other similar factors, the "LC" constant has been calculated for all ordinary wavelengths, and the table at the end of this Lesson will give you the values in most common use.

The first column lists the wavelength in meters, the second, the corresponding frequency in kilocycles and the third, the produce of "LC" with L in microhenrys and C in microfarads.

Because both units are in common use, for the former examples we gave the capacity in mmfd while the table is calculated for capacity in mfd. To compensate for this difference you need remember only that, to change mfd to mmfd, move the decimal point six places to the right and, to change mmfd to mfd, move the decimal six places to the left.

Following this rule, the 350 mmfd condenser of the former example has a capacity of .00035 mfd. The same relationship holds for the "LC" constant of the table and, for capacity values in mmfd, move the decimal six places to the right.

Take the problem we just worked, using a .00035 mfd condenser and solving for the value of L to tune 550 meters. Going down the "Wavelength(Meters)" column to 550 we find the frequency is 545 kc and the "LC", or oscillation constant is .08519. We know the value of C is .00035 mfd and therefore divide .08519 by .00035 which gives us 243+ microhenrys, the same as before.

Changing the capacity value to 350 mmfd, and moving the decimal of the "LC" constant six places to the right, the problem becomes 85190 divided by 350 which again gives approximately 243.

You will find this table useful also for converting wavelength to frequency or frequency to wavelength. All you have to do is read down to the frequency or wavelength you want, and opposite to it, in the proper column, you will find the corresponding value.

For example, to find the frequency at a wavelength of 400 meters, you follow down the "Meter" column to 400 and go over to the "kc" column where you find 750. That tells you a wavelength of 400 meters has a frequency of 750 kc.

By substituting in the formula, or by using the table, you can calculate the value of inductance which is needed to cause a circuit to be resonant at any wavelength or frequency with any given value of capacity. Following the same general steps, you can calculate the required value of capacity to use with any given inductance.

INDUCTANCE FORMULAS

While there are a large number of rather complicated formulas for calculating the inductance of various types of coils, for this Lesson we are interested only in those which, as shown in Figures 8 and 9, have an "air" core.

The following simplified formulas, which are sufficiently accurate for most ordinary work, are known as "Emperical" because they are the result of experimental measurements on many coils of various sizes and shapes. By definition, an emperical formula is one founded on experimental data only and not deduced from purely theoretical considerations.

SINGLE LAYER SOLENOIDS

The type of coil shown in Figures 1 and 11 is known as a single layer solenoid and its inductance can be calculated by the formula,

$$L = \frac{a^2N^2}{9a + 10b} \qquad (1)$$

When L = inductance in microhenrys
a = radius in inches
b = length of coil, in inches
N = number of turns.

Looking at Figure 11, you will see that "a" is equal to 1/2 of the diameter "d", or that "d = 2a". The length of the coil, "b", refers to the winding only, regardless of the length of the form.

While the formula is usually stated in the form shown above, for most practical problems it is necessary to calculate the number of turns of wire which will have the desired value of inductance when made up into a coil of known length and diameter.

For problems of this kind, the simplest method of solution is to first transpose the terms of the formula so that the letter "N" appears as the first member. Without going into detail at this time, formula (1) above can be transposed and written as,

$$N = \frac{\sqrt{L(9a + 10b)}}{a} \qquad (2)$$

To show you exactly how this information can be put to practical use, suppose you are building a short wave receiver, using plug-in coils, and have installed tuning condensers with a maximum capacity of 140 mmfd, which is equal to .00014 mfd. You intend to wind your own coils, on the general plan of Figure 11, and want to start with one which will make it possible to tune from 150 meters down to 70 meters or less.

As the condenser is rated at its maximum capacity, you base your calculations on the highest wavelength, or lowest frequency, because that is where the circuit will be resonant when the coil is properly connected and the movable plates of the condenser are fully meshed. Therefore, you turn to the table and find, with a wavelength of 150 meters, the "LC" constant has a value of .006335. As an equation, for this condition you can write,

$$LC = .006335$$

As the condensers have a maximum capacity of .00014 mfd, you substitute this value for the "C" of the equation and have,

$$L(.00014) = .006335$$

and transposing the terms,

$$L = \frac{.006335}{.00014}$$

Dividing .006335 by .00014,

$$L = 45.25 \text{ microhenrys.}$$

By this plan, it is necessary to make but one simple division to find the inductance required in the coil.

To actually make the coil, you require some sort of bakelite, fibre or other similar material in the shape of a tube or form on which to wind the wire. To have some definite values, we will assume you measure the coil form and find it has a diameter, "d" of 1.5 inches. Also, you decide to make the winding have a length, "b", of 2 inches. Looking at Figure 11, you see that "d = 2a" and therefore a = d/2 = 1.5/2 = .75 inch.

Your next step is to substitute these values for the letters in equation (2), which you write as,

$$N = \frac{\sqrt{45.25(9 \times .75 + 10 \times 2)}}{.75}$$

$$N = \frac{\sqrt{45.25(6.75 + 20)}}{.75}$$

$$N = \frac{\sqrt{45.25 \times 26.75}}{.75}$$

$$N = \frac{\sqrt{1210}}{.75}$$

Following the steps given in an earlier Lesson, you extract the square root of 1210 as follows,

```
           3   4.   7   8
        /12/10./00/00
           9
  64   /  3 10
          2 56
 687   /    54 00
            48 09
6948   /     5 91 00
             5 55 84
```

Then you write

$$N = \frac{34.78}{.75}$$

and dividing 34.78 by .75, find that,

N = 46.37 turns.

Knowing the number of turns and the space in which they must be wound, to select the size of wire to use, you can refer to the following table.

WINDING TABLE

B & S Gauge	Approximate Turns per inch Bare	Enamel	D.C.C.	D.S.C.	Feet Per Ohm	Feet per lb. D.C.C.
14	16	14	13		388	77
16	20	18	16		244	119
18	25	23	20		154	188
20	31	29	24		97	298
22	39	36	29		61	460
24	50	45	34	38	38	745
26	63	57	40	45	24	1120
28	79	71	45	53	15	1760
30	100	88	51	67	9½	2534
32	126	120	60	77	6	3137

D.C.C. - Double Cotton Covered, D.S.C. - Double Silk Covered

As your coil requires approximately 46 turns in a space of two inches you divide 46 by 2 to find a value of 23 turns per inch. Checking back over the table, you see a #18 bare, #18 enamel or #20 D.C.C. wire will meet the space requirements by winding the turns close to each other. However, as the turns must be insulated from each other, it would be poor policy to use the #18 bare wire.

You decide to use #20 D.C.C. wire but want to find out how much to buy as well as the d-c resistance of the coil. To find the total length of the wire, you calculate the length of one turn and multiply this value by the number of turns. No doubt you remember that the circumference of a circle is 3.1416 times its diameter and here, with a 1.5 inch diameter, each turn will be 1.5 x 3.1416 = 4.71 inches.

For 46 turns, the total length will be 46 x 4.71 = 216.66 inches which, divided by 12, equals approximately 18 ft. To this you add a foot or so, to allow for making connections, and decide that 19 feet of wire will do the job.

Going back to the winding table, in the right hand column, you find #20 D.C.C. requires 298 feet to make up one pound so that 19 ft will weigh 19 divided by 298 or .0637 pound. As there are 16 ounces to a pound, and 16 x .0637 = 1.019, you need just a little more than one ounce of wire.

To find the d-c resistance of the coil, you refer to the sixth column of the winding table and find #20 has a value of 97 "Feet oer Ohm". Your coil of 19 feet therefore has a resistance of 19 divided by 97 or approximately .2 ohm.

SIZE OF WIRE

For some applications, the size of wire is determined by the amount of current it must carry but here, as the current is comparatively small, the main requirement is the space the wire will occupy. Therefore, either the #18 enamel or #20 D.C.C. would be satisfactory and, with the turns wound close, would provide the desired inductance in the required space.

Due to "Distributed Capacity", mentioned earlier in this Lesson, it is often desirable to wind the coil with a space between the turns and, as the length of the coil must not be changed smaller wire can be used.

For example, the winding table states that #24 enamel wire winds 45 turns to the inch and using this size, to wind 46 turns in two inches, the space between the turns would be about equal to the diameter of the wire.

Remember here, from formula (2), you found that a coil of 46 turns, 2 inches long and 1-1/2 inches in diameter has an inductance of 45.25 microhenrys. Nothing was said about size of wire or spacing between turns and therefore you know these factors have no effect, as far as the inductance is concerned.

FREQUENCY RANGE

With the coil designed for the highest wavelength, or lowest frequency, you want to find the range over which it will tune. In other words, you want to find the lowest wave length or highest frequency at which the coil and condenser circuit will be resonant.

Most modern tuning condensers are sold with definite stated values of maximum and minimum capacity but, if the minimum is not known, it can be considered as one tenth of the maximum capacity. On this basis, your condenser, with .00014 mfd maximum capacity will have .1 x .00014 or .000014 mfd minimum capacity.

To find the "LC" constant, you multiply the 45.25 microhenrys by the .000014 mfd for a product of .0006335. Referring to the "LC" table you see the value is .00057 for 45 meters and .0007039 for 50 meters. Comparing this with the .0006335, you decide the circuit will tune to approximately 47 or 48 meters.

For this explanation, we have followed the ordinary procedure in which the variable, or tuning condenser is purchased as a finished unit with definite values of maximum and minimum capacity. The coil form is also purchased as a piece of tubing or complete with prongs to plug into a tube socket.

To wind a coil which, when connected properly to the condenser, will make up a circuit that will be resonant at the desired wavelengths or frequencies, the only remaining factors are the length of winding, "b", and the number of turns, "N".

While there are variations, in general, you will find that single layer solenoid coils are approximately "square". That is, the length "b", has about the same value as the diameter "d". Therefore, taking all of these into consideration, it is necessary to calculate only for "N".

DISK WINDINGS

For coils of the general type of Figure 2, the conditions are somewhat different but again, there is a simple formula which is sufficiently accurate for all ordinary work. Looking at Figure 2, you will see the winding has practically no length "b" but, there is a difference between the radius "a" of the inner and outer turns. This difference is marked "c" and for the value of "a", the average radius is calculated.

For example, suppose the radius of the inner turn is 1/2" and that of the outer turn is 1". The difference between them is 1" - 1/2" = 1/2" for the value of the "c". The average radius is (1" + 1/2") ÷ 2 = 3/4" for the value of "a". To find the inductance, these values can be substituted into the formula,

$$L = \frac{a^2N^2}{8a + 11c} \qquad (3)$$

When L = Inductance in microhenrys
a = Average radius, in inches
c = Depth of winding, in inches
N = Number of turns.

Here again, it is usually the number of turns which must be calculated and therefore the terms of the formula can be transposed to,

$$N = \frac{\sqrt{L(8a + 11c)}}{a} \qquad (4)$$

This formula is used with coils of the general type of Figure 2 the same as explained for formula (2) and coils like that of Figure 1.

MULTILAYER COILS

The coils shown in Figure 3 and 4 combine the dimensions of Figures 1 and 2 and for this type the general formula is written as,

$$L = \frac{.8\ a^2N^2}{6a + 9b + 10c} \qquad (5)$$

When L = Inductance in microhenrys
a = Average radius, in inches
b = Length of winding, in inches
c = Depth of winding, in inches
N = Number of turns

Like the other formulas, the terms can be transposed to simplify the problems which require the calculation of the number of turns and formula (5) can be written as,

$$N = \sqrt{\frac{L(6a + 9b + 10c)}{.8 a^2}} \qquad (6)$$

HIGH FREQUENCY RESISTANCE

In a high, or Radio Frequency circuit, the current is not distributed equally through all parts of a wire because the flux, at the center, forces it toward the outer surfaces. This action increases with frequency until, at ultra high values, the current appears to travel in the space adjacent to the outer surface of the wire.

This action, known as "Skin Effect", reduces the effective area of the wire and thus increases its effective resistance. Occurring only at the higher frequencies, this effective resistance is often called the "High Frequency Resistance" to distinguish it from the d-c or ohmic resistance of the wire.

In the case of a coil, the value of high frequency resistance will depend on the frequency, material of the form or core as well as the shape of the winding, and may be many times the ohmic resistance of the winding.

As in other a-c circuits, the resistance consumes or dissipates energy while the reactance does not therefore, as a coil is designed primarily as an inductance, its efficiency is controlled by the ratio of the reactance to the resistance. As previously explained, this ratio is known as the "Q" of a coil and the resistance is the effective value which includes the high frequency resistance.

For this reason, we often think of the resistance as representing the loss of a coil and, naturally want to keep it at as low a value as possible. Although not always true, in general, the best size of wire to use for a coil is the largest that can be wound in the proper space. Due to the skin effect, you will find many high frequency coils wound with tubing instead of solid wire.

For Broadcast coils, the high frequency resistance can be reduced by the use of litzendraht (litz) wire, made up of a number of small separately insulated strands. These strands are properly transposed or woven so that each one successively takes all possible positions in the cross section of the complete conductor. This arrangement reduces the skin effect and thus reduces the high frequency resistance.

Commercial litz wire is made in a number of sizes such as ten No. 38 wires, ten No. 41 wires and seven No. 41 wires, each individual strand being enameled to provide the required insulation. The complete conductor is then insulated by methods and materials similar to those used for solid and other stranded wires. Thus, the plan of winding, explained for Figure 6-B, plus the use of litz wire, provides a coil of high merit or high "Q".

At frequencies above 1500 kc, litz wire shows little advantage over ordinary conductors, therefore, you will find it used mainly for Broadcast Receiver coils.

DISTRIBUTED CAPACITANCE

In explaining the coils of Figures 3 and 4 we mentioned the difference in voltage between adjacent turns and its relation to the "Distributed Capacity" effect.

Going back to the former Lesson on Condensers, we told you that a simple condenser is made of two plates, or some electrical conductor, separated by an insulator. As the turns of a coil are insulated from each other, according to this general difinition, they form a simple condenser.

The fact that the wire is continuous and all adjacent turns are connected does not enter into this particular action because, with a difference in voltage between them, the adjacent turns act the same as if they were connected to opposite terminals of a battery or other source of electricity.

To help you see the action, for Figure 13 we have drawn a few turns of wire and included condenser symbols to indicate the capacity between the various turns. These symbols show the action at separate points only but the effect is the same for the entire length of the winding.

Checking the condenser symbols, shown by dotted lines in Figure 13, you can see there is capacitance, not only between adjacent turns but between each and every turn as well as to ground. The total effect of this action is equivalent to a single capacity, of equal value, connected across, or in parallel to the entire coil.

Thus, in addition to the resistance of the wire, we have an inductance and capacity in parallel, both actually in the coil itself. Therefore, the coil contains the required components of a tuned circuit and will be resonant at some frequency.

In an a-c circuit, a capacity or condenser is considered as a reactance but, in practice, there is always some loss of energy in the dielectric. This is true for the distributed capacity therefore we think of these losses as increasing the effective resistance of the coil. This is one reason why, to maintain a high "Q", the distributed capacity of a coil should be kept as low as possible.

Notice also, the distributed capacity is in the same electrical position as the variable condenser usually used to tune a circuit. Therefore, the distributed capacity is added to that of the variable condenser and tends to prevent the circuit from tuning to a resonant frequency as high as indicated by calculations which include only the capacity of the tuning condensers.

We told you that the main reason for the various forms of coils shown in Figure 5 was to reduce the distributed capacity and thus, because of the actions mentioned above, many of them were sold as "Low Loss" units.

PRIMARY WINDINGS

So far, we have explained only the methods of finding the inductance and number of turns of the winding connected in the tuned circuit which, for the common type coils of Figure 6, is the secondary. This type of coil is known as an r-f transformer because it has a primary winding which is coupled inductively to the secondary.

Unlike the secondary, the primary is not tuned and usually is in the antenna circuit or acts as the "Load" in the plate circuit of a preceding tube. For this latter condition, the units of Figure 6 are used as a method of coupling the plate circuit of one tube to the grid circuit of the following tube.

Due to the comparatively loose coupling, in this case, the secondary voltage depends only to a small extent upon the "Turns Ratio" between the secondary and primary. The main requirement of the primary is that its impedance be of such value, compared to the plate impedance of the tube, that there will be the greatest obtainable voltage drop across it.

Because of the comparatively high plate impedance of the later types of tubes, it is impractical to obtain sufficient inductance with a single layer primary on the plan of Figure 1. Instead, the winding is made on the plan of those explained for Figure 6.

The ratio between the upper and lower frequencies of the Broadcast band is approximately 3 to 1 therefore, the inductive reactance of the primary will vary by a like ratio. As a result of this action, the transfer of energy, from primary to secondary will not be uniform over the entire band. This condition can be improved by the use of a small capacity, usually in the form of a single turn of insulated wire, wound over the grid end of the secondary and connected to the plate end of the primary. This can be seen in Figure 6-A where the central lug has one wire to the primary and one to the upper end of the secondary.

COUPLING

Whenever two coils are used for the transfer of energy, we say there is a coupling between them. This coupling may be "Magnetic" or "Inductive", as shown in Figure 6 where the coils are placed so that the magnetic flux of the primary cuts the secondary. The coupling may also be made by means of a condenser as mentioned above and also explained in the earlier Lessons.

Using the arrangement of Figure 7 as an example, when the coils are close together, we say they are "Tightly Coupled" and when comparatively far apart, we call them "Loosely Coupled".

The coupling has an effect on the action and at this time we want to mention only the general rules: The more loose the coupling, the lower the amplification but the greater the selectivity.

The explanations of this Lesson apply only to coils with air cores, designed to operate at comparatively high frequencies. In Electronic equipment, you will find them in r-f or carrier frequency circuits and in nearly all intermediate frequency amplifiers.

Wave Length (Meters)	Frequency (KC)	(LC)	Wave Length (Meters)	Frequency (KC)	(LC)
1	300,000	.0000003	175	1,714	.008620
2	150,000	.0000011	180	1,667	.009120
3	100,000	.0000025	185	1,622	.009634
4	75,000	.0000045	190	1,579	.01016
5	60,000	.0000070	195	1,558	.01071
6	50,000	.0000101	200	1,500	.01126
7	42,860	.0000138	210	1,429	.01241
8	37,500	.0000180	220	1,364	.01362
9	33,333	.0000228	230	1,304	.01489
10	30,000	.0000282	240	1,250	.01622
15	20,000	.0000634	250	1,200	.01760
20	15,000	.0001126	260	1,154	.01903
25	12,000	.0001760	270	1,111	.02052
30	10,000	.0002533	280	1,071	.02207
35	8,571	.0003448	290	1,034	.02366
40	7,500	.0004503	300	1,000	.02533
45	6,667	.0005700	310	967	.02705
50	6,000	.0007039	320	937	.02883
55	5,454	.0008519	330	909	.02066
60	5,000	.001014	340	882	.03245
65	4,615	.001188	350	857	.03448
70	4,286	.001378	360	833	.03648
75	4,000	.001583	370	810	.03854
80	3,750	.001801	380	789	.04065
85	3,529	.002034	390	769	.04277
90	3,333	.002280	400	750	.04503
95	3,158	.002541	410	731	.04733
100	3,000	.002816	420	714	.04966
105	2,857	.003105	430	697	.05204
110	2,727	.003404	440	681	.05446
115	2,609	.003721	450	666	.05700
120	2,500	.004052	460	652	.05960
125	2,400	.004397	470	638	.06219
130	2,308	.004757	480	625	.06485
135	2,222	.005130	490	612	.06759
140	2,144	.005518	500	600	.07039
145	2,069	.005919	510	588	.07327
150	2,000	.006335	520	576	.07606
155	1,935	.006760	530	566	.07905
160	1,875	.007204	540	555	.08208
			550	545	.08519

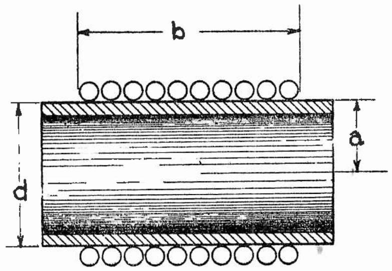


FIGURE 1

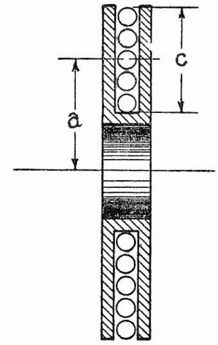


FIGURE 2

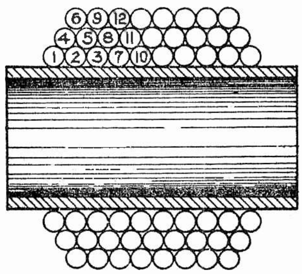


FIGURE 3

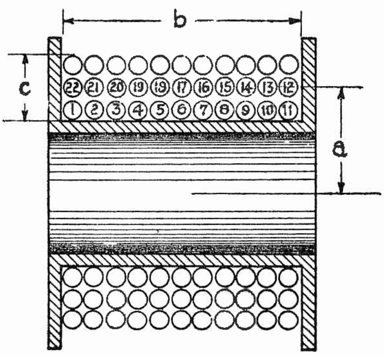
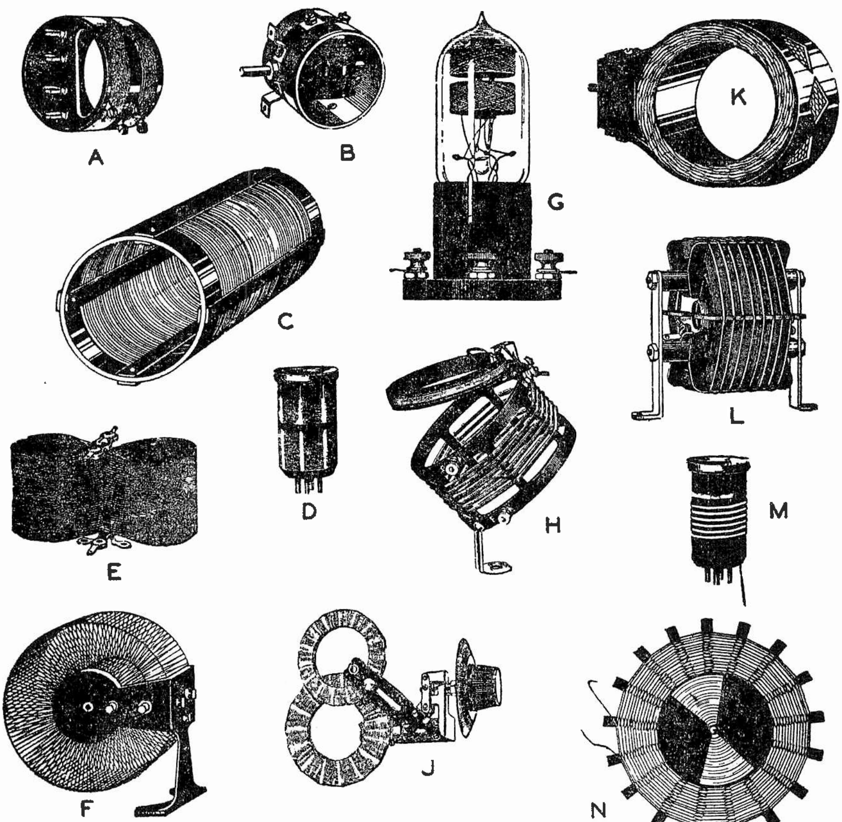


FIGURE 4



TRA-19

FIGURE 5

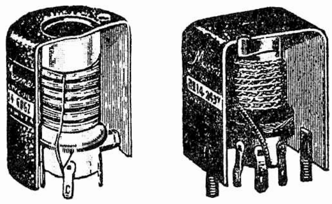


FIGURE 6

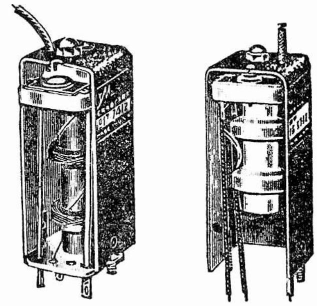


FIGURE 7

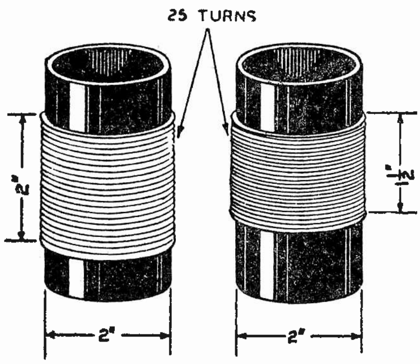


FIGURE 8

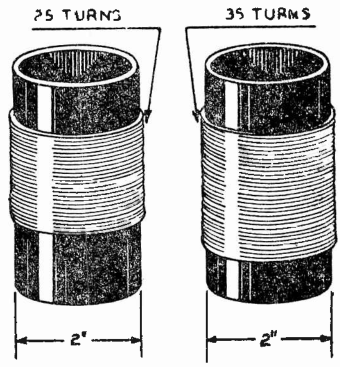


FIGURE 9

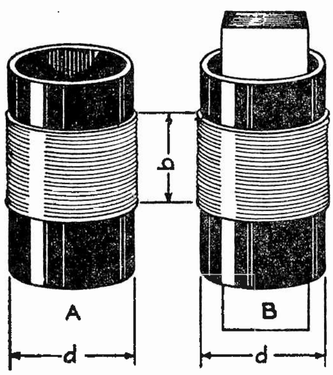


FIGURE 10

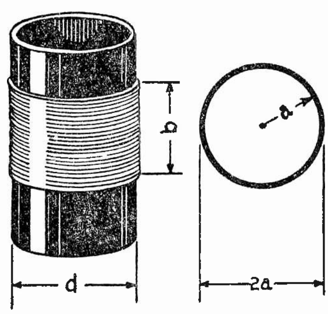


FIGURE 11

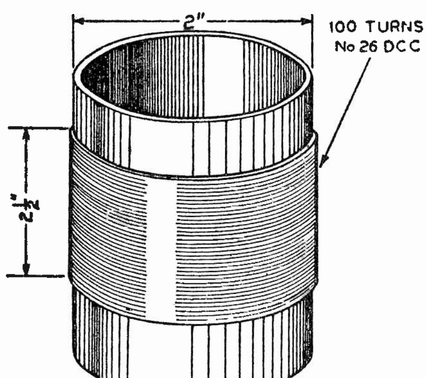


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FIGURE 12

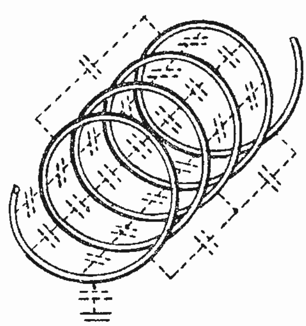

FIGURE 13

DE FOREST'S
TRAINING, Inc.

LESSON TRA - 20
T.R.F. RECEIVERS

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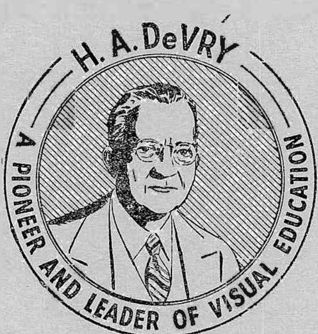
DE FOREST'S
TRAINING, Inc.

LESSON TRA - 20
T.R.F. RECEIVERS

* * Founded 1931 by * *



TUBES - RECEIVERS - AMPLIFIERS

LESSON 20

TRF RECEIVERS

* * * * * * * * * * *

A little neglect may breed mischief.
For want of a nail, the shoe was lost;
For want of a shoe, the horse was lost;
For want of a horse, the rider was lost.

. . . Franklin

TRF RECEIVERS

In spite of the almost unlimited number of developments in Radio, there have been but three basic types of receiver circuits. These are usually considered as the Regenerative Detector, Tuned Radio Frequency (trf) and the Superheterodyne.

As explained in the earlier Lessons, before the advent of Radio Tubes, the common type of receiver employed a crystal detector but there was no satisfactory method of amplifying the signals. As all receivers require some form of detector, this is not considered as one of the basic types mentioned above.

Shortly after its invention, the three element vacuum tube replaced the crystal because of its improved stability and sensitivity as a detector. However, the simple one tube receiver, as shown in Figure 1, did not differ greatly from the crystal receiver, as far as its circuits were concerned.

In contrast, the regenerative detector, explained in the earlier Simple Receiver Lesson, employed a new idea by feeding a portion of the output energy back to the input circuit. That is why this form of circuit is considered usually as one of the three basic types.

During those early days of Radio, the object of most experimenters was to increase the sensitivity of the receiver, because the comparatively small number of Broadcast stations made selectivity of secondary importance. Therefore, as soon as their amplifying action was discovered, triode tubes were employed to increase the amplitude of the detector signal output.

Following this plan, it became common practice to build receivers with one or more stages of audio amplification between the regenerative detector output and the headphones. While this plan increased the amplitude or volume of the signals, it did not improve the sensitivity or selectivity of the detector.

R-F AMPLIFIERS

To make improvements in this respect, it was necessary to increase the amplitude or strength of the signal before it reached the detector and therefore, one or more stages of amplification were built in between the antenna and the detector. To produce the desired result, these stages were designed to operate at the frequencies of the Radio carriers and therefore are known as Radio Frequency (r-f) amplifiers.

To show these developments in simplified circuit form, for Figure 1 we have drawn a simple one tube receiver circuit which consists of an antenna coil, with primary and tuned secondary, a grid leak detector and headphones. As the action of this circuit was explained in the Simple Receiver Lesson, we will not repeat. However, if the various actions are not clear in your mind, a review of the former Lesson will be of benefit.

For the circuits of Figure 2, we show all the units of Figure 1, but here, the voltage developed across the tuned circuit, L2-C1, is impressed on the grid of the "R-F Amp" tube. To simplify this drawing, we show no provision for grid bias voltage therefore you can assume the plate voltage is of a value low enough to allow proper operation when the grid return connects to "A-".

As previously explained, the action of the tuned secondary circuit is to produce a higher voltage at the desired resonant frequency only and thus, compared to the antenna circuit, it provides increased sensitivity and selectivity.

Acting as an amplifier, the tube does not cause a change in frequency and thus, the changes of plate current will vary with the changes of signal voltage on the grid. The changes of plate current cause corresponding changes of voltage drop across coil L3 and these, in turn, induce voltages of like frequency in coil L4 which is tuned by variable condenser C4.

Notice here, the arrangement of L1-L2-C1 is similar to that of L3-L4-C4 and, due to the amplifying action of the tube, the voltage across L3 will be greater than that across L1. This means the voltage across L4-C4 will be greater than that across L2-C1 and, as L4-C4 replaces L2-C1 of Figure 1, the detector input signal voltage is greater.

This arrangement is known as an r-f amplifier and while that shown in Figure 2 consists of but one stage, two or more stages may be connected in cascade to increase the action still further.

Comparing the circuits again, you will find resistor R2 of Figure 2 replaces the headphones of Figure 1, while the circuit of condenser C3 is not changed. Thus, the detector plate current, carried by the phones of Figure 1, is carried by resistor R2 of Figure 2.

To increase the amplitude or strength of the signals, the detector is resistance coupled to the "A-F Amp" tube by the combination of the plate resistor R2, coupling condenser C5 and grid resistor R3. The change of detector plate current

produce corresponding changes of voltage drop across R2 thereby causing coupling condenser C5 to charge and discharge. The charge and discharge currents, carried by R3, cause corresponding changes of voltage drop which are impressed on the grid of the "A-F Amp" tube.

This tube operates as an audio amplifier and the phones, connected in series with the plate, carry the plate current. Due to the amplifying action, the changes of the amplifier tube plate current are greater than those of the detector and thus the phone signals are louder.

Thus, the arrangement of Figure 2 comprises a three tube receiver made up of an r-f stage, a detector and one a-f stage. The operation of the detector is the same as that of Figure 1 but the r-f stage provides added sensitivity and selectivity while the a-f stage adds volume or amplitude to the signal in the plate or output circuit of the detector.

In Figure 1, the "B+" terminal connects to the detector plate through the headphone while, in Figure 2, the "B+" terminal connects to the "A-F Amp" plate through the headphones, to the detector plate through resistor R2 and to the "R-F Amp" plate through coil L3.

All grid returns connect to the "B-A-" terminal -- the "R-F Amp" through coil L2, the detector through resistor R1 and coil L4, while the "A-F Amp" return is through R3.

One side of each tube filament connects to the "A+" terminal while the other side of each filament connects to the "B-A-" terminal. Thus, the supply circuits of Figure 1 have been extended to corresponding elements of all three tubes of Figure 2.

INPUT CIRCUITS

For simplicity, no volume control or power supply is shown in the circuits of Figures 1 and 2. Therefore, for the circuits of Figure 3 we show the diagram of a complete modern type of 4 tube, trf receiver.

As far as the signals are concerned, the arrangement is the same as that of Figure 2, although different types of tubes are installed. Here, there is a 12SK7, r-f Pentode for the r-f amplifier stage, a 12SJ7 operating as a bias type of detector with a 50L6 Beam Power tube as the audio amplifier stage. The 35Z5 is a rectifier to provide the d-c plate power.

We want you to study the diagram of Figure 3 with extra care as it follows commercial practice and is the type of drawing you will work with when doing actual work. The values of most components are shown, those for resistors being given in ohms and those for condensers in microfarads. For simplicity the heaters are not included in the tube symbols but are shown as a separate "Heater Circuit".

While further details will be given in a later Lesson, at this time we want to trace the circuit for you because it is used in the popular a-c/d-c type of Radio equipment. Unlike the power supplies explained in the earlier Lessons, there is no power transformer and the voltage of the ordinary home lighting circuit is applied directly to the heater circuit.

Starting at the common form of plug marked "Line", it is customary to assume a value of 117 volts for the usual 110-120 volt circuit and to connect the heaters in series. To do this with a simple circuit, all of the heaters must be designed to operate at the same value of current.

Checking the tube characteristics, you will find all the types shown in Figure 3 require a heater current of .150 ampere, although the voltages vary. In a series circuit, the voltage drops are added, therefore with a 12SK7, 12SJ7, 50L6 and 35Z5, the total drop is 12 + 12 + 50 + 35 = 109 v. To bring the total up to that of the line, a 60 ohm resistor is connected in the circuit because, with a current of .150 ampere, the drop across it will be .150 x 60 = 9 volts. Adding this to the 109 volts of the tube heaters, the total is 118 volts, approximately equal to the supply voltage. The 35Z5 heater is tapped at a point to provide a 6.3 volt drop and the dial lamp is connected across this part. Thus, when the switch is closed, the tube heaters connected in series with each other are placed across the supply line, which provides the proper current.

For the plate voltage supply, there is a connection from one end of the dial lamp to the plate of the 35Z5 and, due to the rectifying action of the tube, its cathode becomes the source of d-c. The filter is made up of two 16 mfd condensers, with their positives connected to the cathode while the speaker field of 450 ohms, in series with a 20 ohm resistor, is used as the filter choke. This places the choke in the negative or return side of the circuit as explained in the earlier Lesson on Power Supplies.

Thus, the cathode of the rectifier tube of Figure 3 serves the same purpose as the "B+" terminal of Figure 2 and supplies high voltage d-c to the plate and screens of the other tubes at a value usually a few volts lower than that of the a-c

supply line. For a d-c supply line, the action remains about the same but, the plug must be placed in the supply outlet so that the prong, connected to the rectifier plate, contacts the positive side of the supply.

Checking the high voltage circuits by starting at the rectifier cathode, there is one path through a transformer primary to the plate of the 50L6, a direct connection to the 50L6 screen grid, a circuit through a 500,000 ohm resistor to the 12SJ7 plate and one through the 2 megohm resistor to the 12SJ7 screen grid.

Going further to the left of Figure 3, there is a circuit through the r-f coil primary to the 12SK7 plate, a direct connection to the 12SK7 screen grid and a final path through a 25,000 ohm resistor, a 200 ohm resistor and part of the 15,000 ohm volume control to ground.

To complete the circuit, we start at the grounded end of the 20 ohm resistor and continue through the 450 ohm dynamic speaker field winding to the switch and other side of the supply line.

The input circuit for the 12SK7 tube of Figure 3 is much like that for the "R-F Amp" of Figure 2 but the plate and screen grid circuits of the 12SK7 reach ground through the cathode, the 200 ohm resistor and part of the 15,000 ohm volume control. The 200 ohm resistor and part of the volume control carry also the bleeder current in the 25,000 ohm resistor and the resulting voltage drop across them makes the cathode positive in respect to ground. However, as the control grid is grounded through the antenna coil secondary, the grid is negative in respect to the cathode.

Changing the position of the moving arm of the volume control will change the value of resistance, between cathode and ground, and therefore vary the value of negative grid bias voltage. As a change of grid bias voltage alters the gain of the tube, this variable resistance acts as a volume control. To make the action more positive, the other outer end of the volume control connects directly to the antenna and thus, that part of the volume control resistance, shown to the left of the grounded movable contact, is in parallel to the antenna coil primary. That part of the resistance, shown to the right of the grounded movable contact, is in series with the 12SK7 cathode.

When the grounded contact is moved to the left in our drawing, the resistance in parallel to the antenna coil primary is reduced and thus the signal voltages across the coil are also reduced. At the same time, the value of resistance in

series with the 12SK7 cathode is increased and causes an increase of negative grid bias which cuts down the gain of the tube.

For full volume, the grounded contact is moved all the way to the right of our drawing but, the 200 ohm resistor remains in the cathode circuit to provide what is known as the minimum bias. Without this resistance, full volume would reduce the bias voltage to zero and the signal might be distorted. The .01 mfd condenser, connected from cathode to ground, is in parallel to all the resistance which develops the grid bias voltage and acts to maintain a more uniform voltage drop. Used in this way, it is known commonly as a "By-pass" condenser.

DETECTORS

Due to its greater sensitivity, a grid leak detector is shown in the simple receiver circuit of Figure 1 and, to provide a more complete comparison, the same detector circuit is included in the circuits of Figure 2. However, for most trf receivers, there is sufficient r-f amplification to permit the use of less sensitive types of detectors which have the ability to handle larger signal voltages with less distortion.

Thus, you will seldom find a regenerative detector in a trf receiver but instead, a bias type such as the 12SJ7 of Figure 3 or the diode type of the circuits of Figure 4.

On many circuits, the negative grid voltage is obtained from the drop across a 25,000 to 50,000 ohm resistor connected in series with the cathode, such as the 150 ohm resistor in the cathode circuit of the 50L6 in Figure 3. Here however, the cathode of the 12SJ7 detector is grounded directly therefore, the bias voltage must be developed in the grid circuit although the grid current is negligible.

Starting at the grid, and tracing its circuit back to the cathode, we go through the secondary winding of the r-f coil through a 2 megohm resistor, through a 20 ohm resistor to ground and from ground back to the cathode.

With negligible grid current, there will be negligible voltage drop across the 2 megohm resistor but, as already explained for the 12SK7 tube, the plate and screen grid currents of all the tubes return to ground. To complete their circuits, they pass through the 20 ohm resistor and 450 ohm speaker field winding to reach the negative side of the supply circuit. Thus, the voltage drop across the 20 ohm

resistor, caused by all the plate and screen grid currents, provides the negative grid bias voltage for the detector tube.

This arrangement provides what is often called a "Semi-fixed" bias because, regardless of the variations of the separate plate and screen grid currents, the sum of them all will be fairly constant. Unlike self bias, the negative grid voltage does not depend entirely upon the plate and screen grid circuits of the same tube. The bleeder current, carried by the 200 ohm resistor and part of the volume control, has a similar effect on the bias voltage of the 12SK7 tube.

The .05 mfd condenser, connected between the lower end of the r-f coil secondary and the grounded rotor plates of the tuning condenser, is in parallel to the 2 megohm and 20 ohm resistors and can act as a by-pass. Also, it is in series with the tuning condenser, connected across the coil secondary, and thus is a part of the tuned circuit.

As far as the tuned circuit is concerned, the .05 mfd condenser makes but little difference. Assuming the common value of .000365 mfd for the tuning condenser, in series with the .05 mfd fixed condenser, the total capacity is approximately .000362 mfd, a difference of but 3 mmfd which can be compensated by adjustment of the trimmer, mounted on most tuning condensers.

Thus, the .05 mfd condenser completes the tuned circuit of the coil secondary to provide the same action as that of the tuned secondary of the antenna coil but, as far as the grid bias voltage is concerned, provides an isolated d-c path for the grid circuit.

The plate circuit of the 12SJ7 tube of Figure 3 is much like the detector plate circuit of Figure 2 but, as the 12SJ7 is a pentode, its screen grid must be supplied with a positive voltage. This screen grid circuit consists of a 2 megohm resister, connected between the screen grid and supply positive, with an .01 mfd condenser from screen grid to cathode which is grounded. Notice also, the .0005 mfd condenser, connected between plate and cathode, corresponds to C3 of Figure 2.

In addition, the .01 mfd coupling condenser compares to C5 of Figure 2, while the 500,000 ohm grid resistor compares to R3. Thus, the signal circuits of Figure 2 and 3 are almost the same and include the same number and types of stages.

OUTPUT CIRCUITS

For the output circuits of Figure 3, we show a type 50L6 Beam Power Amplifier tube which has a maximum signal power output of approximately 2 watts. Tracing its circuit, you will find the plate connects to the supply positive through the primary winding of the output transformer with a direct connection between the screen grid and supply. The cathode connects to ground through a 150 ohm resistor.

This tube operates an an audio amplifier output stage and the negative grid bias is provided by the voltage drop across the 150 ohm cathode resistor. Unlike the r-f and detector stages, there is no condenser connected across this resistor and therefore the grid bias voltage will vary with changes of plate and screen grid current. While this action reduces the effective gain of the stage, it also reduces the distortion of the signal and, as will be explained in a later Lesson, is known as "Inverse Feedback". We mention this point now to avoid confusion because, at first glance, it might appear that the condenser was accidentally omitted from the diagram.

Although the speaker is not shown, its connections are given. The voice coil connects across the output transformer secondary which is marked "V.C." while the speaker field winding is part of the plate supply filter. Some receivers are equipped with different types of speakers and the "Field" of Figure 3 may be replaced by an audio choke coil or a resistor.

While there are many minor circuit variations, the arrangement of Figure 3 is typical of the smaller, lower priced trf receivers.

R-F STAGES

The third type of basic receiver circuit, known as the "Superheterodyne" and which will be explained in a later Lesson, has almost entirely supplanted the other types but trf receivers still have certain desirable features. Circuits on the general plan of Figure 3, require a minimum number of components and, where a high degree of selectivity is not needed, provide an inexpensive and acceptable type of receiver.

In some Public Address systems, it is desirable to reproduce radio programs as well as those which originate in the microphone or phonograph record. The trf type of circuit is sometimes used for this purpose therefore, for Figure 4 we show the circuit diagram of a unit known as a "High Fidelity" trf type of Radio Tuner.

We use the word "Tuner" instead of Receiver because, as shown in Figure 4, the unit does not include a complete audio amplifier. Instead, it is designed to provide a Radio input for Public Address and other similar sound systems.

Checking through the circuits, you will find two r-f stages with type 6SK7 r-f pentode tubes, a 6H6 detector stage and a 6F8 first audio stage arranged to provide two separate output channels.

Starting at the antenna, the signal passes through a band pass filter arrangement to reach the grid of the first 6SK7 r-f amplifier tube. This filter is similar to those explained in our earlier Band Pass Filter Lesson and includes two tuning condensers. The plate of this tube is coupled to the grid of the second 6SK7 r-f amplifier by a similar band pass filter which also includes two tuning condensers.

Figure 4 shows broken lines which connect all four of the tuning condensers to indicate they are connected mechanically and thus all tuning is done by a four gang condenser with a single control. This arrangement provides a single tuning dial while the band pass filter circuits permit a more uniform response over a wider band of frequencies. Also, sufficient selectivity is obtained by the tuned band pass filter circuits to permit the use of an untuned r-f transformer to couple the second 6SK7 to the 6H6 diode detector. The 50,000 ohm resistors, connected across the primary and secondary of this transformer, provide a more uniform response to the frequencies of the tuning range.

The detector is of the common diode type and its circuit can be traced from the upper end of the untuned secondary to the parallel connected diode plates, through the tube and the parallel connected cathodes to ground. From ground, the circuit continues through two 100,000 ohm resistors and a 50,000 ohm resistor to the lower end of the untuned secondary.

To make up the filter, required for this type of detector circuit, a .0001 mfd condenser is connected between each end of the 50,000 ohm resistor and ground. A connection, made at the junction between the 50,000 ohm and 100,000 ohm resistors, is connected to the .05 mfd condenser which couples the audio signal in the detector circuit to the grid resistor of the 6F8 tube.

This grid resistor consists of a 500,000 ohm potentiometer which acts as a volume control because its movable contact connects to the parallel connected control grids of the 6F8 which is a double triode type of tube. Thus, each triode section of the 6F8 tube will have the same signal voltage impressed on its grid.

With the exception of a decoupling filter, made up of a 5000 ohm resistor and an 8 mfd condenser, connected in one of them, both plate circuits are alike but entirely separate. One plate couples to output terminal No. 1, through a .25 mfd condenser while the other is coupled to output terminal No. 4 through a .1 mfd condenser.

As output terminals No. 3 and No. 5 are grounded, the signal output of one plate circuit will appear across output terminals No. 1 and No. 3, while the output of the other plate will appear across output terminals No. 4 and No. 5.

AUDIO AMPLIFIERS

The resistors between the output terminals are of values to match the common input impedances of audio amplifiers. High impedance inputs are connected across terminals No. 1 and No. 3 while low impedance inputs are connected across terminals No. 2 and No. 3.

In most large public address systems, the operator must be able to hear the program although the speakers may be located in positions where he can not hear them. Therefore, it is common practice to install a special "Monitor" circuit terminating in a speaker close to the operator.

Terminals No. 4 and No. 5 of Figure 4 provide a convenient signal source for a monitor circuit and, due to the arrangement of the 6F8 circuits, switching or other changes in the monitor circuit will have no effect on the signals in the main circuit connected across terminals No. 1 and No. 3 or No. 2 and No. 3.

Most audio amplifiers used for Public Address systems are provided with several input circuits for one or more microphones, or phonographs, and have sufficient gain, as well as power output, to provide the desired signal levels. The output frequencies of the tuner of Figure 4 compare to those of the microphone and phonograph pick-ups and therefore can be plugged into the amplifier input on the same general plan.

The amplitude of the output signal voltages of the tuner of Figure 4 compare to those of a phonograph pick up and are higher than those of modern, low level microphones. That is why most audio amplifiers are arranged to provide an additional stage of voltage amplification for the microphone input circuits.

CONTROLS

For the circuit of Figure 3, there are but three controls, Tuning, Volume and "Off-On" switch. The two tuning condensers

are mechanically "ganged" to provide a single tuning control and the switch, mounted on the volume control, combines both actions. Therefore, but two control knobs are needed for the operation of this receiver.

The controls of Figure 4 are much the same except that here, four tuning condensers are ganged to provide a single tuning control. The volume control does not carry the switch because with an external power supply, the "Off-On" switch will be included as a part of the supply.

In tracing the circuits of Figure 3 we found the detector grid return connected to a point on the common return which was negative in respect to ground. The value of the negative grid bias voltage was due to the drop across a 20 ohm resistor which carries the plate and screen grid currents of all except the rectifier tube. In this way, the detector grid bias is practically independent of the changes of detector plate and screen grid currents.

Looking at Figure 4, you will find a somewhat similar arrangement which has a different purpose. Tracing the grid circuit of the first 6SK7 tube, you pass through a tuned secondary coil, a 2 megohm resistor, the 50,000 ohm and both 100,000 ohm resistors of the detector circuit in order to reach ground. From ground, the circuit is completed back to cathode through a 400 ohm resistor.

For the second 6SK7 tube, the grid circuit is through a tuned secondary coil, a 2 megohm resistor and one 100,000 ohm resistor of the detector circuit to ground. From ground, the circuit is completed back to the cathode through a 400 ohm resistor.

Under ordinary operating conditions, there is no current in these control grid circuits, therefore, with no signal, the grid circuits of the 6SK7 tubes of Figure 4 are similar to the 12SK7 grid circuit of Figure 3 when the volume control is turned all the way to the right. The grid bias voltage is equal to the voltage drop across the resistor connected between cathode and ground.

With no grid current and no signal, in Figure 4 there will be no voltage drop across any of the resistors in grid return or detector circuits. Notice here, the 2 megohm resistor, tuned secondary winding and .05 mfd condenser in each of the 6SK7 grid circuits of Figure 4 are connected the same as similar units in the detector grid circuit of Figure 3. Thus, the .05 mfd condensers of Figure 4 are in series in the tuned circuits and, in conjunction with the 2 megohm resistors form a filter in the grid return circuit.

When a signal voltage is present, there is current in the diode detector circuit of Figure 4 and thus current, in the 50,000 ohm and two 100,000 ohm resistors will cause a voltage drop across them. The direction of this current is such that the grounded end of these three series connected resistors will be positive while the end connected to the coil will be negative.

Thus, the voltage drop across the grounded 100,000 ohm resistor in the detector circuit will be impressed on the control grid of the second 6SK7 tube and added to the drop across the 400 ohm cathode resistor for the total grid bias voltage. The same action takes place in the grid return of the first 6SK7 except that the drops across both 100,000 ohm resistors and the 50,000 ohm resistor will be impressed on the grid.

Thus, an increase of signal voltage will cause an increase of detector current which, in turn, will cause a higher voltage drop across the resistors in the detector circuit. As explained above, this higher drop across the resistors will increase the total negative grid bias on the r-f amplifier tubes and reduce their gain.

This action, known as Automatic Volume Control (avc) will be completely explained in a later Lesson but we have given these few details here in order that you can follow the circuits and controls of Figure 4 in complete detail. Circuits like those of Figures 3 and 4 often contain some form of Tone Control but, as these circuits will be explained in an advance Lesson, we have not included them here.

SELECTIVITY

The selectivity of a radio receiver determines its ability to reject undesired carrier frequencies and can be defined as the ratio of the response at resonance to the response at other frequencies, separated at specified values from the resonant frequency. In the Broadcast Band, the carrier frequencies are 10 kc apart and a receiver, advertised as having 10 kc selectivity means it should receive signals at one carrier frequency without interference from carriers 10 kc above and below.

According to the definition, the selectivity is dependent upon resonant response and therefore will be determined, to a great extent, by the number of tuned circuits in a complete receiver. In Figure 3, for example, there are but two tuned circuits and therefore the selectivity will not be as good as in the circuit of Figure 4 with four tuned circuits.

The "Q" of the tuned circuits will also have an effect and, as explained in the earlier Lessons, the higher the "Q" the steeper the response curve. Now we can add, the steeper the response curve, the greater the selectivity.

To reduce interference, from Broadcast stations in any locality, the FCC allocates carrier frequencies which are separated by more than 10 kc. Because of this policy, satisfactory reception is obtained with receivers of less than 10 kc selectivity. Radio Tuners on the general plan of Figure 4 are often designed for uniform response over a 20 kc band but are sufficiently selective to separate local Broadcast stations and provide high fidelity reproduction without interference.

Keep this explanation of selectivity in mind because, in the later Lesson, on Superheterodyne Receivers, we will use these trf circuits as a basis for comparison.

SENSITIVITY

While the terms are frequently confused and the effects may overlap, the selectivity and sensitivity of a Radio Receiver are separate and distinct characteristics. As a definition, the Sensitivity of a Radio Receiver determines the lowest value of signal input which will cause some definite or desired value of output. Thus, every stage in the complete Receiver can contribute to its sensitivity.

The sensitivity of any particular model of Radio Receiver is uaually stated as a signal input of so many microvolts required to provide an output of so many watts. Some manufacturers specity in terms of input only such as "a sensitivity of better than one microvolt". This is a rather indefinite statement which infers a satisfactory output level at this value of input.

In general, you can think of the sensitivity of a Receiver as being determined by its overall gain from the antenna or input circuit to the final output circuit. Remember here, the gain of the tuned stages, which provide the selectivity, also contribute to the sensitivity.

FEED BACK

From the definitions of selectivity and sensitivity it would seem that both could be improved by the addition of r-f amplifier stages. However, there are other actions which place a rather low limit on the number of such stages that can be used to advantage.

In our explanation of the Regenerative Detector, we told you how energy, fed back from the plate to the grid of a tube could cause oscillation. Using pentode tubes, as shown in Figures 3 and 4, the grid plate capacity is of negligible value but, with several r-f stages, all operating at this same frequency, there are several possible sources of feedback.

The magnetic field, set up around one coil, may extend far enough to couple a coil of another stage. In most cases, the coils are shielded to prevent this action but, with several high gain stages, stray fields may be strong enough to provide unwanted feedback.

The wires of the various circuits may be placed close enough to each other to provide a capacity coupling between stages and, with a common source of voltage, the circuits of the different tubes may be coupled through the power supply.

After taking all ordinary precautions, by means of shielding and filters, to prevent unwanted coupling, three or more r-f stages employing modern high gain tubes, usually provide enough gain to cause oscillation by means of stray coupling which is practically impossible to eliminate.

When oscillation of this type is present in a Receiver, it will "whistle" as the Broadcast stations are tuned in or when the tuned stages are not resonant at the exact frequency of the incoming carrier.

TYPICAL CIRCUITS

As mentioned earlier in this Lesson, the arrangement of Figure 3 can be considered as a typical circuit of the small trf type of Radio Receiver, designed to operate on any common 110 volt lighting circuit either a-c or d-c.

For high fidelity reproduction, the more elaborate arrangement of Figure 4 can be considered as a typical trf tuner. It has sufficient selectivity to separate local Broadcast stations and a sensitivity high enough to provide adequate signal strength for the audio amplifier it drives.

Study these trf circuits carefully because many of the larger types of modern Receivers include one or more r-f stages.

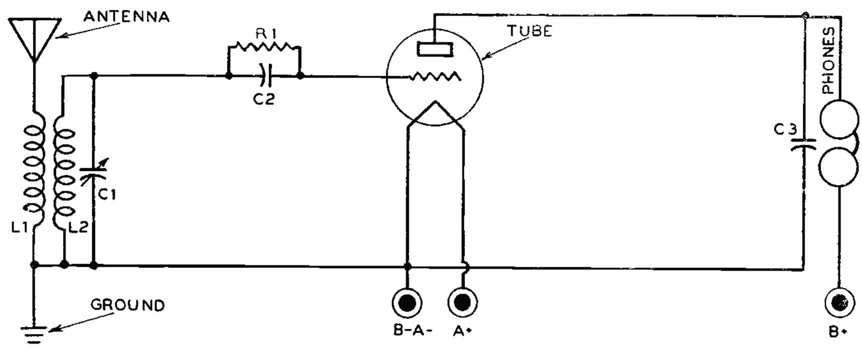


FIGURE 1

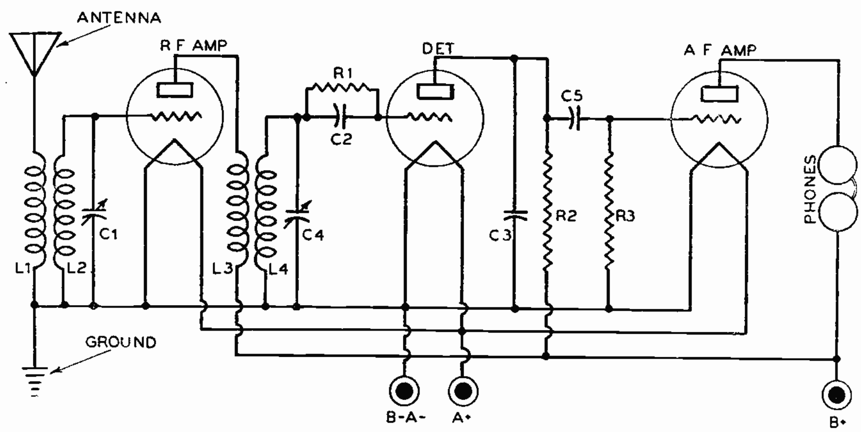


FIGURE 2

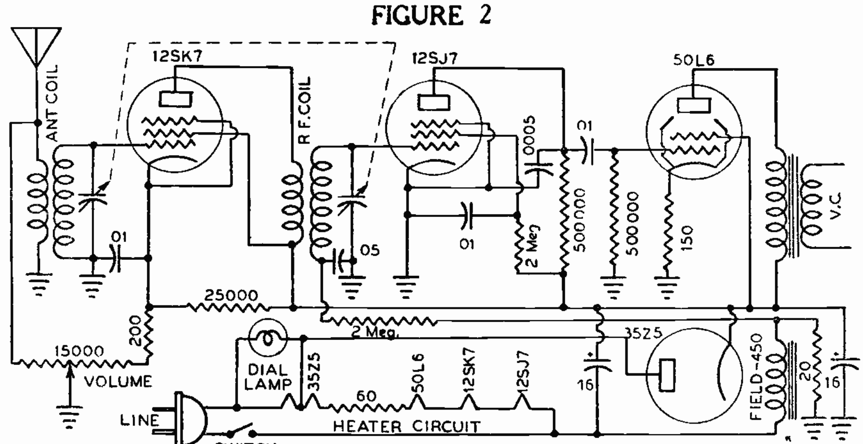
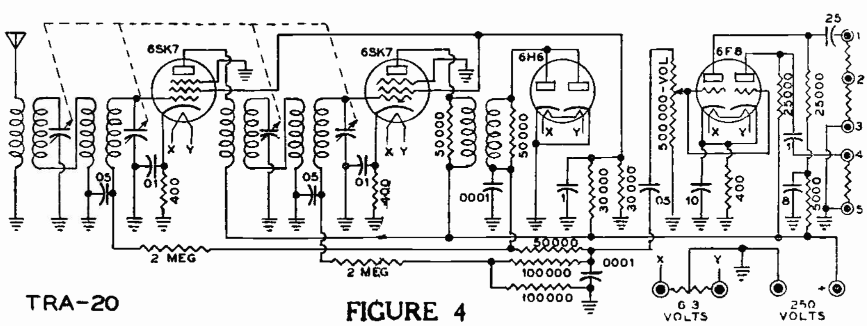


FIGURE 3



TRA-20

FIGURE 4

DE FOREST'S TRAINING, Inc.

LESSON RRT-1

SPEAKERS

* * Founded 1931 by * *

H. A. DeVRY

A PIONEER AND LEADER OF VISUAL EDUCATION

DE FOREST'S
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LESSON RRT-1
SPEAKERS

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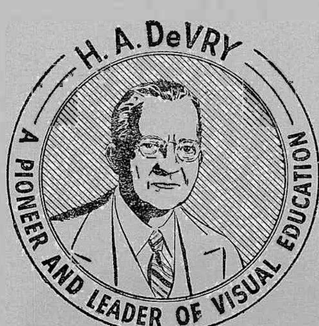


RADIO RECEPTION & TRANSMISSION

LESSON RRT - 1

SPEAKERS

* * * * * * *

Work is the true elixir of life. The busiest man is the happiest man. Excellence in any art or profession is attained only by hard and persistent work. Never believe that you are perfect. When a man imagines, even after years of striving, that he has attained perfection, his decline begins.

— Selected

SPEAKERS

We mentioned speakers and headphones in many of our earlier explanations, and gave you the basic principles of operation, but now want to offer greater detail as to the manner of converting audio electrical currents into sound waves. Sound is a disturbance in the air, or a series of air waves, and no matter how a speaker or headphone is constructed, it must change the electrical energy into acoustical energy which will produce sound waves of the same frequency.

A common method of construction is to arrange the speaker parts so that the variations of electric current set up a magnetic field of changing strength. The magnetic field acts on a piece of iron, causing it to move in the air and produce a sound wave disturbance which varies with the strength of the field.

Looking at the action in a different way, the electrical energy is changed to magnetic energy, which is then changed into mechanical energy or motion. These are the same changes which take place in an ordinary electric motor and therefore the mechanism of a speaker is often called a motor.

HEADPHONES

The earliest and simplest form of speaker was built on the same plan as the ordinary telephone receiver, shown in Figure 1-B, where we have first a strong permanent magnet made in the shape of a U or horse shoe. A small piece of iron, fastened to each of the poles of this magnet, forms the core of a coil of wire as shown by the cutaway section.

Going back to the Lessons on Magnets and Electromagnets, you will remember that current in a coil of wire sets up a magnetic field which is exactly the same as that of a permanent magnet. Here then, with current in the coils, there will be two magnetic fields, one produced by the U shaped magnet, and the other by the electromagnet. As it is impossible to establish two separate magnetic fields in the same space at the same time, these two will combine and form one field.

In the ordinary headphone, the field of the permanent magnet is much stronger than the field of the coils or electromagnets. Therefore, the flux produced by changing current in the coils will simply increase or decrease the total magnetic flux.

Forgetting the coils for a minute, the small pieces of iron extend the low reluctance path for the flux of the permanent magnet, and to complete the magnetic circuit, a metallic diaphragm is placed close to the ends of the iron core.

Tracing the magnetic circuit, we start at the N pole of the permanent magnet, go through the small piece of iron and across the air gap to the diaphragm. A path is provided by the diaphragm from which we pass across the lower air gap, and back through the other iron core to the S pole of the permanent magnet. Magnetic lines have the property of always trying to shorten, and therefore the diaphragm will be pulled in toward the small pieces of iron, and as long as the magnetic pull of the core remains constant, the thin metallic membrane will remain in a fixed position.

Now, if the electromagnets are connected in an electrical circuit and have current in them, they will also set up a flux which will have exactly the same magnetic circuit as that of the permanent magnet. According to the right hand rule, the polarity of the magnetic flux developed by the electromagnets will depend on the direction of current in each coil at that instant.

If the polarity of the electromagnet is the same as that of the permanent magnet, the total flux will be increased and the diaphragm pulled in further toward the small cores of iron. If the polarity of the electromagnet is opposite to that of the permanent magnet, as the result of a reversal of current in the coils, the total flux will be decreased, the pull on the diaphragm will be weakened, and it will move away from the iron cores.

When the coils are connected in an audio frequency circuit, the magnetic pull on the diaphragm will vary with the current changes in them and cause the metallic member to vibrate at the same frequency as the changes of current. These vibrations of the diaphragm cause a disturbance in the air and set up waves of pressure which give the sensation of sound in the human ear.

To increase the strength of the air waves, the diaphragm is partly covered with a cap of non-magnetic material which does not touch it, but leaves a small air space between, so that the vibrations of the diaphragm cause the air to be forced out the opening in the center of the cap with greater strength.

In order to save space, the parts of Figure 1-B are arranged as shown in Figure 1-A. The magnet is made circular in shape and laid flat in the back of the case. The small pieces of iron, mechanically attached to the permanent magnet, stand up at right angles and support the coils. The diaphragm is circular in shape and rests on the case at its outer edge, being held away from the extended iron cores to prevent the diaphragm from touching them even during normal operation of the headphone.

While the headphone of Figure 1 is really a speaker, it is usually classed separately because of its limited action. To be sensitive, the diaphragm must be place close to the cores but if a strong signal causes the thin membrane to touch them, there will be a rattle and the tone of the signals will be spoiled.

To cause louder sensations of sound, the diaphragm must be able to move greater distances and thus produce stronger air waves. Many different plans have been tried, but as the principles of practically all are alike, we will explain only the main types.

BALANCED ARMATURE

At Figure 2-A, we show a common form of the older balanced armature type speaker unit which uses the actions of Figure 1 in a different way. Again, we have the large permanent magnet, but this time the pole pieces, being soft iron extensions of the main pole, are made U shaped. A single coil is placed between the pole pieces and a small movable piece of iron called an armature, is used instead of the usual fixed core.

The path of the permanent magnet flux is from the magnet pole, through the pole piece to its ends, across the air gaps, through the ends of the armature and across the remaining air gaps to the other pole piece.

Perhaps you can follow the magnetic path better in Figure 2-B, where we show a view through the center of Figure 2-A. The pole piece fastened to the N pole of the permanent magnet is shown as N, while the end of the other pole piece is marked S.

The armature is supported at its center and held midway between the poles. Being made of iron it will be pulled toward any of the pole ends when a change of flux exists. An electric current in the coil will magnetize the armature, making

the upper end either N or S, depending on the direction of current.

Suppose the upper end of the armature is N, then the lower end will be S. From the earlier Lessons, you know unlike magnetic poles attract, therefore, under these conditions, the upper end of the armature will be pulled to the right in Figure 2-B, while the lower end will be pulled to the left.

This double pull action will rock the armature on its support and cause the drive pin to move. The drive pin is fastened to a diaphragm, which causes air disturbances, and thus the results are similar to those explained for Figure 1.

In the construction of a unit similar to Figure 2, the diaphragm can be made of any suitable material and of any size or shape because it is not in the magnetic field. The diaphragm or armature of Figure 1 had to be flexible in order to spring back and forth as the magnetic pull changed. In Figure 2, the armature can be made rigid and thus be better able to respond equally to all changes of magnetic flux caused by audio frequency currents in the coil.

Units of this type are no longer popular, but the principles involved are important enough to warrant a clear understanding of these actions. Continual improvement is being made in the design construction and efficiency of loudspeakers. Such changes are made with the thought of improving the tone quality, making the sounds more realistic.

CONE SPEAKERS

Being limited in size, the diaphragms of early designs of speakers could not produce sound waves equally well at all audio frequencies, especially those of the lower notes. To overcome this difficulty, the present magnetic speakers replace the diaphragm with cones of various sizes made of special paper or other composition. However, for larger installations, like those in theatres, ball parks and so on, speakers designed for "heavy duty" service are coupled to large horns in order to distribute the sound to desired areas.

To explain the action of a cone speaker, in Figure 3 we show a view of an early form of unit used for such a reproducer. The permanent magnet is a straight bar and forms the base. Mounted on the magnet, a bracket supports the armature, the outer end of which forms part of the coil core. The other

part of the coil core is fastened to the bar magnet, leaving a gap between it and the armature.

When the current in the coil is in a direction to increase the total flux, the air gap will shorten as a result of magnetic action, and thus the variations of current again cause the armature to move.

By means of the adjusting nuts, the bracket can be moved and thus the fixed length of the air gap is adjusted for best results. For weak signals, the gap is set quite close, but for the stronger signals, it must be widened. A drive pin, fastened to the outer end of the armature, carries the vibration out to the cone.

Checking back on these first three Figures, you will notice the principle of operation is the same in all. A change of current in the coil causes a change of magnetic flux which causes a diaphragm or armature to move. The differences are in the mechanical arrangement of the various parts. In the more improved designs of magnetic speakers, the use of high flux density magnetic materials, and shortening of magnetic paths, has resulted in a unit which, in operation, compares favorably with the smaller types of present day "dynamic" speakers.

From an electrical standpoint, speakers of the magnetic type are very simple, as they have but one circuit. The most common electrical trouble is more often due to an open circuit in the coils, and a simple continuity test between the speaker terminals, will quickly show if this fault is present.

BALANCED ARMATURE CONES

In the assembly of Figure 4, we have a balanced armature unit, on the general plan of Figure 2, but with two coils, on the order of Figure 1. By using a strong permanent magnet and making the coils of many turns of fine wire, a strong pull is produced. To maintain a strong magnetic field, the air gap between the armature and pole pieces must be short and thus, even with a strong pull, the motion of the armature is limited as to the distance it can move.

To increase the strength of the sound waves, the diaphragm, or cone, must have less restriction on its motion and an improvement in operation is secured by the arrangement of levers in Figure 4. The armature is supported and pivoted at the center of the coils, but being extended at the right, the movement of the outer end is increased.

The drive pin is fastened to the extended outer end of the armature and carries the motion to the thrust lever. As drawn in Figure 4, the thrust lever is supported at the left, and thus the movements of the drive pin are increased at its outer end. The drive rod connects between the outer end of the thrust lever and the cone, so that the armature movements, through "lever" arrangements, are made greater.

All the parts are fastened so that there is no lost motion and the cone responds to every movement of the armature. However, a small movement of the armature causes a greater movement of the cone and thus stronger air waves are produced, causing a greater volume of sound.

MECHANICAL ADJUSTMENT

While the electrical circuits of these speakers are very simple, the mechanical adjustments are more complicated. To respond to each small change of current, the armature must be held under tension. The permanent magnet maintains a pull on the armature and the tension on the supported speaker cone must be adjust to counterbalance this pull and permit the armature to be centered. In Figure 4, the effective length of the drive rod can be changed by shifting the position of the nuts on the threaded end at the thrust lever.

In Figure 5-A we show an enlargement of Figure 2-B with the armature in the proper position. Most speakers are protected from the high d-c plate voltage and carry only alternating current. For Figure 5-A, no matter which way the armature tips, it has a chance to move the maximum distance before striking a pole.

In Figure 5-B, the armature is set square with the poles but it is not in the center of the air gap. Here the short side of the gap will not permit the armature full motion in either direction.

The position of Figure 5-C is common when the parts have shifted slightly, after the speaker has been used for some time. As shown here, the armature could move quite a distance to the left at the top but has very little room to move to the right.

With the armature in position B or C of Figure 5, the speaker would operate to a certain extent on weak signal currents but would rattle if the strength of the coil currents were increased, as strong signals would cause the armature to strike the poles. While each make and model have their own particular methods of adjustment the idea is the same for all.

In general, the drive pin is loosened at the armature and, by means of paper, celluloid or thin metal wedges commonly called "shims", the armature is centered between the poles. Starting at the cone, all the nuts, screws or other joints are tightened to eliminate all chances for lost motion. The drive pin is then refastened to the armature, the shims removed and the air gap carefully measured again. The idea is to secure the position of Figure 5-A and it is important to check the gap after the shims are removed.

Very often there is a certain amount of spring in the drive pin, thrust lever or other parts, or fastening the drive pin will cause a strain that pulls the armature off center when the shims are taken out. In many models, the drive pin is soldered to the armature and can be loosened or refastened by a hot soldering iron with little chance of causing strain.

MAGNETIC SPEAKERS

So far, all the speakers we have explained are called "MAGNETIC" because the changing magnetism of a coil combines with the field of a permanent magnet and cause the diaphragm to vibrate. The idea can be simplified to the drawing of Figure 6-A. The armature is mounted near its center to allow pivot action and the varying pull of the magnet causes it to rock back and forth. The motion of the armature is carried over to the diaphragm through the drive pin.

No matter how the parts are arranged, the motion of the armature is limited by the length of the air gap between it and the magnet. To obtain a magnetic field of proper strength, the air gap must be quite short.

Forgetting the size of the parts, you will remember the strength of a magnetic field varies inversely as the square of the distance from the poles. Thus, if the air gap length were doubled, the strength of the flux would be reduced to approximately 1/4 of its former value.

INDUCTOR TYPE

In Figure 6-B, we have a different arrangement shown in the simplest possible form. The armature and drive pin are the same as before, but the position of the magnet is changed. When the strength of the flux increases, the armature will be drawn toward the center of the magnet but on account of their positions, the armature can never actually touch the magnet.

This is the plan used in the "INDUCTOR" type speakers and it allows for greater armature motion without danger of rattling. Notice also, the air gap can be kept as short as that of the magnetic type.

DYNAMIC SPEAKERS

At the present time, practically all audio amplifiers are equipped with dynamic speakers which produce much more natural tones than the other types. Here again, the motion of the diaphragm, or cone, is caused by magnetism but the arrangement of the parts is entirely different.

To show you the idea, in Figure 7 we have a simplified sketch of the general arrangement of an electro-dynamic speaker. Instead of a permanent magnet, there is a large electromagnet, the winding of which is called the field coil. This coil is wound on a large central core which extends around the outside of the coil. A cross section of the core looks like a capital E, except the upper and lower sections nearly close on the middle extension. Technically, an iron core of this shape is known as a ring magnet, and to see the reason for the name "ring", look ahead to Figure 13. The semicircular section is part of the ring magnet, the other portion being hidden by the light metal casing.

Going back to the field coil of Figure 7, an air gap is provided between the central core and outer parts of this frame so that, with current in the coil, there is a strong magnetic flux across the gap.

A second coil, with a small number of turns, is wound on a form and placed in the air gap. This is the "Voice Coil" which connects electrically to the output of the audio amplifier. The voice coil itself thus replaces the armature of the other types of speakers and therefore, you will also hear these called "Moving Coil" speakers. The voice coil moves like a piston under the action of separate magnetic fields, and like the arrangement of Figure 6-B, should never actually touch the field coil core.

The cone is fastened directly to the voice coil form, with the outer edge held securely in place by a clamping ring and fastened to the speaker housing or frame. The diameter of the cone will vary with speaker requirements, but the normal sizes are 2", 3", 4", 6", 8", 10", 12", 14", 15" and 18".

The mechanical motions of a dynamic speaker are simpler than the armature type as there are no levers or drive pins to adjust and no iron in the moving parts. As a result, the

motions of the cone follow the variations of voice coil current more closely and more natural tones are produced.

The purpose of the field coil is to develop a very strong magnetic flux in the air gap, making it possible to achieve a greater movement of the voice coil. In this way, the lower notes, which require more energy for the proper motion of the cone, are produced with the necessary volume.

To explain how it is possible to obtain greater motion of the cone by having a strong field flux, we can turn to a general law of physics. The force between two magnetic poles is directly proportional to the product of the respective charges amd inversely proportional to the square of the distance between them. Written as a general expression--

$$\text{Force} = \frac{\text{Charge No. 1} \times \text{Charge No. 2}}{\text{distance}^2}$$

If we let the strength of the "field" represent charge No. 1, the flux developed by the voice coil as charge No. 2, and the fixed linear separation between the two components as the average distance, then the greater we make either or both charges, and the shorter we can make their separation, the greater the force acting. As the voice coil assembly is the only moveable part, its motion will displace the air and create sound waves.

As we mentioned previously, modern speakers are designed to provide strong field fluxes. Likewise it is desirable to develop a strong flux as a result of audio frequency currents in the voice coil. Increasing the number of turns increases the mass of the moving coil and thus causes "sluggish" reproduction at high audio frequencies. The trend of improvement is toward the use of very light voice coils, some designs using aluminum wire having low resistance to the changes of signal currents.

Looking at Figure 7, we can assume the winding of the central core is connected to a suitable source of d-c, and that the direction of current is such as to make the right end of the core a N pole. At some instant let the current in the voice coil develop a S pole at the left end.

Again applying fundamental principles of magnetism, the attracting force will cause the voice coil assembly to move to the left. When the current in the voice coil is in the opposite direction, the polarity of the coil will reverse, and the repelling action of the fields cause the voice coil assembly to move to the right.

While we will go into more detail later in the training, we want to tell you here the field coil may receive its current from a separate supply. There are two general types of electro-dynamic speakers which have been and are now still in use.

One, called the d-c model, has its field coil designed to operate from d-c supply. The voltage drop across the field coil depends on its d-c resistance and the power required to set up the necessary amount of magnetic flux in the air gap in which its voice coil vibrates.

A second type is the a-c model, and is the same as the d-c unit except that it requires a rectifier and suitable filter. While most units are operated directly from the conventional 110 - 120 volt a-c line, a few higher wattage units include a transformer.

The arrangement of the field supply is identical to the power supply and filter of the usual a-c operated receiver or amplifier, and for reasons of economy, the speaker field coil is often connected in the supply circuit to serve as the "choke" of the filter system.

Although quite well filtered, the choke current usually has small pulsations which are known as a "Ripple". As the speaker field and voice coils are both in the same magnetic circuit, they can be thought of as the primary and secondary windings of a transformer, as far as varying field current is concerned.

With a ripple in the field current, a ripple voltage will be induced in the voice coil, and as it is part of a closed circuit, the ripple voltage will cause current. Thus, the voice coil will vibrate at the frequency of the ripple voltage and cause an undesirable hum. If the rectifier is a half wave unit, the hum frequency will be 60 cycles. If a full wave rectifier is used, the frequency of the hum will be 120 cycles.

To overcome this undesirable hum reproduction, many speakers incorporate a third winding which contains the same number of turns as the voice coil, and is connected in series with it. However, it is placed on the core so that its induced voltage will be 180° out of phase with that induced in the voice coil. In this way, the ripple voltage is neutralized and the hum from this source is reduced. Because of its purpose, this third winding is known as a "Hum Buckling Coil".

These arrangements for supplying the energy for field coils are made to suit various types of amplifiers, but have noth-

ing to do with the amplifier itself. Like the permanent magnets of the magnetic and inductor types, the field coil here must produce a strong, steady magnetic flux, and therefore the coil must be supplied with direct current. The difference in the types is therefore only the difference in the source of electricity for the field winding.

Because its motions are quite fast, the voice coil assembly must be made as light as possible. If it were heavy, it would require more pull to stop and start it, therefore, it could not respond quickly to the changes of current. To keep the coil light in weight, it must have but few turns of wire, yet it must set up a magnetic flux of good strength.

Magnetic flux, you will remember, is measured in ampere-turns therefore, with but few turns on the voice coil, the amount of current must be large. In the Lesson on transformers, we told you the secondary output, in watts, was always a little less than the primary output. Therefore, when the secondary voltage was higher than that of the primary, the current would be lower.

In the same way, when the secondary voltage is lower than the primary voltage, the secondary current is larger than the primary current. We want to make use of this feature of a step down transformer and thus the voice coil of the speaker is connected across the secondary winding.

The primary of this step down transformer connects in the plate circuit of the last audio tubes and thus the magnitude of the changes of plate current are increased in the voice coil. We have already explained the circuits of an output transformer and the connections here are the same. In order to fulfill the conditions just explained, a dynamic speaker requires the correct type of transformer and will not operate properly with just any transformer unit.

In our explanations of audio amplifiers we told you why the unit in the plate circuit required a high resistance or impedance. The headphone of Figure 1, designed for use in the plate circuit, had many turns of fine wire and had a d-c resistance of from 2000 to 4000 ohms. The variations of plate current in the coils connected in the plate circuit induced a large emf and thus the impedance of the coils is many times the value of the d-c resistance. For this reason all the magnetic and inductor types of reproducers are often identified as "HIGH IMPEDANCE" units.

The dynamic type of speaker with its voice coil of but a few turns of wire has a low resistance and would be called a "LOW IMPEDANCE" unit, the voice coil circuits usually having an impedance between 2 and 16 ohms.

The field winding of the dynamic speaker has a comparatively high resistance because it is usually wound with many turns of fine wire. But being supplied with direct current there is no impedance to consider. However, certain types of d-c models of electro-dynamic speakers used in automobile and other 6-12 volt radio or electronic equipment, have low d-c resistances in order that the current be of such value as to give the proper power and magnetic flux. The types designed for 6-12 volt d-c, or 110-120 volt a-c are constructed to give best results at those voltages.

The other d-c types, in which the field coil is used also as a filter choke coil, usually has the coil resistance plainly marked on the unit, and the common values are 1000 and 2500 ohms. The wattage required for the necessary field excitation is also given in the specifications of each particular model, but this requirement will vary, depending on the power output of the speaker.

For example, suppose you have an electro dynamic speaker with a 2500 ohm field which requires 5 watts for proper excitation and you want to connect it in the "B" supply as a filter choke. Using the power formula $P = I^2R$, and transposing it to $I = \sqrt{P/R}$ you can find the necessary current. Substituting the numerical values, $I = \sqrt{5/2500} = \sqrt{.002}$, which is approximately 44.7 milliamperes. By Ohm's Law, the voltage drop across the field must be .0447 x 2500 or 111.75 volts. The B supply must be able to furnish this extra voltage and power in addition to that required by the tube circuits.

In general, the field coil power dissipation should be approximately equal to the maximum audio frequency power expended in the voice coil winding.

SPEAKER CIRCUITS

To help you follow these various methods of supplying the speaker field with direct current, Figures 8, 9, 10 and 11 show practical circuits.

In Figure 8 we show the final audio tube of a receiver with the primary of the output transformer in series with the plate circuit. The voice coil of the dynamic speaker is connected across the transformer secondary.

The voice coil is always connected as the load on the output stage and is independent of the speaker field circuit connections. Usually a transformer or other arrangement is installed for proper impedance match, and sometimes the output unit is mounted on the chassis, but the circuits remain the same. When the last audio stage of the amplifier has two tubes in push pull, the output transformer primary is connected as explained in a former Lesson. The secondary of the output transformer and voice coil however, still have the circuits of Figure 8. For the speaker field, we show only the ends of the circuit which connect to the d-c supply.

DYNAMIC FIELD SUPPLY

The usual a-c dynamic speakers have two general methods of rectifying a-c current. One type uses a dry plate rectifier while the other uses a rectifier tube.

In Figure 9 we show the circuits of the dry plate rectifier type, but here again, there are two common arrangements. For example, suppose the speaker field is designed to operate at 6-8 volts d-c. By means of a step down transformer the a-c potential of the house lighting circuits is reduced to a low value. Then, following the circuits of Figure 9, this low voltage a-c is rectified before reaching the field coil circuit.

To follow the action, notice the direction of current through the rectifier is as shown by the arrows. No matter what the direction of a-c in the supply, the left end of the field coil of Figure 9 will always be positive with respect to the center segment of the dry plate rectifier.

Even though the rectifier operates on both valves of the a-c cycle and is of the full wave type, there will be some variations of current which will cause a hum. To reduce this hum, a large capacity, low voltage condenser of from about 2000 mfd to 4000 mfd is connected across the field winding as shown.

Other models use the same general circuits but the field winding is designed for about 100 volts and the rectifier input is connected directly across the 110-120 volt a-c supply circuit. For this type, a condenser of much smaller capacity can be used because the current variations will be lower in magnitude. The large capacity condensers mentioned above are made only for low voltages, usually 8 volts, and thus cannot be used in circuits where the potential is greater than the working voltage of the condenser.

The second main type of supply is used with a high voltage field winding and the circuits of Figure 10 illustrate a typical arrangement. Here we show a transformer with two secondaries, both of which are center tapped to provide "common return" points. The circuits are about the same as those explained earlier in the training, therefore we will not go into detail again here.

In explaining the power supplies, we showed a filter made up of choke coils and condensers. We have the same circuits here in Figure 11, but the field winding of the dynamic speaker acts also as one of the choke coils. You will find this quite a common plan in many Radio and other Electronic units.

The speaker field coil may be in either the positive or negative side of the circuit. You may even encounter the terms "positive leg" and "negative leg", but this really means the speaker field winding will be connected in series with the highest positive part of the circuit if it is stated as being in the "+" leg. For the speaker field to be in the "-" leg means the total "B" current passes through the necessary tubes and other circuits before passing through the field coil, one side of which connects to the most "-" part of the d-c circuit. Figures 10 and 11 show the field coil in the "+" side of the d-c circuit.

P-M SPEAKERS

As the operation of a loudspeaker does not depend on the manner of obtaining a strong magnetic field flux, recently developed magnetic alloys have made it possible to dispense with the field coil and achieve comparable results using these Permanent Magnet dynamics, more commonly abbreviated "p-m" speakers.

Most of the early types of permanent magnets were made of tempered high carbon steel, but it was found that tungsten steel not only produced a stronger flux, but had a longer life. Colbalt steel magnets and non-ferric alloy magnets, such as Alnico "5" have come into use because they can be magnetized even more strongly than those of tungsten steel.

Looking ahead to Figure 15 you will see a cross sectional view of a p-m speaker, and as the fundamental parts are associated in the same way, the basic action is like that of the speaker of Figure 7. The sketch of Figure 15 shows the "E" shaped magnetic path, but because the permanent magnet has sufficient magnetism for proper operation, no electromagnetic excitation is necessary.

As Figure 15 illustrates the "ring" magnet type of p-m, other designs make use of the same principle except the core is replaced with a "slug" magnet of the proper strength. The outer shell or case then is made of lighter iron material and merely provides a magnetic path to the air gap.

As far a tone quality and frequency response are concerned, the electro-dynamic and p-m speakers are very nearly identical, comparing similar sizes. The larger sizes of p-m's cost more than the equivalent dynamic. For remote placement of speakers, the p-m has the advantage of requiring but two conductors from the audio amplifier.

CENTERING DYNAMIC SPEAKER CONES

Mechanically, it is necessary that the voice coil be concentrically located in the gap of the magnetic circuit at the end of the pole piece.

Air gap clearances must be close for best results and it is desirable to maintain maximum magnetic energy in the gap. However, it is also necessary that the voice coil "ride free" in the space provided. If grit or dust gets into the gap, free motion of the voice coil is no longer attained. Similarly, the voice coil cannot rub on the poles or core and provide good sound reproduction. The latter condition is commonly due to warped voice coil forms, and not only causes losses of power because of the friction between the parts, but also causes distortion. Such off-center operation is apparent in the sound by rasps and rattles.

The common plan of centering the voice coil is shown in Figure 12 where we are looking into the center of the cone. A centering spring, commonly called a "Spider", is fastened to the voice coil form at its outer edge. The spring is then fastened to the center of the core, holding the coil in position.

Being flexible, the spring allows the voice coil to move in and out freely with the changes of current, but will not allow a side-way movement. When the voice coil slips out of position here, it is necessary only to loosen the screw at the center of the spider and place three shims between the coil and core, spaced equally around the core.

These shims can be made of cardboard, celluloid or flexible sheet metal, but must be of such equal thickness that all three will fit tightly. After the shims are in place, the center screw is tightened and the shims removed.

For Figure 13, we show an a-c dynamic speaker chassis and here you can see the dry plate rectifier, cone and output transformer, whereas the field winding and voice coil are inside the main housing. The speaker would be connected in the output circuit as shown in Figure 8, with the a-c cord plugged into a suitable alternating current supply.

BAFFLES

When speakers are used without a horn, the forward movement of the cone compresses the air in front of it. At the same time an area of low air pressure is created behind the cone. As the high pressure area in front of the cone moves forward and spreads out as a sound wave, the surrounding air moves in to fill the area of low pressure behind the cone.

On the next alternation of the audio signal current, the cone will be pulled back and the conditions mentioned above will be reversed.

The speed of sound is generally considered to be approximately 1125 feet per second, at ordinary room temperatures, and at low frequencies, the high pressure area on one side of the cone has time to pass around and help equalize the low pressure area on the other side. Thus, instead of travelling away from the cone as a sound wave, the high pressure area simply slips around the cone to fill in the low pressure area on the other side.

At higher frequencies, the movement of the cone is so fast that the high pressure area on one side does not have time to pass around to the other side before the cone moves and forms a second high pressure area or wave. Thus the high frequency sound waves are heard at a distance from the speaker but the low frequency waves, moving from side to side of the cone to equalize the air pressure, are not properly heard.

To overcome this condition, it is necessary to increase the distance from the front to the rear of the cone so that the low frequency waves will not be able to travel from front to back before the cone moves. This is usually accomplished by mounting the speaker on a flat board which has an opening the size of the cone. High pressure areas caused by the forward movement of the cone must pass around the edges of the board in order to reach the rear of the cone. Instead of a flat board, the same results are secured by placing the speaker in a cabinet or console, and regardless of its shape the material used for this purpose is called a "Baffle".

Thus the primary function of the baffle is to acoustically "load" the speaker to allow it to radiate sound waves more efficiently. In the true sense of the word, the loudspeaker element without the baffle is not a "speaker" because the baffle is part of the acoustical system. Likewise, the baffle structure should not vibrate like a "soundingboard" but rather be rigid and without resonant effects. When the baffle is in the shape of a horn, it serves as a conduit for directing the sound waves.

It has been found that satisfactory speaker reproduction is obtained when the size of the baffle is equal to $\frac{1}{4}$ the wavelength of the lowest frequency desired. A baffle is measured from the center of the speaker opening, around the shortest way and back to the center. Thus, for a circular baffle, the radius would be equal to $\frac{1}{2}$ of the quarter wavelength. However, the diameter is equal to twice the radius which makes the diameter equal to $\frac{1}{4}$ the wavelength.

Although most baffles are either square or rectangular, it is the shortest distance which is measured and thus the sides of a square or the shorter sides of a rectangle should be equal to $\frac{1}{4}$ the wavelength of the low frequency cut off, measured from the center of the core to the closest edge of the baffle.

In Figure 14, we have plotted a curve of frequency in cycles against the baffle size in inches. In other words, the frequency is the lowest which can be reproduced by a baffle of a given size. For example, to reproduce a frequency of 112 cycles, the curve shows a 30 inch baffle is needed , while to reproduce down to 32 cycles, the baffle must be 104 inches.

Since the early days of reproducing sound by electro-mechanical means, steady improvement in the quality of reproducers has been made. It can be understood that no matter how good the electrical circuits of the audio amplifier, if the speaker assembly is inferior, the reproduction will be poor. As the listening public is getting more and more "sound conscious", efforts have been made to improve the audio frequency range of speakers.

BASS REFLEX PRINCIPLE

One effective method of extending the bass response and reducing cabinet resonance is to make use of the back wave of the moving cone such that it adds in phase to the frontal wave moving forward from the face of the cone.

In Figure 16, we show the front and sectional views of a typical Bass Reflex speaker, which operates on this principle and in comparatively small space, provides reproduction similar to that of a speaker mounted on an extremely large flat baffle.

In Figure 16-B, you will note the placement of sound absorbing material and want to tell you that its purpose is to partially absorb the cabinet resonant frequencies which are above the frequency desired to be accentuated. For example, suppose the approximate low frequency cut off of the baffle is 80 cycles. The dimensions of the speaker are then chosen to cause the cabinet to resonate at a frequency about an octave lower than 80 cycles, and in operation, as a result of resonance, the standing waves will reinforce the waves moving out from the front of the speaker.

The action can be shown a little more clearly by the sound wave motion of Figure 16-B. The solid semicircles, moving away from the cone, represent the frontal wave. Similarly, the solid circles, moving to the back plate of the cabinet represent the waves which are 180° out of phase with the frontal waves. If the dimension "D" is of the proper length and the port area is in the correct position, the reflected waves shown by dotted half circles will build up a standing wave and be in the correct phase relationship to add to, or reinforce, the frontal wave.

The overall action is to extend the bass response and to partially eliminate the cabinet resonant effects that very often occur in open back cabinet baffles.

Another method of improving the bass response is to place the speaker driving unit in an enclosed cabinet and then cut suitable slits, usually in the back, for the escape of the back wave. Some enclosures are made air tight and the inside is lined with absorption material. The stiffness due to air compression in the enclosure acts to aid in radiation of lower frequencies.

DISTRIBUTION ANGLES

You may have noticed the difference in the quality of sound emitted from a given speaker at different angles with respect to the axis of the cone. For example, in Figure 17, a listener at L_1 would not hear the same quality of sound as that of a listener at L_2. The reason for this is because high frequency waves, about 3000 cycles, seem to travel in narrow beams at an angle of about 20° with the axis of the cone. The

listener at L_1 then would hear predominately the lower and middle frequencies.

The angle of radiation of "beam like" distribution at high frequency widens out as the frequency decreases. However, as it is the higher frequencies in speech and music which give understandability and brilliance, it is desirable to diffuse or conduct the higher notes to all parts of the listening area.

To accomplish uniform distribution of sound at all frequencies, several methods are used, and one is diagramically shown by Figure 18. Here in the top view at A and side view at B, we show vanes which, if you visualize Figure 18-A replacing Figure 17, will cause the high frequency radiation to be spread. Therefore, with the vane diffusers, listeners at L_1 and L_2 will hear very nearly the same proportion of high and low frequencies.

Figure 18 shows spreading of the high frequencies only in the horizontal plane. Normally this is sufficient for room reproduction of audio programs, but should a greater spread or distribution be desired, vanes can be placed horizontally to provide vertical distribution. Figure 19-A illustrates the double vane idea carried a little further in that the vanes now take the shape of a multicellular horn. Loudspeakers of this type are primarily for use in Public Address installations such as theaters, skating rinks, churches, etc.

In order to achieve 360° sound distribution, the plan of Figure 19-B can be used. The entire unit is suspended from a suitable support and because of the shape of the upper and lower deflecting plates, sound waves will spread, as indicated by the arrows, in a 360° radiation angle with the vertical axis of the speaker assembly. The driving unit is contained in a suitable metallic housing which in turn is attached to the polished deflecting plates.

TWO WAY SYSTEMS

In an earlier part of this Lesson, we indicated the use of the bass reflex principle to increase the bass response of a speaker and although not mentioned previously, we show a high frequency unit in the cabinet enclosure of Figure 16.

It has been found that a single cone speaker does not adequately cover the extended frequency range desirable in high quality reproductions. If frequencies from about 40 to 15,000 cycles are desired, this can best be accomplished by using two separate

speakers - one a "woofer" for low frequencies; and a "tweeter" for high frequencies, to provide a two way system. The woofer can then be constructed to best radiate low notes and the requirement is a rather large cone area and heavy voice coil in order to develop the necessary power. For high frequencies the cone area can be small and the voice coil can be light to move more rapidly and with smaller power requirement.

The object of the two way system, is to provide suitable and uniform frequency response as well as power handling capacity over the desired range of reproduction.

To direct the electrical currents of high and low audio frequencies into their respective channels, a filter system is needed. Although we will go into greater detail on the subject of filters and "cross over" networks in a later assignment, we want to point out the basic principles which are not difficult to follow.

It is desirable that the high frequency speaker receive its correct range of frequencies, and in the circuit of Figure 20, condenser C_1 together with coil L_1 form a "High Pass" filter. Condenser C_1 passes the higher notes readily because at higher frequencies the reactance of the condenser is low. L_1 "chokes" the high frequencies and forces them through the low reactance path of C_1 and the high frequency speaker voice coil. The low audio notes will readily pass through coil L_1, and through the low frequency speaker voice coil, back to the other side of the input circuit. Condenser C_2 tends to bypass any high frequencies that get into the low frequency channel, whereas L_2 tends to bypass any low frequencies that get into the high frequency network.

One model of a two way speaker system uses the plan of supporting the high frequency speaker in the cone cavity of the large speaker. For example, imagine the high frequency unit of Figure 16-B properly supported in the large cone area of the speaker just below. Such a method simplifies cabinet construction and, at the same time, provides some sound distribution.

Another two way speaker design system provides for the mounting of the high frequency unit on the rear of the woofer cone driver, and the high frequency sound is fed through a passage in the center of the woofer pole assembly. In effect, this passage is a horn, and is allowed to expand for proper distribution of the sound waves.

EFFICIENCY

Very little has been said about the efficiency of a speaker. That is, the conversion of electrical power to acoustical energy. It is very difficult to obtain the necessary data for determining speaker efficiencies, and such calculation is usually performed only by the manufacturers in the research laboratories. However, we want to give you an idea of the relative capabilities of different speakers, and it may surprise you to learn that loudspeakers are not very efficient. The efficiency of a loudspeaker may be defined as the ratio of the useful power output (acoustical) to the electrical input (watts) expressed as a percentage.

There are many factors which tend to govern the efficiency of a speaker, one being the flux density in the air gap of the magnetic circuit. Other factors to be considered are the mass and electrical characteristics of the voice coil, the mass and area of the diaphragm.

Of the above mentioned, the most important is the flux density of the air gap. Earlier in the Lesson we explained the requirement of a strong field flux for the proper operation of the voice coil assembly, and the greater the force acting to move the voice coil under a given set of conditions, the greater the resultant motion of air waves. You can now see why air gaps are made as short as possible, and why improved materials for securing stronger fluxes will increase the conversion of electrical power to acoustical energy.

To give you some idea of the relative efficiencies of some speakers and radiators, note the table below. These figures are general deductions based on the use of a 400 cycle test note which approximates the most predominate frequencies in musical reproductions.

SPEAKER TYPE	EFFICIENCY
Small Cabinet	5 to 10%
Large Baffle	5 to 10%
Directional Baffle	7 to 20%
Projection (Horn)	10 to 30%

The projector or horn type speaker is the most efficient yet naturally enough, there will be continued improvement in the design of loudspeakers. However, from the explanations offered you can readily understand the basic principles involved in all reproducers.

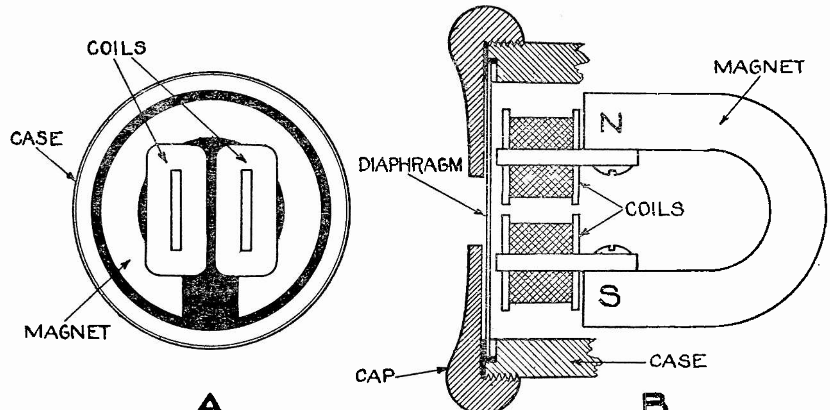


FIGURE 1

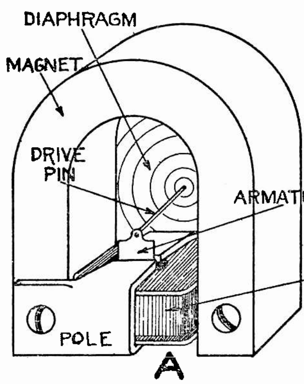


FIGURE 2

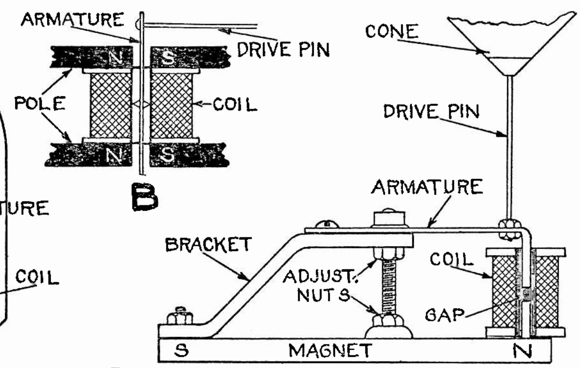


FIGURE 3

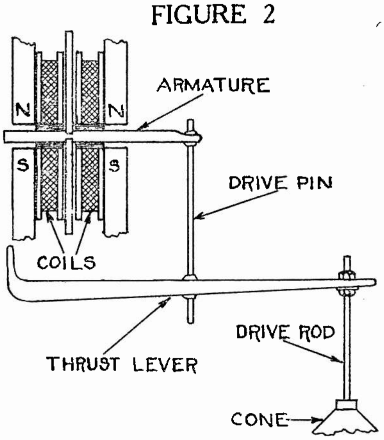


FIGURE 4

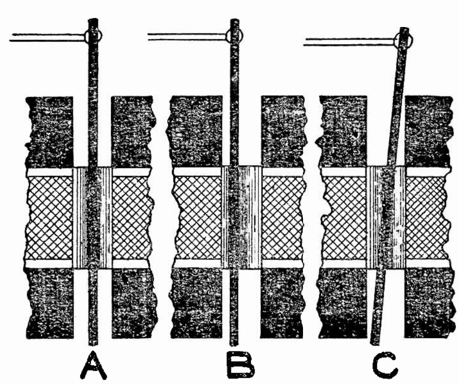
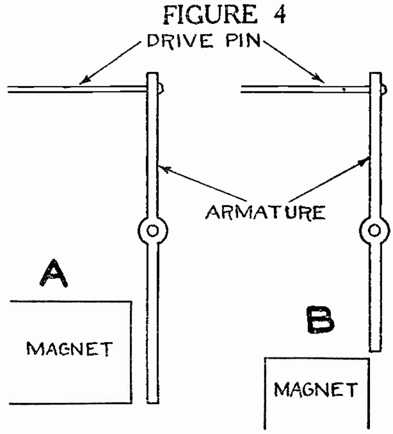


FIGURE 5



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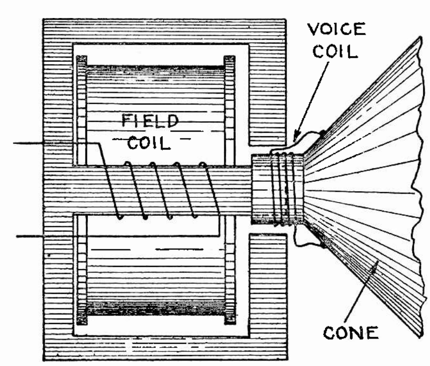

FIGURE 7

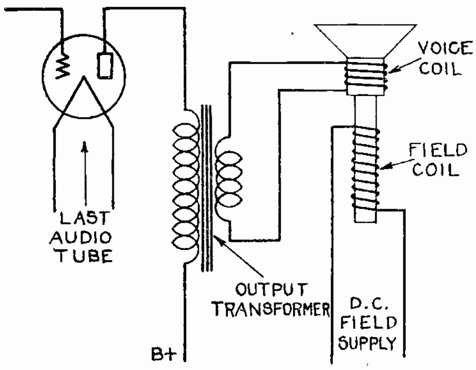

FIGURE 8

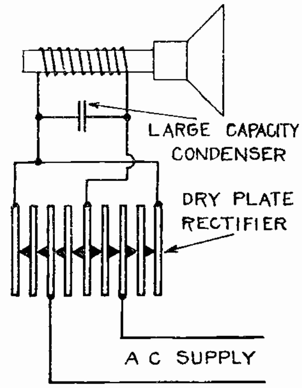

FIGURE 9

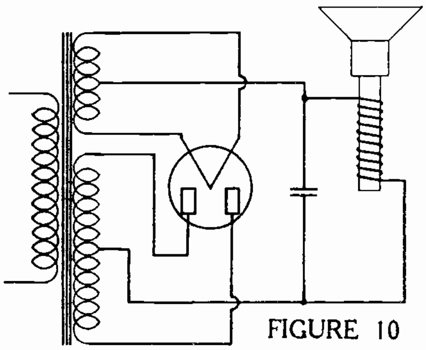

FIGURE 10

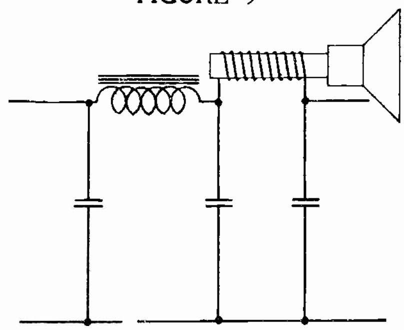

FIGURE 11

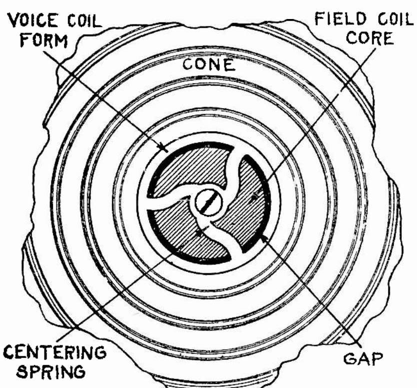

FIGURE 12

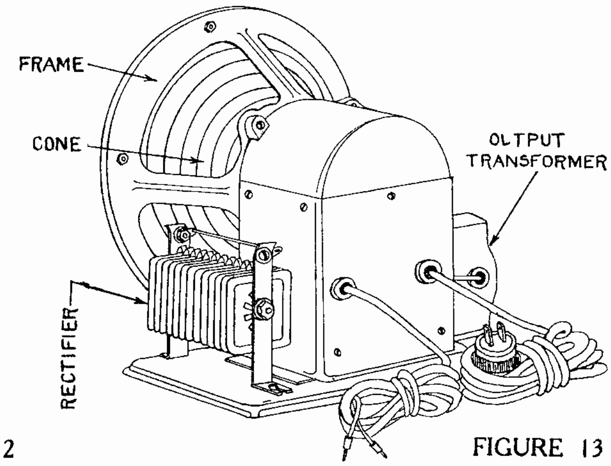

FIGURE 13

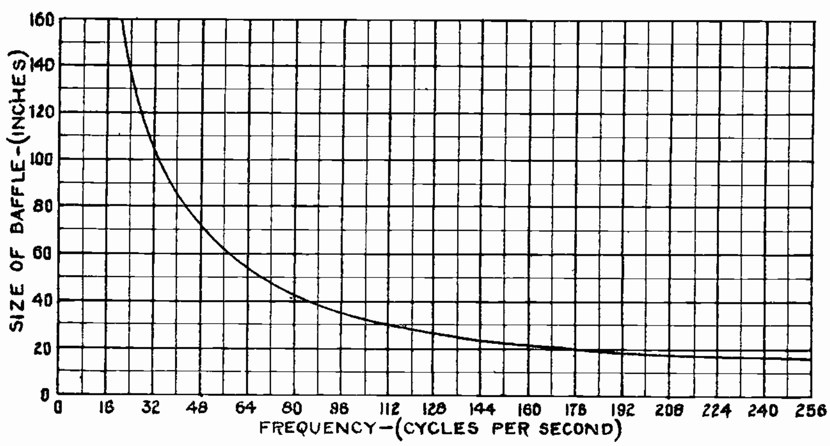

FIGURE 14

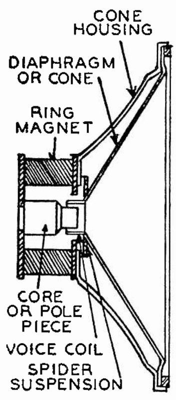

FIGURE 15

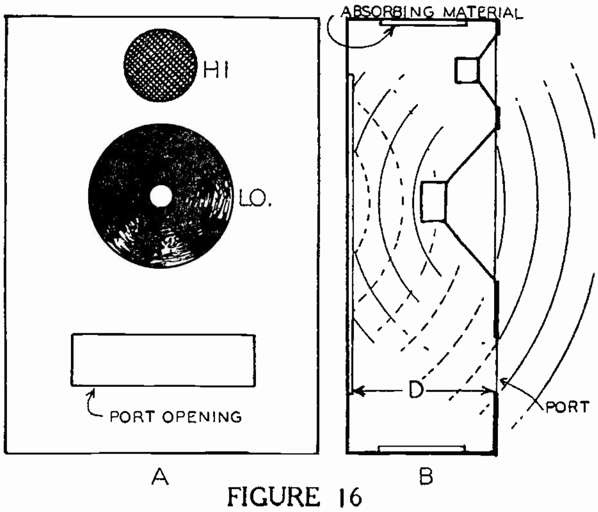

FIGURE 16

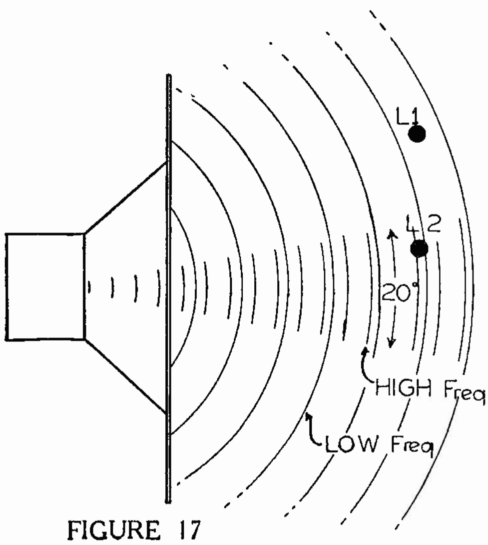

FIGURE 17

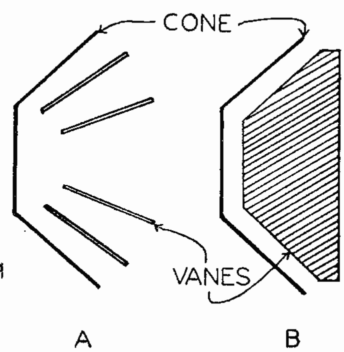

FIGURE 18

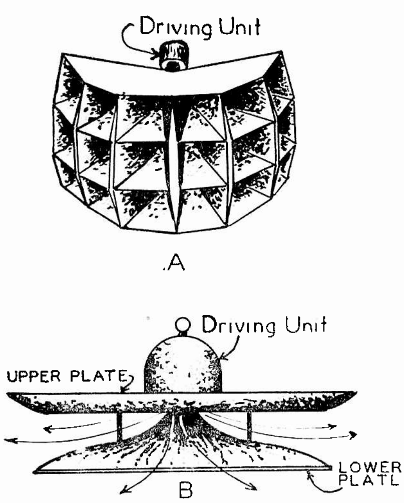

FIGURE 19

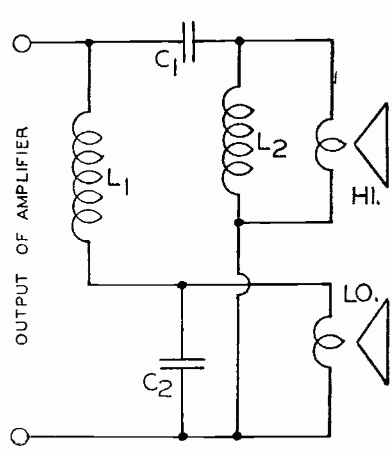

FIGURE 20

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LESSON RRT-2
PHONO-PICKUPS

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A PIONEER AND LEADER OF VISUAL EDUCATION

RADIO - RECEPTION & TRANSMISSION

LESSON RRT-2

PHONOGRAPH PICKUPS

* * * * * * *

The law of worthy life is fundamentally the law of strife. It is only through labor and painful effort, by grim energy and resolute courage, that we move on to better things.

-- Theodore Roosevelt

PHONOGRAPH PICKUPS

In earlier Lessons, we have explained how it is possible to transmit sound by radio carrier waves and in this assignment, we are going to show you how it is possible to reproduce sound from a phonograph record. The "heart" of such a system is the unit which changes mechanical energy to electrical energy and it is known as a "pickup". In fact, a "pickup" is nothing but a form of an electric generator and in this Lesson we are going to explain exactly how it operates.

From your earlier Lessons, you will remember that to produce electrical energy by mechanical means, it is necessary that an electrical conductor cut through, or be cut by, magnetic lines of force. In other words, the generator operates on the principles of electro-magnetic induction.

The part which sets up the magnetic flux is called the field and the part in which the emf is induced is the armature. For most of the smaller sizes of commercial generators, the armature is the moving part.

GENERAL CONSTRUCTION

To show you how these principles are worked out, in Figure 1 we have the main parts of the magnetic pickup assembly. The magnetic flux, or field, is produced by the U shaped permanent magnet and to concentrate the lines of force, soft iron pole pieces are placed between the magnet poles.

The armature is centered between the pole pieces and mounted on a pivot with the needle attached at the lower end of the extended shaft. The variations of the record groove cause the needle to vibrate from left to right in Figure 1, and thus we have an armature which moves in a magnetic field.

A coil of wire is placed around the armature, although not fastened to it, thus completing the necessary parts of an electric generator. The construction is much different from the commercial types of generators with revolving armatures and the output voltage of a pickup is extremely small in comparison. However, the vibration of the armature does produce sufficient emf for the operation of associated audio frequency amplifiers.

PHONOGRAPH RECORDS

Before going ahead with the detailed explanation of the operation of a pickup, it is necessary that you know something about the records themselves.

In Figure 2, we show an enlarged view of a small section of a disk record which is cut with a series of fine grooves in the form of a spiral. Really there is one continuous groove which starts at the outer edge of the playing surface. Cutting through the disk you would see something on the order of Figure 2-B where we show the groove as a triangular slot. At A, Figure 2, we are looking down on the top of the record and show the groove by the heavy black lines.

If we place the needle of Figure 1 in the outer or right-hand groove of Figure 2-A and start the record moving in the direction of the "Record" arrow, the spiral form of the groove will keep forcing the needle toward the center in the direction of the "Needle" arrow. While following the groove, the variations will cause the needle to move sideways, or laterally, and the armature will vibrate between the pole pieces.

From our former explanations, the movement of the armature will induce an emf in the coil, the frequency and strength of which will depend on the size and shape of the variations of the groove.

When the record is made from the original program, the needle which cuts the groove is operated by sound waves and thus the lateral vibrations are really a record of the sounds. The vibrations of the needle of Figure 1 therefore induce an emf with the same frequency as that of the sound waves which operated the cutting needle.

OPERATION OF MAGNETIC PICKUP

Going back to Figure 1, you will notice the armature is supported on a pivot near the lower end, while at the upper end, it passes through a piece of rubber which holds it midway between the poles. The flux of the permanent magnet leaves the N pole, passes through the iron pole pieces, across the left air gaps through the sections of the armature opposite the pole pieces, the right air gaps and the other pair of pole pieces to the S magnetic pole.

The point we want to bring out here is that, with the armature in the center of the air gap, the magnetic flux will divide equally, half of it passing through the upper pair of poles and half through the lower pair of poles. Except for those parts opposite to the poles, there will be no magnetic flux in the armature.

Studying the action in a different way, and thinking of that part of the armature actually in the center of the coil as the

core, under the conditions just explained, there will be no magnetic flux in the core of the coil. As all the flux passes straight across the space between the pole pieces, there will be practically no magnetic lines through the turns of wire which make up the winding of the coil.

When the needle is moved to the right by a variation of the record groove, as shown in Figure 3, the upper end of the armature will move towards the upper N pole piece. From the Lesson on Magnets and Magnetism, you will remember that iron has a much lower reluctance than air, and moving the needle to the right reduces the left air gap, thereby reducing the reluctance of the magnetic circuit.

The reduced reluctance will permit some of the magnetic lines to pass from the N pole of the permanent magnet, through the upper pole piece, across the shortened gap to the lower S pole piece and on to the S pole of the magnet. The number of magnetic lines passing through the armature will depend on the distance the needle is moved to the right at a given instant and the further it is moved, the greater number of lines which will cut the coil.

Some of the magnetic lines will not be inside the armature and, in the following a path from the upper left to the lower right pole pieces, a portion of the total flux will cut through the turns of the coil winding. Going back to the early Lessons again, you will remember that when a wire cuts through, or is cut, by magnetic lines, an emf is induced in the wire.

With the armature properly centered there are no magnetic lines passing through it and hence no lines can pass through the coil. When the armature is moved, the magnetic lines travel across the body of the shaft, some of them cut through the coil and therefore an emf is induced inthe winding, also some of the magnetic lines follow the path of the lower reluctance and travel down through the armature, as shown by the arrows.

In the same way, when the needle is moved in the other direction by the next alternation of the recorded wave, the armature takes the position shown in Figure 4. Here the air gap between the armature and the upper end of the S pole piece has been shortened and some of the magnetic lines passing from the N to S pole of the magnet travel up through the armature.

Following this action, you can see the variations of a wave which has been cut in the record groove will cause like variations of magnetic flux through the armature. In other words,

that part of the armature between the arms of the poles is the core of the coil and the changing flux in the core will induce an emf of like frequency in the turns of the winding. Thus, the recorded variations are changed to electrical energy.

You will also notice, the further the armature moves, the larger the number of magnetic lines it will carry because the air gap between it and the pole pieces is shorter. The emf induced in the coil is proportional to the rate of change in the armature flux and when the needle is moved by a recorded wave of large amplitude, a relatively large emf is induced.

Checking these actions closely, the armature motion induces an emf of the same frequency as the frequency of the recorded wave, and the resultant voltage will have a value proportional to the amplitude of the waves in the record groove. The pickup therefore changes the mechanical motion of the needle, caused by the variations in the record groove, into electrical energy of equal frequency and proportional amplitude.

MAGNETS

In addition to the movement of the armature, the electrical action depends on the magnetic flux which is set up by the magnet, and for satisfactory operation the flux must be of proper strength and remain constant. While the actual dimensions of the magnetic circuit have an effect on the flux, and vary for different makes and models after the unit has been designed and assembled, the magnet must maintain the proper strength, and for all practical purposes, it is a PERMANENT magnet.

The voltage generated in the pickup is controlled not only by the change of magnetic flux in the armature, but also by the number of turns in the coil. Regardless of the coil design, the stronger the flux of the permanent magnet, the more sensitive the pickup. Of course, this is true only up to the point of magnetic saturation of the moving armature, as this condition does not permit changes of flux proportional to the vibrations caused by the moving needle point.

You already know the opposition offered to the passage of magnetic flux lines is called reluctance and its value varies greatly with different materials. For example, in the magnetic circuit of Figure 1, starting at the N pole, there is a low reluctance path through the soft iron pole piece. The air gaps between the pole piece and armature have an extremely high reluctance, whereas the armature has a low re-

luctance. The S pole piece and the material of the magnet have low reluctance, therefore,with the exception of the air gaps, there is little opposition to the flux in the parts assembly of a phonograph pickup.

In order that the armature have unrestricted movement, the air gaps must be quite large and thus the strong cobalt steel and Alnico magnets are in general use.

There are a great many factors which enter into the design of the magnetic circuit and we have given you this explanation to emphasize the importance of maintaining the original adjustments of a pickup. For example, if the air gaps should be widened, the total flux would be cut down, the sensitivity of the pickup would be reduced and the impedance of the coil would be changed.

DAMPING

From our former explanation you may have the idea that a pickup is a perfect generator but unfortunately such is not the case. The armature is made rather light in weight, and has the mechanical characteristics of a vibrating reed. It will then have a natural resonant frequency depending on its mass and dimensions.

When the record causes the armature to vibrate at or near its resonant frequency, its motion increases and the amplitude of the induced emf is also increased. Thus certain frequencies of the record will be reproduced with more than the proper volume.

To hold the armature vibrations more closely to those imparted to the needle, various mechanical dampers are used. In Figure 1, 3 and 4, for example, the upper rubber bearing of the armature acts as a damper and helps to prevent any armature motion except that caused directly by the movement of the needle.

In order to see this action more clearly, think of the armature pivot and needle as a simple vibrator. The displacement of the upper end of the armature from a fixed position will depend on the distance between it and the pivot. Thus, with the pivot below the pole pieces, as in Figure 1, the upper end of the armature will have a greater movement than the needle. In other words, there is a leverage which mechanically amplifies the vibrations of the needle.

Being placed at the end of the long armature, the rubber bearing has the maximum damping effect. Remember here, while the object of the damper is to cut down the resonant frequencies, it also reduces the amplitude of vibration for all frequencies of the armature and tends to reduce the voltage output of the unit.

TYPES OF NEEDLES

Checking back over Figures 1, 3 and 4 of this Lesson, you will notice the needle is always clamped tightly to the armature and thus becomes a part of the vibrating unit. What we said about the stiffening effect of the damper will thus apply to the needle as well.

There are many different types of phonograph needles of various sizes and shapes, but the most common are made in three distinct types. First, a fairly large and stiff steel needle called a "Loud Tone". Second, a smaller and more flexible steel needle called a "Soft Tone" or "Half Tone". Third, a still more flexible "Fibre Needle".

To show you the effect of these various types of needles on the output voltage of the pickup, we have drawn the curves of Figure 5. The scale across the bottom represents the frequencies while that at the left shows the relative generated voltage when the needle is used with a given pickup assembly.

Starting with curve No. 1, which represents the output with a new loud tone steel needle, you will find there is a little over 1 volt produced at a frequency of 50 cycles. This value remains constant, as the frequency increases, up to about 4000 cycles and then drops rapidly, falling to zero at about 7800 cyles.

Curve 2 shows the voltage generated when a worn loud tone steel needle is used. At low frequencies the voltage is the same as for a new needle, but at about 2000 cycles, the worn point, being larger, fails to completely follow the recorded waves. This causes the voltage to drop off rapidly for all frequencies above 2000 cycles.

The soft tone needle, being more flexible, absorbs some of the vibrations of the needle point and thus cuts down the movement of the armature. The result is shown in Curve 3, which at 50 cycles causes the pickup to develop a little over .9 volts.

Following this curve, you will find it maintains a uniform value from 50 to about 1000 cycles. The damping action of the needle prevents the higher frequencies from producing the full movement of the armature and thus the generated voltage drops off at frequencies above 1000, falling to zero at about 4500 cycles.

The fibre needle, being still more flexible than the soft tone steel needle, has a greater damping effect and produces the voltage variation shown by curve 4. The action here is the same as for curve 3 but the effect is more pronounced, producing a lower voltage for the lower frequencies and cutting off more of the high frequencies.

Although not shown in Figure 5, a worn soft tone steel or worn fibre needle will produce a change of voltage similar to that between curves 1 and 2 and a careful study of these curves will show you why, for good reproduction, it is necessary to use a needle which is in good condition.

Another thing we want to mention here is the pressure on the needle point. If the point is circular, its area is approximately .000007 of a square inch. With the pickup exerting a downward pressure of but one ounce on the point of the needle, the pressure would be over 8900 lbs. to square inch.

As the ordinary pickup needle pressure is more than one ounce, you can imagine the conditions under which the needle operates. However, some pressure is needed to hold the needle in the groove and the grinding action between the record and needle, increases the area of the point and thus reduces the pressure per square inch on the record.

The needle, or rather the needle point, is thus one of the most important parts of the complete pickup as it has a great effect on the quality of reproduction and wear of the record. We want to emphasize these facts because, being small and inexpensive, the importance of the pickup needle is likely to be overlooked.

There are three general factors to consider in the selection of a "playback" needle. First, the needle must be of the correct shape to fit the needle holder of the vibrating armature which at the same time will permit the needle point to match perfectly with the record groove. Second, the needle point should have and retain a high polish to prevent scoring or damaging the walls of the groove. Third, it must be long wearing, capable of retaining its manufactured shape.

In general, the final choice of a needle must be a compromise among the factors mentioned above and permissible record wear, as well as the desired quality or reproduction of the selection.

Steel needles usually give the greatest volume, and generally should not be used for more than one record play. As explained for Figure 5, standard types give the greatest high frequency response but since needle scratch frequency and hiss are in the upper audio frequency register, these noises are more predominate.

Chrome plated needles are very similar in character to the standard steel needles except that they have longer playing life. These needles usually give twenty-five to fifty plays, depending on the pickup pressure.

The "flexible" needles are usually made of bamboo, cactus thorns, etc., and are used primarily to reduce the high frequency responce, noise and record wear. These needles are not suitable for record changer type players.

Metal alloy points are polished to a high degree and therefore decrease record wear as the friction between the point and record is reduced. Popular needles of the alloyed point may be used from about 1000 to 5000 plays, and are suitable for record changers.

The Sapphire or "jewel" needles have correspondingly longer life and compare favorably with the alloy tips. Care should be exercised in handling to prevent dropping, as the point is apt to chip or break. Changing the position of the needle in the holder is not recommended as record damage may result. These needles are satisfactory for changers and wide range reproduction systems.

FREQUENCY RESPONSE

For Figure 5 we drew smooth curves to show the relative effect of the different types of needles. For the complete pickup unit however, we have to consider the needle, armature coils, magnets and all the other parts which enter into the changing of the variations of the record groove into sound.

With this in mind, we have drawn the curve of Figure 6 where the bottom scale again represents frequency but the left hand scale represents the relative volume of the reproduced sound.

Starting with a relative value of about 5 at 45 cycles, you will notice the curve is not smooth but drops irregularly to

a value of $3\frac{1}{2}$ at 700 cycles. Then the curve rises rapidly to a peak at about 1500 cycles but drops off even more rapidly to a value of less than $3\frac{1}{2}$ at 2000 cycles.

This hump in the curve is called a "Resonance Peak" and is the resonant frequency of the vibrating part of the pickup. Following the curve again, you will see a smaller "Peak" around 3500 cycles after which it drops rapidly to zero at about 6000 cycles.

Using a pickup of this kind, frequencies around 1500 cycles would be produced with excess volume and spoil the proper reproduction of the record. That is why you will find the various dampers placed around the armature because their action is to cut down these peaks and produce a more uniform volume for the entire range of frequencies.

At this point, we want to emphasize the importance of a chart which indicates the frequency response of a device. While Figure 6 was used to explain that changes of frequency gave rather irregular variations in relative volume for a pickup, similar data can be shown for loudspeakers, audio amplifiers and microphones. In general, an ideal frequency response curve would be one which is relatively "Flat" over the full range of operation. Such a curve would represent "uniform" output without "resonant" effects over the desired range.

CRYSTAL PICKUP

The pickup we have been explaining in the early part of this Lesson operates on the principle of electro-magnetic induction and is therefore commonly called a "Magnetic Pickup". There is another type which operates on an entirely different principle and is called a "Crystal Pickup".

It has been found by experimentation that several crystalline materials, such as quartz, tourmaline and rochelle salt have the property of producing an emf when the crystal is mechanically strained. Furthermore, the action is reversible, so that when an electric charge is properly impressed on the crystal, it changes its shape. This remarkable characteristic is called the "piezo-electric effect" and is present in all so-called piezo-electric materials to a greater or less degree, dependent upon the form in which it is cut, and the manner in which the electric field is impressed.

In Figures 7 and 8, we show two views of a common type of crystal pickup which utilizes a piezo-electric crystal ele-

ment to convert the mechanical motion of the needle to electrical energy. By carefully analyzing Figures 7 and 8, you will see that the crystal is supported by two conductors, insulated from each other, and when the needle vibrates, there will be a strain on the crystal. Then, because of its piezo-electric properties, there will be a difference of potential between the two terminals, which will vary with the amount of mechanical strain.

As this pickup operates by virtue of the piezo-electric ability of the crystal, its output is not subject to the effect of mechanical inertia. This characteristic gives it the name "astatic" which means the pickup, as a body, is in neutral equilibrium and therefore has no tendency toward a change in position with its consequent effect on electrical output. Due to this feature, the frequency response is unusually uniform and without objectionable peaks over a range extending from 30 to 8000 cycles.

Although the voltage outputs of crystals vary considerably, the average output of a crystal pickup is slightly over 2 volts when using a 500,000 ohm load.

PICKUP IMPEDANCE

In our earlier explanations we told you that the coil of a magnetic pickup was made up of a large number of turns of wire. Now we can add that these coils may be wound to most any desired impedance. The impedance will vary with the inductance, distributed capacity and d-c resistance of the winding. Those coils which have a comparatively high inductance are known as "high impedance" pickups, while those with a low inductance are referred to as "low impedance" pickups. The piezo-electric pickups are of the "high impedance" type.

The advantage of low impedance pickups is that they can be used at comparatively great distances from an amplifier without severe attenuation of the high frequencies due to the capacity shunting effect of the transmission line. The advantage of the high impedance type is that it can be connected directly across the grid of a tube without the use of a transformer.

PICKUP CIRCUITS

Throughout the explanations of this Lesson we have told you that the voltage output of a pickup was in proportion to the vibrations of the needle, which in turn depended on the variations of sound on the record, and that it could be amplified the same as any other audio frequency voltages. In Figure 9

we show the usual input connections of a low impedance magnetic pickup coupled to the grid of an amplifier tube.

Due to the low impedance of the pickup, it is necessary to use a transformer to match both the impedance of the pickup and that of the grid circuit in order to get the maximum voltage transfer. In an early Lesson, we told you that the relation between the number of turns on the primary and secondary of a transformer is known as the "turn ratio". Writing this as an equation, we have

$$N = \frac{N_s}{N_p} \qquad (1)$$

Where

N = turn ratio
N_p = turns on the primary
N_s = turns on the secondary

We also explained that the primary and secondary voltages of a perfect transformer were in proportion to the turns ratio. Therefore, we can write,

$$N = \frac{E_s}{E_p} \qquad (2)$$

Where

N = turns ratio
E_p = primary voltage
E_s = secondary voltage

Analyzing the above equation, we can say that the greatest voltage across the secondary will appear when a very high turn ratio is used. This is true when no current or power is taken from the secondary. However, a certain amount of power is always consumed and under these conditions, the maximum voltage across the secondary will be obtained when the square of the turn ratio is equal to the ratio of the primary and secondary impedances. Written as an equation,

$$N^2 = \frac{Z_s}{Z_p} \qquad (3)$$

Where

N = turn ratio
Z_s = secondary impedance
Z_p = primary impedance

Although the above equation is on the assumption of a perfect transformer, its complete derivation is rather involved and, for the time being, we will ask you to take our word for its correctness.

To show you a practical application of equation (3) we will assume that it is necessary to find the turn ratio when the pickup of Figure 9 has an impedance of 100 ohms while it is desired to have a grid impedance of 100,000 ohms. Substituting in equation (3), the proper turn ratio would be

$$N^2 = \frac{100,000}{100} = 1000$$

$$N = \sqrt{1000} = 31.6$$

A transformer used for this purpose is called an "impedance matching transformer" and you will find them commonly employed in all types of Radio and other Electronic equipment.

Getting back to the action of Figure 9, the voltage output of the pickup will cause current in the primary of the transformer and a voltage will be induced in the secondary. As the grid circuit of the tube is connected across the secondary, the variations of voltage will be impressed on it, which in turn will cause variations of plate current at the same frequency as the voltage output of the pickup. These variations of current are then carried through other stages of amplification until the signal is brought to the desired level to operate a speaker.

In Figure 10, we have the circuit connections of a high impedance pickup. Although the symbol shown is for a crystal type, a high impedance magnetic pickup could connect in the same way. The voltage output of the pickup is impressed across the potentiometer, R, and because the grid is connected to the movable contact, various values of pickup voltage, from zero to full potential, can be applied to the control grid element. In other words, the potentiometer, R, acts as a volume control, but the tube action is exactly the same as explained for Figure 9.

The circuits of Figure 11 show the second detector and audio system of a conventional type of Radio-Phonograph combination. The change from Radio to Phonograph is made by a double throw, single pole switch shown at the lower left of Figure 11. When the switch arm is in the upper position, the audio signal is obtained from the Radio circuits, and when the arm is in the lower position, the audio signal is furnished by the Phonograph Pickup.

Although the input circuits of Figures 9 and 10 show triode tubes, it is quite common to use pentode types. All you need remember however, is that the control grid circuit is the input and the plate circuit the output, with the other tube elements being employed only to improve the overall efficiency of the stage. In other words, if a pentode were used in Figure 10, the suppressor grid would be connected to the cathode and the screen grid tied to a suitable source of d-c, the other elements remaining as shown.

SCRATCH FILTERS

Earlier in this Lesson, we told you that by following the variations in the record groove, the needle of a pickup caused the armature to vibrate in a magnetic field and induce a voltage of the same frequencies as the recorded sound. However, due to the texture of the material of which the record is made, other undesirable frequencies are generated and manifest themselves in the speaker as an obnoxious high frequency "hiss" or scratch.

To overcome these undesirable frequencies, a "scratch filter" is often employed and generally placed directly across the output of the pickup, as in Figure 12, where we show a filter made up of L, C and R.

From your earlier Lessons, you will remember that a series resonant circuit has the characteristic of minimum impedance and maximum current at the resonant frequency. In other words, with no d-c resistance, and the reactance of the inductance and capacity equal, the total impedance would be zero.

Looking at Figure 12, let's assume that the variable resistor R is set so that its resistance is negligible and that the values of L and C are such that the circuit is resonant at 5000 cycles. Now, suppose the needle vibrates at a frequency of 5000 cycles. Under these conditions, the series circuit of L and C form a "short" across the output of the pickup and therefore, no voltage will be available at the grid of the tube.

In other words, the frequency response of a pickup, using a scratch filter, will have a "dip" at its resonant frequency. This "dip" can be controlled, to a certain extent, by adding a variable resistance in series as shown by R of Figure 12. You can easily see that by varying the value of R, the effect of the scratch filter can be controlled. The rheostat R thus controls the amount of attenuation at the frequency to which L and C are resonated.

It has been found that the "scratch" frequencies predominate around 3700 cycles and, to find the values of L and C, it is only necessary to make use of the formula for resonance which is given in an earlier Lesson as,

$$f = \frac{1}{2\pi\sqrt{LC}}$$

Where

f = frequency in cycles
π = 3.1416
L - inductance in henries
C = capacity in farads

Solving for LC, we first divide both sides of the equation by f.

$$\frac{f}{f} = \frac{1}{2\pi f\sqrt{LC}} \quad \text{or} \quad 1 = \frac{1}{2\pi f\sqrt{LC}}$$

Multiplying both sides of the equation by $\sqrt{LC}$,

$$1 \times \sqrt{LC} = \frac{\sqrt{LC} \times 1}{2\pi f\sqrt{LC}} \quad \text{or} \quad \sqrt{LC} = \frac{1}{2\pi f}$$

Squaring the equation to remove the square root sign,

$$(\sqrt{LC})^2 = (\frac{1}{2\pi f})^2 \quad \text{or} \quad LC = \frac{1}{4\pi^2 f^2}$$

Thus,

$$L = \frac{1}{4\pi^2 f^2 C} \quad \text{and}$$

$$C = \frac{1}{4\pi^2 f^2 L}$$

From the above equations, you can see that it is necessary to assume a value for either L or C in order to find the value of the other component. In a circuit of this type, the values of L and C are frequently chosen to resonate at a frequency of approximately 5000 cycles. Suppose we have a 100 millihenry coil coil and desire to resonate it at 5000 cycles. The correct capacity would be,

$$C = \frac{1}{4\pi^2 f^2 L} = \frac{1}{4 \times (3.14)^2 \times (5000)^2 \times .1}$$

$$C = \frac{1}{4 \times 9.86 \times 25000000 \times .1} = \frac{1}{98600000}$$

$$C = .0000000101 \text{ farad} = .0101 \text{ Mfd.}$$

The values of the condensers used in ordinary Radio and other Electronic work are not calibrated to very close tolerances, and the above value of C could be assumed as .01 Mfd. Therefore, with a 100 millihenry coil and a capacity of .01 Mfd., the circuit would resonate at approximately 5000 cycles. As R is variable, its value is not critical and will depend on the amount of attenuation desired.

PHONO OSCILLATOR

In order to utilize a radio receiver for the reproduction of phonograph records, it is customary to connect the output of the pickup into the circuits of the detector or first audio stage on the general plan of Figure 11. By means of switches, circuits like those of Figures 9 and 10 are established and the pickup output voltages, amplified by the a-f stages of the receiver, are reproduced by the speaker.

Many of the smaller models of radio receivers do not include sufficient audio amplification to provide satisfactory phonograph signal levels therefore, circuits on the general plan of Figure 13 have been developed to utilize the sensitivity of the complete receiver. These circuits operate as a miniature Broadcast station and permit the phonograph signals to be tuned in the same as regular programs without special connections or changes is the receiver circuits.

To understnad the action here, we want to refer you to the description of the Regenerative Detector given in the earlier Simple Radio Receivers Lesson. There we explained the condition of oscillation when sufficient energy was fed back from the plate circuit to the grid circuit. Also, it will be of benefit to review the explanation of the Pentagrid Converter given in the former Modern Tubes Lesson.

In the circuits of Figure 13, coil L1 and variable condenser C2 are of such values as to form a parallel circuit which will resonate at frequencies of the Broadcast band. This circuit is connected between grid 1 and ground. Grid 2, called an anode because it operates as a plate, connects to the "B" of the plate supply through coil L2 which is inductively coupled to coil L1. Cathode resistor R2, with its by-pass condenser C1, is the common arrangement for providing a negative grid bias voltage.

When the power is turned on, the surge of anode current, carried by coil L2, induces an emf in coil L1, and the resulting voltage drop across it not only charges condenser C2 but impresses a positive potential on Grid 1. This positive potential tends to cause a further increase of anode current which in turn will cause a higher positive potential on Grid 1.

This action continues until a condition of anode saturation is reached and there can be no further increase of current. With no change of anode current in coil L2, there is no induced emf in coil L1, therefore, condenser C2 discharges through the coil, reducing the positive potential on Grid 1 which in turn causes the anode current to decrease.

Decreasing anode current in coil L2 induces an emf in coil L1 but now, the resulting voltage causes grid 1 to become more negative, in respect to the cathode, and reduce the anode current still further. This action continues until the anode current is reduced to zero, the induced emf dies out and condenser C2 discharges to reduce the negative grid potential. As the grid becomes less negative, the anode current increases and the entire action is repeated.

As the voltage across the tuned circuit, L1-C2, is impressed on Grid 1, its control over the anode current causes the induction to occur at the proper instants to maintain the oscillating or circulating current. The speed, or frequency of the changes is controlled by the values of L1 and C2 in the tuned circuit.

Some of the electrons, emitted by the cathode, are attracted by the screen grid and pass through the anode and screen grid to reach the positive plate. However, the action of Grid 1 will cause a variation of this electron stream at the frequency controlled by the tuned circuit L1-C2. As a result, the plate current carried by coil L3 will vary at the frequency of the oscillator.

Forgetting the oscillator circuits for a moment, the plate, grids 3, 4 and 5 and the cathode resemble the arrangement of an amplifier tube with Grid 4 connected to the input circuit acting as the control. With a pickup connected across resistor R1, its output voltage will be impressed on the control grid circuit in the usual manner. Thus, the variations of pickup output voltage will cause corresponding changes of plate current.

However, the plate current is already varying at the oscillator frequency therefore, the action of Grid 4 will be to vary the amplitude of these variations to produce a modulated carrier as explained in the earlier Radio Principles Lesson. Carried by coil L3, the variations of plate current will cause corresponding changes of voltage in inductively coupled coil L4 so that the variations of voltage across the "ANT" and "GND" terminals of Figure 13 will be essentially the same as the modulated carrier transmitted by a Broadcast Station.

As all radiation at radio frequencies is under strict control of the Federal Communications Commission (F.C.C.), certain rules have been set up to permit the operation of this type of curcuit without violation of existing laws. The maximum legal radiation distance can be calculated by the formula,

$$\text{Distance} = \frac{157{,}000}{\text{kc}} \text{ ft.}$$

For example, if condenser C2 of Figure 13 was set to produce an oscillator frequency of 600 kc, substituting in the formula,

$$\text{Distance} = \frac{157{,}000}{600} - 261 \text{ ft.}$$

Thus, operating under these conditions, the antenna connected to the antenna terminal and the power output of the circuit must be adjusted so that the signals can not be picked up or cause interference in receivers located more than 261 ft. distant. For normal use, the receiver will seldom be located more than 25 or 30 feet from the oscillator and therefore the rule does not interfere with the intended purpose of the unit.

To place the arrangement in operation, a short piece of wire is connected to the antenna terminal and the phonograph pick-up is connected across the input circuit. The radio receiver is then tuned to a frequency at which no Broadcast signals are heard, preferably near the lower frequency end of the band. With both the receiver and phono-oscillator in operation, condenser C2 of Figure 13 is then adjusted until the phonograph signals are heard in the speaker of the receiver. After this has been done, no further adjustments are necessary and the phonograph can be tuned in like any Broadcast station.

By replacing the pickup with a microphone, speech or music, picked up by the microphone, will be amplified and heard in the speaker of the receiver. This plan is followed at times to utilize an available radio receiver as a Public Address amplifier.

EQUALIZERS

In an audio frequency amplifier for use in record reproduction, there are several ways in which the adjustments of electrical networks can be made to give tone quality to suit the individual listener. Although most of these circuit vairations come under the heading of "Tone Controls", which will be explained later, simple additions to the input circuits of a crystal pickup may alter the characteristics sufficiently to

give satisfactory results. These simple electrical networks are sometimes called "equalizers" because they change or balance the operation of some unit for desired performance.

Crystal pickups are high impedance units and thus should be connected across a high resistance load. In Figure 10, if R is decreased from an optimum value of 500,000 ohms, the low frequency response of the crystal decreases, while increasing its value increases the response of the low notes. For best results the value should be kept between 250,000 and 1,000,000 ohms.

A crystal pickup circuit may be further equalized to suit individual tastes by dividing the resistive load and using a condenser as shown by Figure 14. The purpose of the condenser C is to provide a low reactance path for the higher audio frequencies, and its value is usually between 50 and 500 mmfd. Resistor R_1 may be between 1 and 5 megohms whereas, R_2 is usually .5 megohms.

In Figure 15, we show a modified form of the circuit of Figure 14 indicating a switching arrangement whereby the high and low frequency response can be varied independently. Switch No. 1 is to control the low frequency response and Switch No. 2 adjusts the high end. Typical values for the circuit of Figure 15 are: R_1 = 2 megohms, R_2 = .25 megohms, R_3 = 1. megohm, R_4 = .5 megohm, C_1 = 50 mmfd., and C_2 = 500 mmfd.

PICKUP DESIGN TRENDS

As is true with practically everything we use, some improvement could be made to increase its usefulness or efficiency. Likewise, phonograph pickups are constantly being improved, and one arrangement is to mechanically attach the vibrating needle to a vane which is placed in the magnetic field of an oscillator coil. In brief then, this vibrating vane will vary the electrical constants of the circuit and change the amplitude of the oscillations according to the audio vibrations of the needle. The output of the oscillator, generating high radio frequencies much the same as the "wireless phono" oscillator described by Figure 13, must then be detected and fed to an audio channel where the action is the same as we have explained for audio circuits.

Another pickup design, developed by RCA, is called the Vibratron. Before offering a brief explanation of the unit, it may be well to mention that some detrimental effect in a receiver or amplifier may put to good advantage in other devices.

For example, in some of the early types of vacuum tubes, the electrode construction was such that a jar or mechanical vibration of the tube would cause a change in the linear distance between the various electrodes. Jarring the tube while in operation would cause the elements to vibrate and thus, in effect, control the strength of the plate current at the frequency of the vibrations. Being audio frequency in nature, this would cause a "howl" in the speaker. Tubes having an action of this kind were called "Microphonic".

In the Vibratron pickup, the needle is mechanically coupled to the plate of a tiny triode vacuum tube. The extended electrode of plate then acts as a lever arrangement and audio variations of the needle will cause corresponding changes in distance between the plate and cathode. Thus the plate current in the output circuit will vary at these audio frequencies, and can be amplified and fed to a speaker in the conventional manner.

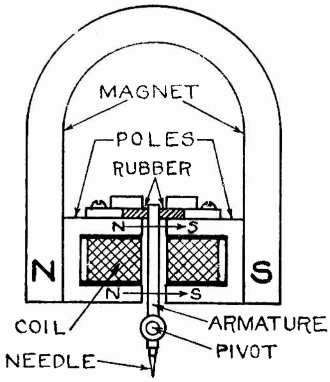


FIGURE 1

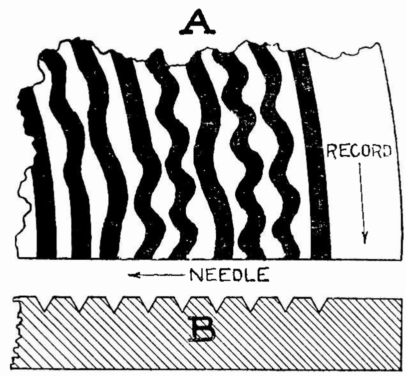


FIGURE 2

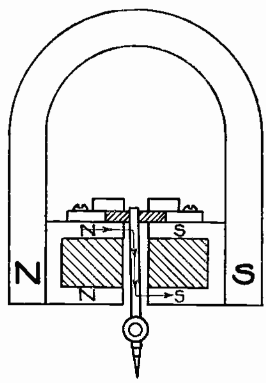


FIGURE 3

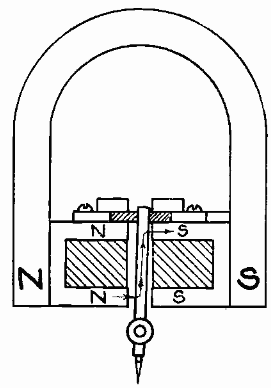


FIGURE 4

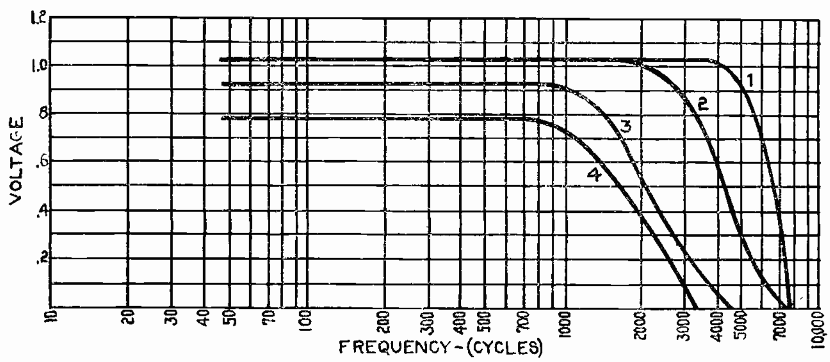


FIGURE 5

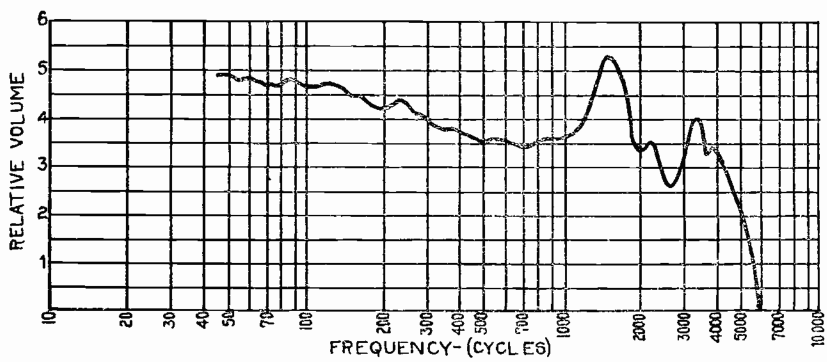


FIGURE 6

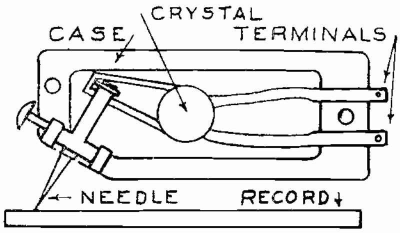


FIGURE 7

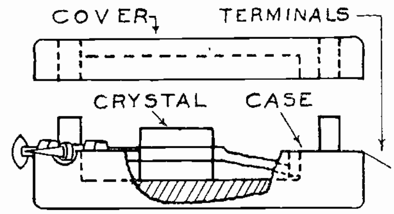


FIGURE 8

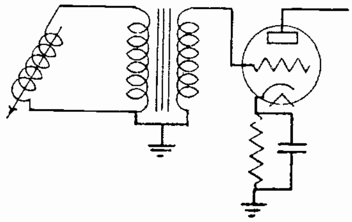


FIGURE 9

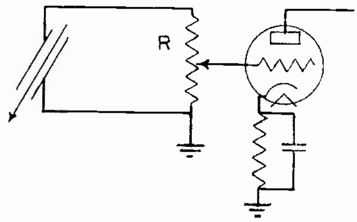


FIGURE 10

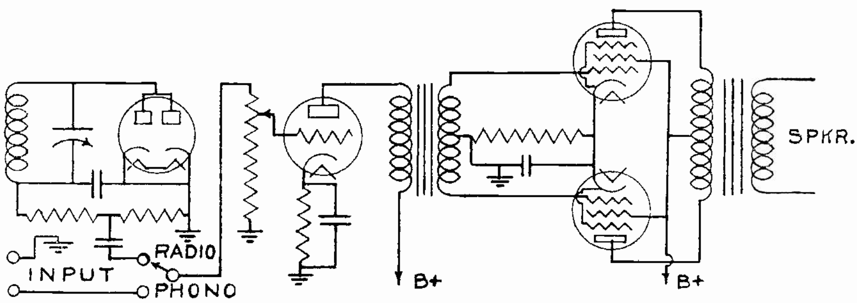


FIGURE 11

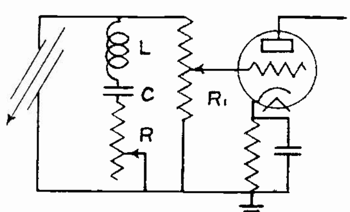


FIGURE 12

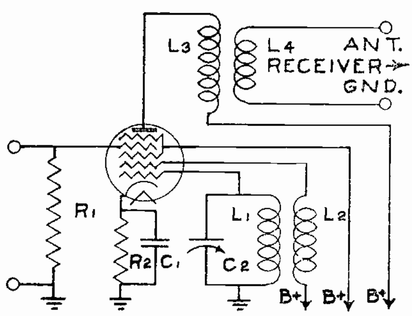


FIGURE 13

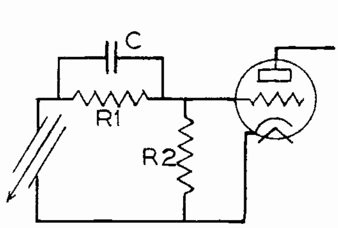


FIGURE 14

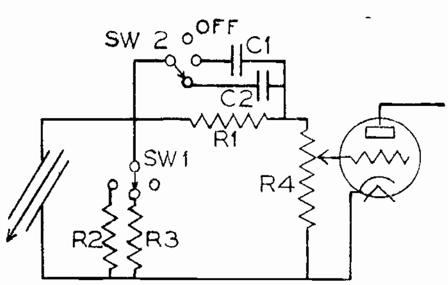


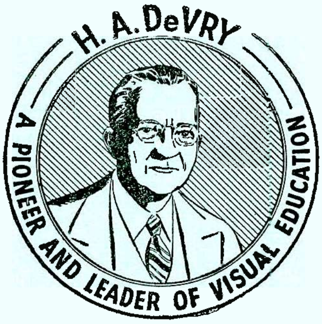
FIGURE 15

RRT-2

DE FOREST'S
TRAINING, Inc.

LESSON RRT-3
MICROPHONES

Founded 1931 by



DE FOREST'S TRAINING, Inc.

LESSON RRT-3

MICROPHONES

• • Founded 1931 by • •

RADIO RECEPTION & TRANSMISSION

LESSON RRT - 3

MICROPHONES

* * * * * * *

When you get into a tight place and
everything goes against you, till it
seems as though you could not hold on
a minute longer, never give up then
for that is just the place and time
the tide will turn.

-- Harriet Beecher Stowe

In the last Lesson we explained the action of phonograph pickups and here we want to take up the action of another accessory of Radio and Electronics which is known as a "Microphone". The purpose of a microphone is to change sound waves into electrical energy which may be amplified by audio frequency circuits to operate a speaker or other device.

SIMPLE TRANSMITTER

The action of the transmitter, or microphone, used in the ordinary telephone is easy to follow and, for that reason, in Figure 1 we show a simplified sectional view. At the left of the diagram there is a cap with the mouthpiece and the diaphragm is supported by the case directly to the right. When you talk into the mouthpiece, the air waves, set up by your voice, strike the diaphragm and cause it to vibrate. Just remember here that the diaphragm will vibrate at the same frequency as the sound waves which strike it.

Looking further to the right, you will see a piece of carbon which fits just inside a container which is called a cup. The diaphragm is attached, at its midpoint, to the small end of the carbon piece. Although we do not show it, the cup is fastened rigidly to the frame of the unit and thus remains stationary. Being fastened to the diaphragm, the piece of carbon will move with it and thus is marked "Movable Carbon".

Inside the container, a second piece of carbon, fastened to the rigid cup, is marked "Fixed Carbon". As air waves strike the diaphragm and cause it to vibrate, the movable carbon, fitting loosely in the cup, will vibrate with the diaphragm. The fixed carbon does not move and thus the vibration of the diaphragm will change the distance between the two carbons.

The space between the movable and fixed carbons is filled with small pieces of carbon, called granules, and as these granules touch each other, there will be an electrical circuit between the carbon particles.

To form a complete electrical circuit, the carbon elements are connected in series with a switch, primary winding of an input transformer and a battery of two dry cells. When the switch is closed, the current is carried by the carbon granules but actually, its path is through only those points at which the granules are actually in contact.

As the movable carbon moves toward the fixed carbon, the granules are squeezed together, touch each other at more

points, and thus provide more paths for the current. When the movable carbon moves away from the fixed carbon, the granules separate, there are fewer points of contact and thus fewer paths for the current.

The result of this action is that the electrical resistance between the movable and fixed carbon will vary with the respective positions of the movable carbon. The part in which the change of resistance takes place is in series with the other units of the circuit and this variation of resistance causes a change of current. The resistance of the circuit changes with each movement of the diaphragm and, initially, the changes of current are controlled by the sound waves which strike the diaphragm.

The changes of current, in the primary of the input transformer, cause a change of magnet flux in the core, and an emf is induced in the secondary. Here then, the sound waves striking the diaphragm are changed into an alternating emf in the transformer secondary, the frequency of which will be the same as that of the sound waves.

In order to secure the best operation, the resistance of the carbon circuit must be quite low in value and therefore the impedance of the primary winding of the transformer is made low. The input circuit of an audio amplifier tube requires a high impedance and, as we have explained in former lessons, to meet this condition, the transformer secondary is made with a large number of turns.

Although the transmitter described above is satisfactory for telephone work, it is not sensitive enough for many installations where the sound must be picked up from a distance. One early method of increasing the sensitivity of a single carbon transmitter, or microphone, is shown in Figure 2. Here you will see the cover has a ring of slots around its outer edge and a circular spacer, inside the slots, with the carbon held in a central block. The diaphragm is held on the spacer by a clamp ring and rests lightly against the carbon. The clamp ring has a small central opening which is opposite the cone mounted in the center of the beveled case.

Sound waves, entering the unit from an angle as shown by line A, strike the case, is reflected to the clamp ring, back to the cone and up to the diaphragm. Sound waves, entering the unit from the direction of line B, strike the beveled corner of the case, are reflected to the cone and up through the central opening of the clamp ring to the diaphragm.

Although we have shown but two lines of sound, the cone and beveled case are arranged so that all sounds, from a com-

paratively large angle, are reflected and focused to strike the diaphragm near its center. This concentration of sound waves causes a greater movement of the diaphragm and thus the unit is more sensitive.

There are many types and models of units which operate on this variable resistance principle and, in general, they are called single button microphones because there is but one group of carbon granules.

TWO BUTTON MICROPHONE

The single button microphone of Figure 2 operates satisfactorily for ordinary speech frequencies but will not faithfully reproduce the wider range of frequencies necessary for the proper reproduction of music. The main reason for this is the mechanical resonant frequency of the diaphragm causes over amplification at those frequencies. By using a thin, tightly stretched diaphragm, working against an air chamber, this effect has been greatly reduced but the frequency response is not uniform for the required range.

To overcome some of these troubles, the two "button" microphone has been developed, one type of which is shown in the sectional view of Figure 3. It is made up of a rigid rear plate and front ring with the diaphragm in between.

Screwed into the front ring, the ridge of the tension ring forces the diaphragm into the groove of the rear plate. As the microphone is circular, this action takes place all the way around, causing the diaphragm to be tightly stretched. A carbon button assembly is then screwed into the center of the rear plate but insulated from the plate, by a rubber bushing. An open spider is mounted on the front ring and a second carbon button assembly is screwed in the center of the spider. Thus there is a carbon button on each side of the tightly stretched diaphragm.

Sound waves, passing through the openings of the spider strike the diaphragm and cause it to vibrate. Notice here, as a sound wave forces the diaphragm toward the rear plate, the pressure on the carbon granules of the rear button is increased while that on the granules of the front button is reduced. Thus we have a sort of "Push-Pull" arrangement between the diaphragm and carbon buttons.

The center of the rear plate is shaped to form an air pocket, or chamber, behind the diaphragm and, as the air cannot readily escape, it acts as a damper. In this way, the effect of the resonant frequency of the diaphragm is reduced and the frequency response is improved.

The diaphragms are generally made of duralumin and, to improve the electrical contact, the carbon granules are carefully selected as to size and quality and often gold plated. In the more expensive types, the diaphragm is carefully stretched until it is resonant at some definite frequency.

TWO BUTTON MICROPHONE CIRCUIT

The circuit of a two button microphone is similar to that of Figure 1 but, to secure proper operation of both buttons, it requires the arrangement of Figure 4. Here, the transformer primary is center tapped to allow two circuits, like Figure 1, to operate from a single battery, usually of about three volts.

To explain the action, we will imagine that both buttons of Figure 4 allow equal currents and the battery positive connects to the center tap of the transformer primary. Thus, current leaving the battery will divide equally, part of it passing through one half of the primary and the other part through the second half of the winding.

As the primary of the transformer is made up of one continous winding, the direction of current in the two parts, or sides, will be opposite and each half will produce equal and opposite magnetic fields which neutralize each other. The direct current therefore has no effect on the transformer core or secondary winding, and any "hiss", which is a thermal agitation voltage developed by current in the buttons, will be balanced out.

However, when a sound wave moved the diaphragm, the current in one button increases while that in the other decreases. At first glance, you may think the increase of current in one half of the winding will neutralize the decrease in the other half but, remember these currents are in opposite directions.

Keeping this in mind and checking up on the laws of induction, you will find the action in both halves of the primary will induce an emf of the same direction in the secondary. Thus, other things being equal, a certain change of current in a two button microphone will induce twice the voltage of a single button type.

As the direct current of the battery has no effect on the transformer secondary, it is only the changes of microphone current which induce an emf. Thus, we have an action like that of push pull connected tubes used in the output stage of an audio amplifier which, as explained in an earlier Lesson, reduces distortion.

In the diagram of Figure 4, we show but one rheostat which is in the common battery circuit, although there is a milliammeter in each button circuit. You will find installations of this type which have a separate rheostat for each button in order that the currents can be balanced. To eliminate the expense of two meters, a jack is often connected in each circuit, making it convenient to plug in a meter while adjustments are being made.

By careful design and assembly, two button microphones are able to reproduce most required frequencies equally well but are sensitive to all vibrations. For this reason, the microphone is generally mounted on springs in the center of a heavy metal ring. Vibrations of the stand cannot reach the microphone and therefore are not amplified.

Moisture or mechanical shocks have a tendency to cause the carbon granules to "pack", and the unit must be tapped gently, with the current off, to restore normal operation.

A good quality, two button carbon microphone is very sensitive, not only to sound waves produced in front, but also to sounds which originate at the side and rear. For that reason, it is necessary that all extraneous noises be kept at a minimum.

Although the carbon microphone has the advantage of inducing a greater voltage than other kinds of microphones, its use is more common in simple application where the disadvantages of the requirement of a battery, noisy operation and poor response are not serious objections.

CONDENSER MICROPHONE

The purpose of all types of microphones is to change sound wave disturbances in the air into electrical currents of like frequency and amplitude. The carbon button type accomplishes the change by allowing a diaphragm, caused to vibrate by the changing pressure of the sound waves, to vary the resistance of an electrical circuit by changing the mechanical pressure on a cup of carbon granules. The condenser microphone, however, operates on an entirely different principle.

From your earlier Lessons, you know a simple form of electrical condenser consists of two metal plates separated by a dielectric. The capacity of the condenser depends on the active area of the plates, the thickness and material of the dielectric.

Suppose we take a rigid metal plate and mount a metal diaphragm on it, using an insulated mounting and let the air between the plates serve as the dielectric. Sound waves,

striking the diaphragm, will cause it to vibrate and thus change the thickness of the dielectric between it and the rigid plate. In this way, the sound pressure waves will cause a change of capacity between the plates.

When connected in an a-c circuit, a condenser has a capacity reactance which is measured in ohms and the reactance varies inversely with the capacity. Thus, by changing the capacity it is possible to cause changes of electrical current which will follow the changes of pressure due to the sound waves.

To use a condenser of this type as a microphone, it is necessary to have a d-c supply but the action remains about the same. When the sound waves force the diaphragm closer to the rigid plate, the capacity increases and current enters, or is said to charge, the condenser. When the diaphragm springs back, the capacity is reduced, the voltage across the condenser increases and current is forced back into the circuit.

Perhaps it may help you to understand this action by repeating the formula for a condenser which states:

Q (Coulombs) = C (Capacity) x E (Voltage)

From the above formula you can see that an increase in capacity, the voltage remaining the same, will cause an increase of Q (coulombs), which means a current into the condenser. A decrease in capacity, on the other hand, will cause a decrease of Q, which means that there will be current out of the condenser.

With these actions in mind, in the circuits of Figure 6 you will find the condenser microphone "M" is in series with resistance "R" across a d-c supply, considering "ground" as B-, and all current in and out of "M" passes through the series resistance "R". These changes of current cause a changing voltage drop across R which replaces the plate resistor of the usual resistance coupled amplifier arrangement.

Thus the voltage, across resistance R of Figure 6, will vary with the sound waves striking the diaphragm of the condenser microphone the same as the voltage, across the secondary of the transformer of Figure 4, varies with the sound waves striking the diaphragm of the carbon button microphone.

Because the movement of the diaphragm is small, the change of current caused by a condenser microphone are also small and the two stage amplifiers of Figure 6 is necessary to bring the voltage output to a level comparable to that of a carbon type microphone.

Although the condenser microphone has low output, it has an excellent frequency response, and proper construction of the unit keeps moisture and temperature effects to a minimum. A study of Figure 6 will indicate that no input transformer is required, and therefore the condenser microphone is considered a high impedance unit. This microphone is particularly adaptable for sound studio and laboratory measurement work.

CONDENSER MICROPHONE CONSTRUCTION

Although the simple arrangement we have explained produces the proper action, its performance would not be satisfactory for practical work because the movement of the diaphragm would not follow the varying pressure of the sound waves with a high degree of accuracy. To secure proper response, many refinements are necessary and, as an example, in Figure 5, we show a sectional view of a typical condenser transmitter.

The diaphragm is made of an aluminum alloy, .0011 inch thick, securely clamped at its outer edge between gaskets of softer aluminum. The stretching ring is then adjusted until the diaphragm has a resonant frequency of 5000 cycles, and for satisfactory operation, the thin membrane has sufficient stiffness. The back electrode is placed very close to the diaphragm, the film of air between them acting as a damper.

To dampen the resonant frequency, yet have only a slight effect on other frequencies, a special damping plate is installed. This damping plate has grooves, cut at right angles, with holes drilled through to the compensation chamber. However, if the air inside were confined between the diaphragm and a solid back, changes of atmospheric pressure would change the distance between the diaphragm and damping plate.

To prevent any change of operation from this source, a more flexible compensating diaphragm is placed in the compensation chamber. Atmospheric pressure is applied to one side of this diaphragm therefore, it will always move to a position which equalizes the pressure on both sides of the operating diaphragm.

Being flexible, the compensating diaphragm would greatly reduce the damping action of the air, therefore the holes, in the damping plate, do not open directly into the compensating

chamber. Instead, there is an acoustical valve which allows the atmospheric pressure to equalize, as previously explained, but prevents the rapid changes of pressure, caused by the vibration of the main diaphragm, from reaching the compensating diaphragm.

The diaphragm and damping plate are assembled in a dustproof cabinet and sealed with beeswax to make the joints air tight and keep out all moisture. A small tube opens into this space and the microphone is filled with nitrogen to prevent corrosion of the operating surfaces.

CONDENSER MICROPHONE AMPLIFIER

As we mentioned before, the output of a condenser microphone is considerably lower than that of the carbon types and thus greater amplification of its output is necessary. Also, as the action of the condenser microphone depends on changes of capacity, the connections between the microphone and amplifier must be short. For this reason, it is common practice to build an amplifier, similar to that shown in Figure 6, in a tubular housing with the unit of Figure 5 mounted at one end and supported so that it may be turned in any direction.

A small amplifier, used only to increase the voltage output of a device and arranged as explained above, is commonly referred to as a "head amplifier". However, it is only an audio amplifier, the circuits of which have been previously explained, therefore, we will not repeat at this time.

RIBBON OR VELOCITY MICROPHONE

Both the carbon and condenser microphones are sensitive to sounds from all directions and, while this is an advantage in many cases, in others it is a decided disadvantage. In recording sound pictures, for example, it is necessary to have all the background noises in street scenes, but for good dialogue between characters in the picture, all background noises must be eliminated.

The "Velocity" microphone was developed to improve this condition, as it is sensitive to sounds from one direction but insensitive to sound from other directions, as shown in the constructional details of Figure 7. The moving element is a thin metallic ribbon suspended between the pole pieces of a powerful, cobalt steel, permanent magnet in such a way that its length is perpendicular to, and its width in the plane of the magnetic lines of force. Due to the fact that permanent magnets are utilized, no external voltage supply is necessary.

The pole pieces are constructed and cut away so as to allow free passage of the sound waves through the microphone. The ribbon element is made of very thin duralumin and is suspended from metal cross pieces which, although not shown in Figure 7, rest on four insulating bushings. These insulating bushings are the only non-metallic parts of the microphone, therefore, temperature and humidity changes will have but little effect on its operation.

The microphone operates on the principle of an electric generator, in that a voltage will be induced in a conductor when it is moved in a magnetic field. In other words, when a sound wave strikes the ribbon, it will vibrate in the magnetic field at the same frequency as the sound and will therefore have a voltage of like frequency induced in it. As the resistance of the ribbon is but a fraction of an ohm, its changing voltage output is transferred directly to the primary of an impedance matching transformer which is considered as an integral part of the microphone. The transformer secondary may be wound to most any desired impedance and thus it is possible to have both low and high impedance velocity microphones.

Referring to Figure 7, you will notice that the pole pieces shield the ribbon from the sound on two sides but it is free to receive sound impulses on either of its broad surfaces. In fact, the "Velocity" principle of operation is dependent on the "pressure gradient" or the difference between the sound pressure on the front and back of the ribbon.

The word "Velocity" is used to describe the type of microphone because the ribbon has very low inertia and actually follows the motion of the air particles of the sound wave. The ribbon microphone responds to sound equally well from either the front or back and is considered bi-directional. However, as the angle at which the sound strikes the microphone departs from 90^0, at either the front or back, the total output falls, dropping off quite sharply when the sound veers around toward either side of the case.

The ribbon is very delicate and must be protected from sudden draughts or puffs of wind. To aid in this, it is surrounded by an inner and outer screen of fine mesh silk attached to its magnetic assembly and outer case, respectively. These and a metallic screen help protect against mechanical injury or the accidental entry of magnetic material into the assembly.

The frequency response is excellent from 20 to 15,000 cycles, provided the source of sound is at a greater distance than about eighteen inches from the microphone. If the source is

nearer than about six inches, distortion may take place causing over-accentuation of the lower notes. This characteristic makes the ribbon microphone difficult to use where unusual sound conditions must be overcome. However, it helps to effect a practical decrease in output, as performers must work at a greater distance from it than they do from other microphones.

The output of the ribbon microphone is somewhat greater than that of the condenser type and therefore it requires moderate amplification. However, it is not necessary to use a head amplifier although, in the case of long transmission lines, it is commonly done.

Velocity microphones are suitable for high quality recording, radio broadcasting and outdoor uses when not exposed to winds. Its bi-directional characteristic is helpful in reducing acoustic feedback, audience noise and room reverberation.

VELOCITY MICROPHONE CONNECTION

In the above explanation, we told you that the secondary of the internal transformer could be wound so that the unit became either a high or low impedance microphone. With the high impedance type, the output of the microphone can be fed directly across the grid load of an audio amplifier tube as shown in Figure 8, where R_1 is the grid load.

When the low impedance microphone is used, an impedance matching transformer must be employed, such as shown in Figure 10. In other words, the input connections must be like those of high and low impedance pickups, as explained in an earlier Lesson.

However, for low level microphones, the audio amplifier must have a high gain in order to bring the signal up to a proper level where it will satisfactorily operate a loudspeaker or other device.

DYNAMIC MICROPHONES

As one would expect from the name, the dynamic or moving coil microphone operates on the same principle as the dynamic speaker. However, conditions are reversed and in the microphone, an emf is induced in the coil as the sound waves cause it to vibrate in a strong magnetic field.

The moving coil microphone is one of the oldest types and was invented as early as 1877 by Siemans. However, due to the fact that its output level is quite low, it was not used until the advent of audio amplifiers.

In Figure 9 we have a simplified cross-sectional view of a dynamic microphone and you will notice the central portion of the diaphragm is dome shaped which makes it quite rigid. A light aluminum coil, fastened to the diaphragm at the base of the dome, projects into the magnetic field between the N and S pole pieces of the permanent magnet which forms the frame for the microphone.

The diaphragm is clamped to, but held a short distance from, the pole pieces by the ring and washer. The small air space, back of the diaphragm, is closed except for the narrow annular slit S1, which connects into the larger space within the body of the magnet. This slit serves to control the response of the diaphragm by air resistance.

A familiar example of air resistance to obtain constant velocity is the parachute. Without a parachute, and falling under constant force of gravity, the speed of a man would be governed almost entirely by inertia; his acceleration would be constant but his velocity would continously increase. With a parachute however, enough air resistance is introduced to become a controlling factor and the velocity of the fall becomes constant. The various slits and openings in a dynamic microphone operate somewhat in a similar way in order that the required damping action of the diaphragm is obtained and a good frequency response results.

Going back to Figure 9, the cavity C is formed within the central pole piece and connected to the air chamber by the narrow slid S2 to further increase the damping action and improve the frequency response.

You can easily see that the stiffness of the diaphragm would control its motion at the low frequencies and produce a velocity that would decrease with the frequency. Such stiffness control begins at about 200 cycles and below this frequency, if this effect were not corrected, the sensitivity of the microphone would tend to fall off. However, if the force on the diaphragm can be increased at a rate corresponding to the falling off of velocity due to stiffness, a uniform response will be obtained.

This action is secured in Figure 9 by an air connection made through the tube from the front of the diaphragm to the air chamber within the magnet. By proportioning the length and diameter of this tube, it is possible to exert a suction, which increases as the frequency decreases, on the rear of the diaphragm at the same time that pressure is applied to the front. At low frequencies, this suction increases the

velocity and thus, by producing an additional force, tends to offset the increasing effect of stiffness at low frequencies.

From the above explanation concerning the research which has been done on the frequency response of this type of microphone, you can easily understand why it is quite uniform over the entire range of audio frequencies. From Figure 9, you can see that, for best response, the dynamic microphone should always directly face the sound source so that the waves will strike the diaphragm at approximately right angles.

The impedance of the coil of this type of microphone is generally between 20 and 250 ohms and therefore it is of a low impedance. However, it is quite common to follow the method employed for the ribbon microphone and mount a transformer as a part of the microphone assembly. Under these conditions, it can be made either high or low impedance. The input connections are similar to those of the ribbon mike and so we will not repeat the former explanation.

The dynamic type is very popular because of its rugged construction and its general applications are similar to those of the velocity microphone.

CRYSTAL MICROPHONE

The crystal type of phonograph pickup operates because of the piezo-electric effect characteristic of certain crystals. That is, when a crystal is properly cut, and subject to mechanical stress, there will be a difference of potential between its two faces. In our explanation of the crystal pickup, this mechanical stress was obtained by the vibration of the needle and, in the microphone, it is obtained by the pressure of the sound waves which cause the crystal to bend and produce a difference of potential between its faces.

The piezo-electric effect of Rochelle Salt has been found superior to other crystals and therefore it is most commonly used in this type of microphone. Although the salts are soluble in solution, rigid experiments have shown that suitable protection against moisture and humidity can be obtained by enclosing the crystal in waterproof paper and waxes.

The effect of temperature variation has also been reduced to a minimum by the use of very thin sections of crystal arranged in two sections or plates connected together in such a manner that when electrodes are attached and an emf applied, one of the plates will expand and the other plate will contract.

This action results in a bending effect, similar to that of a bimetallic thermostat, and when arranged in this way, the crystal is known as a "bimorph element".

There are two common types of crystal microphones, one of which employs a diaphragm rigidly connected to the crystal and the other in which the diaphragm exerts a varying pressure on the bimorph element through a resilient intermediate membrane. Simplified sketches of both types are shown in Figure 11.

The one shown in Figure 11-A, is known as a "sound cell" or "grille type" microphone and it consists of a rectangular frame of bakelite on each side of which a thin Rochelle Salts Bimorph unit is supported by the frame at two points. The space between the crystal and frame is sealed by a flexible but air tight ring which permits the crystal to vibrate freely with variations due to sound pressure. The entire cell is impregnated with wax to maintain the elements in an airtight and moisture proof chamber.

When the entire unit is subject to sound variations, the two sides of the crystal unit vibrate in phase with each other and produce an emf across them in direct proportion to the sound pressure. However, if the unit is subject to mechanical vibration or shock, the voltages, generated by both sides, are out of phase with each other and cancel any generated emf, therefore, no voltages are developed across the input amplifier tube by these disturbances.

Because of the condition of mechanical resonance, the physical dimensions of the sound cell are one of the most important considerations in the design of the crystal microphone. That is, if the mechanical resonance of the crystal is in the frequency band to be reproduced, the response will be seriously impaired. This condition is prevented by designing the crystal to have a natural resonance period above the highest frequency wave to be reproduced.

One of the exceptionally fine characteristics of the crystal microphone is its ability to amplify the higher spectrum of musical frequencies above 8000 cycles. This is due to the increase of voltages developed near the mechanical resonance period of the crystal. Therefore, if the crystal has a resonant period slightly above 10,000 cycles, the frequency characteristic will rise as it approaches this value.

The output of a single sound cell is quite low but this can be increased by connecting the cells in series. Also, the

impedance is very high and to reduce this, the cells may be connected in parallel. In commercial units therefore, the microphones usually consist of from 4 to 24 cells connected in series or series parallel. The output of the ordinary sound cell microphone is comparable to that of a dynamic microphone.

In Figure 11-B, we have the other type of crystal microphone and it consists of conical duraluminum diaphragm which actuates the bimorph crystal element directly. The diaphragm has an effect to cause considerable mechanical stress on the crystal and therefore, as the generated voltages are proportional to the stress, the output of this microphone is greater than the sound-cell type. However, due to the inertia of the diaphragm, microphones of this type do not generally have a very uniform frequency response and, as a rule, are found in the lower price class services such as home recording, small public address systems and Amateur Radio.

In general, crystal microphones are of the high impedance type and may be connected directly across the grid circuit of an amplifier tube as explained for Figure 8. When using a crystal "mike", the grid load R_1, should have a value of approximately 5 megohms.

Unlike the ribbon and dynamic microphones, the crystal is sensitive to sound from all directions and this characteristic may be used to advantage as explained for the condenser and carbon microphones. The crystal microphone however has the advantage of a better frequency response and does not require an external voltage.

MICROPHONE TRENDS

The various kinds of microphones just described have one feature in common, namely they all convert the motion of the air particles into motion of a diaphragm, ribbon or plate, and in turn, these motions lead to the induction of an emf. There are many forms which the above common requirement can take, in order to provide some special characteristic.

For military purposes, for example, lip microphones, pickups which are actuated by throat movement during speech, and others were used as their unique construction permitted some desired characteristic such as interference elimination, compactness, and freedom of movement of the wearer.

Some microphone manufacturers combine the principles of operation of two units into a single assembly in order to gain the advantages of each or some particular combination

characteristic. For example, a crystal and a velocity microphone may be combined into one unit. Recalling the basic principles of operation of each, if a sound wave strikes the "front" of the microphone, moving the ribbon and diaphragm of the crystal in unison, the generated emf's can be made additive and hence the output will be greater.

In addition, such a combination unit can be made "selective". When the sound wave approaches from the "rear", it will actuate the ribbon microphone, but the crystal diaphragm will only respond effectively from the "front" direction, thus the generated emf's tend to cancel, resulting in low output. In such a manner, these two units mounted in a single head have greater output with the property of discriminating against undesired sounds.

It can readily be seen that such microphones are useful in noisy locations and whenever it is necessary to concentrate the pickup of sound. Places of general applications are concert halls, auditoriums and open sound studios.

Another recently developed unit is the differential microphone, and it is responsive not only to sound pressure but also to distance of sound origin. It works on the principle that, from its original disturbance, sound first falls off rapidly in intensity, then remains quite constant, decreasing slightly with distance.

The differential microphone is constructed to admit sound waves equally on both sides of the diaphragm, therefore, random noise, created at a distance, will strike both sides of the diaphragm with about the same intensity and restrict its movement. This action makes it suitable for use in noisy locations and also ideal for public address work, as acoustic feedback, caused by the sound output of a speaker actuating the microphone, is reduced.

Any microphone which has a "flat" frequency response will provide less strain on the listener, higher articulation, and contain less possibility of acoustic feedback because peak resonant effects are eliminated.

TRANSMISSION LINES

Now that we have explained the action of various types of microphones, we will take up the wire, or "Transmission Line", which connects them to the input of the audio amplifier. The subject of "Transmission Lines" is very lengthy and involved, therefore, at this time, we want to give you only a practical idea of the advantages of a low impedance line.

In Figure 12A we show a microphone cable made up of stranded wire, covered by two layers of braided cotton and a shield of braided copper. Then, to protect the shield, there is an outer covering of flexible rubber. When attached to an input circuit, the inner stranded wire is connected to the grid side of the circuit and the shield to the ground side. Looking at Figures 8 and 10, the stranded wire would be connected to the upper input terminals, while the shield would be connected to the lower terminals.

In this way, the shield is at ground potential and as it completely surrounds the "hot" inner wire, it acts to prevent any undesirable fields from inducing a voltage into the input circuit. Therefore, by using this type of cable, the noise level in the speaker, caused by pickup, will be kept at a minimum value.

However, from your early Lessons, you know that a condenser is made up of two conductors, separated by a dielectric and, as the microphone cable of Figure 12A has two conductors, separated by insulation, it is a condenser. The capacity of the cable will depend on the area of the conductors and the distance between them, the same as for any other condenser.

As we will show you a little later in our explanation, this capacity is undesirable and, to reduce it, the common types of "low loss" microphone cables have many more layers of insulation between the shield and "hot" wire than we show in Figure 12-A. This reduction in capacity is due to the increased distance between the conductors or plates.

As we told you above, in order to transfer the energy from the microphone to the input circuit of the tube, the cable is connected across the grid circuit. In doing this, we place a condenser (capacity of the cable) across the resistor R1 of Figure 8.

In order to see this more clearly, in Figure 12-B, we show an equivalent circuit made up of R_1, C and R all connected together by two conductors. You can think of R as being the microphone impedance, R_1 the grid impedance with the capacity, C, and the conductors making up the cable. For maximum transfer of power, the terminating impedances must be equal and therefore, R equals R_1.

Under these conditions, and with a hypothetical "no-loss" cable, the power in R_1 would equal that in R. It is needless to say that such a cable is not available and there will be some losses, the amount of which will depend on several

factors. Here, we are interested only in the effects of the capacity of the cable on high and low impedance lines and will therefore assume there are no other losses. Also, for simplicity, we will consider R and R_1 as resistances.

To show you the losses introduced by the capacity of the cable, we will first consider a high impedance line in which the terminating resistances R and R_1 each have a value of 500,000 ohms. We will also assume the cable is 100 ft. long, with a capacity of 30 micro-microfarads per foot and the output of the microphone R is 1 microwatt.

Under these conditions, the power in the combination of C and R_1 would be equal to that in R. Therefore, in order to find the power in R_1 it is first necessary to find the impedance of the combination made up of R_1 and C. To do this we make use of the formula for parallel resistances given in an earlier Lesson as, $R_t = \frac{R_1 \cdot R_2}{R_1 + R_2}$

Here, one branch is made up of capacity reactance, X_c, and therefore, as stated in the Lesson on impedance, it must be added vectorially, which changes the above formula to

$$R_t = \frac{R_1 X_c}{\sqrt{(R_1)^2 + (X_c)^2}}$$

The right member of the above expression is then the equivalent value of R_2 shown in Figure 12-B.

The capacity reactance X_c is expressed by the equation,

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

Assuming a frequency of 10,000 cycles, which is in the upper band of the audio spectrum, and the 100 foot cable with a capacity of 30 mmfd per foot, the reactance would be

$$X_c = \frac{1}{2\pi f C} = \frac{1}{6.28 \times 10000 \times (.00000000003 \times 100 \text{ ft.})}$$

$$X_c = \frac{1}{.0001884} = 5308 \text{ ohms}$$

The total impedance of the combination R2 would then be

$$R_2 = \frac{R_1 X_c}{\sqrt{(R_1)^2 + (X_c)^2}} = \frac{500000 \times 5308}{\sqrt{(500000)^2 + (5308)^2}}$$

$$R_2 = \frac{2654000000}{\sqrt{250028174864}} = \frac{2654000000}{500027}$$

$$R_2 = 5307 \text{ ohms}$$

The voltage drop across R2 can be expressed by

$$P = \frac{E^2}{R_2} \quad \text{or} \quad E = \sqrt{PR_2}$$

The power in the combination of R_2 was given as 1 microwatt or .000001 watt and substituting,

$$E_{R_2} = \sqrt{.000001 \times 5307} = .0729 \text{ volt}$$

Now, knowing the voltage drop across R_1 and its resistance, the power in it is equal to,

$$P_{R_1} = \frac{(E_{R_1})^2}{R_1} = \frac{(.0729)^2}{500,000} = \frac{.005307}{500,000}$$

$$P_{R_1} = .0000000106 \text{ watt} = .0106 \text{ microwatt.}$$

Without taking into consideration the capacity effect, the voltage drop across R_1 would be

$$E_{R_1} = \sqrt{PR_1} = \sqrt{.000001 \times 500000} = \sqrt{.5} = .707$$

Notice the difference in magnitudes of the power in, and the voltage across R_1, under the conditions assumed.

In other words, using the high impedance line with this type of cable, at 10,000 cycles, there is a great reduction of both power and voltage in R_1.

Now let's see what happens when the frequency is in the lower audio band and, for this, we will assume 50 cycles, with the other values remaining the same.

$$X_c = \frac{1}{2\pi fC} = \frac{1}{6.28 \times 50 \times .000000003} \quad 1061000 \text{ ohms}$$

$$R_2 = \frac{500000 \times 1061000}{\sqrt{(500000)^2 + (1061000)^2}}$$

$$= \frac{530500000000}{\sqrt{(250000000000) + (1125721000000)}}$$

$$R_2 = \frac{530500000000}{\sqrt{1375721000000}} = \frac{530500000000}{1172900}$$

$$R_2 = 452300 \text{ ohms.}$$

To find the voltage,

$$E_{R2} = \sqrt{PR} = \sqrt{.000001 \times 452300} = \sqrt{.452300}$$

$$E_{R2} = .6725 \text{ volt approx.}$$

$$P_{R_1} = \frac{(E_{R1})^2}{R_1} = \frac{(.6725)^2}{500000} = \frac{.4523}{500000} = .0000009046$$

$$P_{R_1} = .0000009046 \text{ watt} = .9046 \text{ microwatt.}$$

Here, we have only slight losses as compared to that at 10,000 cycles. This is easily understood when we will remember that capacity reactance varies inversely as the frequency. With the high impedance line therefore, severe attenuation of the high frequencies is encountered. In other words, as the frequency increases the efficiency of the line is reduced.

Suppose that we again analyze the circuit of Figure 12-B, but this time, we will assume R and R_1 each have values of 50 ohms, the other values being the same as given above. We will proceed the same as before but, to avoid repetition, will not repeat all the steps. From above, at 10,000 cycles,

$$X_c = 5308 \text{ ohms}$$

With a 50 ohm line

$$R_2 = \frac{50 \times 5308}{\sqrt{(50)^2 + (5308)^2}} = 50 \text{ ohms approx.}$$

For 50 cycles,

$$X_c = 1061000 \text{ ohms}$$

$$R_2 = \frac{50 \times 1061000}{\sqrt{(50)^2 + (1061000)^2}} = 50 \text{ ohms approx.}$$

For the 50 ohm line therefore, the capacity of the cable has such a very slight effect that we consider it as being negligible. Under these conditions, there is only a small attenuation of the frequencies in the audio band.

The above examples have been more or less self explanatory and we do not think you will have any difficulty in seeing the advantages of a low impedance transmission line.

No doubt the question has come up in your mind as to how a low impedance line can always be obtained. However, this can easily be accomplished by the use of impedance matching transformers, the same as explained in the last Lesson.

In connecting such a circuit, with a high impedance microphone, a matching transformer would be used with a primary impedance equal to that of the microphone and the secondary equal to the desired line impedance. Then, at the amplifier, there would be another transformer with its primary equal to the line impedance and the secondary of the desired grid impedance. In other words, at the microphone there will be a step down transformer while at the amplifier there will be a step up transformer.

In general, a high impedance line can be used for only short lines without severely attenuating the high frequencies. For all long runs, and good frequency response, low impedance circuits should be used.

The explanations of this Lesson bring to mind the wide variety of microphones that have been developed to meet almost any condition of operation, irrespective of the acoustical problems and transmission difficulties. These well designed units, together with associated electronic equipment, have increased the efficiency of sound communication and have made possible greater enjoyment of your favorite radio and recorded programs.

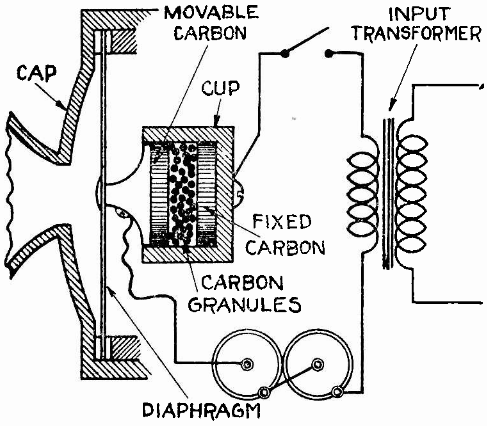


FIGURE 1

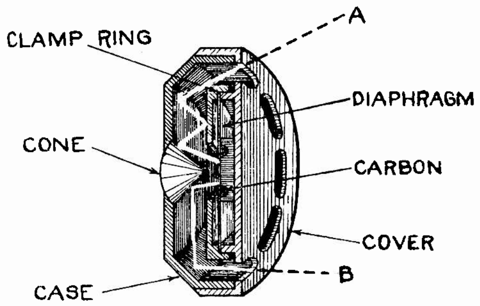


FIGURE 2

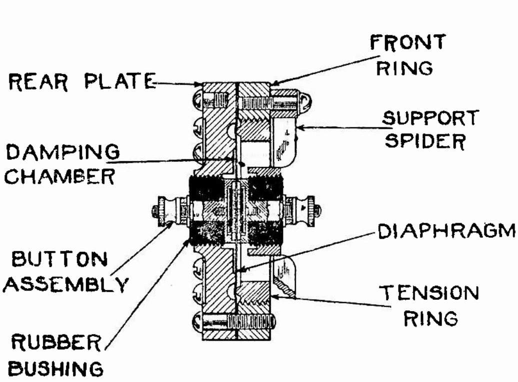


FIGURE 3

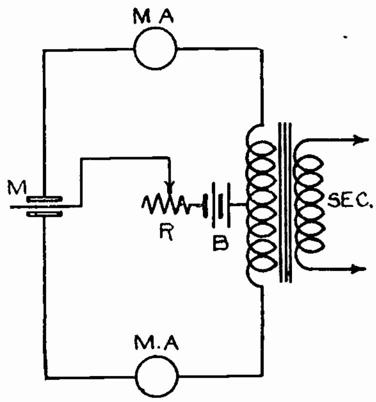


FIGURE 4

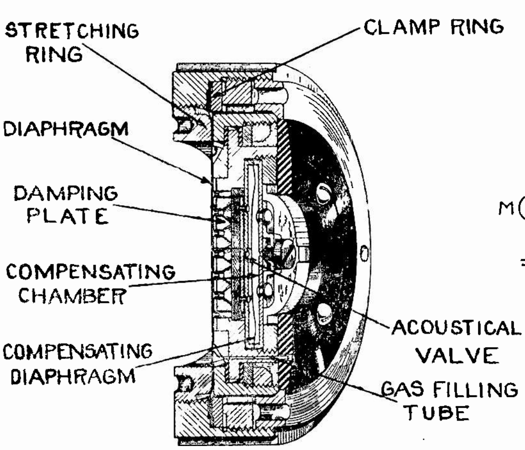


FIGURE 5

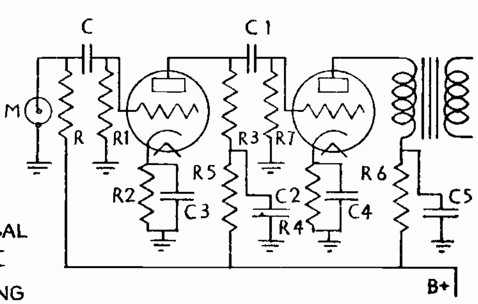


FIGURE 6

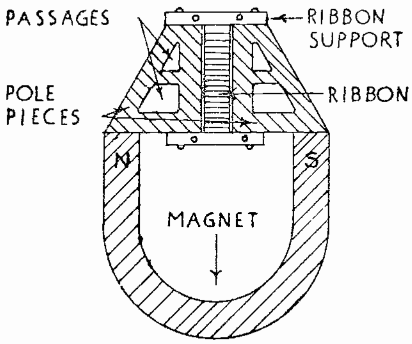


FIGURE 7

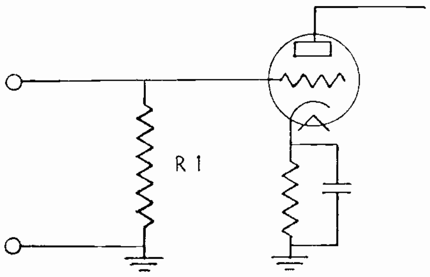


FIGURE 8

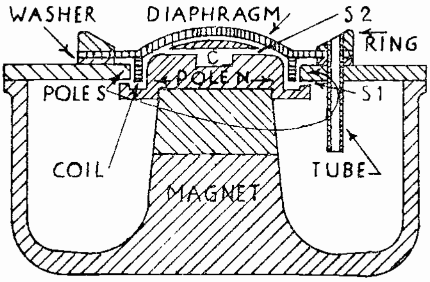


FIGURE 9

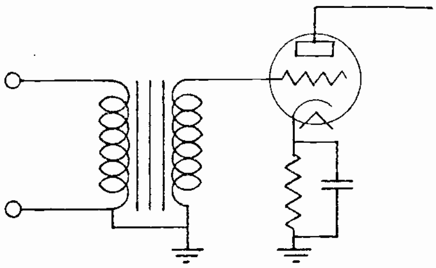


FIGURE 10

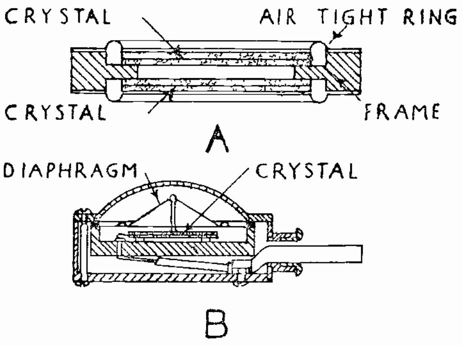


FIGURE 11

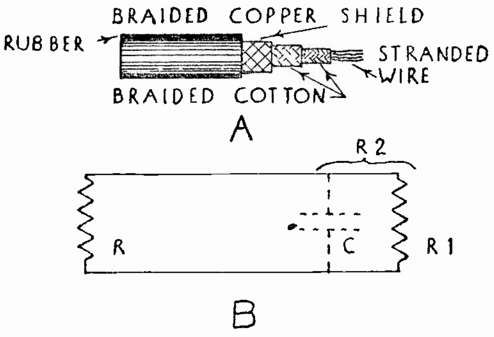


FIGURE 12

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LESSON RRT-4
TONE CONTROL

• • Founded 1931 by • •

H. A. DeVRY
A PIONEER AND LEADER OF VISUAL EDUCATION

DE FOREST'S
TRAINING, Inc.

LESSON RRT-4
TONE CONTROL

Founded 1931 by

RADIO RECEPTION AND TRANSMISSION

LESSON RRT-4

TONE CONTROL

* * * * *

True progress never commands the human race to start over again from scratch. Civilization is an accumulation of living values, an organic thing. Without change, there can be no growth; but without tradition there can be no civilization.

— Dorothy Thompson

Before starting our explanation of tone control circuits, we want to give you an idea of the various audio frequencies which affect the human ear. Like electricity, sound frequencies are measured in cycles per second and in Figure 1 we show the standard piano keyboard with the frequencies of the "C" notes below.

Middle C has a frequency of 256 cycles per second and when this note is struck, the string it operates vibrates at this frequency. Eight notes above is another C note and its frequency is just twice that of middle C or 512 cycles per second.

These eight notes are what we call an "Octave" and the point to remember here is that the frequency doubles for every octave. Starting over at the left of the keyboard, low C has a frequency of 32, the next C, 64, the next 128 and so on, doubling each time to a frequency of 4096 cycles per second at the upper end.

In electrical work, the octaves are known as harmonics, and starting with lower C as the fundamental frequency of 32 cycles, the next "C" is the second harmonic because its 64 cycles frequency is twice the fundamental of 32 cycles.

If you are at all familiar with written music, the notes shown below the keyboard will show you where these frequencies are located on the bass and treble clefs. Middle C, you will find, is between them. The frequencies given here are based on the scientific scale with middle C tuned to 256 cycles. For the orchestral pitch, middle C is tuned to 264 cycles; or perhaps more common, A is tuned to 440 cycles.

Above the piano keyboard of Figure 1 we have listed various musical instruments and voices with their frequency ranges. The Piccolo, for example, has a range from 512 cycles to 5000 cycles, the flute from 256 to 2048 and so on down. The lines marked "Woman" and "Man" show the frequency range of the average speaking voices.

Study these ranges carefully, as they will give you a good idea of the various frequencies and help you in much of your later work. The reason these frequency values are important is due to the fact that, from the time the sounds strike the microphone of the Broadcasting Station until the speaker coil operates its diaphragm, sound frequencies are transmitted, received and amplified as electrical energy. Therefore, as far as the receiver circuits are concerned, the various notes and tones are nothing but a-c of like frequency.

For example, if the voice coil of a dynamic speaker carries an alternating current with a frequency of 256 cycles, the diaphragm will vibrate at that frequency and produce a tone of the same pitch as middle C on the piano keyboard.

The common systems for the distribution of electrical power are operated at some constant voltage and frequency with the load, which may vary from 25% to 100% of the rating, as the only variable factor. To design a transformer for these systems, the amount of iron and size of the windings depend on the load to be carried, but both the primary and secondary circuits operate at one frequency only.

In comparison, the design of a transformer for music and voice is much more complicated. The frequency of an ordinary man's speaking voice varies from 128 to 213 cycles per second, while a woman's speaking voice varies from 192 to 384 cycles per second. For the various musical instruments, the range of fundamental frequencies are from 40 to 5000 cycles per second, while the harmonics, or overtones, are well up into 8000 cycles or more. These overtones are the first, second, third and fourth harmonics which represent the quality and timbre of the voice and music.

These higher frequencies must be amplified in the same way as the fundamental frequencies in order that the human ear can distinguish different instruments and voices. The circuits used to amplify voice and music should handle all frequencies from 40 to 8000 cycles equally well although the power may vary.

For talking pictures, public address systems and all similar Electronic equipment, the amplification of power should be the same at all frequencies, yet very often, one frequency, or group of frequencies, is overamplified.

In this Lesson we will explain the circuits, give you formulas for tuning them to different frequencies and then show you what effects they have on the operation of the amplifiers in which they are used. We will explain how to increase the impedance of a circuit for some definite frequency, and in other cases, how to reduce the impedance at the same frequency.

SIMPLE ACCEPTOR CIRCUIT

To describe these actions, we are going to follow the usual engineering practice and make a series of graphs or curves. For example, at the upper right of Figure 2, we have a simple series circuit made up of a choke coil, or inductance, with

a value of 159 millihenries and a condenser with a capacity of 1.59 microfarads.

While these may seem to be odd values, they work out very nicely, and once you have the idea, it will be easy to substitute any other values in their places. Comparing this circuit with those of the earlier Lessons, you will recognize it as "series resonant", but for the purpose we are going to explain, it is commonly known as an "Acceptor" circuit.

To see just what takes place here, you must remember that when an inductance is placed in an a-c circuit, it becomes an inductive reactance measured in ohms, and its value found by the formula:-

$$X_L = 2\pi fL$$

If you have forgotten how this formula is derived, go back and review the earlier Lesson on impedance. You will notice the inductive reactance varies with the frequency, and to find out what happens, we will substitute in the formula for different frequencies.

With an inductance of 159 mh, which is .159 Henries, and a frequency of 200 cycles, we have

$$X_L = 2 \times 3.14 \times 200 \times .159 = 199.7 = 200 \text{ Ohms.}$$

When the frequency is 400 cycles,

$$X_L = 2 \times 3.14 \times 400 \times .159 = 399.4 = 400 \text{ Ohms.}$$

When the frequency is 600 cycles,

$$X_L = 2 \times 3.14 \times 600 \times .159 = 599.1 = 600 \text{ Ohms.}$$

In the same way, we can find the inductive reactance in ohms for any frequency, but of course, when the frequency is zero, the reactance will also be zero. At zero frequency, the reactance of the choke coil is zero but it will have the ohmic, or d-c resistance of the wire. However, for this explanation we will imagine the d-c resistance is zero.

To show this change of reactance in the form of a curve, in Figure 2 we laid off a horizontal "f" scale from 0 to 1000 cycles and a vertical reactance scale from 0 up to 600 Ohms and from 0 down to 800 Ohms.

Going back to an earlier Lesson again, you will remember that inductive reactance causes the current to lag while capacity reactance causes the current to lead, therefore we will plot the X_L curve above, and the capacity reactance below, the "O" reactance line, or axis.

Taking the values we just worked out, at zero frequency there is zero reactance, therefore, the first point of the curve is located where the zero scale lines cross. With a frequency of 200 cycles, the reactance is 200 ohms, therefore the next point is at "P" where the 200 lines cross. At 400 cycles, the reactance is 400 ohms, therefore point "S" is located where the 400 lines cross.

Plotting the other points in the same way and connecting them, we have the graph X_L which is a straight line and shows how the inductive reactance increases with the frequency.

CAPACITY REACTANCE

As the condenser "C" is in series with the inductive "L", we next find the capacity reactance for various frequencies by substituting in the formula

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

The C of the formula represents farads and as the condenser of Figure 2 has but 1.59 mfd., it must be written as .00000159 Farad. When the frequency is 200 cycles:

$$X_c = \frac{1}{2 \times 3.14 \times 200 \times .00000159} = \frac{1}{.001997} = 500.7 \text{ Ohms.}$$

When the frequency is 400 cycles-

$$X_c = \frac{1}{2 \times 3.14 \times 400 \times .00000159} = \frac{1}{.003994} = 250.3 \text{ Ohms.}$$

At zero frequency, the formula shows the capacity reactance is equal to 1 divided by 0 which is infinity.

Following the plan explained for the inductive reactance, curve X_c, Figure 2, is plotted below the frequency scale or axis. Notice here, the graph is not a straight line and at low frequencies, the capacity reactance is very great, but as the frequency is increased, the capacity reactance reduces very rapidly at first and then more slowly. Saying it another way, at low frequencies the inductive reactance is low and the capacity reactance is high, while at high frequencies, the inductive reactance is high and the capacity reactance low.

CIRCUIT REACTANCE

As both these values are present in the same circuit and act in opposite directions, the total reactance of the circuit must be equal to their algebraic sum. To add, the inductive reactance is thought of as being positive while the capacity reactance is negative.

For example, at a frequency of 200 cycles the inductive reactance has a value of 200 Ohms positive while the capacity reactance has a value of 500 Ohms negative. Adding, the sum is 300 Ohms negative. Adding in this way, we find 150 Ohms positive at 400 cycles, shown by point "a" in Figure 2. At other frequencies, points "b", "c" and "d" are found by the same method and joining them we have the curve X which represents the total reactance of the circuit.

Checking up here, you will notice the curve starts with a large negative reactance at low frequencies but rises rapidly as the frequency increases, reading zero at about 317 cycles. In other words, at a frequency of 317 cycles, the inductive and capacity reactances are euqal and opposite to make their sum zero.

As we explained in the earlier Lessons, the circuit is resonant at this frequency, has zero reactance and thus allows maximum current. Looking at it in a different way, if the circuit of Figure 2 was connected across a 317 cycle supply it would form a short.

SERIES RESONANCE

The subject of resonance seems to cause come confusion, therefore we want to check up a little further at this time. The general formula for resonance is stated:-

$$f = \frac{1}{6.28\sqrt{LC}}$$

and substituting our values of 159 millihenries and 1.59 microfarads, we find f is equal to 316.69 cycles per second. Following the explanations already given, at 316.69 cycles:-

$$X_L = 6.28\ fL = 316.22\ \text{Ohms}$$

$$X_C = \frac{1}{6.28fC} = 316.23\ \text{Ohms}$$

Thus you see, at the resonant frequency of 316.69 cycles as found by the general formula, the values of inductive and capacity reactance are equal. Our figures show a difference of .01 ohm but had we carried the figures out further, the results would have been exactly equal.

For all practical purposes, both inductive and capacity reactance represent an opposition or resistance to an alternating or pulsating current of electricity. Thus, curve X of Figure 2 can be re-drawn with all points above the axis as shown in Figure 3. Check these two curves and you will find points "a", "b", "c" and "d" are exactly the same.

At 200 cycles, Figure 2 shows a net capacity reactance or negative value of 300 Ohms, while Figure 3 shows this same value above the axis instead of below. In this way, Figure 3 is really easier to read as it shows the circuit reactance decreasing to zero at resonance and then increasing as the frequency is increased further.

The small sketch below Figure 3 is merely the graphical method of adding the values of capacity and inductive reactance at different frequencies.

RESISTANCE IN ACCEPTOR CIRCUIT

So far, we considered the circuit of Figure 2 as having zero resistance, but in practice that is never true. For Figure 4 therefore, we have added a resistance of 200 ohms in series with the inductance and capacity.

Once more, we will refer to the earlier Lessons and remind you that when adding resistance and reactance, it is necessary to find the square root of the sum of their squares. The same results can be obtained by graphs or vector diagrams if the resistance is represented at right angles to the reactance.

This is the plan we have followed in the small diagram below Figure 4. For example, at 200 cycles, according to Figures 2 and 3, X has a value of 300 ohms. To find the impedance, with the 200 Ohm resistance of Figure 4, we work like this

$$Z = \sqrt{R^2 + X^2} = \sqrt{(200)^2 + (300)^2}$$

$$Z = \sqrt{130,000} = 360 \text{ ohms}$$

The lower curve of Figure 4 is that of Figure 3, while the upper curve is found by calculating the values as explained above for 200 cycles. The lower diagram of Figure 4 shows

the work for points "a", "b", "c" and "d". The upper curve of Figure 4 thus represents the actual practical values more closely, and at the resonant frequency of 317 cycles, the reactance drops to zero but the impedance drops only to the 200 Ohms of the resistance.

PARALLEL CIRCUITS

Many circuits contain inductance and capacity connected in parallel and to find the reactance and impedance, we have to follow the general plan of simple direct current parallel circuits. In the earlier Lessons, we told you how to find the total reactance of a parallel circuit by adding the conductances of the branches. Conductance is measured by the unit MHO and, as a formula, we can write:-

$$\text{MHOS} = \frac{1}{\text{OHMS}}$$

To find the total reactance of an inductance and capacity in parallel, we can follow the same plan. That will give us a property known as the "Susceptance" of each branch which, like conductance, is measured in "MHOS". Compared to d-c circuits, we have reactance instead of resistance, both measured in ohms, and susceptance instead of conductance, both measured in Mhos.

For Figure 5, we have taken the units of Figure 2, but connected them in parallel and are going to draw curves for the susceptance of each. To make the difference easy to keep in mind, the curve for the susceptance of the inductance will be marked "Y_L", for the capacity "Y_C" and their sum "Y".

Remembering the relation between Mhos and Ohms, if

$$X_L = 6.28\ fL \text{ in Ohms}$$

$$Y_L = \frac{1}{6.28\ fL} \text{ in Mhos}$$

And, in the same way, if,

$$X_C = \frac{1}{6.28\ fC} \text{ in Ohms}$$

$$Y_C = 6.28\ fC \text{ in Mhos}$$

At a frequency of 200 cycles,

$$Y_L = \frac{1}{6.28 \times 200 \times .159} = .005 \text{ MHO}$$

$$Y_C = 6.28 \times 200 \times .00000159 = .002 \text{ MHO}$$

$$Y = .005 - .002 = .003 \text{ MHO}$$

As explained for Figure 2, these points are located for different frequencies and connected to make the curves of Figure 5. Notice here, curve Y has the same general shape as curve X of Figure 2 and also crosses the axis at the resonant frequency of 317 cycles. However, susceptance represents the ease with which a reactive circuit will carry or allow current and as this is zero at resonance, the reactance of the circuit must be very high.

If the frequency is reduced, the susceptance increases which means the circuit will offer less resistance to current. In the same way, when the frequency is raised above resonance, the susceptance again increases, but where most of the current is carried by the inductance at frequencies below resonance, the capacity carries more current as the frequency increases.

REACTANCE OF PARALLEL CIRCUIT

Perhaps it will be easier to follow the action here as we change the susceptance curve, "Y" of Figure 5 back to values of reactance. Remembering the relation between Ohms and Mhos we can use the formula

$$X = \frac{1}{Y}$$

At 200 cycles, curve Y Figure 5 has a value of .003 Mho and substituting in the above formula

$$X = \frac{1}{.003} = 333 \text{ Ohms}$$

Following this plan for frequencies from 0 to 1000 cycles, curve Y of Figure 5 becomes curve X of Figure 6. Notice here, at zero frequency, the reactance is also zero but increases rapidly with the frequency, reaching infinity at the resonant frequency of 317 cycles.

This may be a little hard to follow but, at resonance, $X_L = X_C$ and, being connected in parallel, both will have equal voltage across them which means equal current. However, the current in the inductance lags 90 degrees behind the voltage while the current in the capacity leads the voltage by 90 degrees. Thus we have two equal currents, 180 degrees out of phase which means they are opposite and neutralize each other. As a result, there will be no current in the circuit, even though there is a voltage across it, therefore the reactance must have a value of infinity.

Above the resonant frequency, the capacity reactance drops rapidly and approaches zero, giving a curve which shows conditions opposite to those of the series circuit. Here again, for all practical purposes, the values of reactance can all be thought of as positive and following the plan explained for Figures 2 and 3, the curve of Figure 6 can be redrawn as in Figure 7.

Following the curve here, and keeping the circuit in mind, at zero frequency there is zero reactance. All the current is carried by the inductance and none by the capacity. As the frequency is increased, the reactance of the inductance increases while that of the capacity is reduced. The total reactance however, increases rapidly and still there is more current in the inductive than the capacity branch of the circuit.

At resonance, the reactances are equal, the currents are equal and opposite, making the total reactance rise to infinity.

Above resonance, the capacity reactance reduces faster than the inductive reactance increases, making the total reactance less. Under these conditions, most of the current is carried by the capacity branch of the circuit.

REJECTOR CIRCUIT

Compare the curves of Figures 3 and 7 very carefully and notice their differences. At resonance, the circuit of Figure 3 has minimum reactance and thus will allow maximum current. At resonance, the circuit of Figure 7 has infinite reactance and thus allows minimum current.

The series circuit offers a high reactance to all but the resonant frequency which it "Accepts" while the parallel circuit of Figure 7 offers a comparatively low reactance to all but the resonant frequency, which it "Rejects". For that reason, the parallel arrangement of Figure 7 is often called a "Rejector Circuit".

RESISTANCE IN PARALLEL CIRCUIT

As we explained for the circuit of Figure 3, there will always be some resistance therefore, in Figure 8, we have added 200 ohms to the circuit of Figure 7. To plot a curve under these conditions, we follow the general plan explained for the series circuit curve of Figure 4 by using the formula,

$$Z = \sqrt{R^2 + X^2}$$

or by vectors as shown below Figure 8.

With a frequency of 200 cycles, the curve of Figure 7 shows the reactance has a value of 333 ohms and we know that "R" of Figure 8, has a value of 200 ohms. Substituting in the formula:

$$Z = \sqrt{(200)^2 + (333)^2} = 388 \text{ Ohms}$$

Following this plan for frequencies from 0 to 1000 cycles per second, we are able to draw the curve of Figure 8 which approximates the actual conditions very closely. At zero frequency, the impedance of the circuit is equal to its resistance. As the frequency increases, the impedance rises rapidly, approaching infinity at resonance. At higher frequencies, just above resonance, the impedance drops rapidly and then more slowly, approaching the value of the resistance again.

LOW PASS FILTER

Nowthat we have explained the electrical actions of these series and parallel resonant circuits, our next step is to show you how they are used to obtain practical results.

In Figure 9-A for example, we have the circuit of Figure 2 but have connected the load across the condenser and want you to think of this load as the grid circuit of a tube. Imagine also a constant voltage across the entire circuit with an arrangement to vary the frequency from 30 to 5000 cycles.

Looking at the circuit, the inductance and capacitance are in series across the supply and the load is in parallel to the condenser. Like any parallel circuit, the voltage across the branches is equal and here the voltage across the load will always be the same as the voltage across the condenser. As the impedance of a grid circuit is extremely high, we will imagine it carries no current.

If we let L/2 and C/2 of Figure 9-A have the same numerical values as L and C of Figure 2, at a frequency of 100 cycles the condenser "C/2" has a reactance of approximately 1000 ohms, while the inductance "L/2" has a reactance of 100 ohms. The total reactance is therefore 1000 - 100 or 900 ohms.

With 10 volts assumed across the circuit, the current will be .011 ampere which will cause a drop of 11 volts across the condenser and a drop of 1.1 volts across the inductance. At this frequency, the voltage across the load will be a little higher than the supply voltage.

When the frequency is increased to 1000 cycles, the inductance has a reactance of 1000 ohms while the condenser has a reactance of approximately 100 ohms. With 10 volt supply, again there will be a current of .011 ampere in the circuit, but now there will be 11 volts across the inductance and but 1.1 volts across the condenser and load.

You can figure the voltage drop at various frequencies and will find the lower frequencies are passed on to the load with comparatively high voltage while the higher frequencies reach the load at greatly reduced voltages. In other words, the circuit allows low frequencies to pass with little loss but greatly attenuates the higher frequencies and therefore is commonly known as a "Low Pass Filter".

HIGH PASS FILTER

Using the same circuits, but connecting the load across the inductance, as shown in Figure 9B, the opposite effect is obtained. For convenience, we will say that "2L" and "2C" of Figure 9-B are numerically equal to "L" and "C" of Figure 2 and following the explanation of Figure 9-A, with a 10 volt supply at 100 cycles, there will be a drop of 1.1 volts across the inductance and load. At a frequency of 1000 cycles, there will be a drop of 11 volts across the inductance and load.

Thus, the higher frequencies are passed on to the load with little loss while the lower frequencies are greatly attenuated. The arrangement of Figure 9-B therefore is known as a "High Pass Filter".

When the load of Figure 9 is not infinitely large and carries a measurable current at "A", the inductance is in series with the load and thus causes but a small voltage drop loss at low frequencies, but a large voltage drop at high frequencies. For Figure 9-B, the condenser is in series with the load and causes a large voltage drop at low frequencies with but small drop at high frequencies. Therefore, the explanation given for voltages of different frequencies also holds true when the loads carry current.

T TYPE FILTER

The circuits of Figure 9 represent the simplest form of filters and, in practice, you will usually find a number of inductances and capacities arranged in different ways. The circuit of Figure 10-A is like that of Figure 9-A except a second inductance has been added and connected in series with

the load. Since the layout of the units resembles the letter "T" this circuit is known as a T type filter.

Because the inductances are in series with the load, the action will be similar to that of Figure 9-A and thus again we have a low Pass Filter. The action of the inductance in series with the load will cause a sharper attenuation of the higher frequencies in the T type than the simple type.

For a T type high Pass filter, the same general layout is used, but the parts are connected as shown in Figure 10-C. Here we have the circuit of Figure 9-B with a second condenser connected in series wth the load. This second condenser will cause a sharper attenuation of the lower frequencies, and for the most purposes, is an improvement over the simple type.

The circuits of Figure 10-A and 10-C are single section T type filters and a complete filter is often made up of two or more sections. Suppose two sections, like Figure 10-A were connected in series. There would be a total of four inductances and two condensers. Two of the chokes would be in series between the condensers, and to save space, they could be combined into one unit with twice the inductance. Thus a two section T type filter can be made of three inductances, or chokes, and two condensers, the outer chokes with half the inductance of the center one.

In much the same way, two sections of the T type high pass filter of Figure 10-C would be made up of three condensers and two chokes, the outer condensers having twice the capacity of the center one.

PI TYPE FILTERS

Another common arrangement of a low pass filter is shown in the circuits of Figure 10-B. Notice here, the choke is again in series with the load but has a condenser across the circuit on each side. Because the units here have a layout similar to the shape of the greek letter pi, "π", it is known as a "PI" type. Thus, the circuits of Figure 10-B represent a single section, Pi Type, Low Pass Filter.

Using a similar arrangement, in Figure 10-D, we have the circuits of a single section Pi Type, High Pass Filter with a condenser in series with the load and two chokes across the line.

A two section Pi type low pass filter is made up of two chokes and three condensers, the outer condensers having one-half the capacity of the center one, while a two section, Pi type high pass filter has two condensers and three chokes, the outer chokes having twice the inductance of the center choke.

FILTER CURVES

Another method of showing the action is by means of curves, and for Figure 10-E we have plotted the action of the low pass filters of circuits A and B. Starting with zero at the lower left, the frequency scale is along the bottom and the current scale at the left.

At zero and low frequencies, the current is high, but at some particular frequency, starts to reduce quickly. This is the "Cut Off" of the filter and at frequencies above the cut off, the current reduces rapidly to a comparatively low value.

The curve of Figure 10-F is laid out in the same way and shows the action of a High pass filter. At high frequencies, the current is high, but as the frequency is reduced to the cut off point, the current reduces rapidly, and for all practical purposes, there is zero current at low frequencies.

LOW PASS FILTER DESIGN

In the design of a low pass filter section, it is general practice to consider the cut off value to be two times the resonant frequency of the circuit. Therefore,

$$f_{\text{cut off}} = 2 \times \frac{1}{2\pi\sqrt{LC}} = \frac{1}{\pi\sqrt{LC}}$$

dividing π into 1 results in the constant .3183. For the low pass filter therefore, the formula becomes,

$$f = \frac{.3183}{\sqrt{LC}}$$

In which

f = Cut off frequency in cycles per second.
L = The inductance in Henries.
C = The capacity in Farads.

The value of the load connected to the filter is important and should be approximately equal to the impedance of the filter itself.

As explained in former Lessons, a transmission line has a capacity between its conductors, and any unit length will have a certain value of inductance even though it is not a coil. It is convenient to consider the electrical constants of a circuit "lumped" together, and for example, the low pass filter circuit of 10-B could represent a transmission line.

Any convenient length of a transmission line will have properties of inductance (L) and capacity (C), and such a network connected to a source of voltage, will have what is known as a "characteristic impedance" which is entirely dependent upon the values of L and C.

When the values of L and C are known, the impedance of the line or filter can be found from the general formula

$$Z = \sqrt{\frac{L}{C}} \qquad (2)$$

At this point we want you to accept the correctness of the expression for characteristic impedance as the derivation of the formula is rather involved.

The values of L and C employed in the above and following design formulas are the same as those shown in Figures 9 and 10. However, you must take into consideration the figure "2" and use it as indicated. That is, if C in the formula is 10 mfd., the values of the condensers in Figure 10-B would each be 10/2 or 5 mfd.

For an example solution, suppose we have a 200 millihenry choke coil and 2 mfd condensers connected as in Figure 10-B. "C" will then be equal to 2 mfd times 2 or 4 mfd and substituting in the formula, the cut off frequency will be --

$$f = \frac{.3183}{\sqrt{.200 \times .000004}} \quad \frac{.3183}{.000894} = 356 \text{ cycles}$$

To find the proper impedance for this filter to work into, we substitute in the second formula and have:-

$$Z = \sqrt{\frac{L}{C}} \quad \sqrt{\frac{.200}{.000004}} = \sqrt{50,000} = 223.6 \text{ Ohms}$$

Thus, we find the filter should work in a circuit with an input and output impedance of about 225 ohms and will have a cut off frequency of 356 cycles.

Very often, it is necessary to build a filter to work in a circuit with some definite impedance and therefore we must find the correct values of L and C. To do this in a general way, we will work with equations (1) and (2).

By squaring equation (2), we have

$$Z^2 = \frac{L}{C}$$

From which we know,

$$C = \frac{L}{Z^2} \text{ and } L = CZ^2$$

Substituting this value of C in equation (1)

$$f = \frac{.3183}{\sqrt{L \times \frac{L}{Z^2}}} = \frac{.3183}{\sqrt{\frac{L^2}{Z^2}}}$$

$$f = \frac{.3183}{L/Z} = \frac{.3183\ Z}{L}$$

Transposing these values --

$$L = \frac{.3183\ Z}{f} \qquad (3)$$

Following the same steps, but substituting the value of L from equation (2), in equation (1)

$$f = \frac{.3183}{\sqrt{(CZ^2) \times C}} = \frac{.3183}{\sqrt{C^2Z^2}} = \frac{.3183}{CZ}$$

Transposing these values --

$$C = \frac{.3183}{fZ} \qquad (4)$$

Suppose now we want to use a low pass filter in a 200 ohm microphone circuit and have a cut off at 350 cycles. For the proper values of L and C, we need only substitute in equations (3) and (4) like this --

$$L = \frac{.3183 \times 200}{350} = \frac{63.66}{350} = .1818 \text{ Henry}$$

$$C = \frac{.3183}{350 \times 200} = \frac{.3183}{70{,}000} = .00000454 \text{ Farad}$$

Working this way, we find an inductance of 182 Millihenries and capacities of 4.54 ÷ 2 or 2.27 mfd, will produce a low pass filter, like Figure 10-B, to work in a 200 ohm circuit and have a cut off of 350 cycles.

Of course, the odd values found this way cannot be purchased readily therefore you select standard sizes of the closest values, and substituting in equations (1) and (2) determine what effect they will have on the filter. In our former explanation we found a 200 millihenry choke and 2 mfd condensers would make a filter with a cut off at 356 cycles and an impedance of 223.6 ohms. This would be close enough to the above values for most practical applications.

HIGH PASS FILTER DESIGN

In the design of high pass filters, the cut off frequency is considered to be one half the resonant frequency, therefore,

$$f_{cut\ off} = \frac{1}{2} \times \frac{1}{2\pi\sqrt{LC}} = \frac{1}{4\pi\sqrt{LC}}$$

Dividing 4π into 1 results in the constant .07958 and the general formula for the cut off frequency becomes -

$$f = \frac{.07958}{\sqrt{LC}} \qquad (5)$$

The impedance of the filter remains as stated in Formula (2) and to find the proper values of L and C for a given load inpedance, we follow the plan explained for low pass filters.

Without repeating all the steps, for high pass filters,

$$L = \frac{.07958Z}{f} \qquad (6)$$

$$C = \frac{.07958}{fZ} \qquad (7)$$

To show you how these work out, suppose we again take the 200 ohm microphone circuit with a cut off frequency of 350 cycles.

Substituting in equation (6) and (7)

$$L = \frac{.07958 \times 200}{350} = \frac{15.916}{350} = .0454 \text{ Henry}$$

$$C = \frac{.07958}{350 \times 200} = \frac{.07958}{70,000} = .00000113 \text{ Farad}$$

Reducing these values to the more common units, the choke coil of Figure 10-C requires an inductance of 45.4 Millihenries and the condensers a capacity of 2 x 1.13 or 2.26 mfd. Commercially we might have to use a 50 millihenry choke and 2 mfd condensers and substituting in formula (5)

$$f = \frac{.07958}{\sqrt{.05 \times .000001}} = \frac{.07958}{.000223} = 356.8 \text{ cycles}$$

which is very close to our required value of 350 cycles. When substituting in equation (2),

$$Z = \sqrt{\frac{.05}{.000001}} = \sqrt{50000} = 223 \text{ ohms}$$

These explanations will give you an idea of how the different values are found and the methods apply to all types of filters explained in this Lesson. As a general rule, the T type filter is used for constant voltage circuits while the Pi type is used for constant current circuits.

TONE CONTROL CIRCUITS

The actions of series and parallel circuits containing inductance, capacity and resistance are used in many ways for controlling or improving the tone of audio amplifiers. For example, a low pass filter would reduce the higher frequencies and thus emphasize the lows while a high pass filter would reduce the lows and emphasize the highs. By making either, or both, of these adjustable, we would have a Tone Control.

In Figure 11, we have the circuits of one of the simplest and perhaps the most common type of tone control. The complete circuit is a single stage of a resistance coupled audio amplifier made up of the grid load R, bias resistor R1 and the plate load resistance R3. However, in addition to these units, there is the condenser C and the variable resistance R2 which make up the tone control.

Without taking C and R2 into consideration we will assume that the frequency response of this stage is perfectly flat. That is, both high and low frequency voltages will appear across the load R3, with equal amplitude, provided the input voltages are equal. Now, let's assume that C and R2 are connected in the circuit with the movable contact at the upper end of R2. This, in effect, takes the resistance out of the circuit and places the condenser C from the plate of the tube to ground.

As the reactance of a condenser varies inversely as the frequency, it will tend to provide a comparatively low reactance path for the high frequencies. Under these conditions, the frequency response of the stage is no longer flat and, at the high frequency end, there will be a dropping off in the amplitude of the voltage across R3. In other words, the high frequencies will be attenuated by an amount depending on the value of C.

Therefore, if condenser C were variable, the degree of the attenuation could be controlled. However, a variable condenser of the needed capacity is impractical but the same effect is obtained by the use of the variable series resistance R2. The action of R2, by changing its resistance, is to increase or decrease the total impedance of plate circuit which will have a greater effect at the high frequencies due to the low reactance of condenser C. In other words, R2 controls the authority of condenser C in the attenuation of the high frequencies.

In the design of a tone control circuit of this type, R2 has a resistance value several times greater than the capacity reactance of the condenser, at the lowest frequency chosen, in order that when the moving arm is at the lower end of R2, in Figure 11, there will be little, if any, of the higher frequencies attenuated.

You will also find the tone control of Figure 11 employed in the grid circuit, with the condenser C and resistance R2, connected in series from the grid to ground. The action however, is exactly the same as explained above.

The ohmic value of R2 will depend on the capacity of the condenser C and the impedance of the circuit in which it is placed. The common values vary between 50,000 and 500,000 ohms. The value of the condenser C will depend on the maximum attenuation desired and generally varies between .02 mfd and .006 mfd.

The circuit of Figure 11 will attenuate only the high frequencies, and to attenuate either the highs or lows, the circuit of Figure 12 is commonly employed. You will notice, that the amplifier stage is exactly the same as that in Figure 11, while the tone control is made up of the condensers C, C1 and C2 together with the variable resistors R2 and R4. The two variable resistances are "ganged", or controlled by the same shaft, and the broken line below R2 indicates an "open" while the solid line above R4 indicates a direct connection.

To use definite values, we will assume that R2 and R4 each have a resistance of 500,000 ohms while C is .02 mfd, C1 is .05 mfd and C2 is .00075 mfd. With the movable arm in the position shown in Figure 12, the only active parts are the condensers C1 and C2, connected in parallel, to form the coupling condenser to pass the signal to the grid of the next stage. We will assume that the values of these condensers are such that a flat frequency response is obtainable with the movable contacts as shown.

Suppose now, that the shaft of the control is turned so that the movable contacts are at the lower end of R4. Under these conditions, we have added the 500,000 ohms resistance of R4 in series with condenser C1 and have thus increased the coupling impedance for a given frequency. However, we still have the condensers C1 and C2 in the circuit and, as C2 is very small, the reactance will be so large at the low frequencies that but little signal voltage will be carried over to the grid of the following tube. However, the capacity reactance reduces as the frequency increases and thus the high frequencies will be carried over to the next stage with but little attenuation. Therefore, with these connections the low frequencies are attenuated.

If the movable contacts are at the upper end of R2, condenser C will be connected directly from the tube plate to ground and give exactly the same action as explained for Figure 11, thus attenuating the high frequencies. By placing the movable contacts anywhere between the extremities we have explained, the desired degree of attenuation of either the high or low frequencies can be obtained.

The circuit of Figure 13 is another method of controlling both the high and low frequency response but here we make use of tuned circuits containing resistance, capacity and inductance.

Tracing the circuit, an inductance "L" is connected in series between the plate and transformer primary while a potentiometer, "R2" is connected in series with a condenser "C", across the primary. The movable contact of the potentiometer connects directly to the plate of the tube.

With the potentiometer arm P at the top, or inductance end, of R2, the inductance L is shorted out of the circuit. All the resistance of R2 is in series with condenser C across the transformer primary. The value of R2 is high enough to prevent the condenser from attenuating the high frequencies which are carried over by the transformer to the following stage.

With the arm P at the botton, or condenser end of R2, condenser C is in parallel to the transformer primary and choke coil L while R2 is across the choke. This arrangement places a tuned circuit in series with the plate, producing greater amplification at and near the resonant frequency, while the added inductance of the choke tends to attenuate the higher frequencies. Thus, moving arm P one way will cut down the lows and increase the highs while moving it the other way will attenuate the highs and increase the lows.

RESONANT PLATE CIRCUIT

Not all tone controls are of the adjustable type and in Figure 14 we have a common circuit for increasing the amplification of the lower frequencies. We show only the circuits of the tube which feeds the push pull output stage although there may be several stages in the complete amplifier.

In the ordinary circuit of this type, the "B+" supply would connect directly to one end of the output transformer primary but here, the condenser C has been added in order to make the circuit resonant at some low frequency.

The signal in the plate circuit of the preceding tube is carried over through the coupling condenser and appears as a voltage across the grid resistance R. This voltage is thus across the grid and cathode of the tube, controlling its plate current.

There is a circuit from the plate of tube T1, through the transformer primary and condenser C to the cathode. This is like the circuit of Figure 2 and has values which make it resonant at some low frequency. For signals at or near this frequency, the reactance of the transformer primary and condenser C is very low, allowing a high current. This high current causes a greater voltage drop across the transformer primary and thus tends to increase the amplification of signals, at or near the resonant frequency.

A similar high voltage appears across condenser C which is also in the circuit C, R2, C1 and R1. Condenser C1 has a large capacity and is used to bypass high frequency currents around the B supply therefore R2 is necessary because the voltage drop across it keeps one side of the condenser C above ground potential.

The voltage across C therefore will cause current in the circuit made up of C, R2, C1 and R1, but as R1 is in the grid circuit, current through it will cause a voltage drop which

will be applied on the grid of the tube. Thus, the signal voltages in the plate circuit are fed back to the grid in the correct phase, increasing the signal voltage.

The reactance of condenser C will vary inversely with the frequency and thus this feed back action will take place only at low frequencies. At high frequencies, the reactance of C is low, there is but little voltage drop across it and therefore, no noticeable feed back.

The result of the action is a greater amplification of the lower frequencies with little or no effect on the higher frequencies.

BASS COMPENSATION

The characteristics of the human ear are such that, when sounds are reproduced at lower than normal volume levels, the low notes appear to be abnormally weak, while when the sound is reproduced at greater than normal level, the low notes appear to be abnormally loud.

In order to compensate for this, the manual volume control of many radio receivers and audio amplifiers is arranged so that, at low levels, the intensity of the low notes is not reduced as much as that of the higher pitched sounds.

Such a circuit is shown in Figure 15 and the arrangement is commonly referred to as "Bass Compensation". Tracing the circuit, we have the potentiometer R, which is tapped toward its lower end, and from the tap, the condenser C and resistor R2 are connected in series to ground. The movable contact of the potentiometer, being connected directly to the grid of the tube, allows any value of voltage across R, from zero to full potential, to be applied to it. Due to this action, the potentiometer is a volume control.

With the movable contact at the upper end of R, the full signal voltage is applied to the grid, and the part above the tap is in series with the parallel combination made up of C, R2 and the lower section of the potentiometer. Controls of this type are usually tapped at 30% of the resistance, and using a 1 megohm control, the upper section would have a resistance of 700,000 ohms while the lower section would have a resistance of 300,000 ohms. Therefore, with the movable contact at the upper end of the volume control, there would be little attenuation of any frequency.

However, as the arm is moved towards the tap, where maximum compensation occurs, the condenser forms a comparatively low reactance path for the high frequencies and thus they are attenuated. The resistance R2 is connected in series with C in order that there will not be too great a loss of the higher frequencies and also to fix the output level, when the volume control arm is set at the tap. In practice, using a 1 megohm control tapped at 300,000 ohms, with C having a capacity of .01 Mf., a fairly high order of compensation will occur when R2 has a value of 10,000 ohms. To reduce the compensation, it is only necessary to increase the value of R2.

Summing up the action of this circuit, at low settings of the volume control, the section of the potentiometer in use is shunted to ground through a resistance and capacity combination which has a lower impedance to high frequencies than to low frequencies and which thereby discriminates against the former. With the control set in the high position, there is little attenuation of any frequency.

COMPENSATED VOLUME CONTROL

If, in Figure 15, we place an inductance L in series with C and R, and make the circuit resonant at about 1000 cycles, where the ear has the greatest sensitivity, then the audio frequencies in this region are bypassed more than those at the higher and lower audio frequencies. This series resonant circuit is then a form of an acceptor circuit, sometimes called a "trap", and its effectiveness can be controlled by the value of R. Larger values of R will decrease the attenuating effect of the tuned circuit.

As this circuit arrangement gives an apparent boost of both the high and low audio frequencies, it is called a "Compensated Volume Control", in contrast with the bass compensated circuit of Figure 15. Insertion of the acceptor circuit provides a "loss", therefore the audio amplifier must be capable of supplying the needed additional amplification.

BASS BOOSTER

In Figure 16, we have the circuits of a simplified "Bass Booster". The name is derived from the fact that, instead of attenuating the highs in order that the low notes will be most pronounced, the low frequencies are amplified more than the highs to give a better control of the individual tone desired by the listener.

Checking the circuits of Figure 16, you will notice that the signal voltage is impressed across the volume control R. From here, however, it splits and one path is from the upper end of R to the grid of T1 while the other path is from the movable contact to the left hand grid of T2. Thus, we have what might be called a dual channel audio system.

Following the signal from the grid of T1, it will appear in the plate circuit made up of the tuned circuit L-C. From here, it is carried over to the potentiometer R2, by condenser C1, and impressed on the right hand grid of T2. Let us assume that the combination L-C is resonated at 30 cycles. From your earlier Lessons, you know that at this frequency, the circuit will offer maximum impedance and thus maximum voltage drop. As the frequency increases, or decreases, from resonance, the voltage drop across the circuit will also decrease. Under these conditions therefore, with the circuit resonated at 30 cycles, we have amplified the low notes to a much greater degree than the higher frequencies.

However, the original sound, of all frequencies, is impressed on the left hand grid of T2 and thus, in tube T2, we have not only the amplified bass notes but also the original sound. The next step is to "mix" the two and this is done by simply connecting the two plates of T2 together. From these plates, the resultant audio voltages can be amplified in the usual way.

TUNED PLATE BASS BOOSTER

A modified bass booster, not requiring the use of a separate tube, may be an arrangement whereby an audio frequency tuned circuit is placed in the plate circuit of a tube. Looking at Figure 11, suppose the condenser C is replaced by the tuned audio L-C circuit of Figure 16. Imagine also that R3 of Figure 11 is removed and instead of connecting the variable arm to ground, assume it is connected to B+. The plate load then becomes the tuned circuit and any desired portion of R2.

In practice it is desirable to place a fix resistor of about 25M to 50M ohms in series with the variable resistor in order to prevent excessive amplification at the frequency of the tuned circuit and to provide greater stability. The value of the coil L and the capacity of C will depend on the desired resonant frequency and also on the plate resistance of the tube.

If a tube with a high resistance is used, such as a high mu triode or pentode, L should have a high value of inductance -

say about 100 henries, and for an 80 cycle bass boost, C should be about .04 mfd, whereas 100,000 ohms resistance would be a satisfactory value of R2.

In operation, the audio frequencies at and near resonance of the tuned circuit will develop a greater voltage than frequencies above the resonant value, thus the bass boost is accomplished. The desired amount of accentuation can be controlled by R2.

TREBLE - BASS BOOSTERS

It may be desirable to boost both the high and low frequencies in an audio system, particularly if the program is being operated at low level.

In Figure 17 we show a resistance-capacity coupled stage which is basicly conventional in that the audio frequency voltages are applied to the control grid of the triode tube, and thus appear with greater amplitude across the plate load resistor R5. From this point and coupled through condenser C1, the proportion of the high and low frequency voltages appearing across the input to the following a-f tube will depend on the respective position of the arms on potentiometers R1 and R2.

If the tube is a low mu triode and its grid load, plate load, and cathode resistor with its bypass condenser are of conventional values, to give satisfactory high and low frequency boosting, the other circuit constants may be as follows: - C1 = .25 mfd, C2 = .0008 mfd, C3 = .006 mfd, C4 = .0005 mfd, C5 = .004 mfd, R1 = 500,000 ohm logarithmic control, R2 = 5 megohm linear control, R3 = 250,000 ohms and R4 = 50,000 ohms.

We will assume that the indicated position of the potentiometer arms R1 and R2 give "normal" operation of the circuit such that no tone control effect takes place.

If bass boost is desired, the arm of R2 is moved up which effectively shorts out the parallel network composed of C and part of R2 and therefore decreases the "opposition" to the low frequencies being applied to the following grid circuit.

Now assuming that R2 is returned to normal position, if high boost is desired, control R1 is moved to the left to decrease the shunting of high frequencies to ground through C3.

With R1 in normal position and bass attenuation is desired, control R2 is moved down which effectively provides a "loss"

circuit for low frequencies across its self, yet lets the high frequencies pass to the output terminal through C4 without appreciable attenuation.

High frequency attenuation is then provided by moving R2 to the right which decreases the opposition to high frequencies through condenser C3.

Resistor R5 is about 50,000 Ω in order that its output voltage remains essentially constant irrespective of the change of impedance made in the tone control section of the circuit. R3 and R1 are selected to determine the "high" and normal settings. As the circuit operates on the principle of introducing losses, the amplification of the tube is required in order to compensate for them.

It will be noticed that the basic principles of attenuation in the above described tone control is to provide a low opposition path to high frequencies, and a high opposition path to the low frequencies.

Other types of treble-bass control circuits sometimes used in higher priced audio systems consist of two or more tuned circuits acting as a portion of a load in a tube circuit and desirable accentuation is accomplished by means of series or shunt variable resistances.

AUTOMATIC TONE CONTROL

As you will learn later, it is possible to make a tube, operating under certain conditions, to exhibit properties of a condenser or an inductance. A simple application of this former feature is illustrated in Figure 18 where we show a tube and circuits which function as an automatic tone control.

The principle object of the circuit is to provide changing capacity effects across the portion of the volume control which supplies audio voltage to the succeeding a-f stage at changing volume levels. In other words, the circuit is designed to vary the high frequency audio response automatically in accordance with the strength of the signal in the receiver. When a strong signal is being received, the higher audio frequencies are permitted to pass, while in the case of a weak signal where the noise level is high and is composed largely of the higher audio frequencies, the action of the circuit is such that these frequencies are attenuated by the "condenser action" of the circuit.

The capacity between the control grid and cathode of the tube, acting as a conventional amplifier, is dependent on its mutual conductance. When the amplification of the tube is high, the input capacity of the tube is correspondingly high. When the gain is low, the input capacity is also low.

When a variable mu tube, which means one that the amplification factor varies with d-c grid potentials such as a 6K7, is connected conventionally as shown in Figure 18, and has a change of d-c bias applied from a suitable source in the receiver, then changing signal levels affecting the operating point of the tube serve to vary the input capacity of the tube in accordance with the strength of the signals being received. The input capacity appears as a shunting condenser, shown by the dashed lines, and when the capacity increases, the high audio frequencies are bypassed.

The condenser connected between the plate and control grid serves the purpose of broadening the range over which the input capacity varies as under the action of the d-c bias circuit. The purpose of the switch is to cut off the automatic tone control citcuit if desired. When the switch is open, no audio signals reach the tube and therefore it will have no tone control effect.

In this Lesson, we have given you an explanation of various types of frequency controls and, although you may run into variations of these, the principles will be the same. Therefore, be sure that you are familiar with these principles so that you will not have any difficulty understanding the action of any tone control.

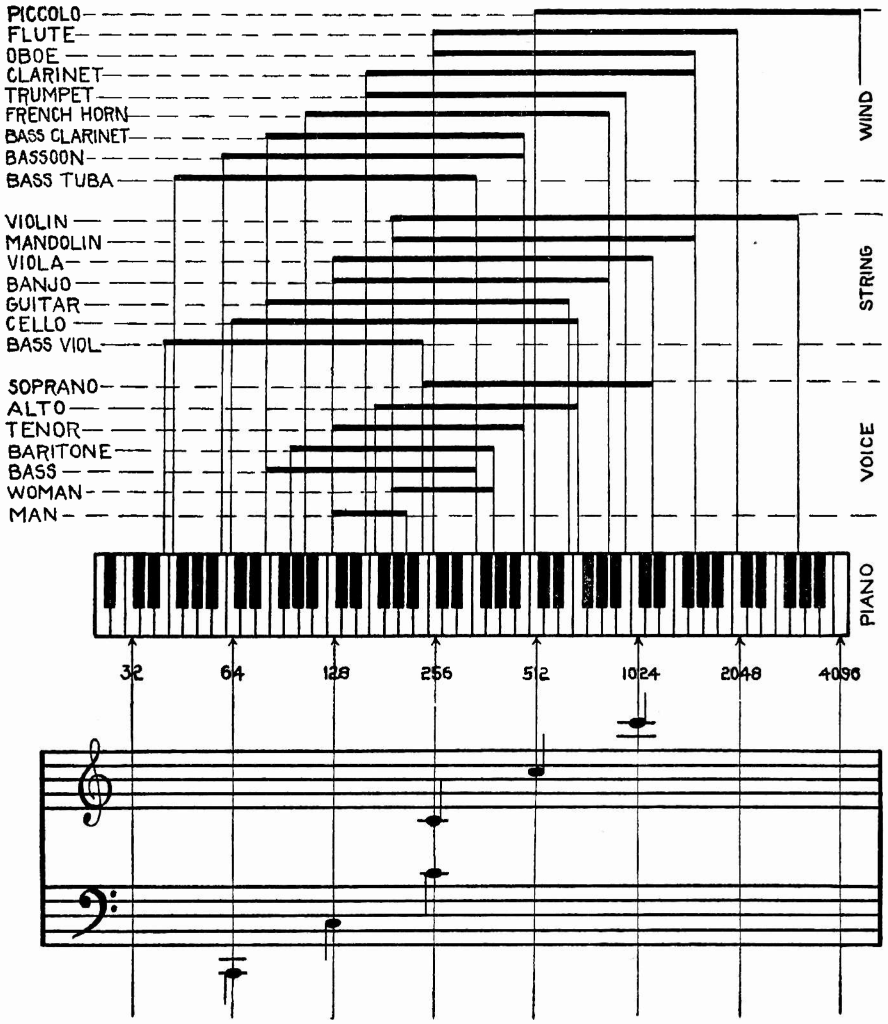
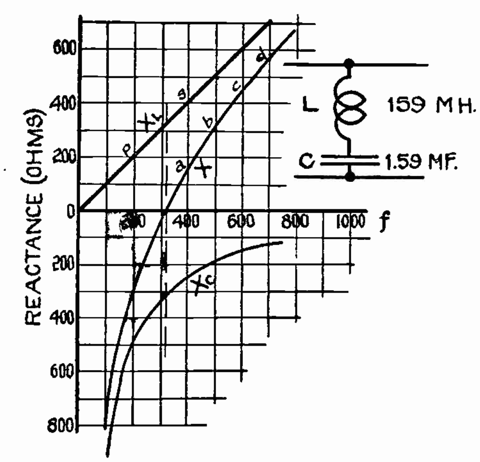


FIGURE 1



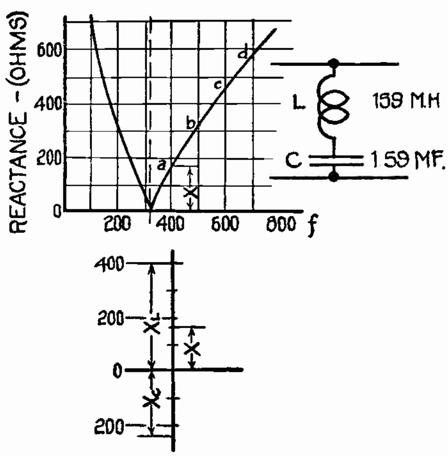


FIGURE 2

FIGURE 3

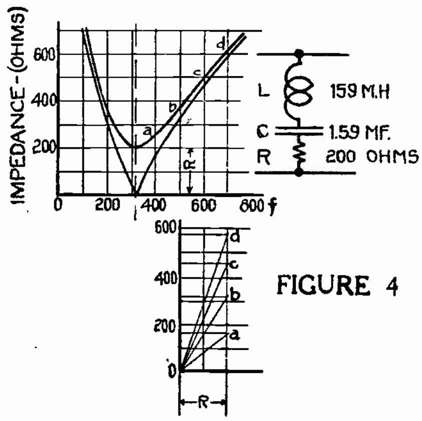


FIGURE 4

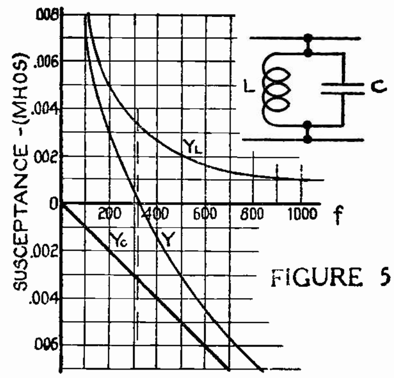


FIGURE 5

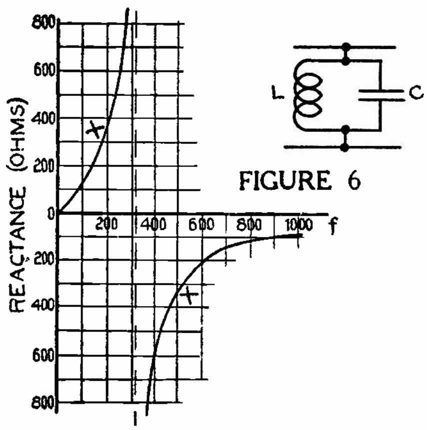


FIGURE 6

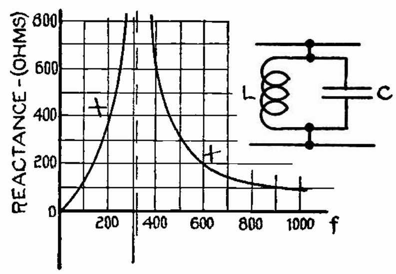


FIGURE 7

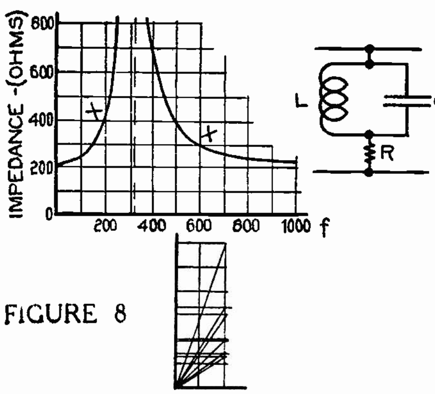


FIGURE 8

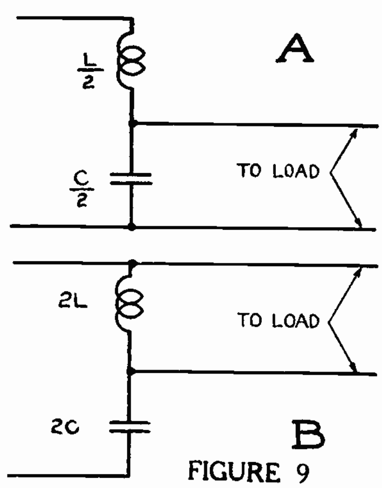


FIGURE 9

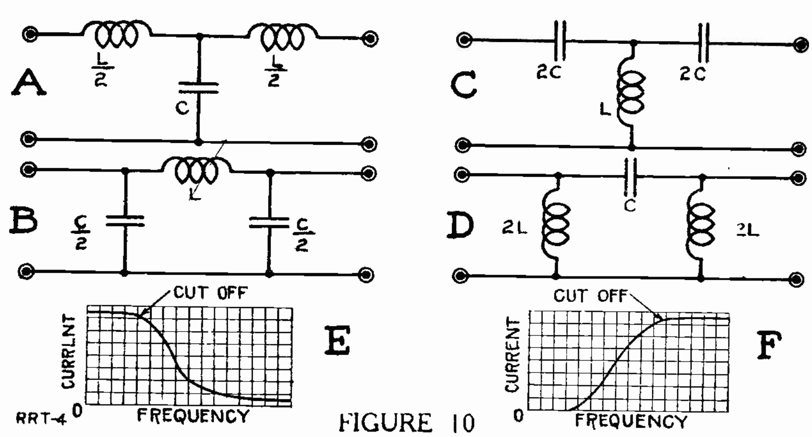


FIGURE 10

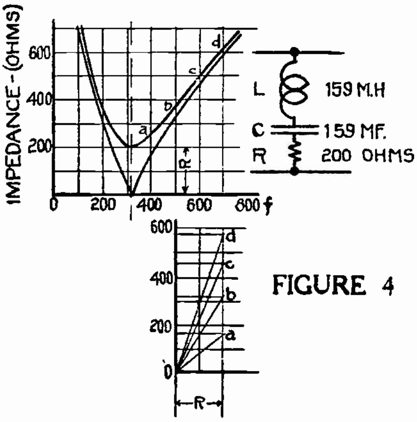


FIGURE 4

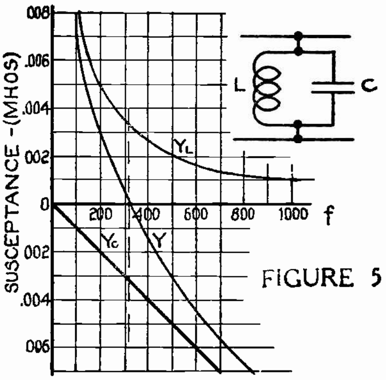


FIGURE 5

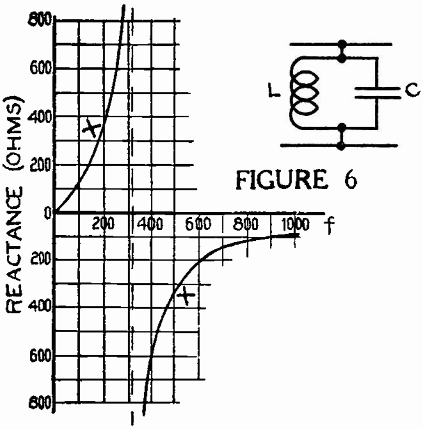


FIGURE 6

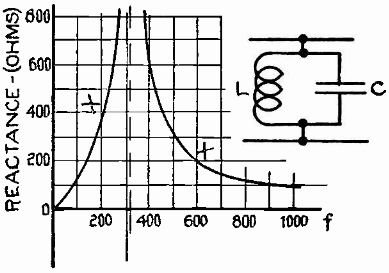


FIGURE 7

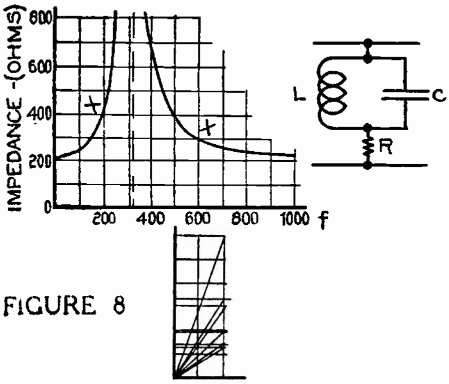


FIGURE 8

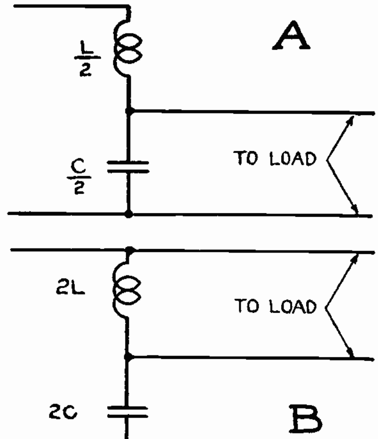
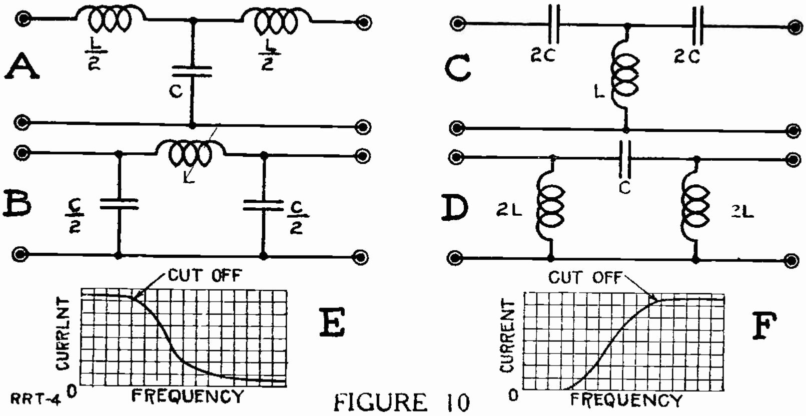


FIGURE 9



RRT-4

FIGURE 10

DE FOREST'S

TRAINING, Inc.

LESSON RRT-5

P. A. AMPLIFIERS

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DE FOREST'S

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LESSON RRT-5

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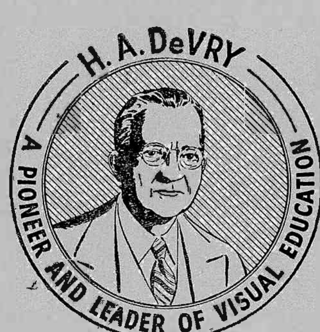

RADIO RECEPTION AND TRANSMISSION

LESSON RRT-5

P-A AMPLIFIERS

* * * * *

The question for each man to settle is not what he would do if he had means, time, influence, and educational advantages, but what he will do with the things he has.

--- Hamilton Wright Mabie

In an earlier Lesson, we explained the action of audio amplifiers are used to build up the amplitude of the sound signals of a radio receiver to a level where they would operate a loud speaker. In addition to this, the audio amplifier has many other applications such as to increase the volume of a phonograph and to amplify a speaker's voice so that he can be heard clearly all over a large hall or outdoor audience. Churches, Baseball Parks, Football Stadiums, Amusement Parks and most places where people gather are equipped with audio amplifiers to furnish music or announcements.

When employed for the above purposes, the audio amplifier is generally called a Public Address or "P-A" amplifier while the complete equipment, consisting of microphones, phonograph and radio tuner is referred to as a "P-A System". The action of a p-a amplifier is exactly the same as for the audio amplifiers explained in an earlier Lesson. However, greater power output and amplification, or gain, is required for p-a work.

Like the former lessons, we will explain the general types and give you the principal circuits so that you can understand any particular make or model.

PHASE INVERSION

In Figure 1, we show the circuits of a common type of push pull amplifier which was completely explained in an earlier Lesson. You will remember that as the control grid of one tube becomes more positive, in respect to the secondary center tap, the control grid of the other tube becomes more negative. Thinking of a negative polarity, when the voltage on one grid is decreasing, on the other it is increasing, and as they are in the opposite direction, or of opposite polarity, we say they are 180° out of phase.

In order to obtain the advantages of push-pull amplification, it is necessary that the signal voltages applied to the grids of the push-pull connected tubes are 180° out of phase. Several types of circuits which have been developed to supply signals at the required 180° phase displacement are known generally as "Phase Inverters".

The circuits of Figure 2 show a simple form of phase inversion and you will notice the grid circuit is very similar to that of Figure 1. However, the signal voltage developed across the load R1 is coupled to the grid circuit by the capacity C1. To fully understand the action, we want you to think of the upper end of L as the primary of a transformer with the lower part, below the tap, as the secondary.

With a voltage applied through the coupling condenser C1 to a grid of T2, a current will exist in the primary of L. This in turn will induce a voltage of the same frequency in the secondary which is across the grid circuit of T3. As the voltages in the primary and secondary of a transformer are considered to be 180° out of phase, the proper phase relationship between the voltages on the grids of T2 and T3 has been effected.

In push-pull operation, it is necessary that the voltages on the opposite control grids be of equal amplitude and this is accomplished by the proper turn ratio between the primary and secondary windings. In practice, the coil L is generally referred to as a center tapped choke while in the above application it really acts as an auto-transformer.

The circuit of Figure 3 shows another method of phase inversion and you will notice that the load of the input tube "T1" is divided into two parts of equal resistance, R3 in the cathode side and R4 in the plate side of the complete plate circuit. Resistance R2 and condenser C2 provide the grid bias in the usual manner, and merely fix the operating point of the tube. The grid of the output tube T2, coupled to the plate end of R4 through the condenser C3 and the grid load R5, completes its circuit to the cathode through R7. The grid of the output tube T3 is coupled to the cathode end of R3 through condenser C4 and the grid load R6.

To obtain equal signal voltages, R3 equals R4, C3 equals C4, and R5 equals R6. Also, due to the blocking action of the coupling condensers C3 and C4, the d-c voltage of the plate circuit of T1 need not be considered. Notice also that the grids of T2 and T3 connect to ground through the equal loads of R5 and R6.

With an a-c voltage on the grid circuit of T1, the action of the grid will cause variations of plate current. For example, suppose we assume an instant when the input voltage is in a direction such as to make the grid of T1 more positive, and cause an increase of plate current.

The point we want to bring out is the fact that an increase of current in the complete plate circuit of T1, made up of R4, T1, R2 and R3 connected across a constant source of "B" supply voltage, is possible only if one of the components decreases in value. The more positive voltage applied to the grid of T1 causes the tube to decrease its effective resistance and therefore greater current exists in the circuit just indicated. In accordance with Ohm's Law, the voltage drops across R3 and R4 will increase respectively. The voltage drop across tube

T1 decreases and thus there will be a decrease of voltage between its plate and ground even though equal increases of voltage drop occur across R3 and R4.

Before signal action takes place, condenser C3 has been charged to the original voltage between the plate of T1 and ground because one terminal of C3 is connected to the tube plate, and the opposite terminal is effectively connected to ground, there being no voltage drop across R5 at this instant.

The reduction of voltage between the plate of T1 and ground must be accompanied by reduction of voltage across C3, and its path of discharge will be through tube T1, R2, R3 to ground, and from ground up through R5 to the opposite plate of C3. This discharge current will develop a voltage drop across R5 and the polarity of the control grid of T2 will become more negative with respect to its cathode.

While condenser C3 is discharging, condenser C4 is charging to a greater potential because the voltage across R3 increases as a result of the increase of plate current. The path of charging current is from the upper end of R3, through C4 and R6 to ground or "B-". This charging current develops a voltage across R6, the polarity of which makes the control grid of T3 more positive with respect to its cathode.

Thus we have the correct conditions for push pull operation of tubes T2 and T3 as the changing potentials of the respective control grids are 180° out of phase. On the opposite alternation of signal voltage, the voltage drops across R3 and R4 will decrease as a result of decreased plate current in their circuit, and hence C3 will charge making the control grid of T2 more positive, whereas C4 will discharge making the control grid of T3 more negative.

It is also possible to achieve phase inversion by making use of the opposite relation between the a-c grid voltage and the a-c plate voltage of a tube. That is, when the signal voltage causes the grid voltage to become more positive, the plate voltage becomes less positive, both in respect to a common reference, usually the cathode. Thus, the action in the plate and grid circuits are 180° out of phase. By amplifying the signal in one tube and picking off from its output, a voltage equal to that of the input, we have a signal voltage of the right phase relationship.

Such a circuit is shown in Figure 4, and the output voltage of T1 is applied to the grid of T3 through the coupling condenser C3 and the grid load R5. A portion of the output volt-

age of T1 is also applied from the tap on R5 to the grid of T2. Then, the voltage output of T2 is applied, through the coupling condenser C4, and the grid load R6, to the grid of T4.

When the output voltage of T1 swings the grids of T3 and T2 in a positive direction, the plate current of T2 increases. This increases the voltage drop across the plate resistor R4 and therefore swings the plate voltage of T2 in a negative direction. Thus, when the voltage output of T1 swings positive, the voltage output of T2 swings negative. In other words, the voltage output of T2 is 180° out of phase with the output voltage of T1.

The voltage output of T2 is made equal to the voltage output of T1 by adjusting the tap on R5. For example, if the voltage amplification of T1 and T2 is 10, the tap on R5 is adjusted to supply one tenth of the audio frequency voltage across R5 to the grid of T2. Also, in order to balance the circuit, R3 equals R4, C3 equals C4 and R5 equals R6. Under these conditions, the a-f voltage across R6 is equal in amplitude to the a-f voltage across R5. Thus, the signal voltage inputs to the push pull grids of T3 and T4 are equal in amplitude and 180° out of phase.

In the above explanation of phase inversion circuits we have not mentioned the output connection to the push pull tubes or their bias resistances and capacities because the action is exactly the same as previously explained for the transformer type of push pull amplification. If these are not clear in your mind, go back and review the earlier Lessons on audio amplifiers.

SELF BALANCING PHASE INVERSION

Although the phase inversion circuits just described operate satisfactorily if the engineered constants of the various components do not change; after a period of service, a noticeable unbalance of operation may be observed. If, for example, resistor R6 in Figure 4 should change considerably in value, or the phase inverter tube T2 alter its characteristics, the predetermined value of the R5 tap would not be correct and unequal signal voltages would be applied to the grids of T3 and T4.

To overcome such faults, a circuit arrangement somewhat on the order of Figure 5 has been developed. You will notice the tube at the left is a duo-triode although we have labeled the separate triode sections as T1 and T2 in order to make references to the tube easier to follow. The input circuit and biasing arrangement has already been explained, and in fact, if you check carefully, the left section of Figure 4 up to

condensers C3 and C4 compares with the input section of Figure 5. Tubes T1 and T2 are essentially the same as tubes T1 and T2 of Figure 5.

We will start our explanations at that point where T1 has provided a positive signal between the control grid of T3 and ground, and a voltage will appear across R5 and R8 connected in series. That portion of the signal voltage across R8 is fed to the control grid of T2 where the tube reverses its phase and the amplified signal will be developed across R4, also R6 and R8, its polarity being negative at the control grid with respect to ground. Again we have the proper conditions for operating T3 and T4 in push pull arrangement.

The essential difference between the circuits of Figures 4 and 5 is in the action of R8. In Figure 4, the grid voltage for tube T2 was obtained from that portion of R5 between the tap and ground. In Figure 5, the grid voltage for tube T2 is obtained from the drop across R8 which is in series with R6 as well as R5. Thus, when current in R5 tends to make the grid of T2 more positive the out-of-phase current in R6 will tend to make it more negative.

For example, if the circuits constants should change to cause a higher voltage across R5 and R8, the increased output of tube T2 would cause a proportionally higher voltage across R6.

As the voltages across R5 and R6 are 180° out of phase, the higher drop across R6 would reduce the effective drop across R8 thereby reducing the output of tube T2 until the drop across R6 is equal to that across R5.

Hence the term "Self balancing" is properly descriptive of the action of this circuit, and changes in resistor values and tube characteristics will automatically be corrected by the degenerative or regenerative voltage fed back to the input circuit of T2.

INVERSE FEEDBACK

From the explanations of the earlier Lessons, you know that the impedance of a transformer varies with the frequency. That is, thinking only of the inductance, the reactance will increase as the frequency increases and decrease as the frequency decreases.

Therefore, if a transformer is employed to couple the plate of an output tube to a loudspeaker, the load impedance on the tube varies with the frequency. Thus, if the output tube is

a pentode or beam power type with a high plate resistance, the variation in plate load impedance produces considerable distortion as a result of the introduction of harmonic frequencies. Likewise, changes of signal frequency will cause the impedance of the voice coil to vary appreciably and hence it will reflect changes of load presented to the tube.

The common method of correcting this condition is by feeding back to the input, in the correct phase, a certain portion of the output voltage. Such an arrangement is generally referred to as an "inverse feed-back amplifier". However, it is also referred to as audio degeneration, degenerative or negative feed-back.

Back in the early Lessons we told you that in order to increase the signals of simple radio receivers, variations of plate voltage were fed back into the grid circuits, and the arrangement was called a regenerative detector. However, this circuit had a tendency to break into oscillation and was not very stable.

For audio amplification, this instability would not be satisfactory and, in order to reduce distortion due to a varying load impedance, a portion of the signal from the output stage is fed back to the grid circuit in the opposite phase relationship. This results in a decrease of amplification and is therefore known as "Degeneration".

To understand how this action reduces distortion, let us first consider an audio amplifier without inverse feedback or audio degeneration. In order to follow this explanation, it may help you to draw out the various wave forms on a separate piece of paper.

Let us suppose that a sine wave input voltage is applied to the grid of an output tube and that the a-f current in its plate circuit has a peak, or irregularity, in its positive alternation. Due to the fact that this peak is not apparent in the incoming wave, there is distortion in the output circuit. Remembering the action in a tube, this plate current will cause a voltage drop having the same wave shape across the load but this output signal voltage is 180° out of phase with the plate current. The reason for this phase relationship is the fact that a plate current increase causes an increase of voltage drop across the load. The voltage at the plate is the difference between the drop across the load and the supply voltage and thus, when the plate current increases, the plate voltage decreases and conversely, when the plate current reduces, the plate voltage becomes greater.

To correct this irregularity in the plate current waveform let us assume that inverse feedback is applied to the amplifier. With such an arrangement, a portion of the output plate voltage is fed back to the input circuit. As this feedback plate voltage is 180° out of phase with the input grid voltage, there will be a plate current component with the same distorted wave form as the feedback voltage but it will also be 180° out of phase with the original plate current waveform. Because of this fact, the current caused by the feedback voltage will tend to cancel the original current but, because it is of smaller amplitude, the result will only be a reduction in the total output plate current.

However, the irregularities in the output wave are also reduced, resulting in a reduction of distortion. This is because the distortion is fed back and is itself degenerated.

The use of negative feedback also reduces the Power Sensitivity which is defined as the ratio of the power output in watts to the square of the input audio signal in volts. Written as an expression,

$$\text{Power Sensitivity} = \frac{\text{watts (output)}}{\text{volts}^2\text{(input signal)}} \text{ mhos}$$

For example, if 2 volts (rms) is required at the input of an audio amplifier to produce 8 watts output, the power sensitivity is $8/2^2 = 8/4 = 2$ mhos or 2,000,000 micromhos.

Figure 6 shows the circuits of a single beam power output stage to which inverse feedback has been applied. The transformer T_i is of the audio input type and the resistance R1 with its bypass condenser C1, provides the grid bias voltages. R2, C2 and R3 provide a voltage divider with R3 in the grid, or input circuit so that the desired amplitude of feedback voltage can be obtained. The condenser C2 acts to block the d-c voltage on the plate but allows a path for the a-c signal. Transformer T_o is for coupling the output tube to a loudspeaker.

From your earlier Lessons, you know that the voltage drop across a resistance is proportional to its ohmic value and thus, neglecting any loss in C2, Figure 6, the feedback voltage will be equal to the total output voltage times the ratio R3/(R2 + R3). The amount of feedback voltage should be such that the distortion is satisfactorily reduced without too great a sacrifice of amplification.

Inverse feedback can also be applied to push-pull amplifiers as shown by the output section of the complete diagram for a P-A system of Figure 8 where the input transformer T_i has two separate secondaries, each with the same number of turns. It is necessary to have this arrangement because the grid

voltages are 180° out of phase and with a common secondary it would be impossible to obtain the correct phase feedback voltage to each grid. Here, the feedback voltage is obtained from voltage dividers across their respective plate circuits, the same as explained for Figure 6. With the exception of the inverse feedback feature, the action in the power output section of Figure 8 is exactly the same as for any other transformer coupled push pull stage.

Although we have given you the basic ideas involved in the application of inverse feedback, there are a multitude of circuit arrangements used in Radio and Electronic Equipment to achieve certain desired results. We believe it will be of help if further classification of these circuits be made known to you.

VOLTAGE FEEDBACK

In Figure 6, the feedback arrangement is the "voltage" type, and occurs when the "return" voltage is proportional to the voltage across the output load, and provides a reduction in the effective internal resistance of the amplifier.

CURRENT FEEDBACK

"Current" feedback occurs when the voltage fed back to the input circuit is proportional to the current through the output load or plate circuit and provides an increase in the effective internal resistance of the amplifier.

A few simple changes in the circuit arrangement of Figure 6 can be made to provide "current feedback". For example, suppose a resistor, which we will call R_X, is connected in series between the lower terminal of the primary of the output transformer and "B+". Then assume the upper terminal of R2 is removed from the plate and connected to the junction of R_X and lower transformer primary terminal. Output plate current passing through resistance R_X will develop a voltage drop, a portion of which will be fed back to the input circuit arrangement of R2, C2 and R3 as already explained for voltage feedback.

VOLTAGE-CURRENT FEEDBACK

Some circuits may even provide both voltage and current feedback, but the circuit of Figure 6 provides only voltage inverse feedback. Connected across R1, condenser C1 serves to maintain a steady d-c bias on T1. This means that when the signal is applied to the control grid of T1, plate current variations caused by the signal do not cause a change in the voltage drop across R1.

Consider C1 removed from the circuit, and when signal is applied, the control grid of T1 swings in a positive direction, plate current increases and the voltage drop across R1 increases in proportion. The direction of current through R1 is such that the polarity of the voltage across R1 is positive at the cathode end with respect to ground.

The resistor R1 is also in series between the control grid and the cathode, and with an increase of signal in a positive direction, the increased voltage across R1 produces greater bias on T1. With the signal increasing in a negative direction less plate current results and the voltage across R1 decreases, providing a reduction in the bias of T1. The signal voltage and the bias voltage across R1 will directly oppose each other, and it can be said that these voltages are 180° out of phase.

Since the actual signal between the control grid and the cathode of tube T1 is the combination of the signal voltage and the voltage across R1, it can be seen that the effective signal is reduced when C1 is not connected across R1. Removing condenser C1 from the circuit provides both voltage and current inverse feedback. Thus we have current feedback which results in degeneration, and this action may be called "Current Degeneration" or "Current Inverse Feedback".

The application of negative feedback is not limited to a single stage, and circuit arrangements are possible whereby feedback is carried forward over two or even three stages.

ADVANTAGES OF FEEDBACK

Inverse feedback can be applied to power amplifier tubes that do not draw grid current but is especially applicable to beam power tubes. This arrangement is not recommended for use in amplifiers drawing grid current because of the resistances introduced in the grid circuit.

Also, the feedback is not generally applied to a triode amplifier because the variation of load impedance with frequency does not produce much distortion in a triode stage having low plate resistance. It is, however, sometimes applied to pentode stages but, it is not always convenient. As we explained above, when inverse feedback is applied to an amplifier, the driving voltage must be increased to give full power output. Using a pentode, this driving voltage, for rated power output, may become so large that it is impracticable.

Because a beam power tube gives full power output on a comparatively small input voltage, inverse feedback is especially applicable to this type of tube. By means of inverse feedback the high efficiency and high power output of the beam power tube can be combined with freedom from the effects of varying load impedances. In addition to the above advantages of inverse feedback, greater stability is maintained, even with changes of tube characteristics and applied operation voltages.

Another advantage of negative feedback is the "flatter" and extended frequency response of the stage. For example, if an audio amplifier without inverse feedback amplifies a certain

frequency, say 300 cycles, 200 times, and a frequency of 1000 cycles, 500 times, the application of negative feedback will cause the amplification of these two frequencies to be more identical, much in the same way that distortion in the amplifier is reduced.

LOFTIN WHITE AMPLIFIER

The Loftin White amplifier employs a different type of circuit, called direct coupling. A circuit illustrating the basic principles of operation is shown in Figure 7, and you can see that it is similar to a resistance-capacity coupling circuit except the plate of the first tube is connected directly to the grid of the second without a coupling condenser. The commonly used resistances and coupling condensers are replaced by the single resistance "A".

In all of our former explanations we have told you that the plate of a tube must be positive in respect to the filament of a direct heating tube, or cathode, while the grid requires a negative bias. In Figure 7, the plate of tube T1 is directly connected to the grid of tube T2 and both will have the same potential with respect to point H which is B-. To provide the proper voltage relations between the grid, plate and filaments, it will be necessary to have the filaments at different potentials.

Tracing the circuits, you will see each tube filament connects to a separate secondary which has no direct connection to any other secondary. Thus, you can think of each filament circuit as being complete in itself.

The power supply filter arrangement is about the same as already explained, but we are more interested in the resistors which form the voltage divider. This divider is shown across the center of the diagram with its positive end at B+ and extends through resistor junction taps C, D, E, F and G to the negative end at H.

For the output tube T2, the plate circuit starts at the input terminal choke "L1", and goes up through the output choke L2, to the plate, across to filament and back through the center tap of the potentiometer to D. The voltage drop across the divider between B+ and D, less the slight d-c voltage drop across L2, will therefore be the plate voltage of the tube. The grid circuit is completed from the grid through resistance A to tap C of the voltage divider.

Suppose the specifications of the tube T2 show that with 250 volts on the plate there will be a plate current of 32 ma and a negative grid bias of 50 volts is needed. To make the explanation definite we will assume the voltage drop across L1 and L2 are negligible, and imagine these voltages are supplied and that there is a 200 volt drop across B+ - C and a 50 volt drop across C - D. That gives us a difference of 250 volts from the plate to the mid-point of the filament.

Now, if a 100 volt drop exists across resistance A, there will be a difference of 300 volts between its negative end and B+. As there is only a 250 volt drop across B+ - D, the negative end of A must be 50 volts negative to point D and therefore we have a 50 volt negative bias on the grid of the tube T2.

If this value of 50 volts is a bit difficult to verify, consider the equivalent situation of connecting the negative terminal of a 100 volt battery to the grid of tube T2. Suppose the positive terminal of the battery connects to point C. Point D is negative with respect to C, therefore assume a 50 volt battery connected between points C and D. The positives of these imaginary batteries are connected together and the voltage between point D and the grid of T1 is the difference between the 100 and 50 volt batteries, which is 50 volts.

Let us assume the operating values of the tube T1 are listed as 180 volts on the plate, 75 volts on the screen grid with a negative bias of 1-1/2 volts on the control grid and the suppressor grid connected directly to the cathode. Being of the heater type, the voltages for this tube are measured between the various elements and cathode.

From these figures, we see there must be a difference of 105 volts between the plate and screen grid. The plate is already 50 volts negative to tap D, therefore we need a drop of 155 volts across DE of the divider.

Next we need a difference of 75 volts between the screen grid and cathode but also desire an additional 15 volts to provide the necessary negative bias for tube T1 which we will explain later. Adding this to the 75 volts, there will be a drop of 90 volts across E-H of the divider. That gives us a total drop of 495 volts across the entire voltage divider between B+ and H.

With a 15 volt drop across H-K the cathode is really 15 volts positive as far as point H is concerned. We want a 1-1/2 volt negative bias on the grid therefore connect the grid return of the input circuit to tap G and have a 13-1/2 volt drop across G-H.

Checking back here and thinking of H as a reference point, tap K and the cathode are 15 volts positive. Tap G is but 13-1/2 volts positive to H, and therefore is 1-1/2 volts negative to the cathode of T1.

Tap E is 90 volts positive to point H, but the cathode is 15 volts positive to point H, therefore the screen grid is 75 volts positive with respect to the cathode. Adding the 155 volt drop across E-D, point D is 245 volts positive to H. Therefore the mid-point of the filament of tube T2 is also 245 volts positive to point H. Then there is a 50 volt drop across D-C which makes tap C 295 volts positive with respect to H.

The plate circuit of tube T1 connects at C but there is a drop of 100 volts across resistance A therefore the plate is 195 volts positive to tap H. The cathode is 15 volts positive, thus the difference in voltage between the plate and cathode is 195 minus 15 or 180 volts.

We have already explained the voltages for tube T2 but with a 200 volt drop across C-B+, point B+ is 495 volts positive to H. Still thinking of point H as zero potential, the mid-point of the filament of tube T2 or point D is 245 volts positive while the plate of tube T1 and the grid of the output tube T2 are only 195 volts positive. That is why, even though they are at the same potential, the grid of tube T2 has a 50 volt negative bias with respect to its filament while the plate of T1 is 180 volts positive to its cathode.

Between G and F there is a potentiometer with its adjustable contact connected to tap K through a fixed condenser. By adjusting the potentiometer to the proper point, there will be a difference in voltage across the condenser which will neutralize the a-c hum voltage caused by the ripple in the divider current. It is because of this feature that but one choke is used in the filter.

The operation of this circuit is similar to that of the other types of amplifiers. Changes of voltage on the control grid of the tube T1 cause changes of its plate current. The changes of plate current cause changes of voltage drop across resistance A and thus cause like changes of voltage on the grid of tube T2.

Another point to notice is the automatic grid control. As we explained before, the grid bias for the tube T1 is secured by the difference in voltage drops across H-K and G-H. Section H-K carries the plate and screen grid currents of tube T1 while

in addition to the bleeder current, G-H carries the plate current of tube T2. In the same way, the grid bias for tube T2 is secured by the difference of voltage drops across resistances A and C-D.

Suppose, because of a strong signal on the control grid of the first tube, the plate current increases. This will increase the voltage drop across resistance A and increase the grid bias on tube T2. An increase of negative grid bias reduces the plate current of T2, reduces the current through G-H and the voltage drop across it. This will increase the negative grid bias on the first tube and reduce its plate current. Because of this automatic control of bias voltage, the amplifier will handle a large range of input voltages with very little distortion.

Direct coupled amplifiers have major applications in Industrial Electronic Fields where the amplification of very low frequencies is desired. Although audio amplifiers of this type have excellent frequency response characteristics, they did not become popular because of the requirement of high plate supply voltages which made the unit more costly. In addition, variation of tube characteristics and component parts had a tendency to affect the voltage distribution within the amplifier and led to some instability.

The advent of more efficient tubes requiring lower operating potentials, the use of self balancing circuits, much like the phase inverter explained in this Lesson, open the field toward more common use of high fidelity, economical, and dependable direct coupled amplifiers.

P-A AMPLIFIER

In Figure 8, we show the schematic diagram of a complete P-A amplifier made up of the separate circuits which have been completely explained in this and preceding Lessons. However, we will give you a brief explanation of the signal paths from the various input circuits to the output transformer.

Starting with input circuit "Mike #2", the output of a microphone will develop a voltage across the grid load R2 and thus apply the signal to the control grid of T2. The bias voltage for this grid is obtained by the drop across R3, and its value is equal to the ohmic value of R3 multiplied by the sum of the cathode currents in T1 and T2. The signal voltage on the control grid of T2 will cause variations of plate current which, in turn, will vary the voltage across the load resistance R10. The voltage changes are carried over to the left hand grid of T3 through the coupling condenser C3 and the potentiometer R12,

which acts as the load for the left hand grid of T3 and also as a volume control for this channel.

The plate voltage on T2 is obtained from a tap on the voltage divider made up of resistances R11, R5 and R4. The screen grid voltage is also obtained from this divider but is tapped off between R5 and R4, and is thus at a lower potential than the plate. The bias voltage on the left hand grid of T3 is obtained from the voltage drop across R13.

With the signal applied to the left hand grid of T3, there will be a variation of current in the load resistance R15 and thus a voltage drop across it which is carried over to the control grid of T4 through the coupling condenser and grid load R18. This coupling condenser is made up of C8 and C9 so that the reactance can be controlled, to a great extent, by varying the position of the contact of R17. The combination of R14, R17, C6, C8 and C9 form a tone control which has been completely explained in an earlier Lesson.

The plate voltage on T3 is obtained directly from the output of the power supply filter choke "CH", through the series resistor R16 and the load R15. The condenser C7 is connected from the connection between R15 and R16, to ground and together with R16 is commonly referred to as a "decoupling filter", to prevent audio frequency oscillation tendencies.

In order to make the pentode tube T4 more stable, the screen grid and plate are connected together so that the tube operates as a triode. Thus, with the signal applied to the control grid of T4, there will be variations of plate current in the primary of the push-pull input transformer T_1. This will induce a voltage in the secondaries and thus the signal will be applied to the grids of the push-pull output stage.

The output stage incorporates inverse feedback which we explained in a former section of this Lesson. Therefore, we will offer no further explanation of the circuit at this time. However, there are two secondaries on the output transformer, both of which are tapped. This makes various output impedances available so as to match the impedance of different loudspeaker voice coils or transmission lines.

Now, let's go back and see what happens when the output of a microphone is applied to the "Mike #1" input channel. This will cause a voltage drop across R1 which is applied to the grid of T1. Like T2, this tube obtains its operating voltages from a divider arrangement and its bias from the common cathode resistor R3, with its bypass condenser.

Variations of voltage on the control grid cause changes of current in the load resistor R8. This, in turn, causes variations of voltage drop which are applied to the right hand grid of T3 through the coupling condenser C1 and the tapped variable resistance R9. This, of course, assumes that the movable arm of R9 is in its present position or somewhere between ground and the condenser C1. By changing the position of the arm of the potentiometer R9, between ground and the coupling condenser C1, the amount of signal voltage from this channel can be controlled. A signal, on the right hand grid of T3, is carried on through the succeeding stages, the same as explained for channel #2.

If the output of a phonograph pickup is applied across the "phono" input connections, there will be a corresponding voltage drop between the upper end of R9 and ground. Therefore, to apply this signal to the right hand grid of T3, it will be necessary to have the movable contact of R9 somewhere between its upper end and ground. The pickup feeds directly into the second stage because the output voltage is considerably higher than that of a low level microphone and therefore requires less amplification.

Now notice, with the movable arm of R9 in the position shown, the input signal to the right grid of T3 will be from the "Mike #1" channel, and when it is moved in the upper position, the input signal to the right grid of T3 will be from the "Phono" input. Thus, R9 not only controls the volume of these two channels but it acts also as a fader so that the signal from either channel can be applied to the right hand grid of T3. In changing from one channel to the other, there is no sudden cut-off but after the volume of one is reduced to zero, the volume of the other starts to increase. It is because of this gradual change, from one signal source to another that a control like R9 is commonly referred to as a "Fader".

Let us assume that a pickup is connected across the "Phono" input and the fader in a position to apply the signal to the right hand grid of T3. Also, we will assume that a microphone is connected to the "Mike #2" channel so that its output will be applied to the left grid of T3, through T2 and the coupling network.

Under these conditions, we have two separate and distinct signal sources applied to the respective grids of T3. However, because the plates of T9 are tied together, there can be but one value of signal current which will have a wave form dependent on the values of the two signals. In other words, the signals will mix and because this has been accomplished electronically, a circuit of this kind is known as an "Electronic

Mixer". Notice that not only the phonograph can be mixed with #2 channel but also channel #1 can be mixed with channel #2.

Possibly you are wondering about the advantage of such an arrangement and a good example is a piano accompaniment for a vocalist. The usual procedure is to place one microphone close to the piano and the other in a position so that the vocalist can be more or less at a distance from the accompanying music. By properly manipulating the controls, the most desired sound levels of each can be obtained.

Without a mixer, it would be necessary to use only one microphone and, unless two separate P-A systems were employed, it would be impossible to regulate the two signals separately in order to obtain the desired levels.

Earlier in this Lesson we mentioned that a complete "P-A System" was made up of the amplifier, microphones, pickup and a Radio Tuner. This latter unit was explained in the section on trf receivers, and the output of such a tuner can be impressed across the "Phono" input circuits of the amplifier of Figure 8. In this way, the level of the audio frequency signals in a radio receiver can be amplified to such an extent that it can be heard over a very large area. Thus, with such a setup, it is possible to provide not only local announcements, or entertainment but also radio programs and recorded selections.

In our explanation, we have not mentioned the power supply but, in checking over the circuit diagram of Figure 8 you will note it is of the conventional full wave type with a choke input filter circuit with condenser C14 and C15 of adequate capacity. A voltage divider, made up of resistances R25, R26, R27 and R28 is connected from B+ to ground or B-, and a tap between R25 and R26 provides the required screen grid voltage for the output tubes.

The connections of the resistors R26, R27 and R28 are brought out to a terminal board and their circuits are completed by the use of "jumpers", which are in reality only common conductors such as copper wire. This is done so that the field coils of electro-dynamic speakers may be excited when connected in series with desired terminal points.

For example, suppose that Resistor R26 has an ohmic value of 1000 ohms and its power dissipation is 10 watts. To connect in a speaker with a field coil of 1000 ohms which requires 10 watts for proper excitation, it will be necessary only to remove the "jumper" from between connections 5 and 6 on the terminal board and connect the field between terminals 5 and 7.

In this way, we have replaced R26 with the speaker field but, as they have equal resistance values, the other voltages of the circuit are not disturbed. When p-m dynamic speakers are used, the jumpers are left in place and the voice coils are connected to the proper impedance on the output transformer.

Summing up, the amplifier of Figure 8 has three input channels which are capable of handling two low level microphones and a phonograph or radio tuner. Also, it is possible to fade from the phono input to channel #1 and to mix either channel #1 or the phono with channel #2. The circuit also incorporates inverse feedback and a tone control, capable of attenuating either the high or low frequencies. The power supply is arranged so that the fields of electro-dynamic speakers can be excited and the output transformer has several taps so that various impedances may be matched.

CLASS A AMPLIFIERS

All the various amplifiers we have been explaining are called Class A because, in every case, the negative d-c grid bias voltage is equal to, or greater than the maximum signal voltage, allowing the tubes to operate on the straight portion of their characteristic curves. To explain this a little more completely we want to review the subject and, for Figure 9, have drawn several curves.

As we told you in the earlier Lessons, these curves are made by applying a steady voltage on the plate and then recording the values of plate current as the value of d-c grid voltage is varied.

Checking up on curve "A", you will notice with 2 volts negative grid potential there is a plate current of 3.75 ma. With 4 volts negative, the current has dropped to 1.75 ma and so on until, with 7 volts negative, the current is zero. Thus, we say there is plate current "cut-off" at 7 volts.

Suppose we adjust the grid voltage to negative 5 allowing a plate current of 1 ma. These are all d-c values and fix the operating point of the tube, as shown by the dot, giving the conditions in the usual amplifier when there is no applied signal.

Without changing these conditions, suppose an a-c signal voltage is impressed on the grid causing changes of grid voltage which in turn, cause changes of plate current. At the top of curve A, we show a 2 volt a-c signal which, starting from the bottom of the wave will be of the same polarity as the negative d-c grid voltage which will increase to a total of 5 + 2 or 7 volts.

As the total negative grid voltage increases from a value of 5 to 7, the plate current will decrease from 1 ma to zero but, as the a-c voltage reduces to zero, the grid voltage drops back to 5 allowing the plate current to return to a value of 1 ma.

The first alternation of signal voltage has thus caused a corresponding change of plate current as shown by the lower left shaded loop.

During the next alternation of the signal voltage, its polarity will be opposite to that of the negative d-c grid voltage which will decrease to a total of 5 - 2 or 3 volts. According to the curve, 3 volts negative on the grid allows a plate current of 2.75 ma and thus, during this alternation, the plate current will increase from 1 ma to 2.75 ma and return to 1 ma as shown by the upper left shaded loop.

The following alternations of signal voltage cause like changes of plate current and thus the signal is carried over from the grid to the plate circuit of the tube. However, on the curve of Figure 9A, you will notice that the lower loops, representing changes of plate current, are shorter than the upper loops although the alternations of signal voltage are all equal.

Because the changes of plate current do not faithfully follow the changes of signal voltage, there is distortion which spoils the quality of the reproduced sound. However, the action shown in curve A is merely another way of explaining the operation of a bias type of detector and we suggest you compare it with the explanations and curves given in the earlier Lesson on Detector Circuits.

In an amplifier, this distortion is objectionable but, being caused by the bend in the lower part of the curve, we can easily improve the action as shown in Figure 9-B. Here, we reduced the d-c grid bias to negative 3 volts, allowing a plate current of 2.75 ma and moving the operating point up into the straight portion of the curve.

Again we have a 2 volt signal and have shaded the loops which represent the changes of plate current. Because of the position of the operating point, the lower loops are nearly the same as the upper ones and the distortion has been reduced. Under these conditions, the tube operates as a class A amplifier.

There is nothing new here as we have already explained the action in the earlier Lessons but we want you to notice, with

no signal, there is a fairly large d-c plate current. When a signal is present, and the upper and lower loops of plate current are equal, the average value of plate current will be the same as with no signal.

Should we increase the signal to 3 volts, in curve B, the grid voltage would vary from -6 to 0 and because of the bend in the lower part of the curve, there would again be distortion.

Increasing the signal to more than 3 volts would cause the grid to go positive, allow it to draw current which really "robs" the plate circuit of some of its current, and again produces distortion. Thus, a class A amplifier not only requires a fairly large plate current but is limited as to the strength of signal it can handle without distortion.

Other causes of distortion would be improper plate loads and operating potentials. Longer and straighter characteristic curves are obtainable with larger values of plate voltage and greater values of load resistances.

Class A operation is characterized by low power output and low efficiency, for a given tube, but when properly operated, there is little distortion of the audio signal.

CLASS B AMPLIFIERS

To overcome these limitations and also secure more efficient operation, vacuum tubes can be operated under different conditions which are known as class B.

To explain the action, in Figure 9-C, we again have the curve of A and B but, by increasing the d-c grid bias to negative 7 volts, have moved the operating point down to plate current cut off. Thus, with no signal, there will be no plate current and the drain on the power supply is reduced.

At the upper part of C we show a 5 volt signal which, during the first alternation, increases the grid voltage from negative 7 to negative 12. As the current is zero at -7 volts on the grid, there will be no plate current during this alternation.

For the next alternation, the signal reduces the negative grid bias to -2 volts causing the plate current to increase from o to 3.75 ma as shown by the shaded loop.

The same action takes place for the following alternations with the results that there is plate current only during those alternations of signal voltage which reduce the negative grid

voltage. Checking back on the earlier Lessons, you will recall that when one alternation is cut off we really have a rectifier.

Working this way, a single tube would be of no use as an audio amplifier but, by using two of them, connected in the ordinary push pull arrangement, we have the conditions shown by curve D. Here, the upper half is a copy of curve C and the lower half another copy in the reverse position.

You can think of the upper part of this curve as representing tube T3, shown at the right of Figure 10, while the lower part of the curve represents tube T4.

As the signal voltage increases the negative bias on the grid of the upper tube, it reduces the negative bias on the grid of the lower tube and thus there is current in the plate circuit of first one tube and then the other.

For the complete action, the loops of curve D are about the same as those of curve B and thus the signal voltage is carried over to the plate circuits with but little distortion.

In curve B, the plate current varies from 4.75 ma to 1 ma for a change of 3.75 ma, with an average value of 2.75 ma. In curve D, the plate current varies from 3.75 ma in one direction to 3.75 ma in the other direction for a change of 7.5 ma with an average value of zero. Thus, using the same tubes, class B arrangement makes it possible to handle greater signal strength and, at the same time, greatly reduce the average value of plate current.

To handle even greater signal voltage, it is customary to allow the signal to drive the grids positive in respect to the cathode or filament. To prevent distortion under these conditions, the input transformer, Ti, of Figure 10, is designed to furnish the necessary power to the grid circuits. This power must be furnished by the plate circuit of the preceding tube which is called a "Driver".

The main difference between the operation of the tubes in class A and class B is the operating point but this brings up other problems. For class A, the average plate current, being of a constant value, can be used to provide the d-c grid bias voltage as explained in the earlier Lessons.

In class B, with the average plate current at a very low value, it is necessary to provide a separate source of grid bias voltage or else use tubes with an amplification factor high enough to cause approximate plate current cut off with zero grid bias voltage.

Class B operation of tubes introduces some distortion due to the curvature of the characteristic near plate current cut off. However, the push pull output connections tend to cancel the second or even harmonics introduced. The odd harmonics cannot be eliminated by push pull operation thus this factor limits the maximum undistorted power output which can be obtained.

The efficiency of class B operation is greater than that for class A. The reason for this is because each tube of a class B (push pull) circuit operates one half the time only, whereas tubes in class A have plate current in them on the full 360° of the signal cycle.

CLASS AB AMPLIFIERS

As the difference between class A and B action is mainly in the operating point of the tubes, other methods are in use which are a combination of both. For example, by operating under the conditions shown by curve A and combining two tubes, as shown by curve D, it is possible to obtain greater output than in straight class A amplification.

These combination types are given various names such as "AB1" "AA", "AAA" and so on, and in general, are class A amplifiers operating with "Overbiased" grids and do not draw grid current. In class AB2, the grids are so biased that with strong signals the amplifier operates in class B and draws grid current, while at low levels it operates as class A.

CLASS C AMPLIFIERS

Although used only in Transmitting circuits, the idea of the curve of Figure 9-C is carried still further and the negative grid voltage increased beyond the point of plate current cut-off. Under these conditions, there will be plate current only during a part of those alternations of signal voltage which reduce the negative grid voltage. Operating in this way we have a class C amplifier.

CLASS B CIRCUITS

In Figure 10 we have the circuits of class B amplifier suitable for installations requiring high output levels. Although we show but one, there is sufficient power output to drive a number of speakers.

As far as the actual connections are concerned, you will find little difference between Figure 10 and those previously ex-

plained for class A operation. However, keeping in mind the curves of Figure 9, there are several points which require explanation.

The input signal voltage is applied across the potentiometer R1 and is impressed on the grid of the tube T1. By adjusting the moving arm, the signal voltage on the grid can be varied, thus providing a volume control.

Tube T1 is resistance-capacity coupled to the tube T2 the same as in the class A amplifier previously explained. Notice here, the screen grid and suppressor grid of the T2 are connected to the plate which makes the tube operate as a triode. So far, we have nothing but the usual type of amplifier with each of the tubes self biased and operating in class A.

Connected as a triode, we will assume T2 has a power output of 1.25 watts and thus there is this amount of power available in the primary winding of transformer T1. Like the usual output transformer, the interstage or driver transformer, T_1 is designed with a secondary of comparatively low impedance in order that it will deliver power. In Figure 10, this output power is applied to the grid circuits of the push-pull output tubes T3 and T4.

Looking at these tubes, you will notice the screen grid is connected to the control grid and suppressor grid connects to the plate. Thus, we again have a triode but, with both inner grids acting as a control, the amplification factor is increased to a point which eliminates the need of a grid bias voltage. For that reason, the center tap of the secondary of T1 connects directly to the cathodes of the tubes.

Under these conditions, with no signal voltage, the plate current does not drop to zero but has a value of approximately 10 ma although during the positive peaks of signal voltage, this may increase momentarily to 200 ma. The low impedance of the input transformer secondary allows it to supply the grid circuits with the necessary current and thus overcome the distortion of class A amplifiers under similar conditions.

To furnish these large surges of plate current, without greatly reducing the supply voltage, the power supply and output transformer are of special design. The rectifier tube, of the mercury vapor type, has a very low internal resistance and the voltage drop across the tube does not increase to any great extent when heavy current is drawn.

The choke has a very low d-c resistance and thus the voltage drop across it is small. The output transformer primary also has a very low impedance, a low d-c resistance and wire large enough to carry the heavy plate current.

The other parts of the circuit do not differ greatly from the types previously explained and we mention the points above to prevent you from making the common mistake of trying to build a class B amplifier with parts designed for class A operation.

The present day selection of tubes and Electronic equipment make it possible to meet the requirement of almost any audio frequency amplification problem. The range of power output may vary from a fraction of a watt, as used in hearing aid amplifiers, to hundreds of watts, such as various equipment used in Military applications.

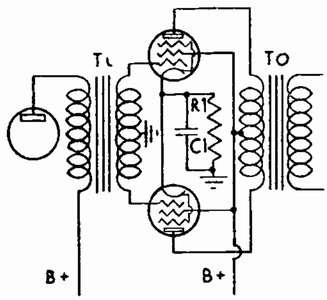

FIGURE 1

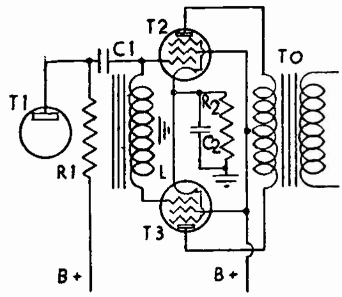

FIGURE 2

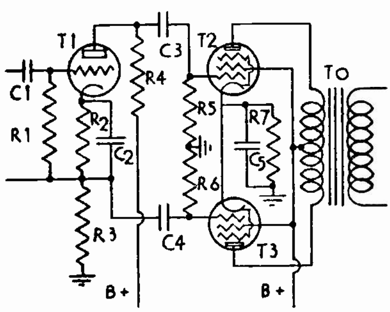

FIGURE 3

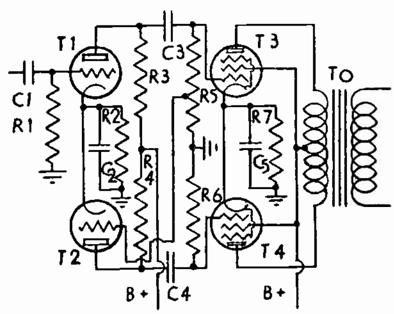

FIGURE 4

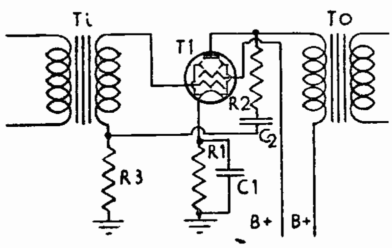

FIGURE 5

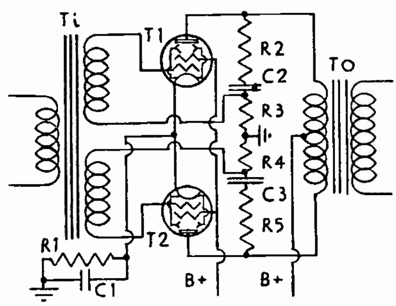

FIGURE 6

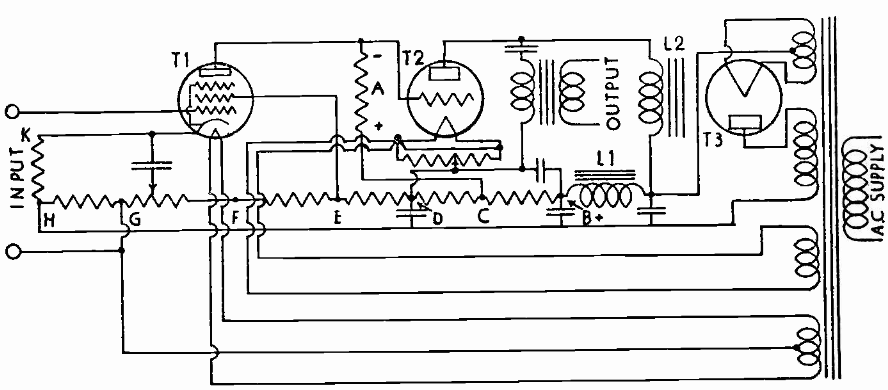

FIGURE 7

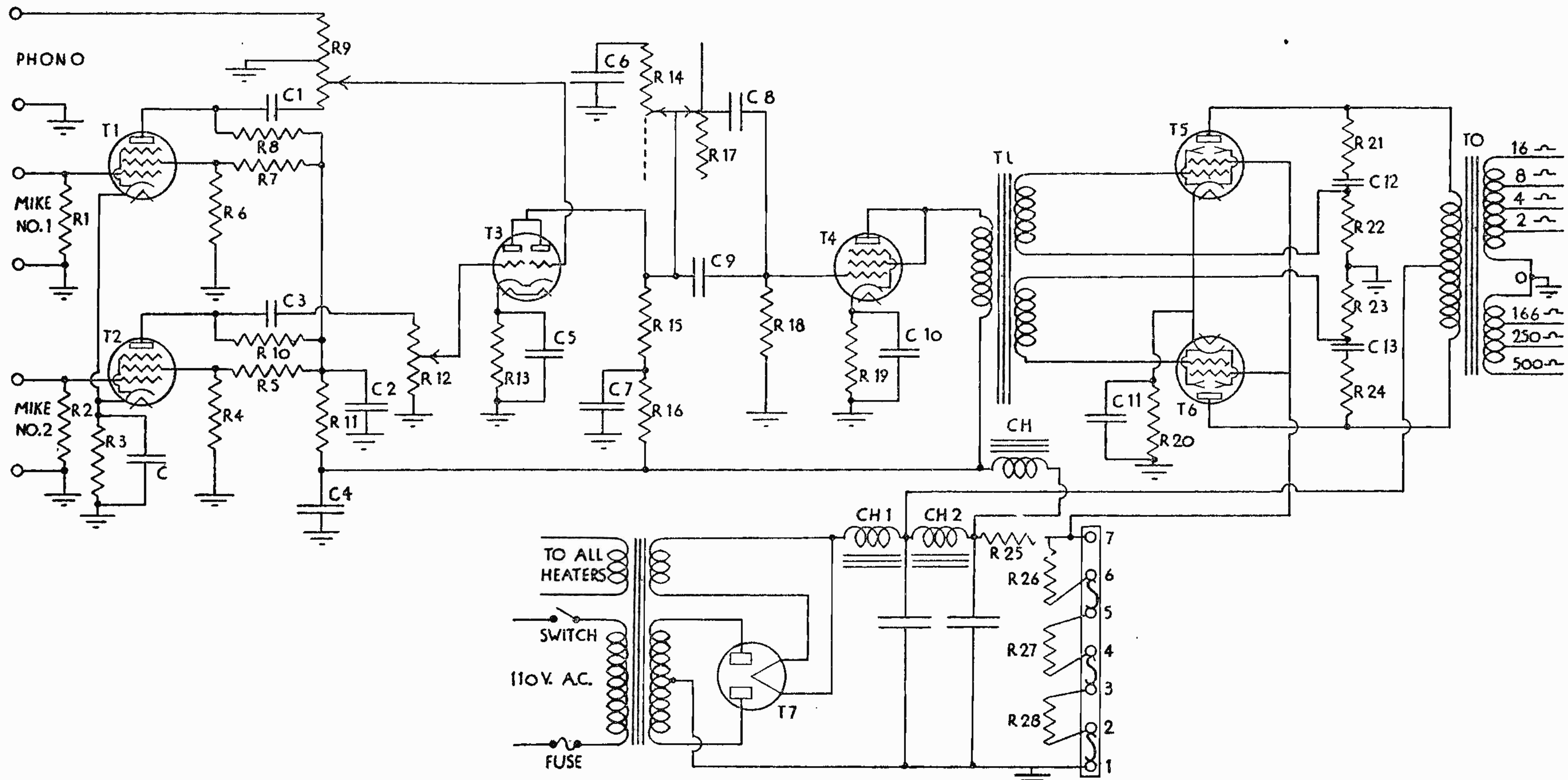
PHONO
MIKE NO.1
MIKE NO.2
T1
T2
T3
T4
T5
T6
T7
TL
TO
CH
CH 1
CH 2
R1
R2
R3
R4
R5
R6
R7
R8
R9
R 10
R 11
R 12
R13
R 14
R 15
R 16
R 17
R 18
R 19
R 20
R 21
R 22
R 23
R 24
R 25
R 26
R 27
R 28
C
C1
C 2
C3
C4
C5
C6
C 7
C 8
C 9
C 10
C 11
C 12
C 13
16
8
4
2
0
166
250
500
TO ALL HEATERS
SWITCH
110V. A.C.
FUSE
7
6
5
4
3
2
1

FIGURE 8

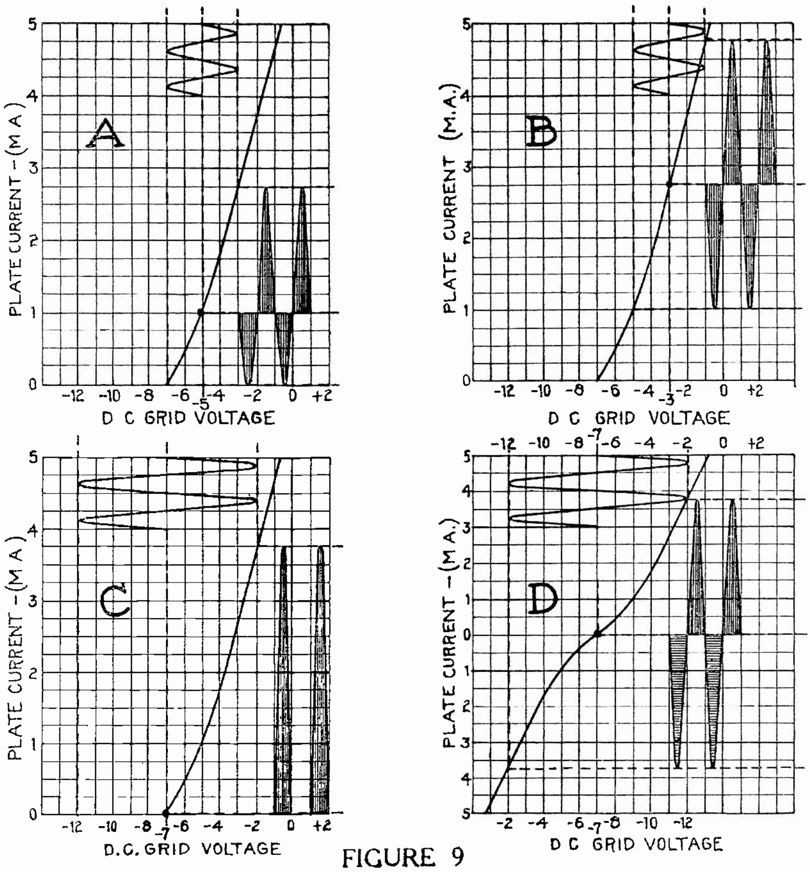

FIGURE 9

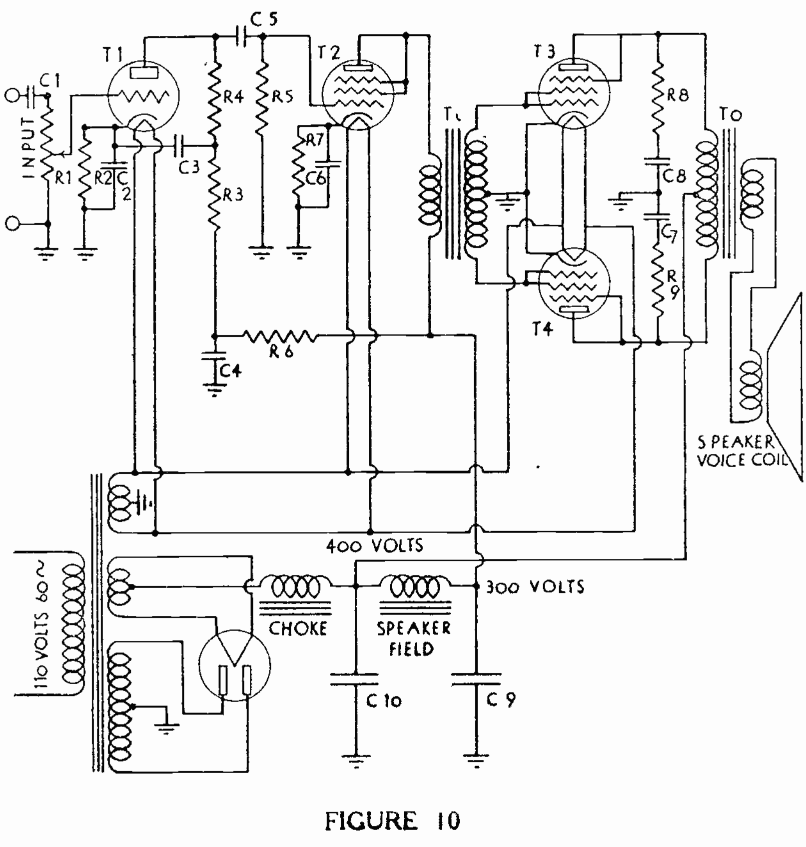

FIGURE 10

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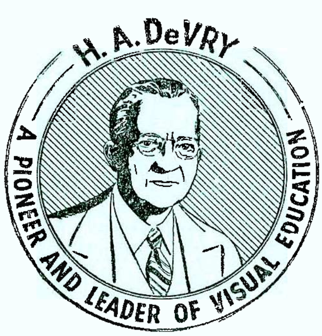

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A PIONEER AND LEADER OF VISUAL EDUCATION

RADIO RECEPTION AND TRANSMISSION

LESSON RRT-6

OSCILLATORS

To achieve what the world calls success a man must attend strictly to business and keep a little in advance of the times. The man who reaches the top is the one who is not content with doing just what is required of him. He does more. Every man should make up his mind that if he expects to succeed, he must give an honest return for the other man's dollar. Grasp an idea and work it out to a successful conclusion.

----- Edward H. Harriman

In many of our former explanations of Radio and Electronic equipment, we have talked about oscillators and oscillating circuits, telling why the action took place and what could be done to prevent it. For the popular type of superheterodyne receiver however, an oscillator is required to generate a frequency which will combine with the signal frequency and produce the beat or intermediate frequency.

While oscillation will prevent the proper operation of some circuits, it is required for others and therefore must be well understood. Also, as electronic equipment is becoming more compact and complicated, oscillators are being used more and more for service and repair work.

For example, Oscillators are used to align or phase radio receivers, to send code, to test Video, Radio and Audio frequency amplifiers for response and amplification. In the later lessons, we are going to explain these various tests, but now, want to give you an explanation of the operation and general construction of the most common types of oscillators.

FREQUENCIES

In the lesson on Tone Control, we gave you an idea of the common audio frequencies with the ranges of various instruments and voices. You will remember, the lowest note on the piano keyboard had a frequency of about 25 cycles per second.

Once again, we want to tell you that a cycle is a series of events which take place over and over in regular order. The earth travels completely around the sun in 365 days and a few hours, and keeps right on thus completing one cycle every year.

Every twenty-four hours, the earth makes a complete turn on its axis and thus completes a cycle each day. The minute hand on a watch, or clock, makes a complete revolution every 60 minutes and thus completes a cycle each hour. The second hand has a similar movement, but completes a cycle every minute.

Frequency is the number of cycles which take place in some given time, but the examples we have just given require a comparatively long time for each cycle and are not often thought of as frequencies. For the pendulum of a clock, or the balance wheel of a watch, the time required for each cycle is much shorter, but your eye can easily follow their movements.

If a cycle takes place in less than one sixteenth of a second, the human eye can not follow the changes because

of what we call "Persistency of Vision". That is why, by showing pictures at the rate of 16 each second, the common movies are possible. Modern sound pictures have been speeded up 50% but, next time you see one, remember there are 24 different pictures being shown on the screen each second. We mention them here only to show that your eye cannot follow frequencies of over 16 cycles per second, which is about the value your ear beings to respond.

For all of your electronic work, the frequency of any vibrating object, or medium, is stated in cycles per second. The usual a-c power supply has a frequency of 60 cycles per second. The frequency at which the speaker diaphragm vibrates is measured in the same way and the sound waves it produces are also measured in cycles per second.

In the earlier Lessons, Radio frequencies were also measured in cycles per second but, because of the high values, we used units of 1000 cycles called kilocycles, or 1,000,000 cycles called megacycles. A frequency of 1500 kc is the same as 1,500,000 cycles per second.

RECEIVER VS. OSCILLATOR CIRCUITS

Nearly all of our explanations, up to this Lesson, have been about circuits which received their signal, or high frequency energy, from some outside source. The ordinary Radio receiver obtains its controlling energy from the antenna circuit. The signals are amplified in the r-f stages but the frequency is not changed until the detector is reached.

For this Lesson, we are going to explain different tube circuits which produce their own radio frequency current and voltage. Because these circuits are much like those of Receivers, we will start our explanation with an ordinary r-f amplifier.

In Figure 1, we have the simplified circuits of the first two tubes of a tuned radio frequency receiver. Reviewing the action, passing radio waves induce an emf in the antenna and cause r-f current in the coil L. Coil L is inductively coupled to coil L1 which is tuned to the carrier frequency of the incoming signal by condenser C1. This tuned circuit is connected across the grid circuit of the first tube at X and Y.

When tuned to the frequency of the incoming signal, the circuit L1-C1 will be resonant and produce a comparatively large a-c voltage, of the signal frequency, across condenser C1. Thinking of the action slowly, step by step, at some instant,

point X will be positive and point Y negative. Then, the voltage reverses and X becomes negative while Y changes to positive. These changes take place for every cycle and thus an a-c signal voltage is impressed on the grid of the tube.

Following the action, the voltage impressed on the grid controls the plate current and causes it to vary with the frequency and amplitude of the signal voltage. Coil L2, in series with the plate, carries the plate circuit current and will thus set up a magnetic field which also varies with the frequency and amplitude of the incoming signal voltage. Coil L2 is inductively coupled to L3 and the action explained for L-L1-C1 is repeated in L2-L3-C3.

Due to the amplifying action of the circuit and tube, the voltage across C3 is higher than that across C1, but the frequency remains the same. Saying it in another way, we are really feeding the signal energy from tube T1 to tube T2 by means of the inductance L2.

FEED BACK

Suppose now we move coil L2 over so that its magnetic field will cut the turns of coil L1 instead of coil L3. Then, instead of feeding the energy forward to another tube we would feed it back to the grid of the same tube.

On account of the tube, transformer action and position of the coil, the voltage induced by the magnetic field around L2 may be in phase, or 180 degrees out of phase, with the incoming signal. If 180 degrees out of phase, the feed back voltage will oppose the signal voltage and reduce the grid voltage. To remedy this condition, the connections to coil L2 can be reversed, thus reversing the magnetic field and causing the feed back voltage to be in phase with the signal voltage.

REGENERATION

In the circuits of Figure 2, we have made these changes and coil L2 is inductively coupled to coil L1. Instead of the second tube, here we have a pair of headphones in the plate circuit with condenser C2 connected so as to by-pass the radio frequency current.

By placing a grid leak and condenser, R and C3, in the grid circuit and using the proper plate voltage, the circuits of Figure 2 are those of the simple one tube regenerative detector type of receiver. Because this circuit is a good oscillator, we will explain its action.

For use as a receiver, we do not want the circuit to oscillate and therefore arrange to control the amount of feed back energy. The early three circuit tuners placed L2 on the rotor and by changing its position, the amount of coupling was controlled.

If you have operated a receiver of this type you will remember how it squealed and whistled when the regeneration control was turned up too far. In fact, most listeners used the squeals to help in tuning the Broadcast Stations.

When the receiver is oscillating, and the rotor plates of condenser C1 are turned slowly, a very high pitched whistle is heard as a broadcast carrier wave is approached. Then, as you keep on turning, the whistle becomes much louder but the pitch is lower.

Still turning the condenser dial slowly, in the same direction the volume of the whistle stays the same, but you will notice the frequency of the sound decreases. Turning a little further, both the pitch and volume drop rapidly and then you hear nothing at all.

Turning the dial slowly, still in the same direction, the whistle comes back gradually, first as a low hum or buzz but rapidly increasing in pitch and volume . Then the volume remains about the same, but the pitch keeps getting higher until finally the volume drops off rapidly and again, nothing is heard.

In Figure 3 we have drawn the entire action in the form of a curve with the scale across the bottom laid off to show the frequency and the scale at the left to show the "Per Cent Audibility" or comparative volume.

Suppose the Broadcasting Station has a carrier frequency of 1000 kc. The receiver is oscillating and we turn the dial slowly until its frequency is 990 kc. That gives us a beat frequency of 10 kc or 10,000 cycles which we can just hear as a high pitched whistle.

As the tuning dial is turned slowly and the receiver is tuned to 995 kc, the beat frequency, or pitch of the whistle, is 5000 cycles and the curve shows the audibility or volume has gone up to 80%. Then, as we keep turning the dial, the receiver frequency goes up to 998 kc, giving us a beat note of 2000 cycles with 100% audibility. Turning the dial further, the receiver frequency goes up to 999 kc, making the beat note 1000 cycles; to 999.5 kc with a beat note 500 cycles and so on.

When the receiver reaches a frequency of 998.8 kc, the beat note frequency is 200 cycles, but the audibility is still 100%. However, as the receiver frequency is increased the audibility or volume of the beat note drops rapidly and at about 50 cycles, we cannot hear it.

To have a beat note of 50 cycles, with a signal frequency of 1000 kc, the receiver must be tuned to 999.95 kc so that when the whistle can no longer be heard, the receiver is tuned to almost exact resonance with the carrier wave.

Turning the condenser dial further and increasing the receiver frequency to 1000.05 kc, we again have a beat note of 50 cycles and hear it as a low hum or buzz. Tuning to 1000.2 kc, the beat note again has a frequency of 200 cycles with 100% audibility and the action, as explained for the other half of the curve, is repeated. The whistle disappears entirely when the receiver is tuned to 1010 kc, and again produces a beat note of 10,000 cycles.

The point we want to bring out here is that the regenerative whistle has two distinct points on the tuning dial, one just above and the other just below the station frequency. The silent spot between these points is the correct position to receive the station.

A SIMPLE ARMSTRONG OSCILLATOR

We mention this action because it is similar to some Electronic service work, which we will explain later, and also because it proves how a simple oscillator can be made. Take Figure 4 for example, where we have the circuits of Figure 2 but have left out the headphones and added the output coil, L2, thus changing the regenerative detector receiver into a usable oscillator.

The circuit of Figure 4 is known as an Armstrong oscillator and the action is exactly the same as that of Figure 2. That is, when the plate potential is applied there will be a surge of current through L1. This current will set up a magnetic flux which will induce a voltage in coil L, causing the grid voltage to change. A change of grid voltage will cause a change of plate current resulting in a change of induced voltage in L.

With the induced voltage fed back to coil L in the proper phase, continuous oscillation will result, the frequency of which will depend on L and C. The frequency, at which a circuit like Figure 4 will oscillate, can be determined by the formula,

$$f = \frac{1}{2\pi\sqrt{LC}}$$

When

f = frequency in cycles
C = capacity in farads
L = inductance in henrys

From the above formula, you can see that if either L or C is changed, the frequency of oscillation will also change. Thus, if L is fixed and C is variable, a certain band of frequencies can be covered, the same as in an ordinary radio receiver. As coil L2 is coupled to L, it will have an induced voltage of the same frequency as that in the circuit L-C, thus providing an a-c signal for external connections.

HARTLEY OSCILLATOR

Perhaps the most common oscillator circuit is the "Hartley" shown in Figure 5. You will notice that the circuit contains but one coil, which is tapped, and is common to both the grid and plate circuits. The tuning condenser C2 is across the complete winding and, being made variable, provides for a change of frequency.

The coupling between the plate and grid circuit is through the mutual inductance between the two parts, L1 and L2, of the tuning coil. A-c current in the plate coil, L2, induces a voltage in L1 which is impressed on the grid, amplified and again applied to the plate coil.

The supply voltage is connected to the midpoint of the coil and, since this would make the grid at the same positive potential, it is isolated, as far as d-c is concerned, by the blocking condenser C. The proper bias is obtained by current in the grid leak R, connected from the grid to the cathode.

The feed back between the grid and plate is adjusted by varying the position of the tap in respect to L1 and L2. If more turns are in the plate coil a greater voltage will be induced in the grid and so greater feed back from plate to grid circuits will result.

Voltages developed by this oscillator are made available for external use by the output connections from the upper end of C and ground. Notice that the upper output terminal is not connected directly to C but is made through C1, thus blocking the d-c from the output terminals.

There are many variations of Figures 4 and 5, being Armstrong and Hartley oscillators respectively, but almost invariably, the former will make use of a "tickler" coil, whereas the latter will provide a tapped coil arrangement.

PURPOSE OF GRID CONDENSERS

In the circuits of Figures 4 and 5 we show a grid leak and condenser which are used to provide a negative grid bias. Both circuits have a comparatively high plate voltage and, without a C battery, require the grid leak and condenser to cause a like effect.

Looking at Figure 4, when the tube oscillates, there is a small current in the grid circuit from the grid to the cathode through coil L and the resistance, or grid leak, R. The voltage drop across R, caused by this current, makes the grid negative in respect to the cathode. As the grid current increases, the voltage drop across R also increases, making the grid more negative and reducing the plate current.

Unlike the grid circuits of ordinary amplifier tubes, the grid of an oscillator is usually positive, in respect to the cathode, for a part of one alternation of each cycle and, as there is grid current only during these periods, the current in R will be pulsating.

Condenser Cl, which is considered as an r-f by-pass, will charge as the voltage drop across R increases and then discharge through R when the voltage drop decreases due to a reduction of grid current. The charge and discharge currents of condenser Cl thus act to reduce the variations of voltage drop across R and provide a more uniform bias.

While not critical, at the operating frequency, the reactance of Cl should be small compared to the value of R. Should the value of Cl be too large, it will not discharge completely, during the periods of zero grid current, and thus the voltage will build up and increase the negative grid bias to a value which will stop the oscillations.

When this happens, the grid current stops, the condenser discharges completely and the tube oscillates again until the above action is repeated. Technically, we speak of this condition as "Blocking" and while it is undesirable in most applications, it also is of benefit.

For example, if the values of Cl and R of Figure 4 are chosen so as to stop and start the high frequency oscillation, 50 to 5000 times a second, an audio signal will be produced. Saying

it in a more technical way, the grid leak and condenser will modulate the radio frequency oscillations at an audio frequency.

CRYSTAL OSCILLATOR

A great deal of publicity has been given to "crystal" controlled Broadcasting stations and because the crystal is part of an oscillating circuit, we are going to explain its action at this time. As we have previously told you, when a quartz crystal is compressed between two metal plates, a strain is set up which causes a difference of potential between the metal plates. An electrical voltage has been produced and we call it "Piezo" electricity.

In addition to quartz, Tourmaline and Rochelle salt crystals are also active in this respect. Also, when placed in an electrical field, these crystals have the peculiar property of expanding in one direction and contracting in the other.

When one of them is placed in an ordinary electrical field, it expands and contracts at the frequency of the impressed current. If the alternations of current occur at the natural frequency of the crystal, it expands and contracts so strongly that it may crack or break.

While quartz is much less active than other crystals, it has greater mechanical strength and can be ground to different thickness to change its natural period of vibration. You can think of a crystal much the same as a pendulum because it will always try to vibrate at its own frequency.

For example, there is a crystal in the grid circuit of Figure 6 and, if the plate circuit is tuned to a frequency slightly above the natural frequency of the crystal, the oscillation of the tube can be kept constant to within a small fraction of a kilocycle.

The action here is similar to that explained for Figures 4 and 5 but the feed back, from the plate to the grid circuit, is obtained through the grid-plate capacity of the tube.

When the plate circuit of Figure 6 is closed, the surge of plate current charges condenser C which tends to discharge through coil L exactly as explained for a resonant circuit. Here however, the action builds up a voltage across the plate and cathode of the tube and, through the feed back coupling of the grid-plate capacity, a voltage is impressed on the grid-cathode circuit and across the crystal.

Because of the metal plates, this voltage sets up an electrostatic field around the crystal, causing it to change shape slightly. As soon as this "surge" voltage diminishes, the crystal resumes its original shape but, in doing so, produces a voltage which is impressed on the grid-cathode circuit of the tube.

Following the ordinary tube action, this voltage is amplified in the plate circuit and some of the energy is fed back to the grid circuit as explained for the initial surge voltage. The action is then repeated and the oscillations build up until the tube is delivering its maximum output for the conditions under which it is operating.

In the ordinary oscillator, the frequency will vary because of changes in plate and filament supply voltage but, with a crystal control, the frequency of the oscillator is kept practically constant. That is why oscillators of this type are used in radio transmitting stations.

However, to keep the crystal frequency constant, the mechanical mounting pressure on the plates must not vary and the temperature must be kept at some exact value. For this reason the crystal is placed in a heat insulated box equipped with automatic temperature control.

The natural frequency of a quartz crystal is determined by its size and the greater the thickness the lower the frequency. In actual figures, it is close to 110 meters per millimeter. The crystals used in Broadcasting stations are from 2 to 5 millimeters thick and about 1 inch square. For the oscillator of Figure 6 we have a tuned plate circuit L-C and the crystal in the grid circuit; the natural vibration period of the crystal determining the oscillator frequency.

DYNATRON OSCILLATOR

In all of the former explanations of tubes, we told you that an increase of plate voltage caused an increase of plate current until a point of saturation was reached. But, if the grid of a three element tube has a higher positive potential than the plate, a different action takes place. Under these conditions, within certain limits, an increase of plate voltage causes a decrease of plate current, and seems to prove Ohm's Law is wrong. However, we know Ohm's Law is correct and think of a tube as having negative resistance.

The same action takes place in a screen grid tube when the screen voltage is higher than that of the plate. For example,

with 75 volts on the screen grid, 10 volts on the plate will cause a certain plate current. As the plate voltage is increased the plate current reduces because the secondary electrons emitted by the plate are attracted to the more positively charged screen grid but, at about 45 volts the current reaches its lowest value and then increases in the usual way as the plate voltage is increased further.

If the tube is used under these conditions, we say it is operating on its "Dynatron" characteristic and usually think of it as a dynatron. When a tuned circuit is placed between the plate and its supply, the tube will oscillate and we call it a "Dynatron Oscillator".

A circuit of this type is shown in Figure 7 and requires little explanation. The control grid circuit of the tube is completed through the adjustable resistance, R, of a potentiometer between the cathode and B negative. The tuned circuit could be placed in the screen grid circuit but the principle of operation is essentially the same in that condenser C alternately charges and discharges through inductance L.

The plate and screen currents pass through the potentiometer resistance R and cause a voltage drop. By adjusting the moving arm the control grid voltage can be regulated. The frequency of the Dynatron oscillator is controlled by the LC ratio in the tuned circuit and the strength of the oscillator by the potentiometer R.

We have explained the more basic type of oscillators in the foregoing sections, and want to mention that other forms, such as the Electron Coupled, Colpitts, Tuned Grid-Tuned Plate and Relaxation Oscillators will be covered in later assignments.

ALL WAVE OSCILLATOR

The oscillators that we have explained are fundamental circuits and, to show you a practical application, in Figure 8 we have the complete circuit diagram of an all-wave test oscillator or signal generator. The purpose of such an instrument is for stage by stage analysis of receivers and amplifiers and perhaps more common, for the alignment or phasing of tuned circuits. In fact, a signal generator is nothing more than a miniature broadcasting station so arranged that its output can be either an unmodulated or modulated carrier wave.

Checking through the circuits, you will notice three triode tubes, T1, T2 and T3 are employed. The grid and plate of T1

are tied together and the tube, connected across the high voltage winding of the transformer, acts as a half wave rectifier to furnish a d-c voltage for the plates of the other tubes. The choke coil "Ch" and condensers C8 and C9 form a condenser input filter to smooth out the pulsations from the rectifier.

Tube T2 operates as a tuned grid a-f oscillator, the basic circuit being much the same as shown in Figure 4, the frequency depending on the inductance of the secondary of transformer T and the capacity of condenser C7. Oscillation is obtained by the feedback action between the pirmary and secondary of transformer T. The purpose of T2 is to generate an audio frequency signal which is used to modulate the high frequency waves. In commercial signal generators, this frequency, usually 400 cycles, is brought out to separate "A-F" terminals as shown in Figure 8.

Tube T3 operates as a high frequency oscillator and, by using a number of separate coils with different inductances, a wide band of frequency coverage is obtained. The oscillator is of the tuned grid type with the grid coils L and feedback plate coils L2. The condensers C1 are trimmers across each grid coil and are employed so that the calibration of the oscillator can be maintained, whereas the main tuning capacity is condenser C.

You will notice that, for each wave band, coils L1 and L2 are connected in the proper circuits by push button switches shown directly below them. The shaded areas represent the movable switch contacts while the arrow heads represent the stationary contacts.

Looking at the left hand switch, the upper movable contact completes a circuit from the upper end of coil L1 to ground and, as the lower end of the coil is grounded permanently, the switch shorts it out of the circuit. The lower movable contact connects only to the lower end of coil L2 and thus does not complete any circuit.

When the button is pressed, both movable contacts shift down and make contact with the next lower stationary contact. Thus, the upper movable contact opens the ground on the upper end of coil L1 and connects it to the ungrounded terminal of tuning condenser C. At the same time, the lower movable contact completes a circuit from the lower end of the coil L2 to the plate of tube T3, thus placing this frequency band in operation. The other pairs of coils are connected in the proper circuits in the same way and the switches are ganged mechanically so that but one button may be depressed at any one time.

The output of this oscillator is from the plate of T3, through condenser C4, and the voltage divider made up of resistances R1, R2, R3, R4 and R5. By the use of switch S1, operating on the taps of the voltage divider and potentiometer R, any portion of the signal voltage from the oscillator can be obtained across the "R-F" terminals.

Now that we have explained the functions of the separate circuits, you are perhaps wondering how the audio frequencies, generated by T2, act to modulate the high frequency waves of T3. In Figure 8, this is accomplished by what is called plate modulation.

The output of an oscillator varies directly with the plate voltage and therefore, if the plate voltage of the high frequency oscillator, T3, is varied at an audio rate, its output will be modulated with a frequency equal to the rate of change of plate voltage.

That is just what is done and, with the left hand switch of Figure 8 depressed, the circuit from the plate of T3 is through the left hand coil L2 directly to the plate of T2. The plate of T2 is also connected to the output of the filter through the primary of transformer T. When tube T2 is oscillating, there will be a variation of plate current and thus a variation of voltage drop, across the primary of transformer T, which will cause a change of plate voltage on T2.

As the plate of T2 is connected to the plate of T3, its plate voltage will also vary causing the output voltage to change. As previously stated, this output voltage will vary with the change of plate voltage and, in this case, will depend on the oscillating frequency of tube T2. Therefore, with these connections, the high frequency output of tube T3 will be modulated with the audio frequency of T2. Switch S2 which closes and opens the plate circuit of tube T2, is incorporated so that the r-f output voltage may be either modulated or unmodulated as desired.

Most of the later models of commercial signal generators have a frequency coverage of at least from 100 kc to 30 mc (megacycles) or higher, with a calibrated dial so that any frequency between the above extremities can be obtained. Considering Figure 8 as having this coverage, we could say that the circuits represented a miniature broadcasting station, whose carrier frequency, either modulated or unmodulated, could be varied from 100 to 30,000 kilocycles.

RECEIVING WAVEMETERS

In many of our former explanations we have talked about audio and radio frequencies but have not told you how they are measured. A frequency meter, sometimes called a wavemeter, is commonly used to measure these frequencies. A simple type of wavemeter for the measurement of radio frequencies is shown in Figure 9.

The circuit is composed of an inductance L and variable condenser C. Coupled to coil L is another inductance L1, which carries the radio frequency we want to measure. By adjusting condenser C, we can tune the circuit LC to the frequency of the current in L1.

To be of practical value, we must add some device to the circuit in order to know when LC is tuned to resonance. While there are several methods, we have shown one of the simplest and have connected a small flashlight lamp in series with the circuit LC.

Thinking of the lamp filament, condenser C and coil L as a series circuit, you know that when tuned to the frequency in coil L1, the current in the resonant circuit will be high and therefore the lamp will light. When condenser C is tuned away from the resonant point in either direction, the current will drop and the lamp will go out. In this way, the lamp acts as an indicator and lights up brightest when the circuit LC is tuned to the frequency of the current in coil L1.

The looser the coupling between coils L and L1, the sharper the resonant peak and thus the more accurate the indicator. Using a wavemeter of this type, it is always best to start with a very loose coupling because, if close to an oscillating power tube, or near the antenna of a broadcasting station, the lamp will burn out when the circuit is tuned to resonance.

Instead of a lamp, a hot wire ammeter or thermo-micro ammeter can be connected in the circuit. Using a meter, as condenser C is tuned, the pointer will move up to some maximum reading, and then drop back. When the meter shows the maximum reading, the circuit is tuned to the frequency of the incoming signal.

The action of this type of wavemeter is the same as that of the resonant circuits we have explained in the earlier Lessons and the range of the circuit of Figure 9 will depend on the inductance of coil L and the maximum and minimum capacity of condenser C.

Using ordinary parts, variable condensers are built for a certain capacity which can not easily be changed. However, by

having a number of coils, with different values of inductance, and a switching arrangement similar to that of Figure 8, a wide frequency coverage may be had.

AUDIO OSCILLATORS

So far in this Lesson, we have explained only high frequency oscillators and the action of a wavemeter in measuring these frequencies. However, in electronic work there are many uses for an audio oscillator, such as providing a signal to check the gain and frequency response of an audio amplifier.

One of the simplest types of audio oscillators is shown in the circuits of Figure 10 and you will no doubt recognize it as a tuned grid type. The feed-back voltage is obtained from the cathode of the tube through the coil L2. The current in L2 induces a voltage into the grid coil L1 in the proper phase to cause oscillation.

Due to the fact that it is impractical to design a variable condenser for use at the audio frequencies, the fixed condensers C1, C2, C3 and C4 are employed to resonate the grid circuit at the desired frequencies. With the circuits of Figure 10, four separate audio frequencies are obtainable across the output terminal. Condenser C5 is employed to block the d-c plate voltage from the external circuit, while the potentiometer R controls the amplitude of the a-f output signal.

BEAT FREQUENCY AUDIO OSCILLATOR

In many cases it is desirable to have a continuously variable audio frequency over the entire audio band and, to do this, a little different method is employed. As will be explained in the following Lesson, when two different frequencies are combined, other frequencies which are the sum and difference of the originals, will result.

That is, if we combine 100 kc and 95 kc, the result will be frequencies of 195 kc and 5 kc. Now notice, that 5 kc is 5000 cycles which is in the audio band. Thus, if we have two oscillators, one with a fixed frequency of 100 kc and the other a variable frequency from 90 to 100 kc, it will be possible to obtain a beat note from 0 to 10,000 cycles, which covers the ordinary audio band.

That is the principle employed in a beat frequency audio oscillator and, in Figure 11, we show a simplified circuit. Tube T1, with its circuits, comprise the fixed high frequency oscillator while T2, with its circuits, make up the variable oscillator.

The coils L1 and L4 pick up the high frequencies from the two oscillators and impress them on the control grid of T3, which acts as a biased detector. The beat note will appear in the plate circuit of T3, which is resistance capacity coupled to the grid of T4. Tube T4 operates as an ordinary a-f amplifier and increases the amplitude of the beat note before it reaches the output terminals. The potentiometer R6 provides a control so the desired output can be obtained.

VACUUM TUBE VOLTMETER

In all of our explanations of test equipment so far, we have used a vacuum tube as a generator of audio or radio frequency. However, it can also be used to measure a-c voltage of any frequency, the current and voltage of audio or radio frequency amplifiers and the radio frequency resistance of coils or condensers. Used for any of these purposes, the tube and its circuits are called a "Vacuum Tube Voltmeter".

Back in the earlier Lessons, we told you how the ordinary types of meters were built and explained how they measured electrical effects rather than electricity itself. Also, you will remember that it required a measurable amount of current to operate the meter movement.

The main advantage of the vacuum tube voltmeter is that it has practically no effect on the circuit to which it is connected because of the extremely small amount of power required for its operation.

To test the many electronic circuits which carry very small values of current or voltage, the ordinary types of meters require so much power or add so much resistance they cannot be used. For this reason, the vacuum tube voltmeter is needed in every electronic laboratory or shop because it operates with minimum power.

Although there are many different circuits employed for vtvm's or vacuum tube voltmeters, they are all basically the same and, in Figure 12 we show a common type. Checking through the circuit, the input terminals are connected directly across resistor R. The grid of T1 is connected to the upper end of R, while its lower end connects to the cathode of T1 through a portion of the potentiometers R1 and R5.

In the plate circuit of T1 there is the load resistor R7, across which condenser C and the grid-cathode circuit of an electron ray type of tuning indicator tube T2 are connected. This is the "Magic Eye" type of tube used as a tuning indicator

in many models of radio receivers and the details of its operation will be described in a later Lesson.

The circuits of the power supply are conventional, with the filter made up of Ch, C1 and C2. A voltage divider, composed of R1, R2, R3, R4, R5, R6 and R9, is connected across the output of the power supply.

Now notice, the plate supply voltage for T2 is the voltage drop across R9, while the bias voltage on the control grid will be determined by the voltage drop across R7. In other words, the greater the plate current in T1, the higher the bias voltage on T2. As the plate current of T1 is from the supply to the plate, the upper end of R7 will be negative in respect to the lower end. Therefore, with a drop across R7, the grid of T2 will be negative in respect to its cathode.

The plate voltage of T1 is supplied by the voltage drop across R6 while its bias voltage may be anywhere from zero to the sum of the voltage drops across R2, R3, R4 and R5, the exact value depending on the settings of the three position switch and the potentiometers R1 and R5.

The circuit of Figure 12 operates on the principle that, for practical purposes, the plate current of a tube can be reduced to zero by applying a sufficiently high negative bias to the control grid. The point to which this negative bias voltage must be increased to reduce the plate current to zero is generally referred to as that negative voltage required to give plate current "cut-off".

To measure an input voltage, the movable contact of potentiometer R1 is set at the extreme right position. Then, with no voltage applied to the input terminals, the potentiometer R5 is adjusted until the bias on the control of T1 is such that there is no plate current. This condition is indicated by a maximum shadow angle in the indicator tube T2. This maximum shadow angle is, of course, caused by the fact that with no current through R7, there will be no difference of potential between the grid and cathode of T2, which means no negative bias on the control grid.

The voltage it is desired to measure is then applied across the input terminals. With the polarity as shown, this will decrease the negative bias on the control grid of T1 by an amount equal to the input voltage. This condition will cause plate current in T1 and is indicated by the closing of the shadow angle on the indicator tube.

Now, without moving R5, the bias is again increased, by adjusting R1, until plate current cut-off is reached and indicated by the maximum shadow angle on T2. Here is the point, in order to obtain plate current cut off, when a voltage is applied, it is necessary to increase the bias voltage to a value equal to the applied voltage and thus balance out its effects. Therefore, the increase of bias voltage must be equal to the peak value of the applied voltage. Under these conditions, a suitable d-c voltmeter connected as E in Figure 12, would read the increase of bias voltage, which is, in effect, the peak input voltage.

With an arrangement of this kind, either peak a-c or d-c voltages may be measured without taking any noticeable energy from the circuit under test. In a simple sense, it might be considered that the unknown voltage is compared to a known voltage, the vacuum tubes merely serving as indicators to tell when the two are equal.

The highest voltage which can be measured is that equal to the voltage applied across the potentiometer R1. It would seem then that from a standpoint of voltage range a high voltage across the potentiometer would be desirable; however, the difficulty in measuring low voltages accurately when the voltage across the potentiometer is high, influences the choice of this voltage.

The inaccuracy in measurement at low voltages arises from the change in bias voltage for a given percentage rotation of the potentiometer. When the potentiometer voltage is high, the bias change will be high even though the rotation is slight; hence, the vtvm will be difficult to adjust for low voltage measurements. To clarify this point, assume that the drop across the potentiometer is 100 volts; a one percent rotation of the control will then change the bias 1 volt.

If the voltage being measured is 2 volts, an error of only one percent in the potentiometer adjustment creates a 50 percent error in the measured voltage. If the voltage across the potentiometer were reduced to 10 volts instead of 100 volts, a one percent error in the potentiometer adjustment would cause only a 5 percent error in the measured voltage. It can be seen then that for greatest accuracy the voltage across the potentiometer should be roughly that of the voltage being measured.

This factor has been taken into consideration in the circuit of Figure 12 in which a tapped voltage divider provides three

different voltages which are applied to the potentiometer R1 by means of the three position switch.

The circuits of this lesson have been employed merely to show you how these units operate and have not been designed for constructional purposes. Although they will operate according to the explanations, they have been simplified to such an extent that we do not recommend these circuits be used for building test equipment.

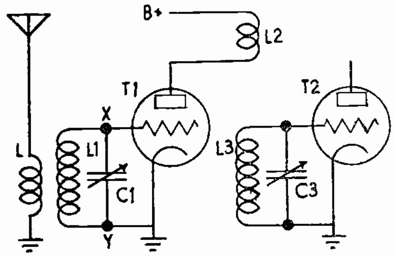


FIGURE 1

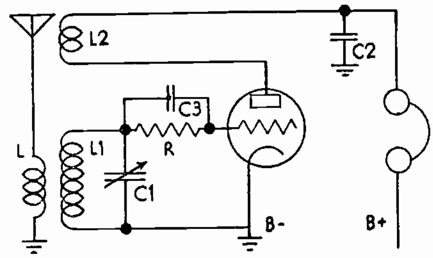


FIGURE 2

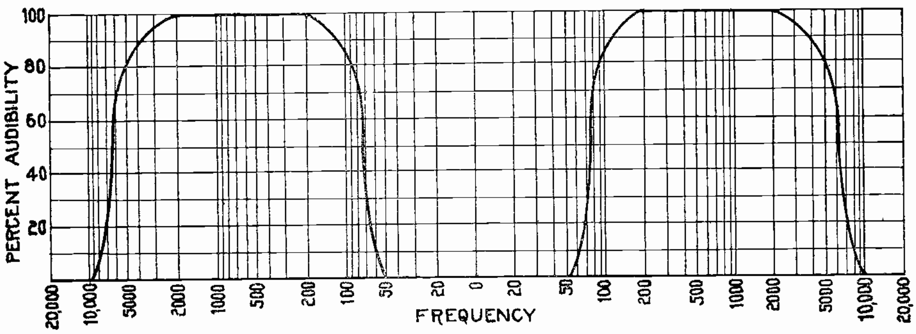


FIGURE 3

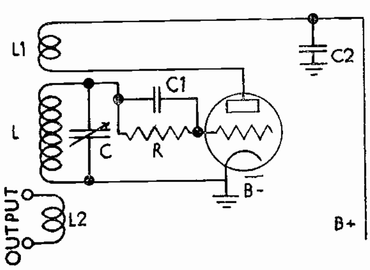


FIGURE 4

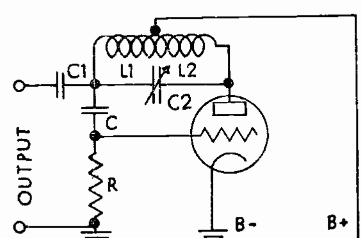


FIGURE 5

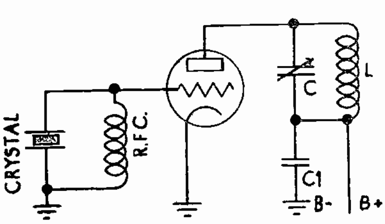


FIGURE 6

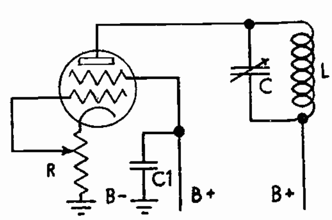


FIGURE 7

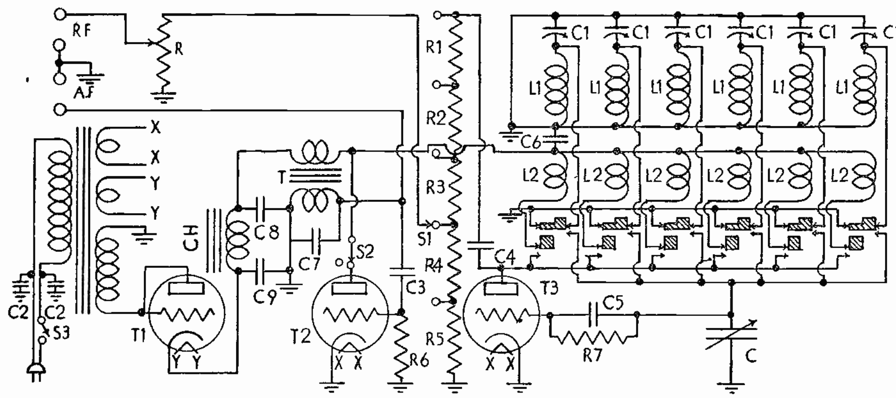


FIGURE 8

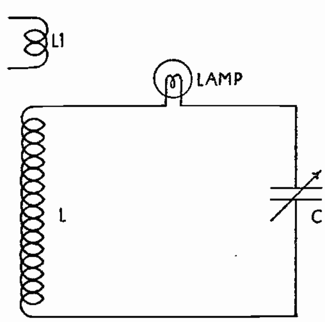


FIGURE 9

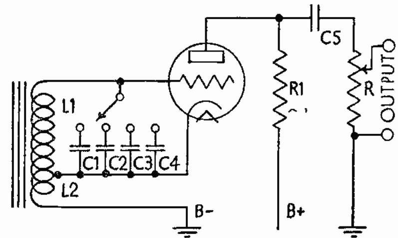


FIGURE 10

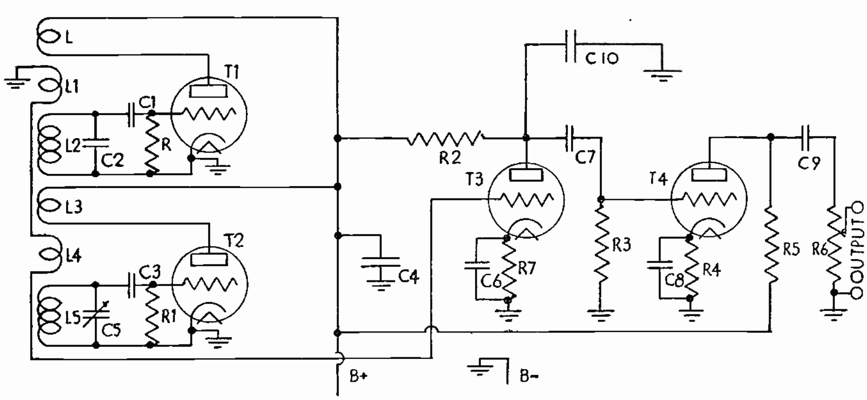
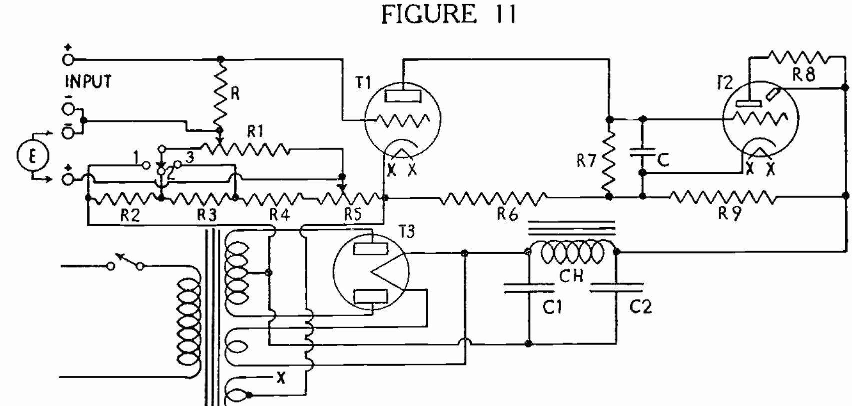


FIGURE 11



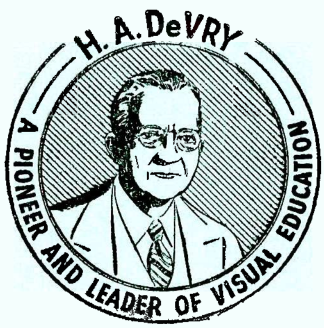
RRT-6

FIGURE 12

DE FOREST'S
TRAINING, Inc.

LESSON RRT-7
SUPERHETERODYNE RECEIVERS

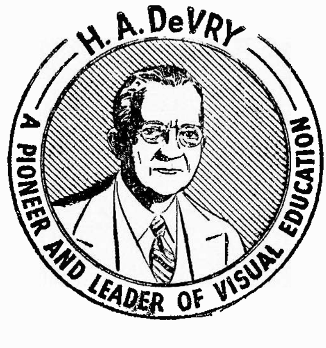
• • Founded 1931 by • •



DE FOREST'S
TRAINING, Inc.

LESSON RRT-7
SUPERHETERODYNE RECEIVERS

Founded 1931 by



RADIO RECEPTION AND TRANSMISSION

LESSON RRT-7

SUPERHETERODYNE RECEIVERS

* * * * *

Twelve Things to Remember-- The value of time; The success of perseverance; The pleasure of working; The dignity of simplicity; The worth of character; The power of kindress; The influence of example; The obligation of duty; The widsom of economy; The virtue of patience; The improvement of talent; The joy of originating.

--- Marshall Field

HETERODYNE ACTION

A simple electrical circuit contains a source of supply, either d-c or a-c, a load, the connecting wires and some means of control such as a switch. In more complicated circuits, the number of loads and controls is increased but usually, there is only a single source of supply, as far as voltage and frequency are concerned.

In the earlier explanations of the electronic circuits of vacuum tubes, it was shown that the plate current, furnished by a d-c supply, can be made to vary in value at the frequency of an a-c voltage impressed on the grid circuit. These variations of d-c plate current, often considered as an a-c component, function as an a-c supply in the operation of the signal coupling circuits between tubes. Thus, in effect, the variations of plate current provide a combination of d-c and a-c.

To investigate further the combination of supply voltages, for Figure 1-A we have drawn a circuit which contains the series connected secondaries of transformers T1 and T2. The primary of T1 is connected across an a-c supply with a frequency of 9 cycles while the primary of T2 connects across a similar supply but with a frequency of 10 cycles. To simplify the explanation, we will assume that both of these sources develop voltages of equal amplitude or value.

As the secondaries are connected in series, the output voltage will be equal to the sum of the separate voltages induced in each. Unlike d-c, a-c voltages are continually changing in value and periodically reversing polarity therefore, the output voltage will vary as the algebraic sum of the instantaneous values of the supply voltages. The term algebraic sum is used because at one instant the two voltages may aid each other whil, at other instants they may oppose each other.

When the voltages aid, the algebraic sum is equal to the arithmetical sum but, when they oppose, the algebraic sum is equal to the arithmetical difference.

To follow these changes in detail, curve T1 of Figure 1-B represents the voltage developed by the secondary of transformer T1 and, in the same way, curve T2 represents the voltage developed by the secondary of transformer T2. To check the action for one complete second, curve T1 includes 9 cycles while curve T2 includes 10 cycles. In each case, the horizontal center or base line is considered as zero, the upper lobes as "pos" and the lower lobes as "neg". The horizontal distances represent the elapsed time, as shown by the scale across the bottom, therefore the left hand vertical line, or ordinate, is considered as the starting point of both curves.

Starting here and going to the right, curve T2 gains on curve T1 until, at the end of 1/4 second, as shown by the .25 ordinate, T2 has completed 2-1/2 cycles while T1 has completed but 2-1/4 cycles. As a result, at this instant, T1 indicates a maximum positive value while T2 indicates zero.

In curves of this type, the length of an ordinate, between the base line and its intersection with the curve, is proportional to the instantaneous value of voltage. Therefore, the instantaneous values of the combined voltages can be found graphically by adding the vertical distances on the ordinates between the base line and the curves. Following this plan, the sum of the instantaneous values of curves T1 and T2 have been plotted to form curve Ts which indicates the output voltage of the circuit of Figure 1-A.

Starting at the left, the instantaneous values of both T1 and T2 increase in a positive direction so that the first alternation of curve Ts has an amplitude almost twice as great as either of them. However, after the third alternation, some instantaneous values of T2 are negative while those of T1 are still positive therefore they oppose each other and the maximum amplitude of the alternations of the sum curve Ts decreases progressively until, at the .5 second ordinate, all three curves have an amplitude of zero.

During this first half second, curve T2 has gained exactly one half cycle on curve T1 therefore they both reach a zero value at the same instant but are 180° out of phase. This phase difference reduces the output voltage but, during the next half second, curve T2 continues to gain, reducing the phase difference and increasing the amplitude of the alternations of curve Ts until, at the end of the second, T1 and T2 are again in phase to provide maximum amplitude for curve Ts.

To be technically accurate, the voltage indicated by curve T2 has gained one complete cycle during the second and therefore there is a phase difference of 360° between it and the voltage of curve T1. However, as the variations of all cycles are alike, a phase shift of 360°, which is one complete cycle, brings the voltages back in phase and the variations, shown by curve Ts, will repeat during each succeeding second.

Compared to the explanations of the earlier Lessons, curve Ts resembles that of a modulated radio carrier and an imaginary line, drawn across its peaks, shows one complete change or cycle during the second. Thus, 9 cycles of voltage T1 combined with 10 cycles of voltage T2 cause one complete change or cycle in the amplitudes of the alternations of curve Ts. Notice carefully, this one cycle is equal to the difference between the frequencies of T1 and T2.

This is known as a "Heterodyne" action and occurs whenever two a-c voltages or currents of different frequencies are impressed on one circuit. The periodic change in the amplitude of the combined voltage is known commonly as a "Beat" frequency and its value is equal to the difference between the applied frequencies. However, as explained in the earlier Detector Circuits Lesson, some form of demodulation may be employed to make the beat frequency available.

As will be explained later in this Lesson, in some electronic circuits the value of one voltage has an effect on the other and thus the combined voltage can be considered as the product rather than the sum of the separate voltages. Following the plan of plotting curve Ts, but using the product of the instantaneous values of curves T1 and T2, a curve like that of Tp results. To keep the curves of uniform size, the vertical scale of Tp has been reduced but notice, the broken line drawn through the vertical center of the alternations has the same general shape and frequency as the imaginary line drawn across the peaks of curve Ts. Also, the 19 alternations of curve Tp are equal to the sum of the 9 and 10 cycle frequencies of the curves of T1 and T2.

Curve Tp is merely a graphical representation of the fact, proven experimentally and mathematically, that when voltages of different frequencies are heterodyned, the output contains frequency components equal to both the sum and difference of the original frequencies which are also present.

For simplicity, the voltages represented by curves T1 and T2 are shown as sine waves but, irregularities in either wave form would appear in the combined voltage. This can be readily understood by remembering that the instantaneous values of curves like Ts and Tp are determined by the instantaneous values of the original voltages. Changes in the wave form of an original voltage change its instantaneous values and thus will have a proportional effect on the wave form of the combined voltage.

SUPERHETERODYNE CIRCUIT

This mixing or heterodyne action is utilized in the operation of most modern radio receivers in what is known as a Superheterodyne circuit, shown in simplified block form in Figure 2. The complete circuit can be divided into six main sections, each of which causes some definite change in the amplitude or frequency of the modulated carrier or amplitude of the signal voltage.

Starting at the left of Figure 2, the modulated carrier of a Broadcast Station is picked up by the usual form of antenna circuit and its amplitude is increased by one or more stages

of r-f amplification. The action here is the same as explained for the trf type of receiver and the amplifier includes circuits which are tuned to the frequency of the incoming carrier. Thus, the function of the r-f amplifier is to increase the amplitude without causing any change in the frequency of the carrier.

The output of the r-f amplifier is fed into the Mixer which connects also across the output of the Local Oscillator. This oscillator generates a frequency of uniform amplitude which heterodynes with the output of the r-f amplifier to produce a beat of lower frequency which carries the modulation of the carrier.

This beat is known as the Intermediate Frequency, (i-f) and its value is equal to the difference between the carrier and oscillator frequencies. In effect, the mixer acts as a detector with the higher values of oscillator and carrier frequencies impressed on its input circuits while the lower intermediate frequency appears in its output circuit.

The mixer output carries the modulation of the original carrier and passes through one or more stages of the i-f amplifier which causes a comparatively large increase in its amplitude but, like the r-f amplifier, causes no change in its frequency.

The output of the i-f amplifier is impressed on the input circuit of a conventional type of detector which demodulates the i-f and provides the audio or signal voltage frequencies in its output. The detector output voltage is then carried through one or more stages of the a-f amplifier which increases its amplitude to a level high enough to operate the speaker.

As the mixer acts to cause a change of frequency between its input and output circuits, it is sometimes known as the "1st Detector" and therefore, the demodulator which follows the i-f amplifier is the "2nd Detector". It is said that with its heterodyne action and two detectors, it followed naturally that the circuit was called a "Super" heterodyne. Due to the design of some of the later types of tubes, the mixer stage is known also as a "Frequency Converter".

The advantages of this type of circuit can be appreciated best by comparing it to the older type of trf receiver explained in the earlier Lessons. By removing the Mixer, Local Oscillator and i-f Amplifier sections of Figure 2, the arrangement is that of a trf receiver and all of the high frequency amplification must be accomplished in the r-f amplifier.

This means that all of the tuned circuits must be designed to resonate at all frequencies of the desired band and, as pre-

viously explained, it is extremely difficult to design a simple circuit which will provide uniform response and adequate gain over a comparatively wide band of frequencies. For example, the Broadcast band extends from about 550kc to 1600 kc, a ratio of over 3 to 1 and a change of circuit values to provide resonance over this range usually causes undesirable changes in response.

In the superheterodyne circuit, the tuning controls of the r-f amplifier, mixer and oscillator can be ganged mechanically so that, regardless of their position, the difference between the resonant frequencies of the tuned circuits and oscillator output will remain the same.

For example, suppose the arrangement of Figure 2 is designed to cover the Broadcast band and the i-f amplifier is tuned permanently to a frequency of 456kc. With the tuned circuits adjusted to resonate at 550kc, the ganged control will cause the oscillator output to have a frequency of 550 plus 456 or 1006 kc.

Then, as the tuning control is adjusted to increase the resonant frequency of the input circuits, it causes a proportional increase in the frequency of the oscillator so that the beat, or intermediate frequency remains the same. This condition holds for the entire band and when the receiver is tuned to 1600 kc, the oscillator frequency is 1600 plus 456 or 2056 kc.

This is perhaps the most important feature of the superheterodyne because, with a mixer output of fixed frequency, the tuned circuits of the i-f amplifier can be designed to operate at this one frequency only. Thus it is possible to select circuit components of values which will provide high gain and also to employ band pass arrangements with fixed tuning, to improve the selectivity. Therefore, most of the gain is provided by the i-f amplifier and its efficiency is so great that but one stage is sufficient in many cases and the r-f amplifier is omitted.

In the trf receiver, it is customary to resonate some circuits in all the amplifier stages between the antenna and detector, each of which must tune the entire band and be set for every individual incoming carrier. While the same general requirements are true for the superheterodyne, only those circuits of the oscillator and between the mixer and antenna have to be set for the individual carriers while those of the i-f amplifier need not be changed. Thus, although the superheterodyne circuit may contain a greater number of tuned circuits than a comparable trf receiver, the tuning components, used when operating, may be less in number.

While it is possible to build a trf receiver with performance characteristics equal to those of a superheterodyne, the greater efficiency of the single frequency intermediate amplifier reduces the number of stages required. Also, the fixed tuning of the i-f amplifier circuits simplifies the operational tuning controls and these advantages, together with those mentioned above, more than compensate for the addition of the local oscillator and mixer stages.

LOCAL OSCILLATORS

Before taking up the details of a complete circuit, we want to explain the operation of the various sections of Figure 2 and, starting at the antenna, the signal picked up by the antenna enters the r-f amplifier. However, the circuits here are like those explained for similar stages of the trf receiver therefore we will not repeat.

Going to the Local Oscillator section, its function is to generate a uniform voltage, the frequency of which can be conveniently controlled. This oscillator voltage is heterodyned with the r-f to produce the desired beat frequency, i-f, throughout the entire tuning range of the receiver. As explained in the last Lesson, there are a number of comparatively simple oscillator circuits which meet these requirements and, for Figure 3, we show the circuits of an arrangement used in many older models of superheterodyne receivers.

The oscillator itself is of the regenerative or Armstrong type with L5 as the plate coil connected between the plate of the tube and the B of the plate supply. Inductively coupled to the plate coil, the grid coil L4 is tuned by the parallel connected variable condenser C2 and coupled to the grid of the tube by condenser C4. Resistor R2 functions as the grid load and the voltage drop across it, caused by the charge and discharge currents of C4, provides the grid voltage.

Inductively coupled to coils L4 and L5, coil L3 is connected in the cathode circuit of the 1st detector tube in series with resistor R1 which, with by-pass condenser C3, provides the usual grid bias voltage. The complete grid circuit of the 1st detector tube can be traced from the grid through coil L2, tuned to the frequency of the incoming carrier by variable condenser C1, to ground and back up through resistor R1 and coil L3 to the cathode.

With a modulated carrier impressed across coil L1, a voltage of like frequency and proportional amplitude will be induced in coil L2 and impressed on the grid circuit. When tuned to resonance by C1, the voltage across L2 will be increased to provide selectivity as previously explained. The plate current, carried by R1 will cause the proper voltage drop to bias the grid and provide the proper operating point for the 1st detector tube.

At the same time, with the oscillator in operation, a voltage at its frequency will be induced in coil L3 which, as far as the grid circuit is concerned, is connected in series with coil L2. Thus, the arrangement in the grid circuit of the 1st detector tube provides conditions similar to those in the simple circuit of Figure 1-A and therefore voltages at the incoming carrier and oscillator frequencies are both impressed on the grid.

As a result, the action shown by the curves of Figure 1-B will occur in the grid circuit and cause corresponding variations of plate current. However, the bias voltage, caused by the drop across R1, is sufficient to provide operation as a detector therefore the beat frequency, which carries the modulation of the carrier, will appear in the plate circuit.

Coil L6, tuned to the beat frequency by adjustable trimmer condenser C5, is connected in series with the plate and thus, the variations of plate current which occur at the beat frequency, will cause maximum voltage drop across the tuned circuit. Higher frequencies are partially shorted by the reduced reactance of C5 while lower frequencies cause a lower drop because of the reduced reactance of coil L6.

With maximum voltage drop across coil L6, there is maximum induction in the inductively coupled coil L7 which is tuned by adjustable trimmer condenser C6 and thus the beat frequency voltage appears across coil L7. The combination of coils L6 and L7, each with its adjustable trimmer condenser, is known as an i-f transformer.

Tuning condensers C1 and C2 are ganged mechanically so that when the capacity of C1 is reduced to increase the resonant frequency of its tuned circuit, the capacity of C2 is also reduced to cause a proportional increase in the frequency of the oscillator voltage. To maintain a constant frequency difference, the circuits of the oscillator and 1st detector grid must be carefully designed and to provide the higher oscillator frequency, assuming C1 and C2 to be of equal capacity, coil L4 must have a lower value of inductance than coil L2. Then, to maintain the proper frequency difference, as condensers C1 and C2 are tuned, it is necessary to install the series connected condenser C7. This is known as a "Padder" and it reduces the total capacity connected across the oscillator coil L4 so that equal changes in the capacities of C1 and C2 will maintain an equal difference of frequencies. To eliminate the padder condenser, many later models have the oscillator gang of the tuning condenser made of smaller, specially shaped plates to provide the proper change of capacity as the rotor plates of all the tuning condenser gangs are turned in unison.

Various combinations of tubes and circuits have been devised to simplify and also improve the actions of the circuits of Figure 3 and one combination, formerly quite popular, is shown in Figure 4. Here, the circuits are quite similar but the oscillator tube has been eliminated and an r-f type of pentode tube acts as both oscillator and 1st detector.

Coil L5 is in the plate circuit and coil L3 is in the cathode-grid circuit to provide the necessary feedback while coil L4, inductively coupled to both, is tuned by condenser C2, in series with padder C7, to provide the desired frequency. The action here is about the same as that explained for Figure 3 and the beat frequency appears across the secondary coil L7 of the i-f transformer. To make comparison easier, corresponding components of both Figures carry the same numbers.

MIXERS

To provide better action and also simplify the circuits, several types of special "Mixer" or "Frequency Converter" tubes have been developed and, while their overall functions are the same, there are some important variations in the details of their operation.

One such type, shown in Figure 5, is known as a Pentagrid Converter because its five grids combine the functions of both oscillator and mixer. Starting from the cathode, the first grid functions as the control grid of a triode oscillator tube while the second grid functions as the oscillator plate. However, although indicated by the same symbol as the other grids, mechanically it consists of two side rods without horizontal wires, and this second grid is known as the oscillator anode.

This anode connects to the B+ of the plate supply through coil L5 and resistor R3 while the 1st grid is coupled through condenser C4 to the tuned circuit made up of a coil L4 and tuning condenser C2. Resistor R2 acts as the grid load while resistor R3 reduces the potential on the anode and, in conjunction with condenser C7, acts as a decoupling filter.

The oscillator circuits here are similar to those of Figure 3 except that coil L3 is omitted. However, feedback from the anode to the grid is provided by the inductive coupling between coils L4 and L5 and the arrangement operates as a triode oscillator.

The electrons emitted by the cathode are attracted toward the positive anode but the action of the grid varies the stream at the oscillator frequency. Grids 3 and 5 as well as the plate of the tube are also connected to the plate supply positive therefore many of the electrons pass through

the anode and continue on to the plate. It may help to think of the anode as the emitting cathode, as far as the plate circuit of the tube is concerned, but its emission varies at the frequency of the oscillator.

Grids 3 and 5, connected together inside the tube, serve a double purpose. First, maintained at a positive potential by the plate supply, they speed up the electrons which pass through the anode and second, they form an electrostatic shield for grid 4. Resistor R4 and condenser C8 act to maintain a uniform but reduced positive potential on screen grids 3 and 5.

Grid 4, connected to the input circuit, operates in the conventional manner to control the electrons which flow from the anode to the plate. As the electron stream is already varying at the oscillator frequency, the variations of plate current are controlled by the combined actions of the oscillator and the modulated carrier impressed on grid 4. Types 1A7G, 1C6, 2A7, 6A8 and 12A8 are common examples of this type of pentagrid converter tube.

To provide better performance at higher frequencies and reduce the effects of interaction between the oscillator and other section of the tube, later types of pentagrid converters are arranged on the plan shown in Figure 6. Here, grid 1 functions as the oscillator control, grids 2 and 4 as the oscillator anode and also as a shield for the signal input grid 3 while grid 5 acts as a suppressor.

The oscillator circuit of Figure 6 consists of coil L3, tuned by variable condenser C2 and coupled through condenser C4 to grid 1. Grid load resistor R2 connects from grid 1 to the cathode which in turn, connects to ground through a tap on coil L3. Thus, that part of L3 between the tap and ground is in the cathode circuit while the entire coil is coupled to the grid. As the cathode is part of the anode circuit, this can be considered as a Hartley oscillator and, as the action is independent of the plate of the tube, it is electron coupled.

Here again, the variations of plate current are controlled by the combined actions of the oscillator voltage on grid 1 and the modulated carrier voltage on grid 3. Types 6SA7 and 12SA7 are common examples of this type of pentagrid converter.

To further isolate the oscillator, the "Triode-Hexode" type of converter tube has been developed and is also in common use. As shown in Figure 7, the electrodes are arranged so that the tube contains a separate triode section in addition to a hexode section. The term hexode is used to signify the six active electrodes of plate, four grids and cathode while

the triode grid is connected internally to grid 1 of the hexode section.

The circuits here are similar to those of Figure 5 except that the oscillator plate coil L5 is tuned by condenser C2 and coupled to the oscillator plate through condenser C7 instead of being connected in series. However, the overall action remains the same and the triode section operates independently as an oscillator.

Because grid 1 of the hexode section is connected to the oscillator grid, the oscillator voltage will exercise control over the hexode plate current as explained for the circuits of Figures 5 and 6. Types 6K8 and 12K8 are examples of triode-hexode converter tubes.

You will find many combinations of these basic circuits used in commercial radio receivers, especially those designed for Communications and high frequency service. For example, the type 6L7 tube contains two well shielded control grids and with a separate oscillator, on the general plan of Figure 3, the oscillator voltage can be impressed on one control grid and the modulated carrier on the other to provide the desired mixing or frequency conversion action.

I-F AMPLIFIERS

As mentioned earlier in this Lesson, most of the selectivity and high frequency gain of a superheterodyne receiver are obtained in the i-f amplifier but the design problems are simplified by the fact that it operates only at one frequency. While any of the conventional coupling methods could be used, the simplicity, economy and opportunity for band pass type circuits, make transformer coupling the almost universal choice.

All i-f transformers contain a primary and secondary winding and because of the single frequency operation, either or both of them can be tuned. In some cases the windings are untuned while in others, one winding is tuned to provide the circuits of Figure 8-A. Most popular is the double tuned arrangement of Figure 8-B while, for broad band or high fidelity, the triple tuned circuits of Figure 8-C may be employed.

In the earlier Lesson on High Frequency Amplifiers it was shown that, for Broadcast service, the response curve of an i-f amplifier should have a fairly flat top, approximately 10 kc wide, with steep sides to provide a sharp cut off. Also, in the Lesson on Band Psss Filters it was shown that loose coupling caused a narrow response while overcoupling caused a double hump which broadened the response.

The double tuned arrangement of Figure 8-B can be considered as a band pass type of coupling, both circuits of which are tuned to resonance at the operating frequency. Mechanically, the coils are universal wound, mounted on a common dowel and the coupling depends on the spacing between them. Thus, by adjusting the position of the coils on the dowel, the desired or optimum coupling can be obtained.

In the arrangement of Figure 8-C, the third coil, sometimes called a tertiary winding will, when its circuit is tuned to resonance, absorb a certain amount of energy which "loads" the circuit and broadens the frequency response curve of the unit. In some receivers which feature variable selectivity, a variable resistance is connected between the tertiary winding and ground. Variable selectivity may be obtained also by changing the coupling between the two coils in a circuit like that of Figure 8-B. This may be accomplished by mechanically moving the coils to vary the distance between them or by switching in a third coil connected in series with one of the tuned circuits.

As shown in Figure 8, the coils are of fixed value and tuning is accomplished by means of trimmer type adjustable condensers connected across the coils. Other types of i-f transformers are made with fixed values of capacity and tuning is accomplished by changing the position of a powdered iron "slug" which functions as the core of the coil. Changing the position of the slug varies the permeability of the complete core, part of which is air, and this, in turn, varies the inductance. Transformers of this type are generally listed as "Iron Core - Permeability Tuned".

A single stage i-f amplifier, with circuits similar to those of Figure 9, provides sufficient gain and selectivity for the ordinary types of Broadcast receivers. The primary of the "1st i-f" transformer is connected in series with the plate of the mixer tube, as shown in the circuits of Figure 3 to 7, while the secondary of the "2nd i-f" forms a part of the input circuit of the 2nd detector. However, some designers prefer to reduce the gain and add a second stage so that the i-f amplifier includes two tubes and three transformers.

The impedance of a parallel resonant circuit can be varied by changing the ratio of inductance to capacity according to the formula of the former Lesson on Resonant Circuits which states,

$$Z = \frac{L}{CR}$$

Thus, as the tuned primary acts as the plate load of the preceding tube while the tuned secondary acts as the grid load of the following tube and the coupling between the coils can be adjusted, the gain and response of the stage can be made to suit the required conditions. That is why, in most catalogs you will find i-f transformers listed as "Input", "Interstage" and "Output" although all three types are designed to operate at the same frequency. The differences are in the values of inductance and capacity, as well as coupling, to provide the proper gain and frequency response for the complete amplifier.

For example, connected in the primary of the mixer tube, the primary of the 1st i-f must carry some of the higher frequencies of the oscillator and modulated input carrier. Thus, a somewhat higher value of capacity here will provide a lower reactance path in parallel to the coil and tend to reduce interaction with the lower intermediate frequency to which the circuit is tuned.

The secondary of the 1st i-f connects across the grid circuit of the following tube which, operating as an amplifier with a negative bias, offers an extremely high impedance. Therefore, in effect, the circuit operates with no load. In contrast, the secondary of the 2nd i-f f Figure 9 connects across the 2nd detector, usually of the diode type, which has a comparatively low impedance and carries current. Therefore this secondary circuit operates under load and must be designed accordingly.

For the interstage transformer, used as a coupling between the input and output tubes of a two stage i-f amplifier, conditions in its primary circuit are like those of the 2nd i-f of Figure 9 with current variations only at the intermediate frequency. Its secondary operates under conditions like those explained for the secondary of the 1st i-f of Figure 9 and therefore it is not loaded.

Each of the three types of i-f transformers is designed to meet its circuit conditions, as mentioned above and, in addition, the coupling is adjusted for each so that, in conjunction with the other transformers of the amplifier, the desired overall gain and selectivity will be obtained. For example, if the input type is adjusted for a gain of 50, the interstage may have a gain of about 20 while the output gain may be about 70. If, at some certain level the band width of the input is 15 kc, that of the interstage may be about 10kc, while that of the output may be 16 kc or 17 kc.

SECOND DETECTORS

Except for a difference in frequency, the output of the i-f amplifier is the same as the modulated carrier transmitted by a Broadcast station therefore the function of the 2nd detector is the same as previously explained for the detectors of the simple and trf types of receivers. Any of the conventional types of detectors will operate in this position in a superheterodyne circuit but, due to the relatively high gain of the i-f amplifier, no additional gain is required in the detector stage. Thus, because of their ability to handle larger voltages with less distortion, practically all superheterodyne circuits employ some form of diode as the second detector.

DIODE DETECTOR CIRCUITS

To review briefly the explanations of the former Lesson on Detector Circuits, for Figure 10 we show the circuits of a typical diode detector. Coil L2, tuned by condenser C2, represents the secondary of the output transformer of the i-f amplifier and thus the modulated i-f voltage is impressed on the circuit which can be traced from the upper end of L2 through the diode plate and cathode of the tube to ground and back up through resistors R2 and R1 to the lower end of L2.

The rectifying action of the diode permits current in one direction only, therefore the current in the circuit will consist of a series of pulses which occur at the intermediate frequency and vary in amplitude according to the modulation or signal frequency. To eliminate the pulses and provide current which varies only in proportion to the signal frequency, condensers C3 and C4 connect from the ends of resistor R1 to ground and form a filter.

The capacity of these condensers must be large enough to eliminate the intermediate frequency pulsations yet small enough to have no appreciable effect on the variations of the audio or signal voltage. Thus the signal voltages appear across resistor R2 and are coupled to the grid of the first audio tube.

As the voltage across filter resistor R1 is lost, as far as the following audio circuits are concerned, it is common practice to select a value for R1 that is about 10°/o of that for R2. For typical values, R2 is 500,000 ohms, R1 is 50,000 ohms, C3 and C4 are .0001 mfd each and coupling condenser C5 is .01 mfd. The value of R3 will depend on the type of tube installed as the 1st audio amplifier and may vary from .5 to 10 megohms.

There are many variations of this typical diode detector circuit but all of them include the basic components just mentioned. Also, as will be explained in the following Lesson, circuits of this type provide a source of voltage for the popular feature of automatic volume control.

AUDIO AMPLIFIERS

The output of the second detector of a superheterodyne circuit is essentially the same as the output of the detectors of the other types of receivers therefore, the conventional types of audio amplifiers are employed. However, the amplitude of the detector output is usually of sufficient strength as to require but two stages of audio amplification to provide ample signal voltage for satisfactory speaker operation.

Depending on the power output requirements, the audio amplifier may terminate in a single or push-pull stage employing any of the circuits explained in the earlier Audio Amplifiers Lesson. To repeat, the superheterodyne differs from other types of receivers only in the arrangement of the mixer, oscillator and i-f amplifier therefore the requirements of the audio amplifier are the same for all.

CONTROLS

Despite its more complicated action, a modern superheterodyne requires no more controls than the simpler types of circuits. As previously explained in this Lesson, a single tuning control is arranged to vary the resonant frequencies of the r-f amplifier if used, the mixer input and oscillator circuits so that they will respond to the carrier frequencies of the band yet maintain a constant i-f at the mixer output. As far as the operator is concerned, this tuning control is no different than that of a simple one tube receiver.

The volume control is usually incorporated as a part of the 2nd detector circuit on the general plan of Figure 10. Here the signal voltage appears across R2 which is a potentiometer. The sliding contact is coupled to the grid of the first audio amplifier tube therefore, only that voltage between the sliding contact and ground is impressed on the grid circuit. Thus, for any value of 2nd detector output voltage, the input voltage to the audio amplifier is controlled by the position of the sliding contact which therefore acts as a volume control.

In addition to the "Off-On" power switch, the tuning and volume controls are all that are necessary for the operation of the receiver. However, Tone Control can be added to the audio amplifier circuits, adjustable selectivity can be incorporated in the i-f amplifier circuits and, as will be

explained later in this Lesson, circuits can be installed to provide for reception on different frequency bands.

SELECTIVITY

Perhaps the most important advantage of the superheterodyne receiver circuit is its inherent selectivity. Operating at a single frequency with band pass coupling circuits, the response of the i-f amplifier can be designed for almost any value of band width. In some of the earlier models, the pass band was so narrow that the higher signal frequencies were attenuated.

To understand this action, it must be remembered that the modulation of a radio frequency carrier involves an action very similar to the heterodyne explained earlier in this Lesson. For example, suppose a 1000 kc carrier is modulated by audio or musical frequencies up to 5000 cycles which is 5 kc. The modulated carrier will then include frequencies from 1000 kc up to 1000 plus 5 kc or 1005 kc and down to 1000 minus 5 kc or 995 kc.

Tuned to this carrier, the oscillator of a 456 kc i-f superheterodyne will operate at 1456 kc and therefore the frequencies at the mixer output will vary from 1456 minus 995 or 461 kc to 1456 minus 1005 or 451 kc. Notice here that although the frequencies have been reduced, the band width of the i-f is the same as that of the modulated carrier.

Assuming the i-f amplifier has a response curve with a flat top but 8 kc wide, when tuned to 456 kc the maximum response will extend from 456 plus 4 or 460 kc to 456 minus 4 or 452 kc. Compared to the values given above, intermediate frequencies between 451 and 452 kc as well as those between 460 and 461 kc will receive less amplification than those between 452 and 460 kc.

Checking back, with an oscillator frequency of 1456 kc, an i-f of 451 kc is produced by a carrier frequency of 1456 minus 451 or 1005 kc. In the same way, an i-f of 452 kc is produced by a carrier of 1456 minus 452 or 1004 kc. At the other end of the band an i-f of 460 represents a carrier of 996 kc while an i-f of 461 kc represents a carrier of 995 kc. As the original carrier was assumed to have a frequency of 1000 kc, frequencies between 1004 and 1005 kc as well as those between 995 and 996 kc are produced by modulating or signal voltages between 4000 and 5000 cycles.

The frequencies of the 2nd detector output voltage are essentially the same as those of the original modulation thus, under the conditions of this example, all signal voltages

between 4000 and 5000 cycles would be attenuated. Signal voltages with frequencies up to 4000 cycles would be fully amplified therefore, when an i-f amplifier is tuned too sharply it "cuts the highs".

In commercial practice it is customary to make a compromise by adjusting the response for a band wide enough to include all the signal frequencies but narrow enough to eliminate most of the interference from adjacent carrier frequencies.

IMAGE FREQUENCIES

In the example just given, the 1000 kc carrier and 1456 kc oscillator were mixed or heterodyned to produce a beat of 456 kc but suppose another carrier, at 1912 kc, was also cutting the antenna and inducing a voltage in it. The heterodyne action between the 1456 kc oscillator and 1912 kc carrier would also produce a 456 kc beat and if both these carriers caused equal voltage in the mixer input circuit, both would be amplified equally by the i-f stages and produce equal signals in the speaker.

Notice carefully, the difference between 1912 kc and 1000 kc is 912 kc which is exactly twice the 456 kc of the i-f. This relationship holds true in all cases and the higher value is known as the "Image Frequency". Thus, in general, the image frequency is equal to that of the desired carrier plus twice the i-f.

Image frequencies were considered an important disadvantage of the early models of superheterodynes but, by ganging the tuning controls of the mixer and oscillator, providing some selectivity ahead of the mixer and increasing the i-f, image frequencies are no longer troublesome in the Broadcast band.

Starting with values of less than 100 kc, intermediate frequencies were increased until a value of 175 kc was considered standard. Over the years, further increases were made passing through bands of 260 to 265 kc, 370 kc and up to the present of 455 to 470 kc for regular Broadcast service. Receivers designed for higher frequency service often incorporate i-f amplifiers which operate at much higher frequencies.

With an i-f of 456 kc, there is a difference of 912 kc between the tuned carrier and the image frequency and, as the Broadcast band covers less than 1200 kc, interference of this type is reduced. Also, for any circuit tuned to the Broadcast frequencies, it does not require a high degree of selectivity to greatly attenuate frequencies 912 kc off resonance. For higher carrier frequencies, the ratio of resonant to image frequencies is less favorable and added precautions must be taken to avoid image frequency signals.

SENSITIVITY

In an earlier definition it was stated that all stages of a radio receiver contribute to its Sensitivity but, due to the high gain characteristics of the i-f amplifier, the superheterodyne circuit will provide satisfactory sensitivity with fewer stages than other types.

The advantages of the superheterodyne are so pronounced that some small four tube receivers incorporate but one i-f transformer, and provide performance superior to trf receivers with an equal number of tubes.

TYPICAL CIRCUITS

Although there are many variations in detail, modern superheterodyne circuits now follow a fairly uniform pattern and can be divided into general classes. From the standpoint of Power Supply, there are the following types.

1. Battery Receivers, used for portable service and containing dry batteries which supply all the operating voltages and current.

2. Receivers which operate on any ordinary lighting circuit, d-c or a-c of any commercial frequency.

3. Receivers which operate only on a-c lighting circuits of one frequency such as the common values of 25 or 60 cycles.

4. A combination of types 1 and 2 which provide portable service but conserve the batteries by operating on lighting circuits whenever they are available.

From the standpoint of operating frequencies there are,

1. Types which operate on the standard Broadcast band only.

2. Dual Band types which operate on the standard Broadcast and another higher frequency or short wave band.

3. All Wave types which operate on the standard Broadcast and two or more bands of other frequencies. Some later models may include the newer frequency modulation bands.

The complete receiver chassis may be installed in a comparatively small "Table Model" cabinet or in a larger "Console", both of which are available in a wide variety of shapes, sizes, colors and finishes.

DUAL BAND TYPES

To illustrate the complete assembly of the various receiver components, explained earlier in this Lesson, for Figure 11 we show the schematic diagram and chassis layout of a Sentinel, 6 tube dual band a-c/d-c superheterodyne receiver. Starting at the upper left of the diagram and following the path of the signal, there is a 12SK7 tube, used as an r-f amplifier, resistance coupled to the 12SA7 tube marked "OSC-MOD". This tube functions as the mixer and the oscillator coils are shown directly below at the lower part of the diagram.

The 12SA7 mixer tube is coupled through the 1st i-f transformer to the 12SK7 i-f amplifier tube and its output is coupled through the 2nd i-f transformer to the diodes of the 12SQ7 tube. The diodes are a part of the detector circuit which is coupled to the grid of the triode section of the 12SQ7 through the .005 mfd condenser shown below the tube and to the right of the volume control. This triode section acts as the 1st a-f amplifier and is resistance coupled to the 50L6-GT beam power output tube which, in turn, is coupled through the output transformer to the speaker.

As shown at the lower right, the heaters of all the tubes are connected in series across the 117 volt supply while the plate of the 35Z5 half wave rectifier tube connects to one side of the supply line through the parallel connected 100 ohm resistor, 6-8 volt pilot lamp and part of the 35Z5 heater. As the other line wire is grounded, the d-c voltage output of the rectifier is available between its cathode and ground.

From the cathode there is one circuit over to the right, up, over and down through the speaker field to ground. Another circuit is through a part of the output transformer primary, down through a 1000 ohm resistor and over to the left to the plates and screen grids of the other tubes. The filter is made up of the 30 mfd condenser connected from cathode to ground, part of the output transformer primary and 1000 ohm resistor and the 40 mfd condenser connected from the output end of the resistor to ground. The plate of the 50L6 power output tube connects to the upper end of the output transformer primary. The cathodes of all except the rectifier tube connect to ground to complete the circuits to the grounded line wire.

The band switch, at the left center of the diagram, is shown in the Broadcast position and its contact No. 3, shown at the extreme left, connects to the grid of the r-f tube and the stator of the antenna gang of the tuning condenser. Contact No. 9, shown at the center of the switch, is coupled to

the oscillator grid of the mixer tube and connected to the stator of the oscillator gang of the tuning condenser.

The loop, shown at the upper left, mounted on the chassis and of a size to fit inside the cabinet, acts as the antenna and also as the tuned secondary of an r-f transformer. One end of the loop connects through switch contacts 2 and 3 to the grid of the r-f tube while, as far as r-f is concerned, the other end is grounded through the .05 mfd condenser, shown at the lower left and connected also to the lower end of the antenna coil secondary. The d-c grid bias is obtained by the voltage drop across the volume control in the circuit which continues from the lower left corner across the bottom, up and over through the 3 megohm resistor and volume control to ground.

The oscillator grid circuit is completed through contacts 9 and 8 of the switch, the padder condenser and lower oscillator coil to ground. Both oscillator coil primaries are in series between the mixer tube cathode and ground.

Switch contacts 11 and 12 complete a circuit from ground through trimmer condenser B and the r-f choke to the control grid of the mixer tube. For this circuit, the values of inductance and capacity are chosen so that it can be tuned to resonance at the intermediate frequency of 455 kc. As the impedance of a series resonant circuit is minimum, this arrangement acts as a "trap" to short out any unwanted 455 kc frequencies which may be present in the input circuits and prevent them from reaching the i-f amplifier.

Switch contacts 5 and 6 connect trimmer C across the oscillator gang of the tuning condenser to provide a high frequency adjustment of the oscillator circuit.

When the switch is turned to the "Short Wave" position, contact 3 connects to contact 4 and the grid circuit of the r-f tube is completed through the secondary of the antenna coil to the d-c bias circuit. The signal frequencies are grounded by the .05 mfd condenser connected to the lower end of the antenna coil secondary. The signal, picked up on an external antenna, enters at the upper left terminal and is carried to ground through the primary of the antenna coil and the series connected .005 mfd condenser.

Through switch contacts 9 and 10, the oscillator grid of the mixer tube is coupled to the upper oscillator coil through the .005 mfd condenser while contacts 1 and 12 short the lower primary and leave only the upper coil in the cathode circuit. Thus, the switch operates to connect new coils in both the antenna and oscillator circuits and although

the circuits are tuned by the same two gang condenser, the inductance of the new coils is such that the receiver responds to an entirely different band of carrier frequencies. In this particular circuit, the Broadcast band tunes from 540 kc to 1620 kc while the Short Wave band tunes from 5.7 mc to 18.3 mc.

As the input circuit is tuned to much higher frequencies on the Short Wave band, when switch contact 12 connects to contact 1 it opens the trap circuit. Also, when switch contact 6 connects to contact 7, it opens the circuit of trimmer condenser C.

From the triode plate of the 12SQ7 tube there is a path through a .002 mfd condenser and switch to ground. This arrangement acts as a tone control because, in the switch position shown, the condenser provides a capacity reactive path from plate to cathode. As capacity reactance reduces at increased frequencies, in effect, the higher frequencies are shorted out of the 500,000 ohm plate load resistor and therefore are not carried over to the grid circuit of the output tube. To the listener, this loss of the higher frequencies make the low notes more pronounced.

Tracing the control grid circuits of both 12SK7 tubes, they connect to ground through the 3 megohm resistor and 500,000 ohm volume control. As will be explained in the following Lesson, the voltage drop across the volume control is thus impressed also on these grid circuits. However, the 3 megohm resistor, in conjunction with the .05 mfd condenser shown at the lower left, operates to provide the grid circuits with a d-c voltage, the amplitude of which varies as the average strength of the demodulated i-f. As the polarity of this voltage is negative toward the grids, an increase of signal strength increases the negative grid bias which reduces the signal and provides automatic volume control. To improve the stability of the oscillator, the 3 megohm resistor connects through a 10 megohm resistor to the oscillator grid.

ALL WAVE RECEIVERS

All wave receivers are similar to the type shown in Figure 11, but three or more sets of coils are provided and connected into the proper circuits by the Band Switch. When a tuned r-f amplifier stage is used, three coils are needed for each set, or band, and the tuning condenser requires three gangs. However, for each position of the band switch, the circuits are essentially the same as explained in this Lesson.

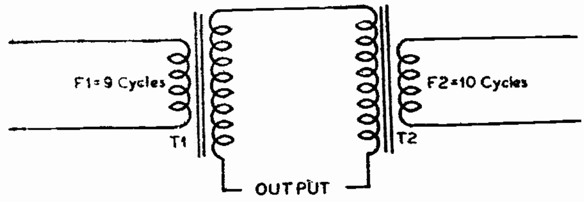


FIGURE 1-A

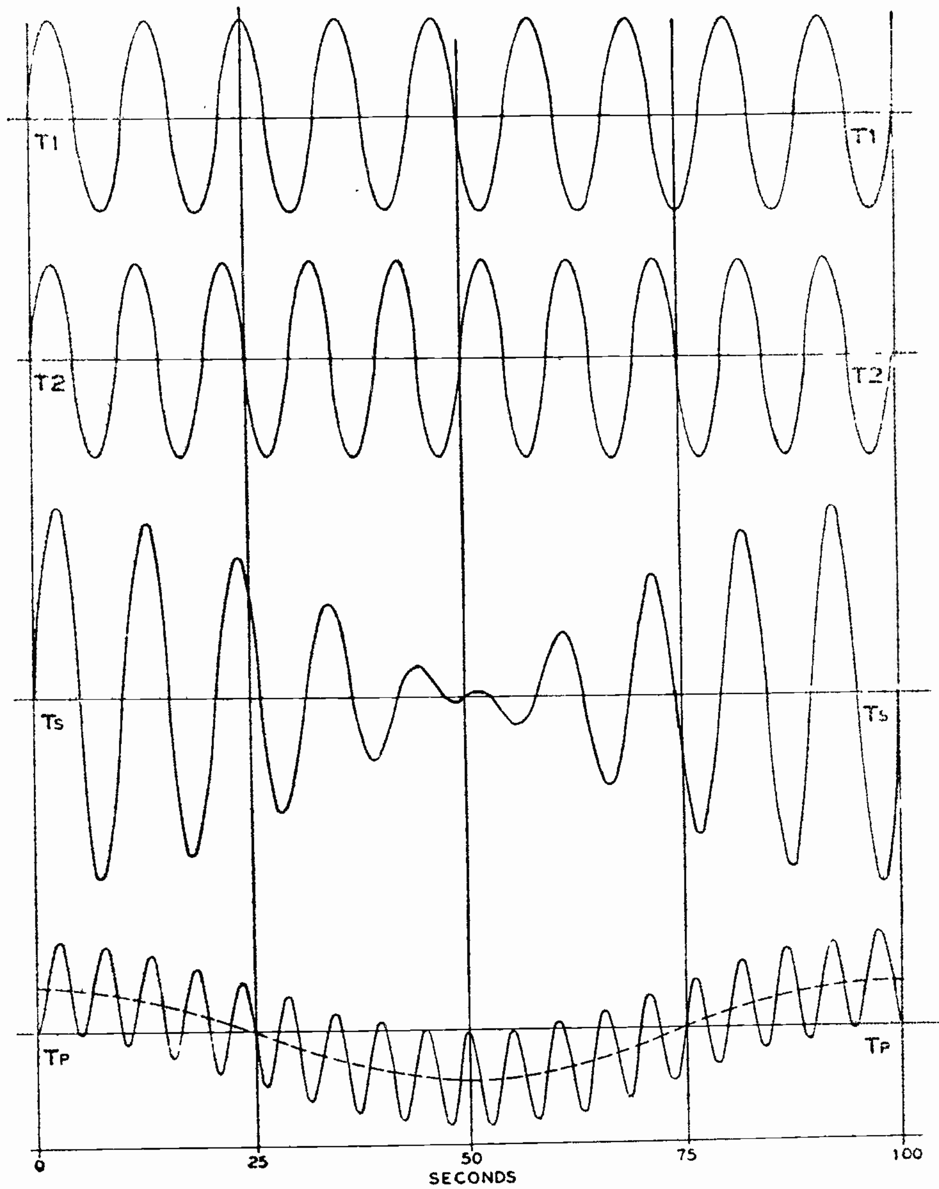
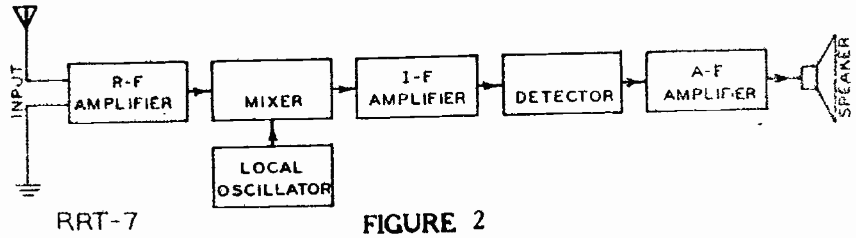


FIGURE 1-B



RRT-7

FIGURE 2

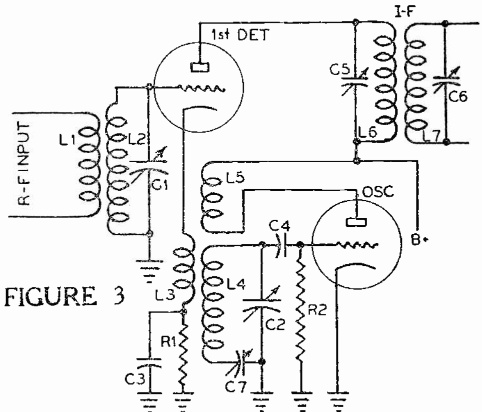


FIGURE 3

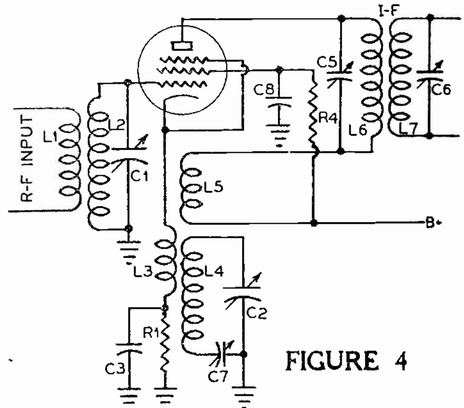


FIGURE 4

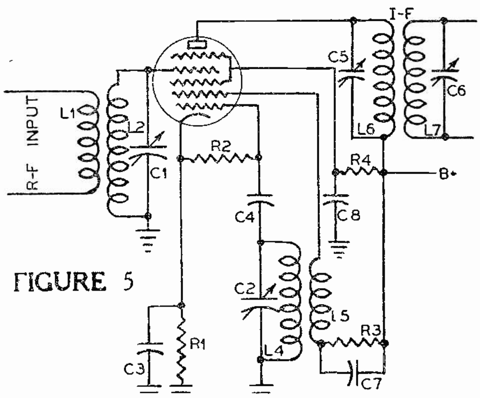


FIGURE 5

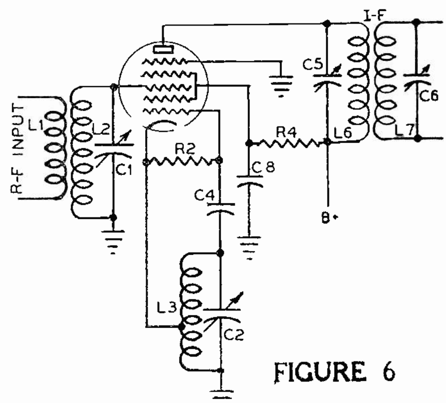


FIGURE 6

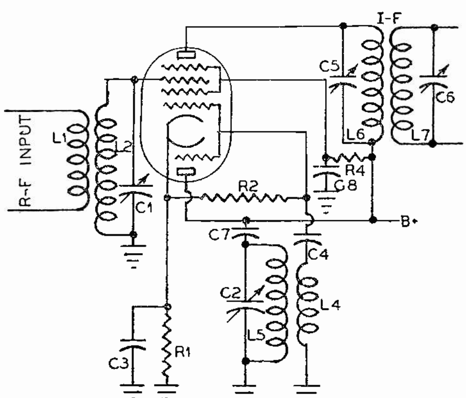


FIGURE 7

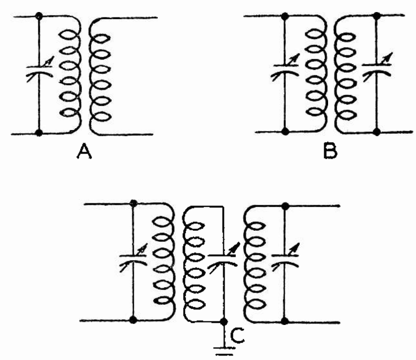


FIGURE 8

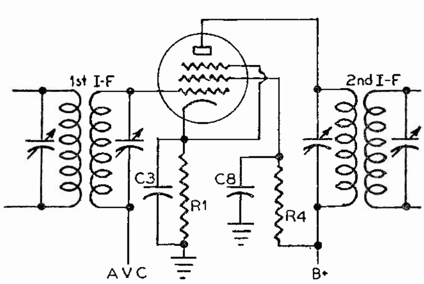
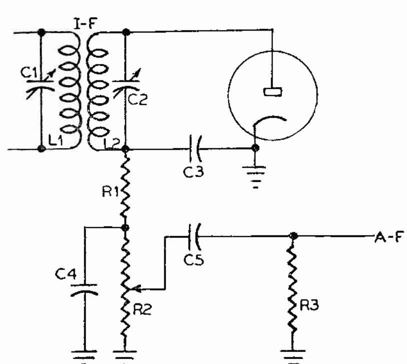


FIGURE 9



RRT-7

FIGURE 10

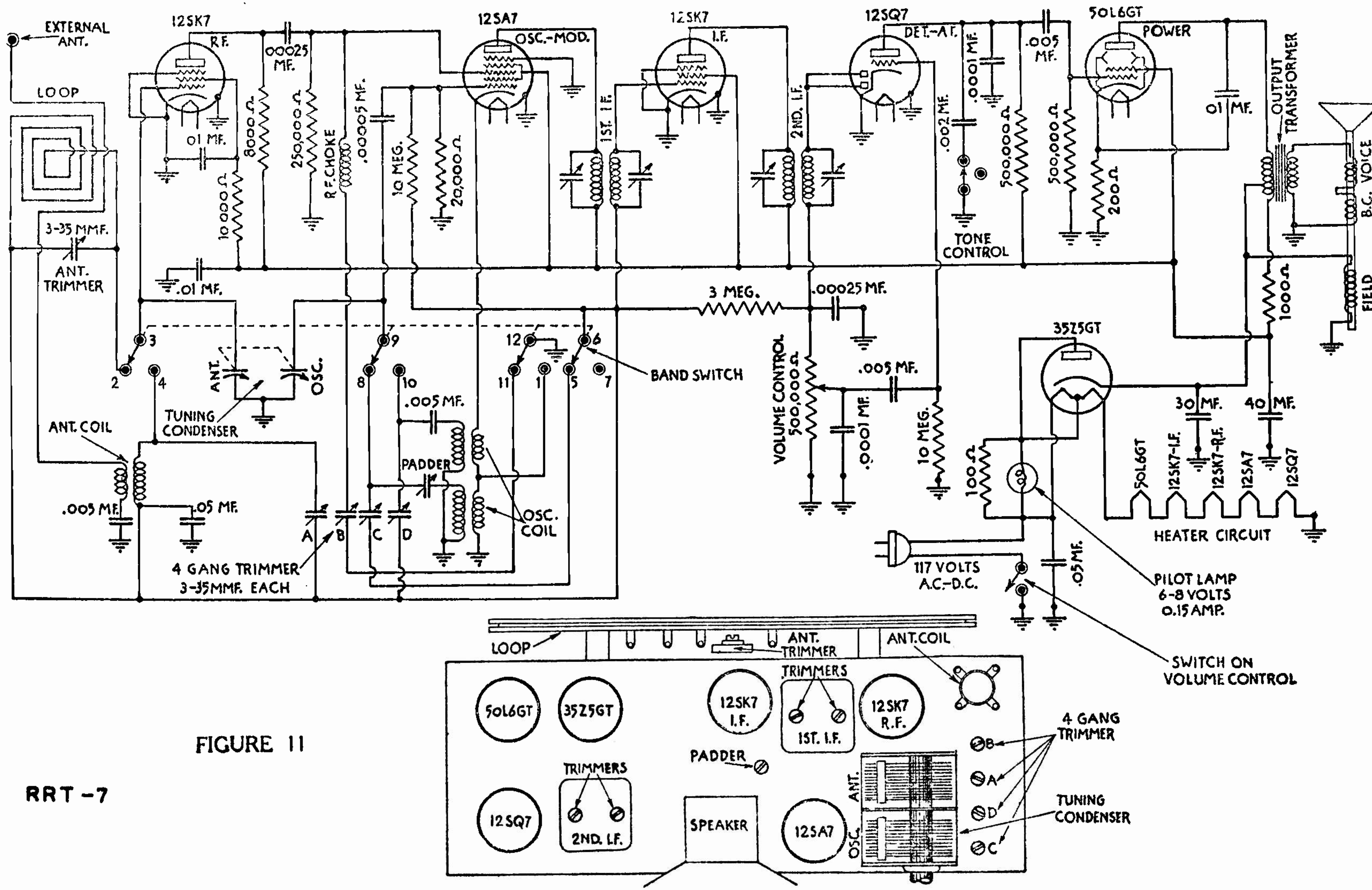


FIGURE 11

RRT-7

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LESSON RRT-8

AUTOMATIC VOLUME CONTROL

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A PIONEER AND LEADER OF VISUAL EDUCATION

RADIO RECEPTION AND TRANSMISSION

LESSON RRT-8

AUTOMATIC VOLUME CONTROL

* * * * * *

An education may be obtained in a high school or a college. It also may be obtained in an office, the home, or a factory. It is willingness to learn; a desire to acquire a knowledge; a determination to advance that gives one an education.

----- Selected

Automatic volume control, commonly abbreviated "avc" was briefly explained in the earlier Lessons but, because of its application to practically all present day commercial superheterodyne receivers and other electronic devices, we want you to have a more complete understanding of its action and therefore will devote this entire Lesson to the subject.

When we stop to consider the usual conditions of signal input, it is not difficult to understand why "avc" has been so universally applied to radio receivers. The electromagnetic waves cutting the antenna of most any radio receiver installation will be of various amplitudes, depending on the strength of the transmitters and their distance from the receiving station. In the case of weak carriers, the signal strength may be as low as 2 or 3 microvolts, whereas with a powerful local transmitter, it may be as high as 1 volt.

Therefore, without avc, tuning the receiver from a weak to a strong signal, without changing the gain or volume control, will result in a loud, and probably distorted, sound from the speaker. However, this difficulty, commonly referred to as blasting, can be minimized with automatic volume control.

Then also, as explained in an earlier Lesson, a change in the Kennelly-Heaviside layer produces a variation of signal strength, the effect of which, commonly called "Fading", can be reduced to a low value by applying avc.

Going back to the earlier Lessons on vacuum tubes, you will remember that an increase of the negative bias voltage, applied to the control grid, reduces the plate current and likewise reduces the gain or available amplification. This means that an increase in negative control grid bias, applied to the r-f and i-f stages of a receiver, reduces the sensitivity of the complete system.

Thus, if we devise some method by which the negative control grid bias on the r-f and i-f stages of a radio receiver will be changed automatically in proportion to the incoming signal strength, an automatic control of the sensitivity is secured. This will provide an approximately constant signal level at the detector, which in turn will result in a constant audio output although there is a change of signal voltage in the antenna. This is the general method employed in present avc circuits and the following explanations will show you how it is possible to obtain this "automatic" control of the negative grid bias voltage.

RECTIFIER ACTION

Due to the amplifying action of the radio and intermediate frequency stages of a receiver, the carrier wave has its greatest voltage at the demodulator or detector. Therefore, we will investigate its action to determine if it is possible to obtain a d-c voltage which will vary with the applied signal and be available as a negative bias to the control grids of the r-f and i-f stages.

Looking at Figure 1, we want you to think of the circuit as that of the last i-f stage of a superheterodyne receiver, coupled to a diode second detector T2, by the i-f transformer of a tuned primary and secondary. As you know, the diode detector is really a rectifier and perhaps it will help you to follow this explanation by considering the secondary of the i-f transformer as that of a power transformer. The tube and load resistance R complete the circuit of a conventional half wave rectifier system.

Since we are interested in obtaining a fairly high d-c voltage and because it is essential to apply a minimum load on the i-f transformer, so as to reduce detuning and damping of the circuit, R has comparatively high value, usually several hundred thousand ohms. The bypass condenser C is installed to provide a low reactance path for the intermediate frequency currents so they will not pass through resistor R.

From the earlier Lessons, you know that a diode rectifier is essentially a linear rectifier which means that an increase of input results in a proportionally greater output. For simplicity of explanation, we will assume a 2 to 1 ratio between the carrier voltage and the rectified d-c. That is, with a 10 volt carrier across the secondary L, a d-c voltage of 5 volts will appear across the load resistor R. Thus, if the strength of carrier increases, the d-c voltage output also increases.

However, from your study of the diode detector, you know that the voltage appearing across R, with a modulated i-f input, is going to vary with the modulation and is therefore not steady, but pulsating d-c. In this form, it is not possible to employ it as the control voltage for avc because its variation at an audio rate, representative of the modulation component of the carrier, would be the equivalent of applying an audio signal to the r-f and i-f stages.

This pulsating d-c however, is made up of two parts or components. One part is the modulation component and the other

is the steady d-c voltage. The next step therefore is to separate these two voltages so that the steady d-c can be made available for the avc voltage.

The method by which these are separated is exactly the same as in any other system wherein we wish to remove the a-c component from a pulsating d-c voltage. You will notice that the network used for this purpose, as shown in Figure 2, is very similar to the conventional type of filter found in the normal power supply system. In comparison, resistors R1 and R2 occupy a position similar to that normally occupied by the filter chokes in a power supply, and condensers C1 and C2 occupy the normal filter condenser positions. Considering all facts, the filter system employed in an avc circuit to secure a pure d-c output is basically the same as the filter employed in a conventional power supply system.

ACTION OF AVC FILTER

The action of the avc filter network is not hard to understand and we want you to imagine the circuit of Figure 2 is connected across the output load resistance R of Figure 1. That is, point A would be connected to the lower end of L, with point B connected to ground. Thus, between points A and B there will be a steady d-c voltage plus an a-c voltage, but in analyzing the action, we will consider each of these voltages separately.

As we are interested in the steady d-c voltage as a source of control grid bias, an examination of Figure 2 shows no d-c path between A-B or X-Y. Suppose we assume a 5 volt battery is connected across A-B and terminals X-Y are unloaded. Condensers C1 and C2 block d-c, consequently there is no d-c voltage drop across R1 and R2. Under such a condition, the voltage between X and Y is also 5 volts.

Still comparing the circuit of Figure 2 with a conventional power supply filter network, only d-c voltage is desirable at X and Y for negative bias control; whereas, to supply the plate and screen grid circuits of vacuum tubes with proper energy, both voltage and current must be available at the output terminals of the filter. Just as the voltage divider and tube circuits form the load across a power supply, the grid circuit of a controlled tube is connected across X and Y of Figure 2. However, there is one big difference, and that is the fact that avc circuits do not draw current from the source of voltage, and therefore R1 and R2 can be high resistance values compared to the low d-c resistance values of the chokes in a power supply filter.

To further clarify the fact that the voltage at X-Y, Figure 2, is almost identical with that at A-B, let us assume R1 and R2 each have a value of 500,000 ohms. Consider also that the grid circuit connected to X-Y has a d-c resistance of 99 megohms. The total series resistance between A-B is .5 megohm plus .5 megohm plus 99 megohms, or 100 megohms. As the voltage drop across a portion of a series circuit is proportional to the resistance of that part, and if we still assume 5 volts d-c across A-B, the voltage at X-Y is 99 parts of the total. The voltage across X-Y = 99/100 x 5 = 4.95 volts. The loss of .05 volt is negligible and for all practical purposes, the d-c voltage at points A-B and X-Y are the same value.

To eliminate the a-c component of the pulsating d-c voltage, the capacities C1 and C2 are so chosen to provide a low reactance at audio frequencies. This means that only a small a-c voltage will be developed across the first filter condenser C1 because of its relatively low impedance with respect to the first resistance R1. This small a-c voltage across C1 is further reduced by the same action in the R2-C2 combination with the result that very little a-c voltage appears across C2, which is the output of the filter.

To offer greater detail on how the a-c is removed by the filter, we have rearranged the circuit of Figure 2 to that of Figure 3, the connections however remaining the same. To make use of some definite quantities, we will assume R1 has a value of 1 megohm, R2, 500,000 ohms and the condensers C1 and C2 each have a capacity of .05 mfd, and provide a reactance of 10,000 ohms at some definite frequency. In our example, we will consider this reactance as a resistance and also assume that the signal input to the filter is composed of a 5 volt a-c component and a 5 volt d-c component.

With a 5 volt a-c signal across A-B of Figure 3, there will also be a 5 volt a-c drop across R1-C1. Applying the rule of series circuits that a voltage drop is proportional to the resistance of that part, when R1 = 1,000,000 ohms and the reactance of C1 = 10,000 ohms, the voltage drop across R1 will be the same proportion of the total voltage as the value of R1 is to the total resistance being considered in this part of the network. As the total resistance is 1,000,000 + 10,000 or 1,010,000 ohms. The resistance ratio is then--

$$\frac{1,000,000}{1,010,000} = \frac{100}{101} = .99+$$

Therefore .99 or 99% of the applied voltage is developed across R1 as a voltage drop. According to the assumption made, the voltage drop across R1 will be .99 x 5 or approximately 4.95 volts. Applying the same line of reasoning, .01 or 1% of the total voltage will occur as a voltage drop across C1, and will be .01 x 5 or approximately .05 volts.

As the combination C2-R2 is connected across C1, the applied voltage to this section is .05 volt. With R2 having a value of 500,000 ohms and C2, 10,000 ohms, the total resistance is 500,000 + 10,000 or 510,000 ohms. The resistance ratio is then--

$$\frac{500,000}{510,000} = \frac{50}{51} = .98+$$

The voltage drop across R2 will be .98 x .05 or approximately .049 volt, whereas the voltage drop across C2 will be .02 x .05 or approximately .001 volt. Thus, the filter system has attenuated the a-c component so that at the output of the filter, the a-c voltage is equal to about 1/5000th of the a-c voltage present at the input of the system.

To continue our explanation, the filter has no effect upon the d-c of the detector output, which is the part we seek for automatic volume control purposes. Inasmuch as we have stated there is no direct current through the filter, the d-c voltage across the output is approximately equal to the input which in this case is 5 volts.

Although the above explanation is suitable for the assumed condition, in actual practice the filter system must be capable of separating the a-c and d-c components for all audio frequencies. You know the reactance of a condenser varies inversely with the frequency and therefore, at the lower values of audio frequency, the efficiency of the filter described above will be reduced because the ratio of the reactance to resistance will be reduced. That is, the reactance of the filter condensers will increase while the ohmic value of the resistors will remain approximately the same. As the voltage drop across the circuit is in proportion to the resistance and reactance, the drop across the condenser will increase, allowing a greater a-c voltage at the output of the filter.

However, at the higher frequencies, the efficiency of the filter will be increased, due to the reduction of the capacity reactance of the filter condensers. This gives a lower voltage drop across C1 and C2 of Figure 3 and therefore a lower a-c voltage at the output of the filter.

In analyzing this variable situation, one's first thought is that the values of the filter components should be so chosen as to give good efficiency at the low-audio frequency. This would of course mean increasing the capacity of C1 and C2 or increasing the values of the filter resistance R1 and R2. A design of this type would give the desired d-c component, but at the same time would slow up the "speed of action" of the avc system. In other words, the time delay of the system to perform its function would be too great for efficient avc action and therefore a compromise between filtering efficiency and time delay must be made in the practical design of a complete network. An explanation of this "time delay" action will be given a little later in this Lesson.

By the addition of the filter of Figure 2 to the output of Figure 1, we provided a steady d-c voltage which will vary in value with the applied modulated i-f voltage. So far, we have said nothing about the polarity of this voltage, but by checking the circuit of Figure 1 and considering the direction of current to be from plate to cathode, the voltage drop across R will be positive at the cathode and negative at the end connecting to the i-f transformer. Therefore, with the filter of Figure 2 connected as before, point X will be negative in respect to point Y or ground.

Considering a 10 volt i-f signal applied to T2, Figure 1 and assuming a 2 to 1 ratio between the applied voltage and d-c output, there will be a 5 volt drop across R. With the filter properly connected, and no d-c current, point X of Figure 2 will be 5 volts negative in respect to point Y. If the i-f signal voltage is increased to 50 volts, then point X will be - 25 volts in respect to point Y.

Thus, we have accomplished what we set out to do and that was to obtain a negative voltage which would be automatically controlled by strength of the modulated carrier. If the control grid of a tube were connected to point X of Figure 2, with the cathode connected to point Y, its bias voltage would increase or decrease with the strength of the carrier voltage and its sensitivity or gain would be automatically controlled.

A.V.C. CIRCUIT

Now that we have explained the action of the avc rectifier and filter, in Figure 4 we have the complete circuit showing the connection to the grid of a tube controlled by avc. In checking through this circuit, you will notice that we have combined Figures 1 and 2 and have added the grid and cathode circuits of T1.

In the cathode circuit of T1, Figure 4, we have the resistor R3 with its bypass condenser C3. The control grid circuit of T1 is from the upper end of the i-f transformer secondary L, through R2, R1, R to ground, and the circuit is completed from ground through R3 to the cathode. Thus, with no signal input to cause the avc to function, there will still be a bias voltage on the control grid due to the voltage drop across R3 caused by the plate and screen currents through T1.

With adequate capacity provided by C3, the voltage drop across R3 can be assumed as constant and therefore the negative bias on the control grid of T1 will not be lower than the voltage drop across R3. This may bring to your mind a question as the necessity of this minimum bias voltage, but you must remember that most tubes operate at their maximum sensitivity with a definite bias voltage. Therefore, the ohmic value of R3 is chosen to develop the required voltage drop for maximum sensitivity of the stage. Used in this way, the voltage drop across R3 is commonly referred to as the "initial" bias voltage. To illustrate with definite values, we will assume this drop to be 3 volts, giving an initial negative bias of 3 volts on the control grid of T1.

Now let's see what happens when a carrier voltage from the secondary L is impressed on the control grid of T1. As T1 is an i-f amplifier tube, the signal will be amplified and appear in the plate circuit primary L1 of the i-f transformer. Because of the inductive coupling, the signal voltage will appear across the secondary L2 and be impressed on the detector T2 and resistance R. Let's assume this signal has an amplitude of 10 volts, and with a 2 to 1 ratio, there will be a 5 volt steady d-c component across R.

As "R" is in the control grid return circuit of T1, this applied voltage will make the grid 5 volts negative in respect to ground. However, the cathode is the reference point of the tube and we must consider the voltage drop across R3. Checking the polarity of the voltage drops across R3 and R, you will notice they are in series and thus the negative bias on T1 is now 5 + 3 or 8 volts, resulting in a reduction in the sensitivity of the i-f stage.

From the above explanation, you can see that the avc action tends to maintain a uniform output from the detector, regardless of the signal strength at the input of the receiver. The action of an avc circuit is not perfect and the output of the detector is not the same for all values of input. However, a receiver equipped with avc is far superior in operation than one without this feature. By distributing

the steady d-c voltage output of the avc filter to the control grids of the several tubes, the desired degree of control over the amplification in the r-f and i-f systems is obtained.

TIME DELAY

In our explanations so far, we have mentioned that the purpose of an avc system is to provide substantially constant output regardless of changes in the signal input. As far as the changes of received signal intensities are concerned, they may be either rapid or slow, but whatever the condition, the control voltage must be able to increase or decrease as the occasion demands.

Earlier in this Lesson, we told you about the difference in the efficiency of the avc filter, with respect to changing frequencies, and also that the values of filter resistance and capacity reactance had a great influence upon the ability of the control voltage to follow rapid changes in output voltage. This action is known as the "time delay", but before going into detail, it is necessary that you know what takes place when a condenser is charged and discharged through a resistance.

As a rule, if the voltage is changed in one part of a circuit, there is an instantaneous change in every other part. In general, this is true but when a circuit contains large values of capacity and resistance, there is a definite and appreciable time between the instant that the initial voltage change is made at one point and the instant the corresponding effect is felt at the other points of the circuit.

It has been found that if a condenser is connected in series with a resistance and the combination connected across a d-c supply, the condenser will gradually be charged to the full potential of the source. A definite amount of time is required for the flow of electrons necessary to charge the condenser.

When in series with a resistance, the exact amount of time required for a condenser to reach 63% of its final charge is known as the "time constant" and this percentage holds true for any combination of resistance and capacity. From a practical standpoint however, the time constant in seconds is equal to the product of the resistance in megohms and the capacity in microfarads.

Written as an equation, T = RC, when
T = time constant in seconds
R = resistance, in megohms
C = capacity, in microfarads

As can be seen from the equation, the magnitude of the source of voltage will have no effect on the time constant and the condenser will charge to 63% of its final value in the same time regardless of whether the source is 1 volt, 5 volts, 75 volts or 1000 volts

When speaking of time constant, it is also necessary to mention the discharge of a condenser through a resistance. Just as a certain amount of time is required for a condenser when in series with a resistance, to charge to its final value, it is necessary for a certain amount of time to elapse for it to discharge. As far as the discharge is concerned, the time constant RC, as explained above, is the time required for a condenser in series with a resistance to discharge to 37% of its initial value.

Now that we have a good idea as to just what is meant by "time constant", let's go back and look at Figure 3. Here we have combinations of resistance and capacity in series and therefore have a definite time lag between the applied voltage at AB and the output voltage at XY.

If you will check the time constant equation you can see that increasing either R or C will result in a greater time constant and thus a greater time delay. If we reduce the values of R and C, the time delay is reduced but the filtering efficiency of the system is also impaired. Therefore, as we stated before, a compromise must be made between time delay and filter action.

To obtain a definite example of time delay, we will substitute the values, previously given for R1, R2, C1 and C2 of Figure 2, into the time constant formula.

The total resistance of the filter will be R1 + R2 or 1 megohm + .5 megohm which is 1.5 megohm, while the total capacity will be .05 mfd + .05 mfd, or .1 microfarad.

The time constant then is, T = RC = 1.5 x .1 = .15 second.

This means that the time required for the control voltage at the output of the filter to change in accordance with a shift in the signal level, which means a change in the control voltage at the detector, is approximately one-seventh of a second.

From the explanations thus far in this Lesson, you can see that the optimum value of the time constant used in receivers is a compromise of resistance and capacity values, large enough to provide adequate filtering, and values small enough to allow the control voltage to follow rapid fading or tuning operation. For Broadcast receivers this optimum value of time constant is approximately .1 to .3 second. For example, a value of .1 second can be obtained when the total resistance of the filter is 1 megohm and the total capacity is .1 microfarad, but of course, there are various combinations of resistance and capacity which will give the same result.

Suitable time constant values for high fidelity Broadcast receivers range from .25 to .5 second, whereas, dual and multiwave band receivers employ values between .1 and .2 second. A time constant which permits rapid action reduces the audio frequency bass response since audio notes are fundamentally of longer time duration. A more rapid time constant is desired for short-wave reception because of the fading characteristics at higher radio frequencies.

SERIES FEED AVC

The object of an avc is to affect the sensitivity of the controlled tube. As in any electrical network, there are two basic circuits, series or parallel and their combinations. An arrangement of series feed avc is shown by Figure 4, in which the d-c grid circuit from the control grid of tube T1 is completed through L, R2, R1 and R to the cathode, all components connected in series.

In an r-f controlled stage where one section the gang condenser is grounded, a blocking condenser of relatively large capacity is placed between the coil and grounded gang section to prevent shorting out of the avc voltage. The tuned i-f circuit of T1, Figure 4, need not be grounded as condenser C2 provides sufficient bypass for i-f currents.

SHUNT FEED AVC

Shunt feed avc is an arrangement whereby the d-c control voltage is fed directly to the control grid, usually through a one half megohm resistor connected to the filtered avc voltage source. However, a blocking condenser must be connected between the control grid of the tube and the tuned circuit to prevent shorting out of the avc voltage. The 500,000 ohm grid resistor mentioned above, is the usual value of resistance to use for the grid leak, as greater resistance has a tendency to cause grid blocking.

It is therefore possible to use combinations of series and shunt feed avc circuits to provide some desired characteristic action with minimum damping or detuning of r-f and i-f circuits.

DELAYED AVC SYSTEMS

The simple avc system of Figure 4 becomes effective in reducing the gain of the i-f or r-f stages even on the weakest signals, and therefore is really a disadvantage at low input signal levels. To overcome this undesirable action, a little different design has been developed which, because of its action, is called "Delayed AVC".

Fundamentally, the action of a delayed avc system depends upon the fact that the generation of the avc voltage is "delayed" until the input signal to the receiver reaches a certain predetermined value. As an example, we can say that the simple avc will operate at all signal levels about 1 microvolt while the delayed avc will not function until the level is greater than 50 microvolts and the receiver will therefore operate at its maximum efficiency. Using the simple system, the avc will be operative at all signal strengths and thus reduce the sensitivity of the receiver on weak signals.

These actual values are given only as an illustration and should not be considered as standards for receivers which employ delayed avc systems. You will find some receivers which operate over wider ranges than these limits. That is, the receiver may be designed so that the avc functions at less than 50 microvolts input and still others at more than 50 microvolts input.

The value of signal strength, at which the avc starts to function, is known as the threshold voltage. For values of input below the threshold voltage, the receiver will operate at its maximum sensitivity, as the initial bias is the only negative voltage on the control grid.

To show you just how this delayed action is accomplished, in Figure 5 we show the conventional circuits of a delayed avc system. Checking through the circuits, you will find an i-f amplifier tube T1 and a duo-diode T2, which functions as a second detector, or demodulator, and avc rectifier. In reality, T2, consists of two half wave rectifier tubes in one envelope.

Following the signal through the demodulator, we start with L, go to the control grid of T1, to the plate and then through

the i-f transformer windings L1 and L2, the output of which is applied to plate D1 of tube T2 and condenser C5. From the plate D1, the rectified signal circuit is completed through the cathode, R4, back to the lower end of L2. The condenser C4 provides a low reactance path for the intermediate frequencies and thus allows the audio component to develop a voltage drop across R4 which is shown as a potentiometer, and this voltage is the source of the audio signal, as explained in the Lesson on diode detectors.

Forgetting the signal for the time being, let's trace the circuit, of the other half wave rectifier of T2. Starting at the right hand plate, we find it connected to one side of C5 and also to R, the lower end of which is connected to ground, the circuit being completed through R5 to the cathode.

Now, notice that R5, R6 and R7 form a voltage divider from B+ to ground and as the cathode is connected to a point between R5 and R6, it must have a positive potential in respect to ground. With zero current in R, the plate, D2, is at ground potential and will be negative in respect to its cathode.

From your study of vacuum tubes, you know the plate should be positive in respect to the cathode in order to serve as a rectifier, and therefore, with a negative plate, there will be no plate current. In order to allow current in the plate circuit of D2, the signal must develop a plate voltage greater than the difference of potential between the cathode and plate, and when this occurs, the path of the current will be from the plate D2, to the cathode, through R5 and R to complete the circuit.

With current in this direction, the polarity of the voltage drop across R will be positive at the ground and negative at the upper end. The control grid circuit of T1 is completed through the filter system of R1, R2, C1 and C2, from the negative end of R to ground and back to the cathode through R3. Thus, it will be controlled by the avc action only when the carrier signal on the plate D2 exceeds the "delaying voltage" applied to the cathode.

When the conditions are such that the input signal is not great enough to overcome the "delaying voltage", the tube T1 will be negatively biased only by the drop across R5 and thus operate at its maximum efficiency. As we previously stated, the magnitude of the "delaying voltage" will depend on the desired requirement and will vary in different receivers.

Another method of delayed avc, and one which is quite commonly employed in radio receivers, is shown in Figure 6. Only the plate circuit of tube T1 is shown, and the signal from it is impressed on T2 by the output i-f transformer with its primary and secondary L and L1. Tube T2 is a duo-diode-triode, and in this circuit functions as a demodulator, delayed avc rectifier and first audio stage.

As before, we will first trace the signal path through the demodulator and then into the first audio stage. The i-f signal will appear across the secondary L1 and be impressed on the lower diode plate of T2. There will then be current from this plate to the cathode and back through R2 to the lower end of L1, completing the circuit. The condenser C2 provides a low reactance path for the i-f currents and thus the audio component will appear across R2.

The audio signal resistance coupled through condenser C3 and the grid load resistor R4 to the triode grid of T2, is amplified and will appear across the plate load resistance of the triode section.

For delayed avc circuit, the upper diode plate and common cathode of T2 is employed. Tracing the circuit, we start from the upper diode plate to the cathode, through resistance R3 and back through R1 to the avc plate.

The plate current of the triode section passes through the cathode resistance R3, being properly bypassed by condenser C4, and thus develops the necessary negative control grid bias on the triode section. However, as long as the avc plate is connected to ground through its load resistance R1, it is also biased to the same potential as the triode grid. In other words, the upper diode plate is negative in respect to the cathode by the voltage drop across R3.

Thus, we have similar conditions of delaying voltage, as explained for the circuit of Figure 5. The i-f signal is applied to the avc plate through the condenser C1, but before there will be any rectified current, or any d-c voltage drop across R1 for the avc action, this signal must be greater than the voltage drop across R3. That is to say, we must drive the avc plate positive in respect to the cathode before there will be any automatic control of the sensitivity of the receiver.

The delaying voltage, in a circuit of this kind, will be determined by the required negative bias voltage on the control grid of the triode section. If we assume this negative bias to be 9 volts, the i-f signal must exceed this value before

there will be any avc action. With signals below this value, the receiver will operate at its maximum efficiency.

In Figure 6, the resistance R and capacity C compose a single section avc filter, the action of which is the same as for R1 and C1 of Figure 2. The arrow of Figure 6 marked "avc" connects to the grid returns of the r-f and i-f tubes controlled by the automatic volume control.

The avc circuits we have explained here are basic, and in practice, you will no doubt run into many variations of them. However, if you fully understand the principles we have set forth, you should not have difficulty following the actions of any automatic volume control circuits.

NUMBER OF TUBES CONTROLLED BY AVC

In our previous explanations, we told you that the tubes controlled by avc were in the r-f and i-f stages. However, we said nothing about the number which were to be controlled and can add now that there is no definite set rule. In some receivers of low sensitivity, only one tube will receive the control voltage while in the others, of high sensitivity, as many as four tubes may be automatically controlled.

This variation is due to a definite relationship between the number of tubes automatically controlled and the performance of the avc system with respect to a uniform audio output.

To show you this relationship, we will assume a certain receiver in which only one tube is controlled by avc. In this case, we will say that a 2 to 1 increase in voltage output will be accompanied by a certain control voltage that will decrease the sensitivity of the receiver by a definite amount. The exact amount of reduction depends upon how much the gain of the controlled stage is influenced by the control voltage.

Now, if two tubes in this same receiver are controlled, then the increased signal input required to produce the same 2 to 1 voltage increase in output will have to be much greater. This is because the sensitivity of the receiver is less than in the first case, as the gain of two tubes has been reduced.

As a general rule, you will find the large receivers, with high sensitivity, employ avc on several stages while in the smaller receivers, with low sensitivity, only one or two stages will be controlled.

AUTOMATIC VOLUME EXPANSION

Automatic Volume Expansion, commonly referred to as ave, finds its greatest application on audio amplifiers used for the reproduction of phonograph records. Its purpose is to make the reproduction of music more natural, from a record which has a large volume range. For instance, in the music of a symphony orchestra, the sound intensity of the loud passages is much higher than that of the soft passages.

The distances between the grooves of a record when music is recorded is small, therefore, the ratio between the maximum amplitude to minimum amplitude is not as large on the record as it is in the original music. The recording process is therefore monitored so that the volume range of the original is compressed on the record.

The circuits of Figure 7 show the arrangement for a volume expander and you will see that three tubes, T1, T2 and T3 are employed. Tube T1 is a pentagrid converter such as the 6L7, T2 is a triode and T3 is a duo-diode. The action of this circuit depends on the fact that the gain of T1 as an audio amplifier can be varied by variation of the bias voltage on the #3 or modulator grid, and when the bias is made less negative, the gain of T1 increases.

Checking the circuit of Figure 7, the a-f signal is applied across the two potentiometers R1 and R4, which are connected in parallel. The movable contact of R1 is connected to the control grid of T1 through the coupling condenser C1. The grid load resistance R2 is connected to a negative point on the voltage divider and thus the tube is provided with a bias.

While we are speaking of the voltage divider, point "O" is considered as a reference and therefore, the voltages above it will have a positive potential while those below will be negative.

Going ahead with the circuit discussion, the modulator grid of T1 is also connected to a negative point with respect to "O", through R9 and R8. Condenser C2 provides a bypass for a-c and also prevents coupling. The screen grid of T1 and the plate through its load resistance R3 are connected to a positive point on the divider, the plate of course being at the higher potential. The condenser C3 acts to block the d-c from the output terminals and yet allows a path for the signal.

The movable arm of R4 is connected directly to the control grid of T2 which is biased by the voltage drop across R5, and condenser C4 acts to maintain a steady d-c voltage across the bias resistor. The plate of T2 is connected to a high positive potential through its load R6, and is coupled to the diode plates of T3 through the condenser C5. Resistors R7 and R8 provide the load for T3.

Now that we know where the various elements of the tubes are connected, let's see what happens when a signal is applied across the input terminals. The signal will be split, one part of it being applied to the control grid of T1 to be amplified and appear across the plate resistor R3. The other part is applied to the control grid of T2, amplified, and then rectified by T3. The rectified voltage will appear across R8 which is in the modulator grid circuit of T1. Notice, the polarity of this voltage drop is such that it applies a positive bias to the modulator grid. As the grid is already negatively biased from the voltage divider, we have two voltages opposing each other with the result that the bias on the modulator grid of T1 will become less negative.

In case this is a little difficult for you to see, we will assume that the modulator grid is negatively biased to a value of 10 volts and the drop across R8 is 5 volts. Under these conditions, the resultant bias voltage on the modulator grid would be -10 + 5 or -5 volts.

Because this decrease of bias voltage increases the gain of tube T1, the gain of the amplifier increases with an increase in signal amplitude and thus produces volume expansions of the signal.

When used with a phonograph, the output of the volume expander of Figure 7 is fed to the input of an audio amplifier. Employed in this way, the ratio between the maximum and minimum amplitudes of the original sound can be restored from a recording.

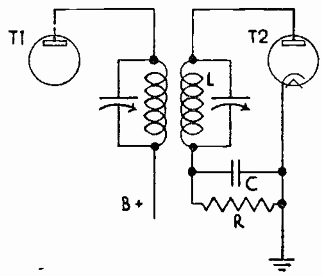

FIGURE 1

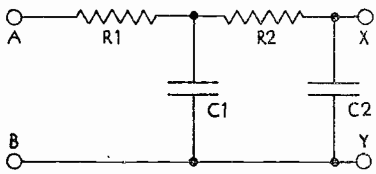

FIGURE 2

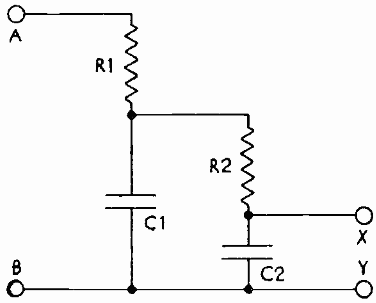

FIGURE 3

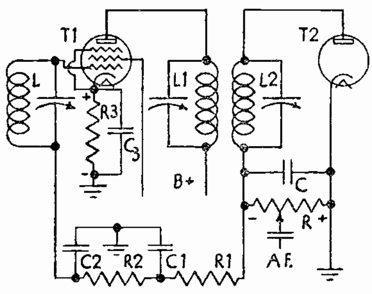

FIGURE 4

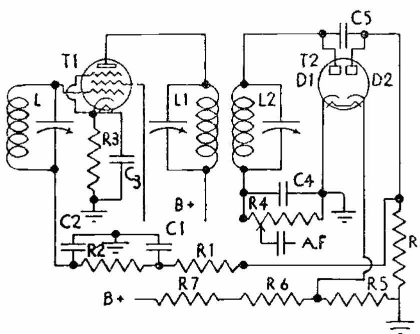

FIGURE 5

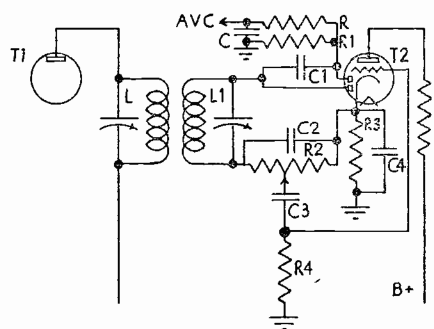

FIGURE 6

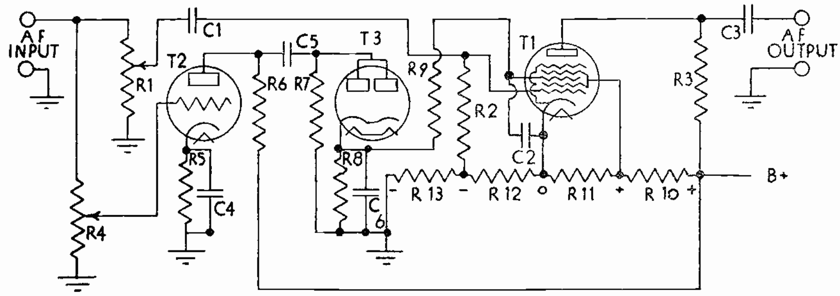

FIGURE 7

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PUSH BUTTON TUNING SYSTEMS

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LESSON RRT-9
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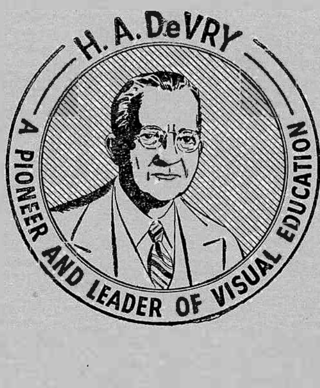


RADIO RECEPTION AND TRANSMISSION

LESSON RRT - 9

PUSH - BUTTON TUNING SYSTEMS

* * * * * * * * * *

Initiative - The men who exercise initiative are the builders of the world, All others are merely tenants or janitors.

Enterprise - People who aren't afraid to roll up their sleeves seldom lose their shirts.

Knowledge - The only jewel which will not decay is knowledge.

Self-Analysis - If you're willing to admit you're all wrong when you are, you're all right.

Opportunity - Opportunity seldom calls on people who aren't worth a rap and who can't stand a knock.

**Selected

In the past years, automatic or push-button tuning has been adopted by practically every manufacturer of radio receivers. However, automatic station selection is not new but rather a refinement and perfection of principles which have been in use for many years.

Although the subject seems very broad, there are only three main types of automatic station selector systems which may be classified as,

1. Mechanically Operated Manual Types
2. Motor Operated Types
3. Tuned Circuit Substitution Types

The object of this Lesson is to give you an explanation of these basic systems so that you will not have any difficulty understanding the principles of operation in any automatic tuning system.

MECHANICALLY OPERATED MANUAL TYPE

As the heading indicates, this type of system is mechanically operated and functions without any electrical action. Due to this fact anyone, without technical training, can understand the operation simply by inspecting the system.

In general, however, the tuning condenser is rotated to the desired station reception position by direct mechanical effort of the person operating the receiver. This is accomplished by an arrangement of push buttons mechanically connected to a system of gears, cams and levers which are in turn connected to the rotor of the condenser gang.

The stations are pre-selected and the system is "set up" to them and locked. When this has been done, it is only necessary to push a button, or lever, which mechanically rotates the tuning condenser to the corresponding station.

MOTOR OPERATED TYPES

With the motor operated type or system, the rotation of the variable condenser gang, to a position corresponding to a desired station tuning point, is accomplished by means of an electric motor. This system usually includes an electric motor, a station selector switch or selector buttons, a selecting commutator or other device for stopping the motor and an audio silencing circuit which operates when the motor is running.

To show you the actual operation, in Figure 1, we have the simplified circuits of such a system in which you will find the commutator, mechanically connected to the condenser gang.

The selector switches, are connected in the electrical circuits of the motor winding, L, L1 and L2, the commutator and supply transformer. The motors employed in these systems are split phase induction type which merely means that the current in L1 or L2 may be out of phase with the current in L, and such arrangements permit greater torque or turning effort of the armature. No direct electrical connections are made to the armature. Although not shown in Figure 1, the armature is mechanically coupled to the condenser shaft.

Tracing the motor circuit, we start at the secondary of the supply transformer, go through switch #5 and the motor windings up to the commutator. From here, the circuit is completed through the selector switches to ground and through it to the grounded end of the secondary.

Looking at the switches, you will notice that numbers 1, 2, 3 and 4 are normally open, closing their circuits when pushed or depressed. Switch #5, which is used to change from manual to automatic tuning, has the opposite action and is normally closed but opens its circuit when depressed.

Mechanically, the arrangement operates so that when any one switch button is depressed, all of the others are released. Thus, in normal operation, only one switch button will be depressed at any time. However, should two or more buttons be depressed at the same time, they will remain in that position until released by the operation of another button.

In order that you can understand the action, we will assume that you have the receiver in operation and desire to set up the push buttons to your favorite stations which we call A, B, C and D. As button #3 is shown depressed in Figure 1 your first step would be to depress push button #5, which would release #3, and then manually tune in station A, which we will assume moves the insulated strip of the commutator to a position between contacts 1 and 2. With station A carefully tuned in, you depress push button #1, while holding in #5, thus opening switch #5 and closing switch #1.

Under these conditions let us follow the action in the electrical circuits. From the supply secondary, the circuit is through the indicator lamp connected across switch #5, through coils L and L1, to the commutator, to contact #1 and through switch #1 to ground. Therefore, there is a complete current path which will cause the indicator lamp to light. The current, of course, will also be in the motor but, because of the lamp in series, will be too small to cause the armature to rotate.

Now, with the insulated section of the commutator between contacts 1 and 2, contact #1 is moved until it rests on the insulated section, breaks the circuit, and causes the indicator lamp to go out. Remember also, that this is the position of the selected station A. With this setup, suppose we release push buttons 1 and 5 and revolve the commutator to the position shown in Figure 1.

Then, as switch #5 is closed, the indicator lamp is shorted out of the circuit and by depressing push button #1 only, there will be current in the motor coils L and L1, the commutator, contact #1 and to ground through switch #1. This current will cause the armature of the motor to revolve in a counter-clockwise direction and because of its mechanical connection to the condenser shaft, will cause both the condenser and commutator to revolve in the same direction. This motion will continue until the insulated segment of the commutator is under contact #1, breaking the circuit, and stopping the motor. As the position of contact #1 conforms to the tuning condenser's manual setting for station A, the motor has automatically tuned in this station.

Starting with the commutator insulation in a horizontal position, instead of vertical as shown, the motor current will be from the supply through coils L and L2, thus making the armature revolve in a clockwise direction until the circuit is broken by the insulated segment, again tuning in station A.

Buttons #2, 3 and 4 are set up in exactly the same way as button 1 and will correspond to stations B, C and D. Once these buttons are set up, it is only necessary to depress one of them and the station corresponding to it will be automatically tuned in. In Figure 1, button #5 is used only to change from manual to automatic tuning and to assist in the original setting up of the selectors or push buttons.

In the beginning of this explanation, we told you that usually an audio silencing system is applied to this type of automatic tuning. This action is generally accomplished by positioning the armature of the motor slightly out of the center of the magnetic field set up by the motor coils. It is held in this off center position by a flat phosphor bronze spring which is electrically connected to ground. A contact, connected to the grid of the first audio tube, is placed close to the spring. When the motor windings are energized the armature is drawn into the center of the magnetic field, pushes the spring over and closes the circuit between it and the audio contact. This grounds the grid of the first audio stage and thus silences the system. When the motor windings are not energized, the spring holds the rotor out of position and opens the contact circuit thus allowing the audio amplifier to operate normally.

There are many variations of motor driven tuning systems but, basically they are all the same. Therefore, if you fully understand Figure 1, you will not have any difficulty with others. The number of push buttons will depend on the designer and you will find systems using more or less than the number shown in Figure 1.

TUNED CIRCUIT SUBSTITUTION TYPES

In this type of automatic tuning, a latching or ladder type push button switch selects pre-calibrated tuned circuits which are substituted for the usual variable condenser tuned input and oscillator circuits. In general, there are two types of pre-set circuits in use: 1. Trimmer condenser tuning and 2. Iron core or "Permeability" tuning.

In Figure 2, we have an arrangement using trimmer condenser tuning and, in order to simplify our explanation, have shown only those circuits which are directly affected. That is, the condenser tuned input, LC, and the oscillator C1-L1. In all of these circuits, a switching arrangement is necessary to change from manual to automatic tuning and in Figure 2, this is accomplished by switch #1. The upper pair of contacts control the tuned input circuit and the lower pair of contacts control the oscillator circuit. Each paid of contacts, of course, is insulated from the other.

Notice, when button #1 is depressed, the upper pair of contacts are shorted, thus closing the circuit between C and L, which also connects to the input grid of T1. This tube is a pentagrid converter, and the associated circuits serve as the 1st detector and oscillator sections of a superheterodyne receiver. Button #1 also closes the lower contacts, connects C1 to L1 which, in turn, connects to the oscillator grid of T1. Under these conditions, the circuits are conventional and the receiver tunes manually.

Suppose now we depress button #2 which, as explained for Figure 1, releases #1. This will disconnect condenser C from coil L and substitute trimmer condenser C2 in its place. Likewise, in the oscillator section, condenser C1 will be replaced by trimmer condenser C3. However, coils L and L1 remain in their proper circuits.

Thus, if C2 and C3 are adjusted and set to properly tune some desired station, it can be received by simply depressing button #2. The other buttons, 3, 4 and 5, operate exactly the same as #2 and it is only necessary to tune their trimmer condensers to the desired stations. Once this is done, the stations can be received by simply depressing a button. For manual tuning, button #1 is pushed in and will lock in position until another button is depressed.

In Figure 3, we have a little different system of substitution push button tuning and, before explaining the action, want you to understand the operation of switch #5. This switch is made up of two parts, one contact of which is connected to condenser C3. As shown by the broken line, this switch arm also controls a sliding contact which changes the operation of the receiver from manual to automatic tuning.

Notice, that when this switch is closed, both ends of condenser C3 are at ground potential, thus making the push button assembly inoperative. Closing this switch also moves the sliding contact so that the upper three circuits on each side are connected together while the lower contacts are open.

If you will trace through these circuits, you will find this movement of the contact simply makes connections so that the manual tuning circuits, L2-C2 and L6-C8, are operative. The resistance condenser combination of C5 and R1 is employed so that the input grid circuit can be controlled by avc.

The automatic tuning system of Figure 3 makes use of the fact that the inductance of a winding varies directly with a change in the permeability of its core material. To make use of this action, specially prepared iron slugs, which have very low loss at radio frequencies, are placed inside of the coils and so arranged that they can be mechanically moved in or out.

From your earlier Lessons, you know that the permeability of these iron slugs will be much higher than that of air and, as they are moved in and out of a coil, its inductance will vary accordingly. Due to the fact that this inductance can be varied, it is possible to tune over a definite band of frequencies using a fixed condenser, the same as a circuit can be tuned with a fixed inductance and variable condenser.

In Figure 3, we show four sets of these coils and have indicated their functions by marking them "Ant. Coils" and "Osc. Coils". It is quite easy to gang these coils and iron slugs so that each pair may be tuned by one adjusting knob, such as shown by the arrows. Turning this knob, will move the slugs in or out of the coils as desired.

Checking over the push button circuit, you will see that the arrangement is very similar to that of Figure 2 except here we employ tuned inductances instead of tuned trimmer condensers. Like the trimmer condensers, the inductances are preset, or tuned, to the desired station, which can then be heard simply by depressing a button.

The antenna is coupled to the input grid of the first detector by condenser C1, and condenser C3 is employed to compensate for variations in antenna capacity. In the oscillator circuit, it is necessary to include adjustments which provide tracking between the oscillator and first detector circuits.

As we explained in the earlier Lessons, for the normal tuned circuit, this may be accomplished by means of a trimmer and padding condenser working in conjunction with the oscillator section of the variable condenser. However, as no variable condenser is used with the iron core coils, a different method must be employed.

It has been found that a small winding, connected in series with the oscillator grid end of the automatic windings, and so placed as not to be affected by the iron core will, if properly designed, permit proper tracking at the high frequency portion of the coils's range. Also, when two inductances are connected in parallel, the maximum inductance is limited by the size of the smaller of the two, just as the equivalent resistance of two parellel connected resistance is limited by the value of the smaller.

In Figure 3, coil L3 is the padder winding and also serves as a means of coupling to the oscillator plate coil L4. When used in conjunction with the smaller winding mentioned above, which is L5 in Figure 3, the arrangements allow excellent tracking. Variations of temperature and humidity are compensated by means of C6 which is a small fixed condenser composed of silver surfaces sprayed on a special ceramic tube. Constructed in this way, changes of capacity due to temperature and humidity are opposite to similar changes in the coil.

Another variation in the arrangement of the circuit components in Figure 3 is that of the "shunt feed" avc circuit mentioned in a former assignment. Instead of the "series feed" circuit to the control grid of the tube as illustrated by the avc "Bus" leading to coil L of Figure 2, the avc circuit of Figure 3 does not contain the tuned circuit, whereas the control voltage is routed through R1, and signal voltages are coupled to the control grid through C4.

The main advantage of the substitution type of automatic tuning, compared to the motor driven type, is that a station is tuned in as soon as the button is depressed. In the motor driven type, one must wait until the commutator and condenser gang have rotated to the desired setting. Both however, have an advantage over the mechanical systems which are sometimes difficult to tune exactly to resonance.

TUNING INDICATOR

Since the advent of avc, Radio Receivers have been equipped with various types of tuning indicators practically all of which operate because of the avc action.

A number of factors are responsible for the widespread adoption of tuning indicators of one type or another. In addition to their usefulness in tuning to exact resonance, manufacturers realize that their incorporation constitutes an important item in increasing the attractiveness and salability of their receivers.

You have no doubt seen various shapes and sizes of receiver tuning indicators and, for the most part, probably each seemed separate and distinct. However, in general, we can put all types in three classes, and list them as,

1. Meter type indicators
2. Saturable core type indicators
3. Cathode ray indicators

For the remainder of this Lesson, we will explain each type and show you how they are connected in the circuit.

METER TYPE TUNING INDICATOR

From the explanations of the earlier Lessons, you will remember that avc operates by feeding a control voltage to one or more r-f, mixer, and i-f tubes. The magnitude of this control voltage depends upon the amount of signal which reaches the second detector and, applied to the grid of the controlled tubes as a negative bias, it will have an effect on their plate current. That is, when a strong signal reaches the avc rectifier, there will be a high negative bias on the control grid and the plate current will be reduced. When a weak signal reaches the second detector or avc rectifier, the controlled tubes will have a minimum negative bias and comparatively high plate current.

From your former study of tuned circuits, you know that, at resonance, the amplitude of the impressed a-c voltage will be maximum. Applying this to the functioning of a receiver, as a station is tuned in, the voltage at the second detector will gradually increase and be maximum at resonance. This will cause a maximum control voltage, the magnitude of which will depend on the strength of the signal, to be applied as a negative bias to the controlled tubes, reducing their plate current.

Therefore, if a sensitive current meter is placed in the plate circuits of the controlled tubes, it will register minimum current when a station is properly tuned in. The exact swing of the meter pointer will depend on the negative bias voltage applied to the controlled tubes which, in turn, depends on the strength of the input signal.

In Figure 4, we show a simplified arrangement of such a system and you will notice the meter is connected in series with the plate circuit of the controlled tube T1. Tube T2 acts as a second detector and avc rectifier, the avc control voltage being developed across R2 and C4 while resistor R1 and condenser C5 form a one section avc filter. The control grid of T1 is connected to the lower end of R1, through the i-f transformer secondary L1, and the circuit is completed to ground through R1 and R2.

With no signal on the control grid of T1, there will be minimum bias voltage and maximum plate current which will be registered by the meter. When a signal is tuned in, there will be a voltage drop across R2, which will increase the negative bias on the control grid of T1 and thus reduce the plate current. Therefore, to tune to resonance with an incoming carrier, the tuning controls are adjusted until the meter registers the lowest plate current for that station.

In practice, you will find the indicating meter camouflaged in many different ways, the most common, perhaps, being the shadowgraph or shadow meter. In construction, the shadowgraph indicator mechanism employs a small permanent magnet which is in the form of a circular flat ring having a small air gap.

The moving armature, which forms the indicating part of the system, consists of a flat disc of soft iron, with a rectangular slit in the center, and is mounted within this ring, so that it pivots on two opposite supports.

A thin, black opaque vane, is mounted in the middle of this slit and rigidly attached to the iron armature so that any movement of the armature is accompanied by a corresponding rotation of the vane. A coil of wire surrounds the permanent magnet in such a way that the magnetic field, due to current in it, is at right angles to the plane of the permanent magnet.

With this mechanical arrangement in mind let's see just how the unit functions. First, the magnetic field of the permanent magnet tends to keep the armature in a horizontal plane because the air gap allows the leakage flux to penetrate the soft iron of the armature. Under this condition, the armature assumes a position which enables the maximum amount of leakage flux of the permanent magnet to pass through

it. In other words, the permanent magnet acts as the force which holds the armature at the zero current position.

The deflection of the armature and therefore the vane, is due to the magnetic field created when there is current through the shadow-graph coil. Its field is at right angles to that of the permanent magnet and therefore the combined field is distorted or changed in direction sufficiently to rotate the armature and attached vane. The greater the current in the coil, the greater its magnetic field and consequently the greater the angle through which the armature and vane are rotated.

From your former studies, you can see that the action of the shadow-graph is essentially that of a meter and therefore it can be used in place of the meter shown in Figure 4. The only difference being that instead of an ordinary pointer indicator, it has an optical system arranged so that the reading is represented by the width of the shadow formed on a screen.

The simple optical system is composed of a pilot lamp, placed behind the slit, so that the light is transmitted through the slit to a small screen. As the vane is located in the slit, the width of the shadow, cast on the screen, will be determined by the position of the vane, which is controlled by the current in the coil.

In most cases, the position of the vane is such that at maximum current, the shadow will have its greatest width. Therefore, when tuning in a station the shadow will narrow, due to the avc action, and become minimum at resonance.

SATURABLE CORE TUNING INDICATORS

The saturable core tuning indicator operation depends upon the variable impedance of an iron core inductance which carries direct magnetizing current. This may seem rather complicated but the principles involved have already been covered.

Filter chokes, as used in the ordinary power supply, carry both a-c and d-c components and are usually rated in accordance with the values of direct current they will carry safely. This value of direct current must not be exceeded if the inductance of the filter choke is to be maintained.

In other words, the inductance of the choke coil depends in a marked degree upon the value of direct current in the coil. When the direct current in an iron core coil is excessive, the core is said to be "saturated" and its inductance falls to a very low value.

Saying it in a little different way, when the core is saturated, it is impossible for the flux to change in accordance with the applied a-c voltages. This means there will be less reverse voltage set up and thus a lower value of inductance, or impedance.

In Figure 5, we have plotted a curve of direct current against inductance, or impedance, in an iron core coil. You can easily see that as the direct current increases, the impedance of the coil decreases. We do not show any actual values because, at the present time, we are interested only in the general shape of the curve.

To employ this principle to tuning indicators, it is generally found necessary to isolate the d-c winding, used to saturate the core, from a-c winding which operates the tuning indicator. This is accomplished by using a transformer with two windings as shown in Figure 6.

Although this circuit is a simplified arrangement, it will show the action which takes place in a saturable core tuning indicator. The primary winding L1, connected in series with the battery and variable resistor R, is used to carry the d-c and saturate the core. The secondary L2, in series with the lamp, is connected across a low voltage a-c supply. In a receiver, this a-c supply is generally obtained from a winding on the power transformer.

Keeping the former explanations in mind, let's assume the variable resistor R is so set that the d-c in L1, is small in value. From Figure 5, this shows that the impedance, or inductance, of coil L2, Figure 6, is high. Due to this high impedance, the current through the lamp will be of small value and it will light dimly.

Now, let's imagine the resistance if R is adjusted to a low value and allows a high d-c through L1. As shown by the curve, this will cause a decrease in the impedance of L2, allow more current through the lamp and cause it to light more brilliantly.

The simple transformer arrangement of Figure 6 is not favorable for use in radio receivers because the a-c voltage in coil L2, will induce a voltage in L., which is usually connected in the plate circuits of the avc controlled tubes. This condition of course, would cause an a-c hum in the speaker.

To overcome this difficulty, the windings are placed on a three-leg transformer cone as shown in the lower part of Figure 6. The primary winding L6, wound on the middle leg,

has one end connected to the plates of tubes T1 and T2, through the primaries of their i-f transformers, and the other end is connected to B+. Thus, coil L6 will carry the plate current of both T1 and T2.

The secondary winding is in two sections, L5 and L7, wound on the outer legs of the core. These two sections are joined in such a way that the a-c current in each of them will induce equal and opposite voltages in the primary L6, so that no net a-c voltage appears across it. The lamp is in series with the outer ends of the secondary sections which are connected in series across an a-c source.

Examining the rest of Figure 7, we see the partial circuits of two i-f amplifier tubes, T1 and T2, the control grids of which are connected to an avc voltage. When there is no input signal to the amplifier, the negative bias on the control grids of T1 and T2 will be minimum and the plate current maximum. As this current is in L6, it will tend to saturate the core of the indicator transformer, lower the impedance of the secondary and allow the lamp to burn brightly.

When a signal is tuned in, the avc action will increase the negative bias on the control grids of T1 and T2, and cause a decrease of their plate currents. This, in turn, will increase the inductance of the secondary and dim the lamp. It can therefore be seen that with this system, resonance with an incoming signal will be indicated by a dimly lit lamp.

Another application, of the saturable core principle, makes use of different colored lights to indicate resonance. As far as the mechanical arrangement is concerned, the dial scale lighting is accomplished by means of four red bulbs and three green bulbs spaced alternately behind the linear scale.

When no signal is tuned in, the red bulbs light brilliantly and the green bulbs are so dim that the net result is a red glow over the entire scale. When the signal is accurately tuned in, the red bulbs are dim and the green bulbs are sufficiently brilliant to cast a green glow over the scale. For intermediate positions, when the signal is only partly tuned in, the illumination is a combination of green and red which combines to produce a whitish light. The sequence of changes as a signal is tuned in, will be from red to white to green, the latter condition indicating resonance.

The electrical system employed to accomplish this action is shown in the circuits of Figure 8, where coils L1 and L2 are the primary and secondary of a saturable core transformer,

like that explained for Figure 6. A separate tube T1, is employed to provide the d-c saturating current and its control grid is connected to the source of avc voltage.

The lamp network consists of seven pilot lights connected to the secondary L2, while the a-c voltage is obtained from a winding on the power transformer of the receiver. In our explanation, we will consider the lamps T1, T2 and T3, green, with T4, T5, T6 and T7 red.

Also, we will assume the impedance of L2 varies from 25 ohms to 700 ohms, the exact value at any instant, depending on the plate current of T1. That is, with no signal, the negative bias on T1 will be minimum and the plate current high, resulting in an impedance of 25 ohms for L2, With a strong signal, the negative bias on T1 will be maximum and the plate current low, causing the impedance of L2 to increase to 700 ohms.

Now, let us see what happens when we have a "no signal" condition in the receiver. As mentioned above, tube T1 will draw its maximum plate current and cause a 25 ohm impedance in L2. The resistance of the three green lamps will be quite high in comparison and the current in them so small that they will barely light. Under these conditions, however, the total current in L2 and the green lamps will be quite high and passing through the red lamps will cause them to be brilliantly illuminated.

When the receiver is tuned to a signal, we have an entirely different set of conditions. Due to the increased negative bias, the plate current of T1 will be low, and cause the impedance of L2 to increase to 700 ohms. In comparison to the resistance of the green lamps, this value is large enough to consider L2 as being open circuited.

With L2, thus eliminated, in effect we have nothing but a simple series circuit but the total current is less than in the former "no signal" condition because the shunting effect of L2 is removed. Not only is the total current reduced, but because of their paralled-series connection, the current in each red lamp will be only half of that in the green lamps.

The decrease in total current, and the division of current between the two parallel branch circuits of red bulbs, causes them to light dimly when a signal is received. The total current from the a-c source however, must pass through the green lamps and therefore they light to full brilliancy.

Summarizing, the red lamps light brilliantly with no signal . while the green lamps are brilliantly illuminated when the station is correctly tuned in and the entire action depends on the variable impedance characteristic of the secondary coil L2.

CATHODE RAY TUNING INDICATOR

Perhaps the most common type of tuning indicator in use today, is the "Magic Eye" tube of which the 6E5 and 6U5 are examples. The action of this tube is very interesting but before going into detail, it is necessary that we explain the location of the various elements which make up the entire assembly.

For Figure 9, we show a simplified, cross sectional view of the tube, with all of the various elements properly marked. The left-hand lettering refers to external terminals and we want you to pay particular attention to the respective location of the active elements. You will notice there are essentially two separate tubes with a common heater and a split cathode. One of these is a triode which functions normally and, in case you have forgotten its operation, we suggest that you review the earlier Lessons.

The other section consists of the cathode with a light shield on its outer end, the ray control electrode and the target which is coated with a material that glows or fluoresces when electrons strike it. The purpose of the target is to attract electrons from the cathode and provide a visual indication by fluorescing over a certain part of its coated area.

The ray-control electrode, shown between the cathode and target is tied directly to the triode plate. As we will explain later, its action controls the area of the target which is struck by the electrons emitted by the cathode.

The purpose of the cathode light shield, which is made of an opaque substance and placed directly over the outer end of the cathode is to eliminate any of the light produced by the heater. Usually black in color, it gives the impression of being the pupil of an "eye".

Tracing the circuit of Figure 10, the plus terminal of the 250 volt supply connects directly to the target and to the triode plate through resistor R2 while the cathode connects to the negative of the supply, as a return for the plate circuit. From the triode grid, there is a connection to the center arm of potentiometer R1, connected across a 12 volt battery, the plus of which is tied to the negative of the plate supply.

Forgetting the visual indicating section for a moment, we have the normal connections for the grid and plate voltages of a common heater type triode with the potentiometer, R1, as a means of varying the grid voltage.

From our former explanations, you know that if the arm of the variable resistance is at the plus side of the battery, there will be zero bias, the plate current will be maximum and the voltage drop across R2 will be the greatest. However, if the arm is at the extreme negative position, the grid bias will be maximum, there will be low plate current and the voltage drop across R2 will be small.

Go over the above explanation serveral times because, as the ray-control electrode is connected directly to the plate of the triode, it is actually the triode section which controls the electrons that strike the target.

Looking at Figure 10 again, and thinking of the tube as a whole, with the filament heated, the cathodes giving off electrons and the arm of the potentiometer set for zero bias, there will be maximum current in the plate circuit. Under these conditions the voltage drop across R2 will be maximum.

With an assumed maximum drop of 200 volts across R2 and a 250 volt supply, there will be 250 minus 200 or 50 volts actually on the plate of the triode. As the ray-control electrode is connected directly to the plate, the 50 volts will be applied to it also. The target is connected directly to the positive of the 250 volt supply thus, there is a difference of potential of 250 minus 50, or 200 volts between it which is 200 volts negative in respect to the target. Go over this last statement again because it is important.

Before going further, we want you to go back to Figure 9 and notice that the ray-control electrode is placed between the target and cathode. When it is 200 volts negative in respect to the target, it will repel the electrons around it so that practically none will reach the portion of the target affected by this section.

Figure 11-A, is a top view of the "magic eye" tube with the cathode light shield removed to show the position of the elements. The shaded area is that part of the target which no electrons strike and, in actual operation, resembles a shadow while the other portion glows or fluoresces a greenish-yellow color. This large shadow is due to the repelling action of the ray-control electrode, which does not allow any electrons to strike that section of the target and appears when the control grid bias voltage is practically zero.

Going back to Figure 10 again, but this time with the potentiometer arm in the negative position to provide a high bias voltage, the plate current will be small and we will assume the drop across R2 is only 5 volts.

Thus, with 245 volts on the ray-control electrode, the difference of potential between it and the target will be 250 minus 245 or 5 volts. Hence, the ray-control electrode will be but 5 volts negative in respect to the target and will have no noticeable repelling action on the electrons.

Therefore, as shown in Figure 11-B, with a high negative voltage on the control grid of the triode section of the tube, the width of the shadow will be practically as narrow as that of the physical dimensions of the ray-control electrode.

In order that you may become familiar with its application to radio receivers, in Figure 12 we have the simplified connections of a "Magic Eye" to a half wave rectifier tube T1 which functions as a second detector and avc rectifier.

Tracing the circuit, you will find the 250 volt supply connected directly to the target and through a dropping resistor, R2, to the plate of the triode section of the tuning indicator tube T1. The grid circuit is connected across the diode load resistor R and the drop across it, which depends on the signal strength, provides the negative grid bias.

With these connections, when slowly tuning in a station, the voltage at point X will gradually become more negative with respect to ground until, at resonance, (when the station is exactly tuned in) it will have maximum value. As this voltage is applied to the grid of the triode section, it will cause a variation of plate current which, in turn, will vary the voltage on the ray-control electrode.

Thus, when no station is tuned in, the ray-control electrode will have its greatest negative potential in respect to the target and the shadow on the screen will look like that of Figure 11-A. As resonance is gradually approached, the ray-control electrode becomes less negative, the shadow tends to narrow and, at resonance, will look like Figure 11-B, the size of the minimum shadow being determined by the physical dimensions of the electrode.

There are several types of cathode ray tuning indicators in use but they all operate on the principles explained in this Lesson. Some are arranged to give a circular shadow instead of the angular type explained and there are various values of cut-off bias voltage of the triode section. For example, one type cuts off at -8 volts on the control grid while

another has a -22 volt cut-off but, in both instances, there is +250 on the target. This variation of bias voltage is to compensate for the different control voltages developed across the avc rectifier.

The magic eye is not limited to use on receivers with avc since it operates to indicate a change of voltage across any part of a circuit to which it is connected. For example, it may be connected in the diode circuit of a receiver irrespective of the presence of avc, or it may be connected across the cathode bias resistor of a plate detector. The correct type of indicator tube to be selected for any position then depends on the controlling voltage available.

NULL POINT INDICATOR

The magic eye indicator has many applications in various types of test equipment, one being a null point indicator in bridge circuits. In an earlier lesson, we explained the basic principles of the Wheatstone Bridge, and you will recall that some method of indicating "balance" is required. In modified bridge circuits, the use of the magic eye is preferable since it can be made very sensitive in its operative, and is capable of withstanding considerable overload voltages without damage.

Although the explanations of this lesson have been on the so-called "accessories" of a radio receiver, their wide spread application makes a complete understanding of their operation necessary. Therefore, before going to the next Lesson, make sure that you know their principles and applications.

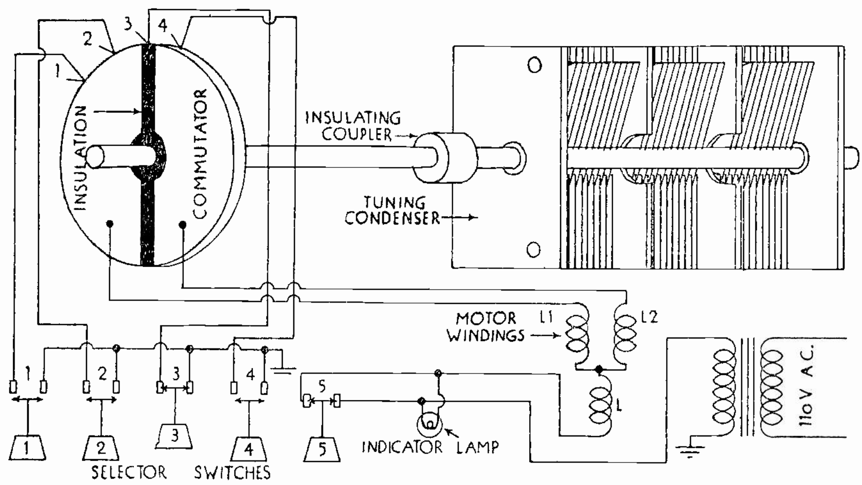


FIGURE 1

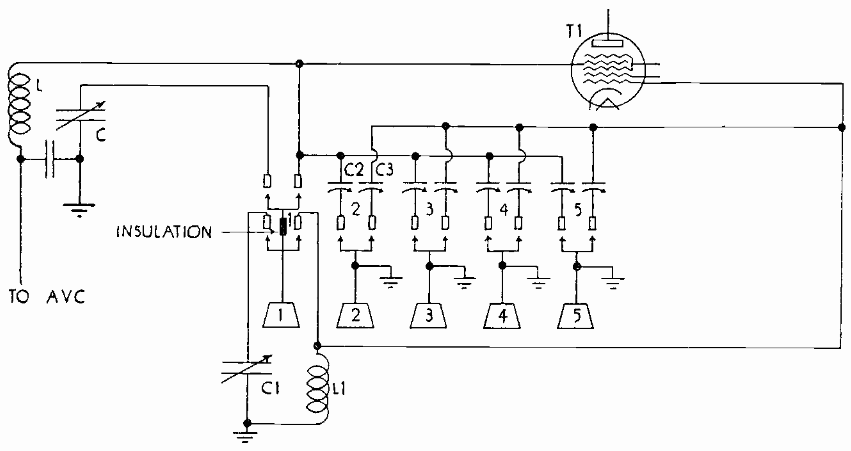


FIGURE 2

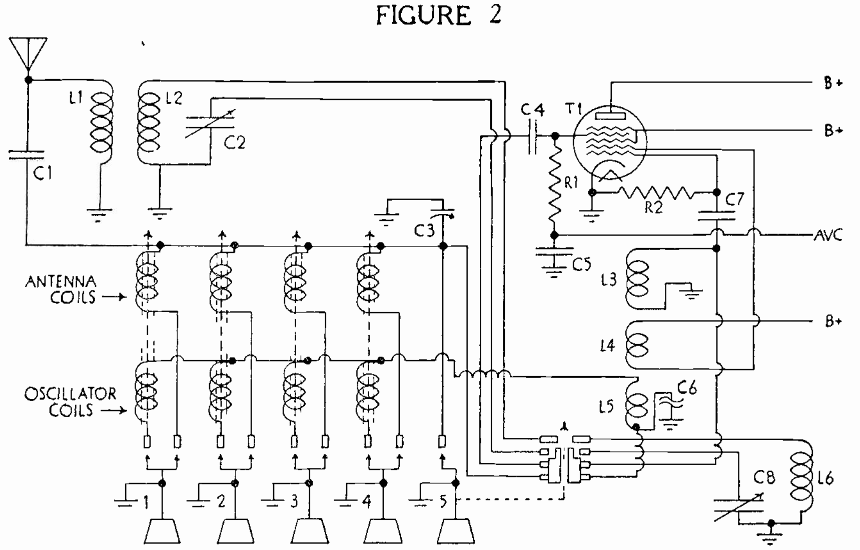


FIGURE 3

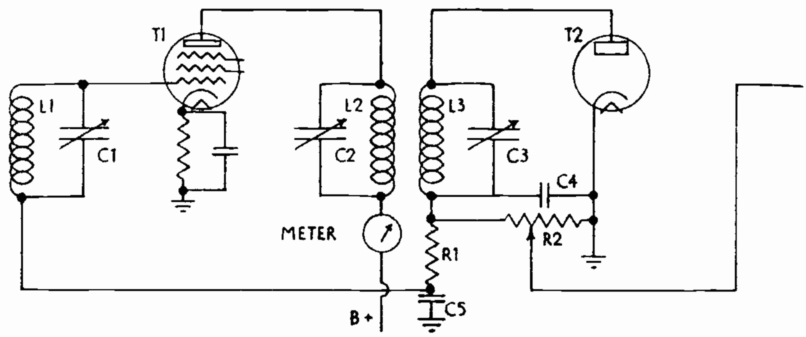


FIGURE 4

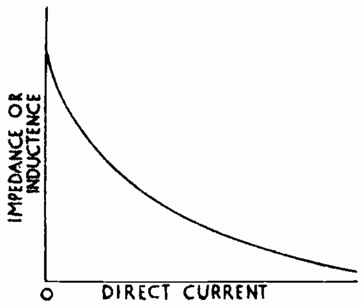


FIGURE 5

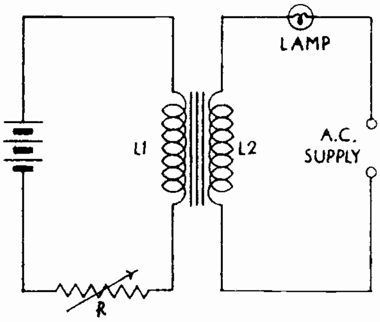


FIGURE 6

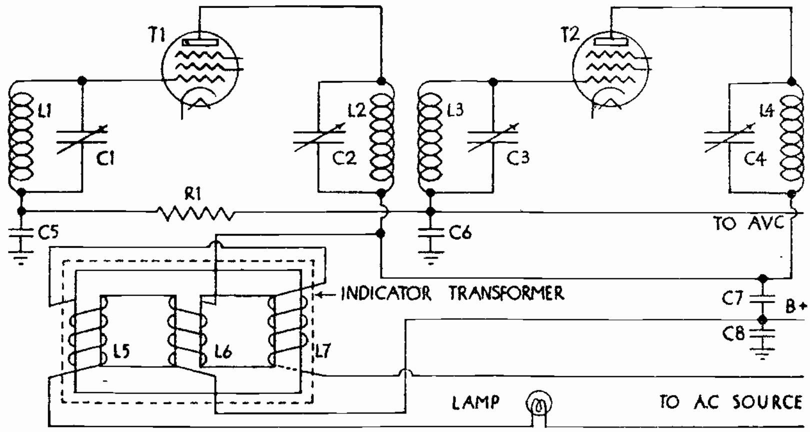


FIGURE 7

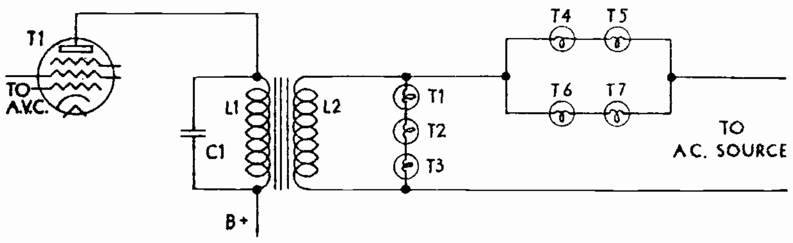


FIGURE 8

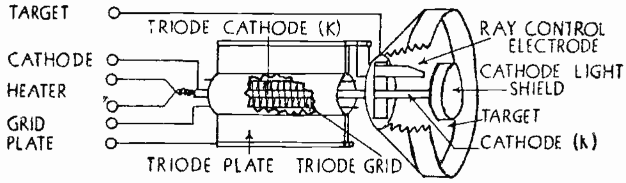


FIGURE 9

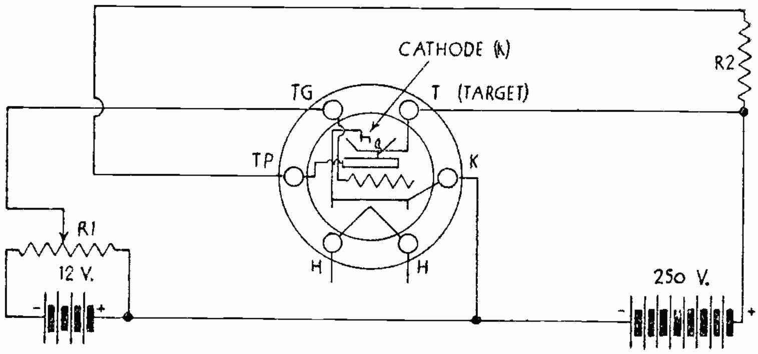


FIGURE 10

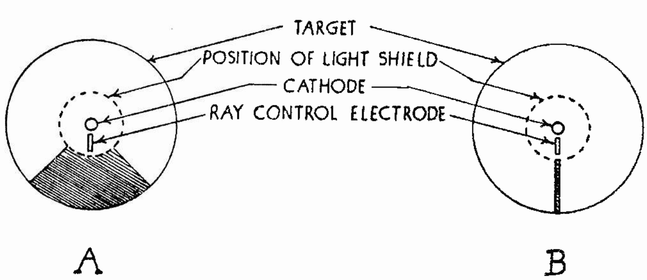
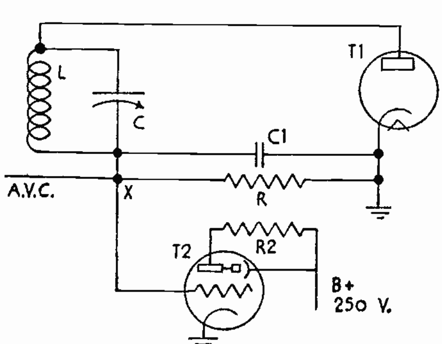


FIGURE 11



RRT-9

FIGURE 12

DE FOREST'S
TRAINING, Inc.

LESSON RRT-10
AUTOMATIC FREQUENCY CONTROL

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LESSON RRT-10

AUTOMATIC FREQUENCY CONTROL

• • Founded 1931 by • •

RADIO RECEPTION AND TRANSMISSION

LESSON RRT-10

AUTOMATIC FREQUENCY CONTROL

* * * * * * * *

Education is a controlling grace to the young, consolation to the old, wealth to the poor and an ornament to the rich.

--- Diogenes

AUTOMATIC FREQUENCY CONTROL

Automatic frequency control, commonly referred to as "afc", is employed in some modern superheterodyne radio receivers to vary the frequency of the oscillator over a predetermined range so that the frequency difference between it and signal carrier is always equal to the intermidiate frequency for which the receiver has been designed or tuned. This takes care of improper tuning adjustments, oscillator drift, tracking inaccuracies and makes some of our present day push-button tuning systems commercially possible.

The afc circuits, there are two separate functions which must be performed and they are accomplished by the "Discriminators" and the "Frequency Control" tubes.

The purpose of the discriminator is to convert i-f frequency variations into voltage variations, and the name is appropiate since it can distinguish changes in i-f and compensate for them. If the incoming i-f is higher than that of the receiver the discriminator must produce a voltage at one polarity, but when the incoming i-f is lower than the resonant i-f of the receiver the discriminator must produce a voltage of the opposite polarity.

The function of the "Frequency Control" tube is to vary the frequency of the oscillator, and its circuits must be arranged so that voltage variations of one polarity tend to increase the frequency, and voltage variations of the opposite polarity tend to decrease the frequency of the oscillator.

In Figure 1, we represent the major circuit sections of an afc system by a "block" arrangement. The "overall" picture of the function of the discriminator and control tube can be seen from these units. For example, following the conventional superheterodyne sequence of circuits, an r-f carrier is conducted to the mixer which, as a result of "beating" with the frequency generated by the local oscillator, converts the signal to the approximate desired i-f.

Should the oscillator frequency be of such value as to produce a beat differing slightly from the correct resonant i-f, some manner of correction is required which will eliminate the manual adjustment of the tuning condenser by the operator or listener. In other words, once the desired station is tuned in, it must remain correctly tuned even though slight electrical changes take place in circuit components.

From the final i-f amplifier, a portion of the signal is conducted to the discriminator which, electrically, determines whether or not a "correction" of the oscillator frequency is .

needed. Assuming that some change in the oscillator frequency is required, the discriminator supplies the frequency control tube with a voltage which, by virtue of its function, causes the local oscillator to generate the correct frequency for obtaining the resonant i-f.

Although it may seem difficult to perform these functions automatically, in the following paragraphs we will show you just how they are accomplished by the use of radio tubes.

DISCRIMINATOR

As we mentioned above, the purpose of the discriminator is to change frequency variations into voltage variations, and for Figure 2 we have drawn a simplified circuit which performs this function. Although two tubes are shown the function of T_1^1 is to develop the signal voltage in its plate circuit, while T_2 is a duo-diode rectifier, more often called the discriminator tube. The transformer with its tuned primary L-C_2, is called the "Discriminator Transformer".

The operation of this circuit depends entirely on the signal voltages and therefore, in our explanation we will ignore the various supply voltages which maintain the operating conditions of the tubes. From the earlier Lessons, you know that when a signal voltage is impressed on the grid circuit of T_1, Figure 2, there will be corresponding changes or plate current.

These changes of plate current, in the plate load, L-C_2, cause variations of voltage drop across it and thus the a-c signal voltage appears across the primary of the Discriminator Transformer. For the explanation of this circuit, therefore, we will consider the transformer primary as the source of the signal voltage and have indicated it as "E_1".

Remembering that the signal voltage is a-c, there is a circuit from the upper end of "E_1", Figure 2 through C_1 and to the junction of resistors R_1 and R_2. From this point there is one path through R_2 to ground, over left to C and back to the lower end of E_1. Going back to the junction again, there is a second path through R_1 and C_4 to ground, then through C and back to the lower end of E_1.

Thus, neglecting the condenser losses, R_1 and R_2 are connected in parallel across E_1 and the full signal voltage will be impressed across each of them. The output voltage of the circuit will appear across terminals X - Y, and we want you to check the following action very closely.

As the junction between the resistors connects to one end of the a-c signal voltage supply, we will assume the voltage is of such polarity as to cause current through R_2 to Y and through R_1 to X. On the reverse alternation, current will be from Y through R_2 to the junction, and from X through R_1 to the junction.

If the resistors have equal values, the voltage drop across them, caused by current in them, also will be equal. The direction of current through R_1 and R_2 will always be opposite, as far as terminals X and Y are concerned. The polarity of the voltage drops will be equal and opposite, resulting in zero r-f voltage between terminals X and Y.

Because of this action, the signal voltage E_1 will be neutralized or balanced out and will not appear across X - Y. This is important and if not quite clear in your mind, go over the explanation again.

Going back to the Discriminator Transformer, the changes of plate current, which cause the voltage E_1, also produce a changing flux which cuts the secondary L_1 and, like any transformer, induces a voltage in the secondary. This secondary voltage will have the same frequency as the primary voltage and thus the signal voltage E_1 appears across the secondary.

Like the primary, the secondary circuit is tuned but the winding is center tapped. To simplify our explanation, we will assume the induced voltage in each half of the secondary is equal to the primary voltage E_1. Under these conditions, E_1, E_2 and E_3, of Figure 2 will all be equal in magnitude.

Starting at the center tap of the secondary L_1, there is a circuit through the upper half of the winding to diode plate D_1, to the cathode, through R_1 to the junction of the two resistors and back to the center tap.

Tracing the other way, there is a path from the center tap, through the lower half of L_1 to diode plate D_2, to the cathode, through R_2 to the junction and back to the center tap.

Thus we have a sort of full wave rectifier arrangement but notice, R_1 is in one diode circuit and R_2 in the other diode circuit. As the voltage E_1 appears across R_2, which is in series with the lower half of L_1, the total voltage of this diode circuit between D_2 and its cathode will be equal to $E_1 + E_2$. In the same way, the voltage E_1 appears across R_1 which is in series with the upper half of L_1, and thus the total voltage of the diode circuit between D_1 and its cathode will be equal to $E_1 + E_3$.

Because of the action of the rectifier, the current in the diode circuits will be pulsating d-c but C_4, connected across R_1 and R_2 functions much like the filter for a cathode bias resistor, and thus the voltage drops across these resistors are considered d-c.

The path of the direct currents, in R_1 and R_2, is the same as previously explained for the a-c circuit and when they are of equal value, the d-c voltage drops will also be equal, but of opposite polarity. Thus, the effective d-c voltage across X - Y will be zero.

As we stated at the beginning of this Lesson, the purpose of the discriminator is to convert changes of frequency into changes of voltage out, under the conditions just explained, the effective voltage across X - Y is zero. However, this is true only under certain conditions and we want you to closely check the following explanation.

PHASE RELATIONS

Thinking back to the earlier Lessons on a-c Principles, Inductance, Reactance and Transformers, you will notice that coil "L", of Figure 2 is in series with the plate of tube "T_1" and is also the primary winding of a transformer.

Changes of voltage, on the control grid of T_1, will cause changes of plate current and these, in turn, will cause changes of voltage drop across coil "L". As we mentioned before, the direct current in the plate circuit does not interest us at this time because it causes no induction in the transformer and therefore has no effect on the operation. The changes of plate current however, cause changes of magnetic flux around the coil and this induces an emf in both transformer windings.

In our earlier explanations of a-c principles, we illustrated the general method of showing a changing magnitude of voltage by rotating vectors. For part of this explanation pertaining to phase relationships, we want to make use of the same idea. You have already studied curves which show lead or lag of current with respect to a voltage, and in Figure 4-A we have used rotating vectors to show the phase relationship between current and voltage of the discriminator transformer at any instant of cycle of operation. In other words, the vector diagrams of Figure 4-A show how the primary voltage E_p or E_1, the primary current I_p, the induced secondary voltage E_{L1}, and the voltage drops E_2 and E_3 maintain their phase relations.

Also, from explanations of Lessons on Induction, the current in an inductance lags the impressed voltage by 90°. In Figure 4-A, the primary current I_p lags the impressed voltage E_1 by 90°. The maximum emf is induced when the current is changing at the greatest rate and, thinking of a-c, this means maximum induction when the current is zero. As the current lags the impressed voltage by 90°, by Lenz's Law, the induced voltage is 180° out of phase with the impressed voltage and lags the current by 90°.

Again checking Figure 4-A, the induced voltage E_{I1}, is shown 180° out of phase with E_1, and likewise this induced voltage is 90° behind the primary current.

Notice here, the flux which cuts the primary winding L of Figure 2 also cuts the L_1 winding. Thus, there will be a self induced voltage in L and a voltage of mutual induction in L_1 but, both induced voltages will be in phase, However, the voltage induced in the secondary L_1 will cause a circulating current I_s in the L_1C_3 circuit and, if the capacitive and inductive reactances are equal, the current will be in phase with the induced voltage.

Figure 4-A shows the circulating current I_s to be in phase with the induced voltage EL_1 and this current passing through inductance L_1 of Figure 2 causes voltage drops E_2 and E_3. To show these two voltages correctly on a vector diagram, it must be seen that inductance L_1 has a center tap which is the common return for both diode circuits of T_2.

At any instant, the voltage drop, caused by the circulating current, is in but one direction for the entire coil which means that the plates of the diodes D_1 and D_2 will be of opposite polarity. With the center tap as a common return, the total voltage drop across L_1, caused by the circulating current, consists of the two voltages E_2 and E_3 which, like the respective polarities of the diode plates, are 180° out of phase.

Vector E_3 is 90° ahead of I_s which is correct for the voltage and current phase relation in an inductance, but E_2 is drawn 180° out of phase with E_3 to maintain their respective positions.

Following a different plan to show the various phase relations between E_1, E_2 and E_3 we have drawn the curves of Figure 5. In Figure 5-A curve E_1 indicates the voltage across the primary, and curve E_2 leads E_1 by 90 because it has reached its maximum value 90° ahead of E_1. For Figure 5-B, curve E_3 lags E_1 by 90°

because it reaches its maximum value 90° after E_1. Notice here curve E_1 is the same in both A and B of Figure 5 while E_3 and E_2, are 180° out of phase in respect to each other.

Going back to the earlier explanations of this Lesson, voltages E_1 and E_3 are in series in the circuit of diode D_1, Figure 2, while voltage E_1 and E_2 are in series in the circuit of diode plate D_2. For this reason, we have added the curves, as shown in A and B of Figure 5 and find that "$E_1 + E_2$" has the same amplitude as curve "$E_1 + E_3$". The vector addition of these voltages is further verified by checking back on Figure 4-A. Here, $E_1 + E_2$ equals $E_1 + E_3$ in value.

This merely bears out our former statement that the circuit of Figure 2 is balanced and, with voltages of equal amplitude in both diode circuits there will be equal and opposite voltage drops across resistances R_1 and R_2 which are of equal value. Thus, the net voltage across terminals X and Y is zero.

I-F CORRECT

In the beginning of this explanation we stated that the purpose of the discriminator was to convert changes of frequency into changes of voltage but so far, we have considered the circuit balanced with zero voltage across X-Y.

In our explanation of Figure 2, we assumed the circulating current to be in phase with the induced voltage in the secondary L_1. This will be true only when the circuit $L_1 - C_3$ is tuned to resonance because then, the inductive and capacity reactances will cancel and, as far as the current is concerned, the circuit acts as if it contained only resistance. As you already know, in a circuit containing resistance only, the current and voltage are in phase.

From a practical standpoint, these conditions exist when the primary circuit, LC_2 and the secondary circuit $L_1 - C_3$ are both tuned to the proper i-f which is present in the plate circuit of T_1.

I-F BELOW CORRECT VALUE

From your study of the super heterodyne circuit, you know that the intermediate frequency is equal to the difference between the frequencies of the receiver oscillator and the signal carrier. The tuning condensers of the receiver control the oscillator frequency and while tuning the input circuits to resonance, can not control the signal carrier frequency.

Therefore, if a receiver is tuned very near the correct frequency, the input circuits, although not at exact resonance, will admit and amplify the signal carrier. The receiver oscillator frequency is controlled by its tuning condenser and, for illustration, we will assume the resonant i-f is 450 kc and that careless tuning caused the oscillator frequency to be low resulting in an i-f of 443 kc. This lower beat frequency will appear in the plate circuit of T_1, Figure 2 and thus in coil L of the transformer.

The phase relationship, previously explained, remains approximately the same, as far as E_1 and the induced emf's are concerned, but there is this important difference. At the lower frequency, the reactance of the secondary, L_1, is reduced while the reactance of the tuning condenser is increased.

These changes of reactance values are due entirely to the different frequency values and, in case you are not entirely sure of this point, a review of the earlier "Resonance" Lesson will be of benefit.

Here, at the lower i-f frequency, the tuned circuit L_1C_3 is no longer resonant and, considering L_1-C_3 as a series circuit with a value of capacity reactance, greater than the inductive reactance, the current will lead the voltage. The induced emf in the secondary remains exactly as before but remember the voltages E_2 and E_3, are due to the voltage drop caused by the current in L_1.

For a definite illustration, we have assumed that the circulating current I_s is leading the induced emf by 45° and, on this basis, have drawn the vector diagrams of Figure 4-B. You will find E_1 maintains the same relative position in Figures 4 and 5, whereas E_1 leads E_3 45° in Figure 4-B. Notice that E_2 and E_3 will always be 180° out of phase in respect to each other, even though the voltage drops have shifted 45° from the resonant circuit condition.

Adding the vectors E_1 and E_3 and also E_1 and E_2 we find that "$E_1 + E_3$" has a greater amplitude than "$E_1 + E_2$". Thus a change of the intermediate frequency from 450 to 443 kc has caused the circuit of Figure 2 to become unbalanced.

The higher "$E_1 + E_3$" voltage, in the circuit of diode D_1 will cause a larger voltage drop, across R_1, than the drop across R_2, caused by the lower "$E_1 + E_2$" voltage in the circuit of diode D_2. The effective voltage, across X - Y, is equal to the difference of voltage drops across R_1 and R_2. Thus, under the conditions just explained, there will be a voltage across X - Y with the polarity as marked for R_1.

In other words, X will be positive, in respect to Y which is grounded.

To continue our practical illustration, in which we assumed that the receiver was mistuned to provide an i-f of 443 kc, the values of 450 kc - 443 kc results in a shift of 7 kc below the resonant i-f. We will further assume that, as a result of this tuned condition, 6 volts appears across X - Y of Figure 2. As we will explain subsequently, this voltage then is available to govern the action of the afc tube. Figure 3 is drawn to represent the changes of net voltage which is developed between points X - Y of Figure 2. Referring to the 6 volts assumed, "a" of Figure 3 then shows the positive value with respect to the reference axis at a value of -7 kc off the resonant i-f. That is, "O" represents the i-f of 450 kc, and 443 kc is a 7 kc deviation below the correct i-f.

If mistuning had caused the i-f to be but 4 1/2 kc below the correct value, the phase shift of voltages E_2 and E_3 from their normal position would be less. Let's assume that the resultant voltage drops across R_1 and R_2 of Figure 2 result in a net voltage of 4 volts. This value is represented by "c" at a value of -4 1/2 kc on Figure 3. From these two examples, you can see that any deviation from "o", which is the resonant i-f, will develop a voltage across the output terminals x-y of the discriminator.

If the deviation extends a little more than 9 kc, the afc control action is no longer able to effect the change necessary to produce the correct i-f. In this case, the set should be more closely tuned, just as any receiver which is off or out of tune.

I-F ABOVE CORRECT VALUE

Should conditions in the receiver provide an i-f higher than that for which the circuits were tuned, the circulating current I_s in L_1 would lag behind the voltage. This would cause a shift of the phase of the current and voltage drops, "E_1 + E_2" would have a greater amplitude than "E_1 + E_3", as shown in Figure 4-C and curves C and D of Figure 5. Checking corresponding vectors and curves, it can be seen that E_2 leads E_1 by 45°, and that E_3 lags E_1 by 135°.

Under the conditions of voltage $E_1 + E_2$ greater than $E_1 + E_3$, the voltage drop across R_2 would be greater than that across R_1, the difference between these two drops would be the effective voltage across "X - Y", and X would be negative, in respect to Y.

As the frequency deviation is above the resonant i-f, then paralleling the examples for the deviation below the correct i-f, let's assume that an i-f of 457 kc results in a net voltage of

6 volts across X - Y. Now the polarity of these points have reversed with respect to each other. Point "b" of Figure 3 represents this numberical value of discriminator output voltage.

If the deviation is only +4.5 kc or an i-f of 454.5 kc is produced, the control voltage is but 4 volts as shown by "d", Figure 3.

The scale at the right of Figure 3 merely indicates that with respect to Y as a reference, point "X" will be positive when the i-f deviation is negative or below the resonant i-f, whereas "X" will be negative when the i-f deviation is positive or above the resonant i-f.

Checking back on these explanations, you will find that the lead or lag, of voltages E_2 and E_3 as compared to E_1, depends on the frequency at which L_1 - C_3 is tuned. The larger the phase shift between the secondary L_1 voltage and circulating current and, as shown by the vectors of Figure 4 and curves of Figure 5, the greater the difference in the voltage impressed on the respective diode circuits.

To sum up the various actions, the circuit of Figure 2 will convert changes of frequency, in the plate circuit of T_1, into changes of voltage across X - Y. The amplitude or value of the voltage will depend on the difference between the plate circuit frequency and the resonant frequency of L_1 - C_3. The polarity of X, in respect to Y, will depend on whether the plate circuit frequency is higher or lower than the resonant frequency.

We want to mention here that while C_2, Figure 2 , is tuned like any i-f trimmer, the adjustment of C_3 is much more critical because only a slight shift from the correct capacity will cause a relatively large unbalance of voltage drops across P_1 and R_2.

FREQUENCY CONTROL TUBE

The purpose of the "Frequency Control" is to provide some way of either increasing or decreasing the oscillator frequency of the receiving set without changing the condenser gang setting. To accomplish this action, we connect an imaginary inductance across the oscillator coil and, by means of the discriminator, provide a means of making this imaginary inductance either larger or smaller.

In Figure 6, the imaginary inductance is the frequency control tube T_2, while tube T_1 is the set oscillator, connected as a conventional grid-leak type with its tuned circuit L - C_2. R_1

provides the necessary grid-leak bias voltage, whereas C_1 couples the tuned oscillator circuit to the control grid of T_1. Coil L_1 is the conventional "feedback" winding, and C_3 simulates the position of a padder condenser.

From your earlier Lessons, you will remember that in an inductance, the current lags the voltage by 90° while, in a condenser, the current leads the voltage by 90°. Also, when two inductances are connected in parallel, the resultant inductance is always less than the smaller of the two.

In a parallel tuned circuit, decreasing the value of the inductance permits an increase in the value of the current in the inductance. Therefore the inductive or lagging current will be more predominate.

Thus, in order for the frequency control tube to act as an imaginary inductance, in parallel with the oscillator coil, "L", Figure 6, it must cause a lagging current, with respect to the oscillator voltage across the coil. This is exactly the same action as if a second coil were shunted across the oscillator coil.

With the frequency control tube T_2 shunted across Coil L, but without any a-c excitation on the control grid, it will parallel the coil with a definite resistance or impedance, the magnitude of which will depend on the grid bias voltage. Under these conditions, tube T_2 will draw current from L and this current will be in phase with the oscillator voltage, since the tube acts as a resistance. Therefore an increase or decrease of its bias voltage will have no effect on the oscillator frequency.

The energy for the oscillator and the a-c component voltage for the frequency control tube is supplied by L_1 through mutual induction to coil L.

In Figure 6, however, notice that R_2 and C_4 are also connected across L and the voltage across C_4 is applied to the control grid of T_2. The values of R_2 and C_4 are chosen so that the resistance of R2 is much greater than the reactance of C_4 and therefore, the combination may be considered a voltage divider which appears as a resistive load to the oscillator voltage. Thus, the current through R_2 and C_4 is nearly in phase with the voltage across coil L. Stated another way, the current through the voltage divider is in phase with the a-c plate voltage of T_2.

Since the current in C_4 is nearly in phase with the oscillator voltage, the voltage across condenser C_4 lags the oscillator voltage by nearly 90°. If you have difficulty following the above statement, just remember that in a capacity, the current leads, or the voltage lags, by 90°.

This voltage across C_4, which is the a-c grid voltage, is then applied to the control grid of tube T_2 and if it is properly biased, the plate current will be in phase with the grid voltage. Since, under this condition, the a-c grid voltage lags the a-c plate voltage of T_2 by 90°, this means that the plate current will lag the voltage across coil L and the tube will function as an imaginary inductance.

From your earlier Lessons, you will remember that the inductance of a circuit will have an effect on the current. That is, with a large value of inductance the current will be small and as the inductance decreases, the current increases. Here, we provide the opposite action and vary the amount of current in a tube to change its apparent inductance.

This is possible because the control tube draws a lagging current, with respect to the oscillator voltage across L, and the amount of this current is determined by the bias voltage on the control grid. In effect, we have an imaginary variable inductance across the oscillator coils the amount of which is controlled by the bias voltage on the control tube.

Now that we have explained the separate function of the discriminator and frequency control tube, let's assume that point X of Figure 2 is connected to the grid and point Y connected to the cathode of T_2, Figure 6. As explained for Figure 2, with an incoming signal frequency equal to the resonant i-f of the receiver, there will be no difference of potential across points X and Y and therefore, there is no effect on the control tube and oscillator circuit.

However, with the incoming signal frequency higher than the resonant i-f, point X becomes negative with respect to Y, and causes the frequency control tube to draw less current. This increases the effective inductance of the oscillator circuit and decreases the oscillator frequency until the tuned circuits produce the resonant i-f.

With the incoming signal frequency lower than the resonant i-f, point X will be positive with respect to point Y and causes the frequency control tube to draw more current. This decreases the effective inductance of the oscillator circuit and with less inductance, the oscillator frequency is increased until the i-f frequency is equal to the resonant i-f of the receiver. Because of the actions in these two circuits, we have "Automatic Frequency Control".

OSCILLATOR DRIFT CAUSES

We have explained how it is possible to correct the frequency of the oscillator when conditions of improper tuning, tracking inaccuracies and oscillator drift occur, and we now want to mention a few facts about one of these discrepancies.

Of those faults just mentioned, the condition of oscillator drift is most variable. Some common causes of drift are temperature and humidity changes, mechanical vibration, line voltage variations and operating potential fluctuations. You already know that changes of temperature have a tendency to change the value of a resistor. In a similar manner condensers may change slightly in capacity. A unit which has a positive temperature coefficient is defined as one which permits an increase in capacity with an increase of temperature. A negative temperature coefficient is a decrease of capacity with an increase of temperature.

An increase in the temperature of the receiver usually causes a decrease in the oscillator frequency, and the drift is most apparent at the high frequency range of the receiver.

In practice, you will no doubt find variations of afc circuits but, basically, their principle of operation will be the same, Therefore, if you fully understand the basic circuits, you should not have any difficulty following other discriminator and frequency control systems.

ALL WAVE SUPERHETERODYNE

In a previous Lesson, we mentioned the all-wave Superheterodyne but now want to offer more complete details of a modern receiver.

With the exception of the smaller "midget" type radios, practically all of the receivers on the market today incorporate the superheterodyne circuit and tune to more than one band of frequencies. In most three band receivers, commonly called all-wave, the bands covered are the regular broadcast, 535 kc to 1605kc, police, 1605 kc to 1850 kc and short wave 2850 kc to 18,000 kc.

In order to accomplish this wide frequency coverage, it is necessary to change either L or C of the tuned circuits. As C is usually a gang condenser, it isn't practical to incorperate a different gang for each band and therefore, the value of L is changed. This is generally done by using separate coils for each band and, the proper ones for a definite band, are placed in the correct circuit by means of a switching arrangement.

For Figure 7, we show the complete circuits of an all wave superheterodyne which, at first glance, may seem rather complicated. However, there are no circuits in this receiver which have not been previously explained. As a matter of fact, we have merely combined the circuits of the earlier Lessons into a complete receiver.

Checking through Figure 7, you will find that, in addition to the conventional superheterodyne receiver, we have condenser type push-button tuning, automatic frequency control, delayed avc, bass compensation, bass booster and a cathode ray tuning indicator. In order that you may not have any difficulty in recognizing these circuits, we will go through and give you the function of each tube.

Tube T_1 is an r-f pentode and functions as an r-f amplifier. That is, it amplifies the incoming modulated carrier before it reaches the pentagrid converter, or mixer, T_2. Tubes T_3 and T_4 are r-f pentodes and serve as i-f amplifiers while T_5 is a duo-diode tube which operates as a second detector and avc. Tube T_6 is a triode functioning as the first audio amplifier and excites the grids of the beam power output tubes T_7 and T_8 which are connected in push-pull to drive the speaker.

Tube T_9 is an r-f pentode whose function is to further amplify the i-f signal before it reaches the duo-diode T_{10}, which is the discriminator. The frequency control tube is the r-f pentode T_{11} while the oscillator is the triode T_{12}. T_{13} and T_{14} are the first and second bass amplifiers and T_{15} is the full-wave rectifier of the power supply while the cathode ray tuning tube is T_{16}.

D.C. VOLTAGE DISTRIBUTION

Now that we know the function of the various tubes, let us see where they obtain the necessary d-c voltage for operation. From the 110 volt supply winding, there is a voltage induced into the high voltage secondary which is connected to the plates of T_{15}, the center tap being connected to ground through the resistor R_{21} and by-passed by condenser C_{30}.

The filament of T_{15} is connected to its supply winding and with respect to the high voltage secondary center tap, is at a high positive d-c potential, However, this voltage is pulsating d-c and to smooth it out, the filter, composed of Ch, speaker Field, C_{24}, C_{23} and C_{22}, is employed. The plates of T_7 and T_8 operate at a high potential which is obtained from the junction between Ch and the field. As the screen grids operate at a lower voltage, they are connected to the output of the filter.

Through their respective loads, tubes T_1, T_2, T_3, T_6, T_9, T_{11}, T_{12}, T_{13} and T_{14} also receive their plate voltage from the output of the filter while tube T_4 receives its plate voltage from the same point but through its load and the series resistance R_{11} which is by-passed by condenser C_{16}. Notice also, that the target of the tuning indicator is also connected directly to the output of the filter.

The resistors R_{16}, R_{17}, R_{18} and R_{19}, in conjunction with R_{21}, form a voltage divider from the output of the filter to the center tap of the high voltage winding. The screen grid of T_2, receives its voltage from the junction between R_{16} and R_{17} which is by-passed by condenser C_8. The screen grids of tubes T_1, T_3, T_4 and T_9 obtain their voltage from the junction between R_{17} and R_{18} and are by-passed by condensers C_3 and C_{17}.

The right hand cathode of T_5 is connected to the junction between R_{18} and R_{19} and is therefore positive in respect to the right hand plate which is connected to ground through resistor R_{10}. Saying this in another way, the right hand plate of T_5 is negative in respect to its cathode. Applied to the cathode, this potential is the delaying voltage for the delayed avc action, the same as explained in an earlier Lesson on avc systems.

Notice that we also have a second voltage divider, paralleling the one just explained, which is made up of resistances R_{31}, R_{40}, and R_{32}. From the junction between R_{31} and R_{40}, the screen grid voltage of T_{11} is obtained.

Tubes T_1, T_2, T_3, T_4, T_7, T_8 and T_9 are all self biased by their respective cathode resistors R_1, R_3, R_5, R_6, R_{14} and R_{37} all of which are condenser by-passed. We also have a resistor, R_{32}, in the cathode circuit of T_{11} but, it is a part of a voltage divider and therefore, carries bleeder current as well as the plate and screen current of T_{11}. The circuit is so-designed that the bleeder current is large compared to the tube current, resulting in semi-fixed bias which provides better stability for the frequency control tube.

Tubes T_6, T_{13} and T_{14} obtain their negative bias from the voltage drop across R_{21}. This may be a little confusing but you must remember that the bias voltage is the difference of potential between the control grid and cathode of a heater type tube. As the cathodes of these tubes are connected to ground, and their control grids to the negative side of R_{21}, through which the current of all the tubes must pass in order to complete the high voltage circuit, the voltage drop across R_{21} is utilized. Resistors R_{27} and R_{26} are grid loads while the combination of R_{20} and C_{29} is a resistance-capacity filter.

SIGNAL CIRCUITS

Now that we have the d-c voltage distribution, let's check the signal circuits of Figure 5, with the switches in their shown positions. Starting at the antenna, there is a circuit through the primary of the r-f transformer directly to ground. One end of the secondary of this transformer connects to the control grid of T_1, while the other end is grounded through resistors R_2, R_4, R_9 and R_{10}. The circuit is tuned by C_{43}, which is a section of the gang condenser and its connections are from the control grid of T_1, through the upper left pair of contacts of the push-button tuner to ground. The smaller condenser, directly across the secondary, is a trimmer used to properly align the gang condenser.

In the plate circuit if T_1 there is the primary of a second r-f transformer, which is connected to B+. The secondary circuit is exactly as explained for the other r-f transformer but is tuned by the gang condenser section C_{44}. The connections to it are made through the upper middle pair of contacts, of the push-button tuner, which also connect to the control grid of T_2.

For the load in the plate circuit of T_2, there is the tuned primary of an i-f transformer, the tuned secondary of which is connected from the control grid of T_3, to ground through resistors R_9 and R_{10}. The plate circuit of T_3 contains the tuned primary of the second i-f transformer, with the tuned secondary connected between the control grid of T_4 and ground.

The tuned primary of the third i-f transformer is connected in the plate circuit of T_4. The upper end of the tuned secondary connects directly to the left hand plate of T_5 and also to the right hand plate through the coupling condenser C_{15}. The lower end of this secondary is connected to ground through resistances R_7 and R_8 which form the load for the diode detector section of T_5. However, the combination of R_7, C_{11} and C_{12} is an i-f filter. R_8 is the volume control potentiometer and is the source of audio voltage. As R_8 has a tap, connected to ground through condensers C_{12} and C_{13}, it forms a bass compensation circuit. The right hand section of T_5 functions as the delayed avc rectifier and its circuit is from the plate to ground, through R_{10}, and is completed back to the cathode through R_{19}, with the avc voltage devoloped across R_{10}. You can see that the combination of R_2, R_4, R_9, C_1, C_4 and C_7 form a three section avc filter and that tubes T_1, T_2 and T_3 are controlled by avc.

Getting back to the signal circuits, C_{14} is an audio coupling condenser and applies the audio signal to the control grids of T_6 and T_{13}. In the plate circuit of T_6, the voltage drop

across the load resistor R_{13} is applied to the grid of T_7 and the upper end of the tapped choke coil L, through the condenser C_{18}. As previously explained in the earlier Lessons, coil L acts as an auto transformer, giving the desired phase inversion of the signal applied to the grid of T_8, thus allowing these two tubes to operate in push-pull.

Going back to the grid of T_{13}, R_{27} forms the grid load of both T_6 and T_{13}. In the plate circuit of T_{13}, the combination of resistance and capacity, R_{23}, R_{24}, R_{25}, C_{26} and C_{27} form the load and also act as a filter to attenuate the high audio frequencies. The low frequencies are applied to the grid of T_{14} through the coupling condenser C_{28} and the grid load R_{26}. As R_{26} is a potentiometer, the magnitude of the signal voltage, applied to T_{14}, can be controlled. R_{22} is the plate load of T_{14} and the signal is coupled to the choke L through condenser C_{19}, where it mixes with the original audio frequencies. The audio signal is then fed over to the speaker through the push-pull transformer T_0.

Notice also that resistor R_{15} and condenser C_{21} are connected in series across the primary of the output transformer. Such an arrangement is called a "corrective filter" and it improves the frequency response of a beam power or pentode output stage by making the effective load impedance on the output tubes practically constant over a wide band of audio frequencies.

The resistance to be used in the corrective filter for a push-pull stage is 1.3 times the recommended plate to plate load resistance while for a single output stage, it is equal to 1.3 times the recommended plate load. The capacity should have a value such that the voltage gain, at a frequency of 1000 cycles or higher, is the same as that at 400 cycles.

To determine the proper value of capacity, it is necessary to make two measurements on the output voltage across the primary of the output transformer. First, when a 400 cycle signal is applied to the input, and second when a 1000 cycle signal, of the same voltage, is applied to the input. The correct value of capacitance is the one which gives equal output voltage for the two signal inputs. In practice, this value is usually found to be on the order of .05 microfarad.

Going back to Figure 7, the control grid of T_9 is excited by the i-f from the secondary of the second i-f transformer, through the condenser C_{41} and grid load R_{39}. The signal is then fed into the discriminator transformer and applied to the discriminator tube T_{10}. The control voltage, developed across the discriminator diode load resistors R_{35} and R_{36}, is applied to the grid of T_{11} through a resistance-capacity filter R_{34}, C_{37} and C_{38}. As previously mentioned, the screen grid of T_{11} obtains its voltage from the junction of

R_{31} and R_{40} which is part of the d-c voltage divider. The d-c voltage drop across R_{32} serves to bias the control grid of the automatic frequency control tube.

In Figure 6, the plate-cathode elements of the afc tube are connected across Coil L. In similar manner tube T_{11} of Figure 7 is effectively connected across L_1 and its variable condenser forming the tuned grid circuit of the oscillator tube T_{12}. Condenser C_{33} serves to block the high d-c of tube T_{11} and yet provide the a-c path to permit current changes in the oscillator tuned grid circuit. In other words, the changing a-c plate current affects the necessary change in the inductance of the oscillator coil.

The a-c voltage excitation for the control grid of T_{11} is obtained by coupling it to the r-f voltage present across the oscillator padder C_p through condensers C_{34} and C_{36}. The values of C_{34} and C_{36} are chosed to provide an a-c path and thus the r-f voltage for the control gird of T_{11} appears across R_{33}.

In order that T_{11} can serve as an imaginary inductance, the tickler coil L of the tuned grid oscillator circuit has high reactance in comparison to that of the series padder condenser and therefore the current in this path lags the voltage by nearly 90°. In a series circuit the condenser voltage and inductance voltage are 180° out of phase, therefore the condenser voltage lags the circuit current by 90°.

The reactance of C_{34} is large in comparison to the resistance of R_{33} and therefore the current in the resistor leads the padder condenser voltage by nearly 90°. Thus the voltage across R_{33} lags the circuit voltage by nearly 90°. As the control grid of T_{11} connects to R_{33} through the low reactance condenser C_{36}, its exciting voltage also lags the tuned circuit voltage by 90° and tube T_{11} functions as an imaginary inductance.

As we previously explained, T_{12} is the set oscillator of the grid-leak condenser type and is tuned by the gang condenser section C_{45}. C_{32} is the grid condenser while R_{29} is the grid load. From the ungrounded end of R_{29}, there is a direct connection to the modulator grid of T_2, which applies the oscillator voltage to the converter. The combining, or mixing, of the oscillator frequency with the incoming carrier, produces the i-f frequency.

The tuning indicator tube T_{16} obtains its necessary change of bias voltage from the avc rectifier, being tied back to R_{10} through resistors R_2, R_4 and R_9. The circuit is complete to ground through R_{10}, which is the point to which the

cathode of T_{16} is directly connected. Thus, any change of voltage across R_{10} will cause a corresponding change in the shadow of the tuning indicator.

As you have no doubt noticed, the push-button tuner is of the tuned condenser substitution type. Due to the fact that the gang condenser contains three sections, it is necessary to incorporate three trimmer condensers, one for each corresponding section of the gang condenser. The upper button is used to change from manual to automatic tuning while the lower six buttons are for automatically tuning in pre-selected stations.

To tune from one band to another, the switches S_1, S_2, S_3, S_4, S_5 and S_6 are all connected together, or ganged, and controlled from the front of the panel by a single knob. The only changes made in the complete circuit are the substitution of tuning coils for the different bands. The switch S_7 is employed so that the afc system may be cut out if it is so desired. Closing this switch simply grounds the grid of the frequency control tube, thus allowing no changes of bias voltage on the control grid.

Although we have explained the circuit of Figure 7 quite fully, we want you to go over it several times until you understand the action of every unit in it. We say this because it is a very good example of a modern all-wave receiver and if you fully understand it, you will not have any difficulty with others.

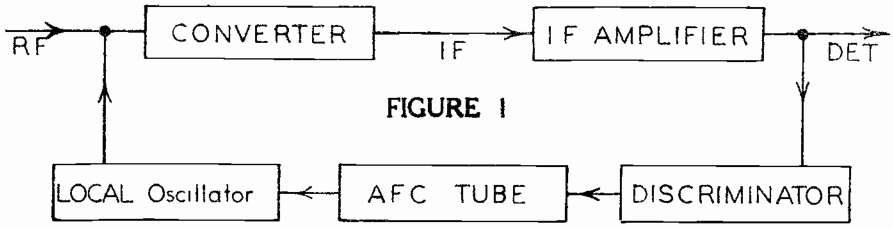


FIGURE 1

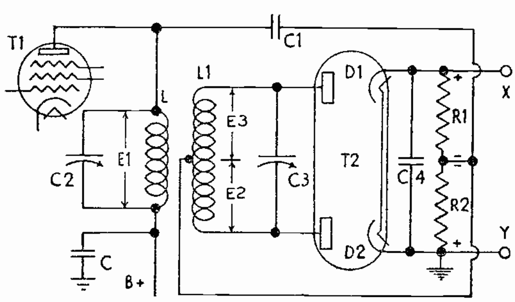


FIGURE 2

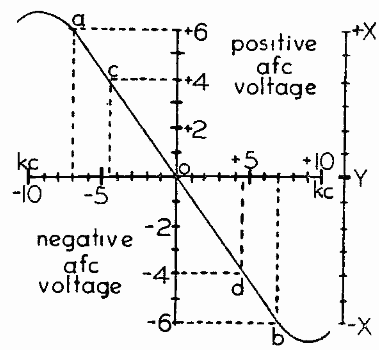


FIGURE 3

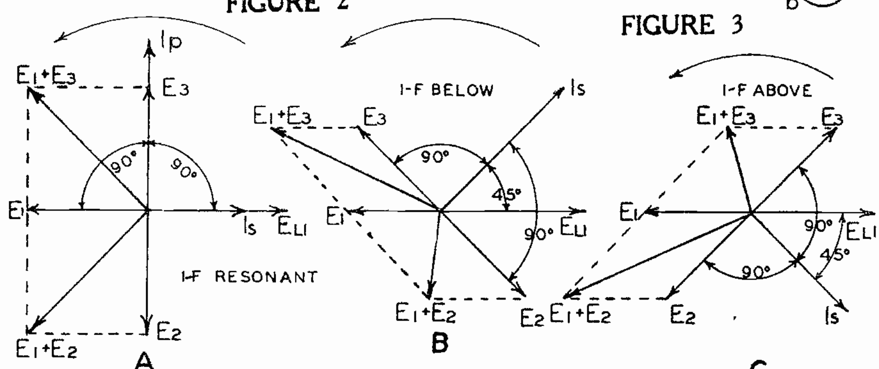


FIGURE 4

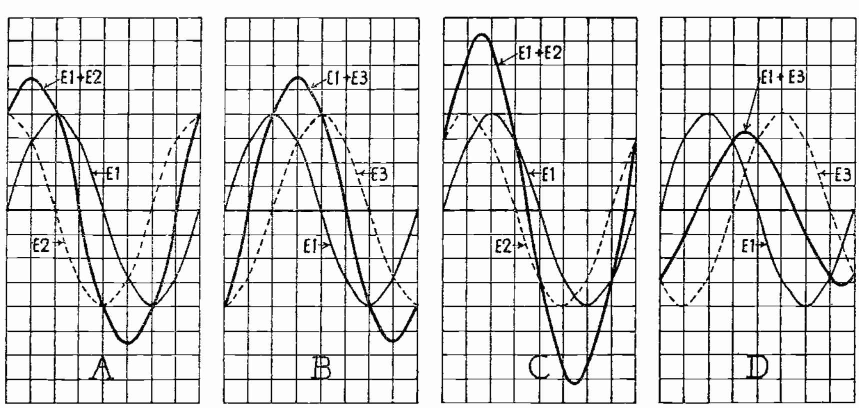


FIGURE 5

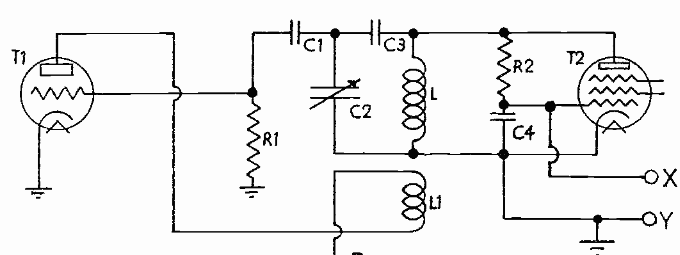
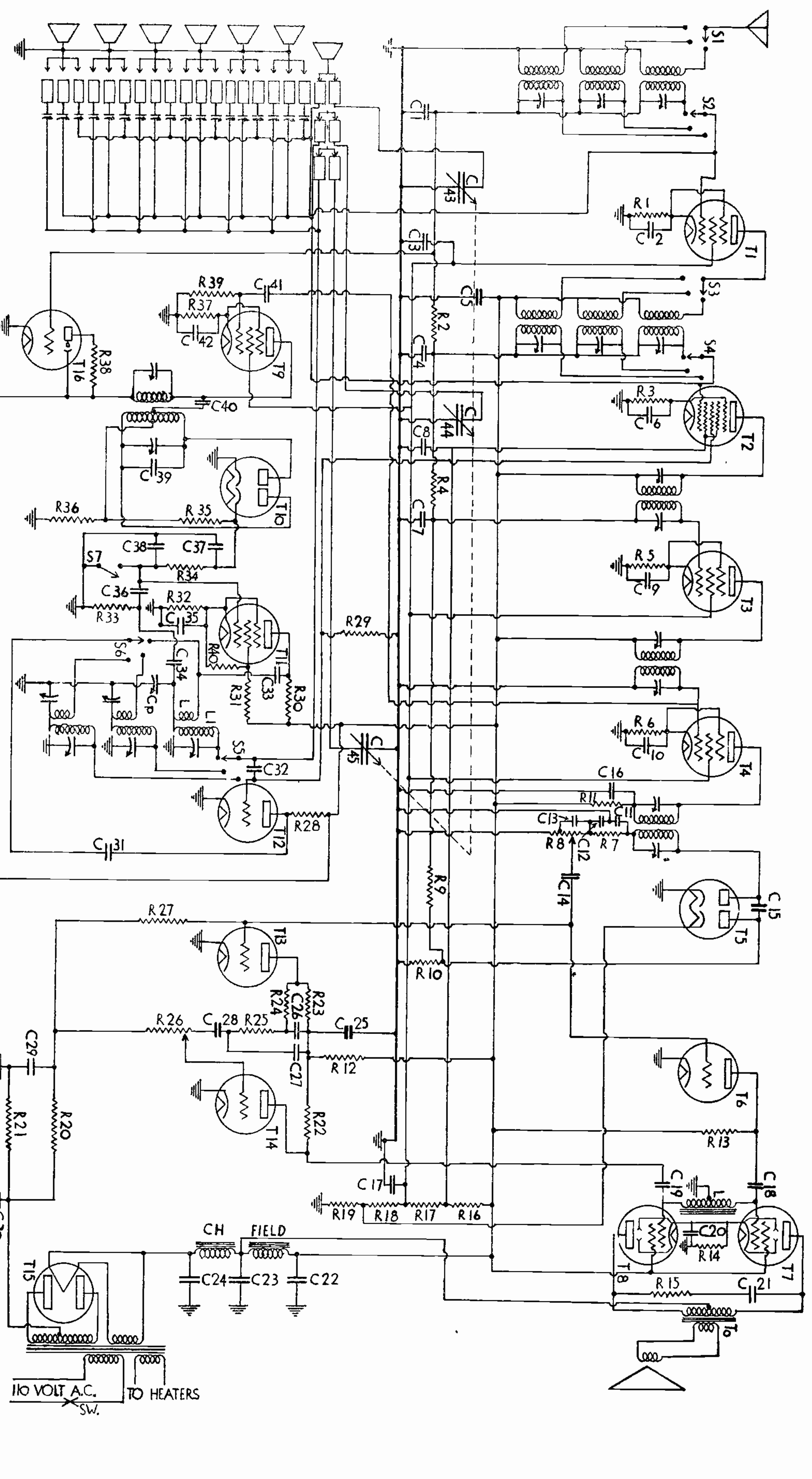


FIGURE 6



RRT-10 FIGURE 7

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RADIO RECEPTION AND TRANSMISSION

LESSON RRT-11

UNIVERSAL AND AUTO RECEIVERS

* * * * * * * *

Self-confidence is the first requisite to great undertakings.

---Samuel Johnson

AUTOMOBILE RECEIVERS

In the first models of automobile Radio Receivers, various circuits arrangements were used to make possible the operation of the existing types of 5 volt and 2 1/2 volt tubes, by means of the ordinary 6 volt auto battery. The results were not satisfactory as the filaments, of those tubes requiring comparatively low current, were too fragile, while those requirng larger current placed a heavy drain on the battery.

To overcome these difficulties, a new series of tubes were developed with a heater designed for operation on a nominal rating of 6.3 volts at a currentof .3 ampere. Several power tubes in this series require a higher value of current but in all of them, the required heater or filament current is low, compared to the older types.

In addition to this economy of current, the heaters are of rugged construction and not at all critical, in respect to the voltage changes which occur in the average auto electrical system. Like auto type lamp bulbs, they will operate satisfactorily from 5.5 volts up to 8.5 volts.

The development of these tubes has eliminated all complicated filament circuits as it is now only necessary to connect the heaters in parallel across the supply, without any series resistors, the same as is done in the usual a-c Broadcast receiver used in the home. For the auto, the regular 6 volt car battery is the source of electrical energy and, for reasons we will explain later, the receiver connections are usually made directly at the battery terminals

HIGH VOLTAGE SUPPLY

Although the 6.3 volt tubes have solved the problems of the filament and heater circuits, like other receivers, the auto Radio requires a high voltage d-c supply for the plate and screen grid circuits of the tubes. In the older types of receivers, B batteries made up this high voltage supply and although giving satisfactory and fairly economical service had to be replaced periodically. This feature was objectionable to the average owner who, with his home receiver in mind, demanded an "All Electric" auto radio.

As you already know, by means of transformers, it is a comparatively simple job to change the voltage of an a-c supply to almost any desired value but, in an auto, we have a low voltage d-c supply. As the usual form of transformer will not operate on direct current, various other methods have been developed.

SERIES VIBRATOR TYPE

The most popular method to change the battery d-c to a-c is to use a vibrator and increase the a-c voltage by means of a transformer, then rectify it by means of a tube. The circuits of an arrangement of this type are shown in Figure 1 where you will find one Low Voltage Terminal grounded while the other connects to an r-f filter through a switch.

Because some Auto Electrical Systems connect the battery positive to the chassis or "ground" and others ground the battery negative, it is customary to speak of the battery connections as "Hot A" and Ground. Thus, in Figure 1, the upper Low Voltage Terminal is "Hot A" and the lower one is "Ground". To simplify our explanations, we will consider the "Hot A" as positive but, the unit will operate equally well when the "Hot A" is negative.

The vibrator, shown at the left of the transformer "T", is made up of a magnet coil, a vibrating armature and two pairs of contacts. The armature and one end of the magnet winding are grounded on the vibrator frame.

Starting at the "Hot A" terminal of Figure 1, there is a d-c circuit through the switch and through the filament of the Rectifier tube to ground. Condenser C4 connects directly across the filament and helps to by-pass any electrical disturbances of the auto system.

From the switch "SW" there is another d-c series circuit through the radio frequency choke "RFC" and up to the center tap of the primary winding of the transformer, through the upper half of the winding, through the upper pair of vibrator contacts and armature to ground. Also, there is a circuit from the center tap of the transformer through the lower half of the primary and the magnet winding to ground.

Resistances R1 and R2, connected across the contacts, have a value of about 200 ohms each, the current through them being negligible for this explanation. However, the magnet winding, with a relatively high resistance and large number of turns, holds the current in its circuit to a low value, yet the current produces sufficient magnetic flux to attract the armature, opening the upper pair and closing the lower pair of contacts.

With the upper contacts open, resistance R1 is in series with the upper half of the transformer primary reducing the current to a negligible value. With the lower contacts closed there is a d-c circuit from the center tap, through the lower half of the transformer primary and through the lower pair of contacts to ground. Notice also, closing the lower pair of contacts shorts out the magnet winding resistance R2.

Shorting the magnet winding reduces its current to zero, reduces the magnetic flux it sets up and allows the spring to pull the armature back to the position of Figure 1, and the action starts all over again

As far as the transformer is concerned, when the upper contacts are closed there is current in the upper half of the primary and when the lower contacts are closed, there is current in the lower half. Then, because the center tap connects directly to the battery, the current in each half of the primary is in opposite directions, setting up magnetic flux of opposite polarity and inducing an alternating emf in the secondary

In other words, the action of the vibrator is to cause the steady direct current of the battery to keep changing in value and direction as it passes through the transformer primary. The changing primary current provides changes of magnetic flux which cut the turns of the secondary and induce an alternating emf.. Like that of ordinary transformers the value of this emf will depend on the turn radio between the primary and secondary.

As we explained in the earlier Lessons, when an inductive circuit, like the transformer primary, is suddenly opened, the magnetic flux collapses and, by self induction, induces a high voltage in a direction to try and maintain the current. Here, this action will take place as the contacts open and the induced voltage will be high enough to cause an arc between them.

Because arcing contacts wear away rapidly and become pitted, in Figure 1 the 200 ohm reistors, R1 and R2 are connected across them. Then, when the contacts separate, the circuit is not opened but the 200 ohm resistance is placed in series, forming a path for the current caused by the self induction and reducing the magnitude of the arc.

The same general action takes place in the primary circuit of the auto ignition system but there you will find a conden- connected across the contacts. While the condenser absorbs the arc between the contacts, it also discharges rapidly and then charges in the opposite direction producing a few high frequency cycles.

The discharge action of the condenser causes a more rapid change of flux in the ignition coil thereby increasing the secondary voltage and improving the spark. In the circuit of Figure 1, however, the use of a suitable condenser would cause noisy reception as a result of the high frequency discharges, without greatly improving the action.

Although non-inductive resistors are connected across the vibrator contacts, the action is not perfect and some unwanted frequencies will appear in the secondary. To eliminate these, condenser C1, usually with a capacity of about .02 Mf., is connected across the entire secondary winding.

The tube is a full wave rectifier with circuits like those of the common type 80 but it has a cathode which is the positive or high potential terminal of the high voltage circuit, while the center tap of the secondary winding is the negative terminal, or considered "B-".

The action in this secondary circuit is exactly the same as that explained for full wave rectifiers therefore, we will not go into further detail. However, there is a rectified a-c voltage across the high voltage terminals of Figure 1 and the usual form of filter will be needed between the recifier and plate circuits of the tubes of the receiver.

The vibrator arrangement of Figure 1 is a series circuit type because the current from the battery, at any instant, passes through one section of the transformer, through the magnet winding back to the other side of the battery. This means that, for starting, the armature reed must be in contact with the upper vibrator points.

The series type vibrator then has only the resistance of upper transformer in series with the battery at the instant of starting, and if the series resistance is low, the current is relatively high. Should the battery be undersize or partly discharged, the voltage drop across the primary winding may be enough to cause an inadequate voltage for operation of the magnet winding. In other words, if the contacts fail to open, the large current could burn out the vibrator magnet winding of the transformer primary winding, over heat the contacts, or at least open a protective fuse in the battery circuit. It is therefore, essential that the battery voltage be adequate in order to prevent "blowing" of fuses or other damage to the vibrator system.

SHUNT INVERTER - RECTIFIER

To further simplify the electrical circuits like those of Figure 1 and save the power required to operate a rectifier tube, the vibrator action has been extended on the general plan of Figure 2. Here you will find five pairs of contacts, the single pair at the left in the circuit of the vibrator magnet, the center double pair in the secondary circuit and the right hand double pair in the primary circuit.

As Figure 1 shows the magnet winding to be in series with component parts and the battery, the magent winding of Figure 2 is essentially in parallel with the battery, and hence is known as the shunt type vibrator.

With the armature in the position shown, there will be a circuit from the Hot A, through the switch and "RFC", through the magnet winding and single pair of contacts to ground.

As we explained for Figure 1, current in the magent coil sets up a magnetic flux which pulls the armature down and separates the upper contacts. At the same time, this action breaks the direct path from the upper magnet terminal to ground and causes closing of the lower contacts. Under these conditions, the magnet coil circuit reduces the current and flux to a value low enough to allow the spring to pull the armature away from the core and again close the upper contacts.

In Figure 2, the vibrator circuits are entirely separate and the armature will vibrate at a frequency which depends on its mechanical construction and spring tension. In practice, the frequency is approximately twice the commercial power line frequency. When the frequency of the alternations is higher, the size of the power transformer may be reduced as less inductance is required.

The primary circuit of Figure 2 is similar to that of Figure 1 and the action is exactly the same. As the armature vibrates both double pairs of contacts will be opened and closed. We do not show any resistance connected across the primary contacts because the inductance of the primary winding is so low that some manufacturers do not install them.

Because the action in the primary circuit changes d-c to a-c, this part of the unit is often called an "Inverter" to distinguish it from the more common rectifier which changes a-c to d-c. However, as d-c is required, the secondary contacts must operate as a Rectifier and thus the complete unit is known as an "Inverter-Rectifier" or Synchronous Vibrator.

To simplify our explanation, we want you to imagine that when the direction of primary current is up through transformer T of Figure 2, the direction of the induced voltage is down through the secondary winding.

In the position shown, the path of the primary d-c will be from the Hot A, through the switch and RFC to the center tap, up through the top half of the primary winding, through the upper right pair of contacts and through the armature to ground.

The induced secondary current, passing down through its winding, has no circuit from the lower end, because the lower left secondary contacts are open but, there is a circuit from the center tap to the "pos" high voltage terminal and through the circuits of the receiver to the "neg" or ground. The path is completed from ground, through the armature and upper left pair of contacts to the upper end of the secondary.

Should it confuse you to follow the primary and secondary currents through the armature in opposite directions at the same time, you can think of the secondary circuit as being completed from ground through the battery, Hot A terminal, switch, RFC, upper half of the primary and upper right primary contacts to the armature.

When the magnet pulls the armature down, all the upper pairs of contacts are opened while both pairs of lower contacts are closed and there is current down through the lower half of the primary. The direction of the secondary current is up and its path will be from the center tap to the high voltage "pos" terminal, through the receiver circuit to ground. From ground, the path is as previously traced except the current passes through the lower left pair of contacts to the lower end of the secondary.

C1 and C2, sometimes called "Buffer" condensers are connected across the secondary contacts, act to reduce the arc when the circuits are opened but, as both condensers are in series across the entire secondary winding, they also provide a filtering action as explained for C1 of Figure 1.

The shunt type vibrator decreases the magnitude of starting current, compared to the series type, and should the unit fail to start, there is less possibility of damage to the vibrator or associated parts. The shunt type is considerably more efficient and has longer life at the same time delivering higher currents at steadier output voltages.

Many years of research has resulted in better spring steel for the armatures, better tungsten for the points, and better bronze for the contact arms. Proper selection of the buffer condenser also contributes to longer, steadier and lower "interference" operation.

While there are many mechanical variations in vibrator type high voltage supplies, electrically, they can all be roughly divided into the general classes of Figure 1 and 2. In both cases, you will find a filter in the low voltage or car battery supply circuit to keep electrical disturbances of the auto electrical system out of the receiver circuits. Although not shown, it is necessary to have the usual type of filter between the high voltage terminals and the circuits of the receiver.

As far as actual size is concerned, the units of Figures 1 and 2 are made in compact form, small enough to build into the receiver chassis. Although the general trend seems to be toward building the power supply, the receiver chassis and speaker in one complete unit, you will still find many installations in which they are made up as separate units. However, the difference between the single and separate units is entirely mechanical, the electrical circuits remaining practically the same in all cases.

SYNCHRONOUS VIBRATOR CONNECTIONS

It must be understood that in the synchronous vibrator type, which serves as an inverter for the primary circuit and a rectifier for the secondary circuit, the polarity of the input determines the polarity of the output voltage to the receiver.

In the non-synchronous type described by Figure 1, the primary or battery polarity is immaterial because the tube will rectify the a-c with the result that the cathode is always positive with respect to "B-" or the center tap of the secondary winding.

However, the synchronous vibrator is essentially a two way circuit and thus reversing the polarity of the primary source voltage will reverse the output polarity.

To compensate for the fact that some autos operate the electrical circuits with a grounded negative, while in others the positive is grounded, the primary or secondary connections of the transformer may be reversed when required.

Therefore if the Hot "A" of Figure 2 is negative, and the contacts are in the position shown, current will pass from the grounded armature to the upper right contacts, through

the upper half of the primary winding to the center tap and back to Hot A "negative" through the RFC. The induced current in the secondary passes up through the winding, and will follow a path from the grounded high voltage "negative" through the receiver circuits in the wrong direction. Consequently, for the receiver circuits to operate, reversal of either the primary or secondary winding of the transformer is necessary.

TYPICAL AUTO RECEIVER

To give you a more complete idea of the application of the power supplies shown by the circuits of Figures 1 and 2, for Figure 3 we have drawn the complete circuit of a typical superheterodyne automobile receiver. Then, in order that you may completely understand it, we are going to take each of the circuits and explain them separately.

HEATER CIRCUITS

In Figure 3, the "Hot A" terminal connects to the insulated post of the car battery while the "Gnd." terminal is usually connected directly to the frame of the car, which is the other terminal of the car battery. Tracing the heater circuits, from the "Hot A" terminal we follow through an r-f choke "Ch 2" to an arrow indicating a connection to all heaters. One side of each tube heater is grounded and therefore is connected directly across or in parallel to the car battery. Notice, there are no resistors of any kind, the heater circuits being as simple as those of a-c home type of radio receiver.

Let us assume the heaters of tubes T1, T2, and T3 each require a heater current of .3 ampere while tubes T4 and T5 require .4 ampere. The total heater current will then be .3 x 3 or .9 ampere plus .4 x 2 or .8 ampere which is 1.7 amperes.

In addition to the tube heaters, the field winding of the dynamic speaker also connects across the battery and assuming a resistance of 4 ohms, draws a current of 6 ÷ 4 or about 1.5 amperes. Adding this to the value given above, the battery drain for heaters and field will be 1.7 + 1.5 or 3.2 amperes.

Suppose the power supply of this receiver developes 250 volts at 30 milliamperes which is equal to 250 x .03 or 7.5 watts. Whenever energy is changed from one form to another there is a loss and we will assume this power supply is approximately 50% efficient. On this basis, the output of 7.5 watts means an input of 7.5 x 2 or 15 watts which, at 6 volts, requires a current of 2.5 amperes.

Adding this value to the current required for the heaters and speaker field, the total battery drain will be 2.5 + 3.2 or 5.7 amperes.

Figuring roughly, automobile lamps require about 1 watt per candle power and as the receiver of Figure 3 requires 5.7 amperes at 6 volts, for a total power of 5.7 times 6 or 34.2 watts, the drain on the battery is only slightly more than that required for a 32 candle power headlamp.

HIGH VOLTAGE CIRCUITS

The high voltage supply of the complete receiver is practically the same as that explained for Figure 1 and because of this, we will not repeat the action. Tracing the current path from the cathode of the rectifier tube, T5, we go through the choke coil "CH" which has a low d-c resistance with a comparatively high inductance. Condenser C19, between the input end of the choke and B- has a capacity of about 8 microfarads, and C18, connected between the output end of CH and B- has a capacity of nearly the same value. The choke coil CH and these capacities make up an efficient condenser input filter which delivers practically humless direct current to the receiver proper.

From the output end of the choke, there is one circuit directly to the screen grid of the output tube T4. Other circuits from this same point are through the load resistance R8 to the plate of T3, through primary L6 of the 2nd i-f transformer to the plate of T2 and through the primary L4 of the 1st i-f transformer to the plate of T1.

Also, below this connection to L4 you will find a circuit through R1 to the screen grids of T1 and T2 together with a circuit through L3 to the anode grid of T1. R1 is of such a value that, with normal currents in these circuits, there will be sufficient voltage drop across it to allow proper voltages on the screens of T1 and T2 and the anode grid of T1. The condenser, C10, with a capacity of approximately .1 Mfd., forms a low reactance path for r-f frequencies, thus preventing any unwanted coupling between screen grids and other circuits connected to the same supply.

The plate of the output tube operates at a high voltage and is connected to the input end of the choke, CH, through the primary of the output transformer T_o. The condenser C16 connected from the plate of T4 to ground attenuates some of the tube noises and higher audio frequencies and thus, in effect, acts as a fixed tone control.

GRID VOLTAGES

Like most home radios, it is quite common practice to bias the grids of the tubes in an auto receiver by a combination of resistance and capacity in their cathode circuits. However, in Figure 3, the bias voltages are obtained by a little different arrangement.

Tracing the circuit, you will notice that the cathodes of T1, T2 and T4 are connected directly to ground. Then, the input grids of T1 and T2 are connected to R2 and from there to ground, through R3 and R6 while the control grid of T4 connects to ground through its load R9 and resistances R4, R5 and R6.

As the cathodes of T1, T2 and T4 are grounded, in order for their current to return to B-, it must pass through the resistances R6, R5 and R4. Also, the cathode of T3 is connected between R5 and R6 and so its current must pass through R5 and R4 to reach B-.

Here is the point. In order to arrive at B-, the current of these tubes must pass through a resistance network and therefore, we can say that ground is positive in respect to B- or, in other words, any voltage drop across resistances R4, R5 and R6 is negative in respect to ground.

As the cathodes, or reference points, of T1 and T2 are grounded and their input grids connect to the negative end of R6 through R2 and R3, these tubes receive their initial bias voltage by the drop across R6. R2 is part of the avc filter and R3 is the diode detector load. As we are considering the bias voltages without application of signal, there will be no voltage drop across R3 and as in an avc filter, there is no voltage drop across R2.

The cathode of T3 connects between R5 and R6 while the control grid of the triode section connects between R4 and R5, through its grid load R7 and therefore, obtains its bias voltage from the drop across R5.

The cathode of T4 is connected directly to ground while the control grid is connected to B- through its load R9. With these connections, there is a difference of potential between the grid and cathode caused by the total drop across resistance R4, R5 and R6 and, as this is negative in respect to the cathode, which is grounded, the necessary bias is obtained. Condenser C17 is connected directly across the bias resistors R4, R5 and R6 and serves to provide a more uniform d-c potential.

DUO-DIODE-TRIODE

Tube T3, Figure 3, is a duo-diode-triode type which functions as the second detector, automatic volume control and first audio amplifier. The signal voltage appears across the tuned secondary, L7-C12, as the modulated intermediate frequency. The upper end of this circuit connects to both diode plates, which act as a half wave rectifier, and continues through the cathode, the potentiometer R3 and then back to the lower end of the tuned circuit.

Thus, the signal voltage, caused by the rectified current, will appear across R3 and we can consider it as the source of the audio signals. The direction of the rectified signal current will be from the plates, through the tube to the cathode and back to the lower end of the tuned circuit through R3. Thus, an increase of signal voltage will cause more rectified signal current and make the lower end of the tuned circuit more negative in respect to ground.

In our former explanations we told you the input grid circuits of both T1 and T2 were connected to this same point and thus, an increase of signal strength will increase the negative grid voltage, thus reducing their amplification providing avc as previously explained.

Considering R3 as the audio signal source, the movable arm is connected to the control grid of the triode section of T3, through the coupling condenser C14 and thus the signal voltage will appear across the grid load R7 and be impressed on the grid. By varying the position of the arm of R3, any amount of the signal voltage can be applied to the grid of T3 and thus R3 acts as the manual volume control.

Under these conditions, the avc action tends to maintain a constant signal voltage across R3. In other words, the desired level is obtained by adjusting the manual volume control and the automatic action tends to maintain it.

SIGNAL CIRCUITS

Now that we have explained the various d-c circuits and part of the signal action of Figure 3, we are going to start with the antenna and follow the path of the signal through to the speaker. The modulated carrier wave cutting the antenna will induce a voltage across the series combination of C1 and the lower end of the antenna coil L1. This coil acts as an autotransformer with the part below the tap being the primary and the entire winding the secondary.

Thus, with current in the primary, a larger voltage will appear in the secondary. Tuning condenser C3, with its tirmmer C2, connected across the secondary in series with the blocking condenser C4, allows the circuit to be tuned, thus increasing the voltage of the resonant frequencies.

The exact purpose and action of the condenser in the position of C4 seems to be confusing, therefore, an explanation will be of benefit. In the common types of tuning condensers, the rotors of all the sections are grounded, making it necessary to ground one end of the coil which the condenser connects across. However, the coil is also in the grid circuit and a direct ground means a grounded grid return. For the older circuits, this is a satisfactory arrangement but, when automatic volume control is used, the grid return is grounded through various other resistances.

As far as the tuned secondary of L1, Figure 3 is concerned, condensers C3 and C4 are in series across the winding. You already know that the total capacity of two condensers in series is equal to the product of their capacities divided by their sum. Here, assuming C3 has a capacity of .00035 m-f and C4 a capacity of .05 m-f, connected in series, their total capacity is .0003475. Thus, for tuning, C4 has caused a change of but .7 of 1% in total capacity.

This small change can be compensated easily by adjusting the trimmer condenser and, from a practical standpoint, the addition of C4 does not change the tuning, conditions remaining the same as if the coil were actually grounded.

However, grid bias is a d-c voltage and the presence of C4 effectively insulates the coil from ground, as far as d-c voltages are concerned, allowing the grid return to be completed through the desired resistances before being grounded.

Getting back to the signal, the voltage across the tuned circuit of L1-C3 is impressed on the input grid of T1 and mixed with the local oscillator frequency so as to form the modulated i-f which appears across the tuned circuit L4-C8 that makes up the primary of the 1st i-f transformer.

The local oscillator is made up of the primary coil L3, inductively coupled to L2, and connected to the anode grid of T1. The oscillator control grid is connected to the tuned circuit composed of L2 in series with C7 and the combination in parallel with the oscillator tuning condenser C6, the trimmer C5 and resistor R. Condensers C5 and C7 are really verniers on the main condenser C6 and are adjusted so that

the beat frequency between the carrier and local oscillator is the same as that to which the i-f transformers are tuned. Then to maintain this same frequency over the entire broadcast band, the rotors of condensers C3 and C6 are mechanically ganged and turn on one shaft. The resistance R is connected from ground to provide the bias voltage for the oscillator section at the converter.

With the i-f signal in the primary of the 1st i-f transformer, a voltage of like frequency will be induced in the secondary L5 which is tuned by condenser C9. This tuned circuit impresses the signal on the control grid of T2, in the plate circuit of which is the primary of the 2nd i-f transformer, L6 tuned by condenser C11.

The secondary of this transformer, coil L7 is tuned by C12 and the signal voltage is impressed on the diode plates of T3, which act as a rectifier and cause the audio signal to appear across R3. Then, as previously explained, the desired part of the audio voltage is impressed on the triode grid of T3.

The rectified signal, or audio voltage, is carried over from the plate of T3 to the grid circuit of T4 through the coupling condenser C15. Changes of plate current in the output tube, T4, cause changes of voltage across the primary of the output transformer T_o, the secondary of which connects to the voice coil of the speaker.

Checking back, on the more common plan, the tube, T1, acts as an oscillator and first detector, or mixer, T2 as an intermediate frequency amplifier, T3 as a second detector, avc and 1st audio amplifier, T4 as a power output and T5 as a full wave rectifier.

OVER-ALL CHARACTERISTICS OF AUTO RECEIVERS

While there are an almost endless variety of makes and models of auto radios, the circuits of Figure 3 give the fundamental principles of all types and if you fully understand them, you will not have any difficulty with Modern auto receivers. As examples of variations of Figure 3, you may find receivers of this type with an r-f stage or an additional audio stage. Also, the output tubes may be connected in push-pull and the power supply may incorporate an "inverter-rectifier" instead of a tube.

Economy of operation is also of importance as prolonged operation places a rather heavy drain on the storage battery. It is for this reason that special purpose and dual-type tubes have been developed.

The OZ4 cold cathode gaseous rectifier tube has found favor in auto radios and since it requires no filament current, it represents some saving in battery power. Permanent magnet speakers are now almost universal in auto sets, and here again the power required to excite a field coil is saved

In general, the automobile receiver is much more sensitive than the home receiver. In order to obtain a high degree of sensitivity, the over-all amplification of the receiver must be large, and this necessitates high gain stages stability of operation and adequate shielding.

As the Superheterodyne circuit is universally employed in auto sets, high gain per stage can be obtained by the use of high gain tubes, and the use of iron coil i-f and r-f transformers. Complete shielding of the receiver by a metal container reduces the tendency for feedback difficulties, and further excludes "pickup" of extraneous voltages which are in the nature of noise or interference, as well as to afford protection of the component parts against damage.

Automobile receivers have been constructed along two general types. One is the entirely self contained receiver with manual and sometimes push-button tuning, as well as speaker, all being within a single housing. In most cases, the receiver is mounted under the dash of the automobile. The other type makes use of remote cable controls often with push-button tuning. The container may be mounted in any convenient portion of the car whereas the "controls" are usually fitted into the dash or a remote "head" mounted on the steering post. The location of the speaker is generally optional, and varies with different makes of automobiles.

UNIVERSAL RECEIVERS

The development of smaller and smaller midget or "Personal" Radio receivers has led the designers to simplify their circuits and eliminate all parts possible. Because of their small size and weight, receivers of this type are readily portable and therefore, it is desirable that they operate on any lighting circuit d-c or a-c and, in some cases, be arranged for battery operation as well.

For the rest of this Lesson, therefore, we want to explain the common a-c/d-c type of radio Receiver which usually operates on any 110-120 volt lighting circuit. While our examples are Radio receivers, the same general plan is used for public address amplifiers and other Electronic equipment.

SERIES FILAMENT CIRCUITS

Looking through the tube tables of an earlier Lesson, you will find that the filaments, or heaters, operate at comparatively low voltage and high current. Therefore, it is easy to see that, with a high voltage supply, it will be most economical to operate a number of heaters by connecting them in series.

As you already know, the voltage across a series circuit is equal to the sum of the voltage drops across the part connected in series but, at any instant, the current is the same in all parts of the circuit. Because of these conditions, it is practical to connect heaters, of various voltages, in series, provided they require equal current.

Going back to the tube tables again, you will find a wide variety of tube types, the heaters of which require .3 or .15 ampere of current for proper operation. Some of these were developed particularly for auto receivers and while the heaters are rated at 6.3 volts, their construction is rugged and they will operate satisfactory from 6 to 8 volts. Other types have heaters rated at 12.6 volts, 25 volts, 50 volts, 70 volts and 117 volts.

Back in the earlier Lessons, we told you that alternating current was compared with direct current by its heating effect and therefore, .3 ampere, either a-c or d-c will provide equal heat. Also, you will notice, that all of these tubes are of the cathode type which makes the heater circuits independent of the signal circuits. Thus, there will be a minimum of hum when a-c is used to operate the heaters.

With these facts in mind, we want you to look at the circuits of Figure 4 which is a four tube Universal type Radio Receiver containing an r-f amplifier tube, Detector tube, an a-f amplifier tube and a Rectifier tube.

To trace the heater circuit, we will start at the lower "110 volt supply" wire, and follow the path of the current through the switch, resistance "R2", and the heaters of the Rectifier, the a-f tube, the r-f tube and the detector. One side of the detector heater connects to the common return, which you can think of as the metal chassis, and following this return to the right, we come down and then left, to the upper "110 volt supply" wire.

To make a definite example, we will assume the following type tubes. 6K7G - r-f, 6J7G - Det., 25A6G - a-f and 12Z3 rectifier. Checking back in the tube tables you will find the following heater ratings.

Tube	Volts	Amps
6K7G	6.3	.3
6J7G	6.3	.3
25A6G	25.0	.3
12Z3	12.6	.3

Notice here, the current is the same in all cases and, connected in series, the total drop across the four tubes will be equal to 6.3 + 6.3 + 25.0 + 12.6 = 50.2 volts. Resistance R2 is also in series and, following common practice, if we consider the supply as 117 volts, the drop across R2 must be 117 - 50.2 = 66.8 volts.

Knowing the values of current and voltage, we substitute in Ohm's Law and find R2 requires a value of 66.8 volts divided by .3 amps or 222.7 ohms. The tube heaters, with a total drop of 50.2 volts at .3 amp have a total resistance of 50.2 divided by .3 or 167.3 ohms.

The complete filament or heater circuit therefore, has a total resistance of 222.7 + 167.3 = 390 ohms which, at 116 volts, allows a current of .3 ampere.

Going back to the earlier Lessons, you will remember that electrical power, in Watts, is equal to volts times amperes or amperes squared times ohms. Here, with 117 volts and .3 amp, the power in the entire circuit will be 117 x .3 = 35.1 watts. For the tube heaters only, 50.2 volts x .3 amp = 15.06 watts and, for R2 only 66.8 volts x .3 amp = 20.04 watts.

We mention these values to bring out the fact that the power in R2 is greater than that in all the tube heaters. As this power is dissipated in the form of heat, R2 will become quite warm, if not hot, when the receiver is in operation.

To keep this heat out of the receiver chassis and also to provide better radiation, the resistor R2 may be located inside the supply cord between the receiver and attachment plug. This arrangement is known as a "Line Cord" and can be purchased complete with resistance values from 135 to 360 ohms.

There is a special RMA color code for identifying the value of the resistance employed in resistor cords such as the type commonly used in a-c/d-c receivers for voltage dropping purposes. The power supply cord has three separate connector wires, one wire connects directly to one terminal of the line plug while the other wire and the resistor wire connects to the other terminal of the line plug.

The two line wires are always either red and blue or red and black. The color of the third, or resistor, wire depends on the resistance. The resistor wire is covered with a colored insulation and its value is determined by the following code.

Color	Resistance
Yellow	135 ohms
Blue	160 ohms
White	180 ohms
Green	200 ohms
Light Brown	220 ohms
Orange	260 ohms
Grey	230 ohms
Maroon	315-320 ohms
Dark Brown	350-360 ohms

From a practical standpoint, cords of this type become noticeably warm during normal operation and therefore, a hot cord is not an indication of trouble. Should it become necessary to replace the attachment plug or make other repairs, the cord must not be shortened as this will reduce the value of resistance and allow the tube heaters to operate at voltages high enough to shorten their life.

Resistances used for the purpose of R2, Figure 4, are often enclosed in a glass or metal bulb, mounted on a base the same as the regular tubes and are known as "Plug-in Voltage Dropping Resistors". The plug base arrangement provides ease in replacement and testing problems.

There are "Ballast" tubes which have the special operating characteristic of greatly decreasing their resistance if the magnitude of current through them tends to decrease. These units are normally connected in series with vacuum tube filaments and help to maintain relatively constant current over a considerable range of operating voltage. In reality, they act as current regulators and this current regulating feature is what distinguishes them from the simple plug in "voltage dropping" resistors described above.

PLATE SUPPLY

Starting at the lower wire of the "110 Volt Supply" of Figure 4, you will find a direct path to the plate of the rectifier tube. When the plate is positive, in respect to the cathode, current will pass through the tube, from plate to cathode which is, therefore, often considered as the supply positive.

From the rectifier cathode, the circuit is through the choke which, with condensers C9 and C10, composes the filter that smooths out any variations of cathode current. From the

choke, there is a connection to the screen grid of the a-f tube and, through the primary of the output transformer T3, to the plate. Starting at the choke again, there is another path down, ovdr to the left, up through R6 to the Detector Plate and up through T5 to the detector screen grid. Going further to the left, the circuit continues to the screen grid and, through the primary of T2, to the plate of the r-f tube.

All of these circuits are completed to the other side of the supply circuit through the metal chassis or common return. For the r-f tube, the cathode connects to the return through the fixed resistance R3 and variable resistance R1 which controls the bias voltage. As a change of bias voltage varies the mutual conductance of a tube and therefore its effective amplification, R1 acts as a volume control.

The detector tube circuits are completed from the cathode to the return through the bias resistor R4. The same general plan is followed for the a-f or output tube, the cathode being connected to the return through the resistance R8.

For all three tubes, the control grid circuit connects directly to the return while the plate and screen currents of each tube pass through its bias resistor. The voltage drops, across these bias resistors, equal to the current times the resistance, make the cathodes positive in respect to the return. As the grids connect directly to the return, they will be negative, in respect to the cathodes.

Each bias resistor has a condenser connected across it to maintain a more uniform voltage, as already explained in the earlier Lessons. In fact, the signal circuits of this receiver are the same as explained for similar units with other types of power supply.

Here, when connection is made to a 110 volt a-c circuit of any frequency, the heaters will operate properly, as already explained and the rectifier will allow current only when the supply wire, to which the plate connects, is positive.

When connection is made to a 110 volt d-c supply, the attachment plug must be placed in the receptacle so that the positive side of the supply circuit connects directly to the rectifier plate. Under these conditions, there will be a continuous current from the rectifier plate to the cathode.

Keeping the action of the rectifier tube in mind, should the supply cord plug be inserted so that the plate connects to the negative side of the line, there will be no plate voltage, although the tube filaments will burn normally. Thus you can understand why, with a d-c supply, it may be necessary to reverse the position of the supply cord plug in the power outlet in order to secure operation.

BATTERY OPERATION

To show you how circuits of this general type have been adapted for battery operation, in Figure 4 we have added a 5 prong socket which connects to the batteries through a plug. To provide proper operation, the a-f tube must now have a 6.3 volt and .3 amp filament, the same as the r-f and Detector tubes.

Instead of the type 25AG6 of the former explanation we will assume the a-f tube is a type 38 which was popular for this purpose. For 117 volt operation with this tube, the total heater drop will be 6.3 + 6.3 + 6.3 + 12.6 for a total of 31.5 volts.

Resistance R2 must now cause a drop of 117 - 31.5 = 85.5 volts which, at .3 ampere requires a value of 85.5 ÷ .3 = 285 ohms. Figuring as before, it will now be necessary for R2 to dissipate 85.5 volts x .3 amp = 25.65 watts.

As both the plug and socket are shown from the top, when the plug is in position in the socket, the corresponding pins will be connected. Thus, the A+ battery wire, which connects to the top and left hand plug pin, will make contact with the top and left hand socket connections.

With this in mind, we can trace a circuit from A+, through the left hand pin of the socket up and over through the a-f heater and back to the lower left socket contact which connects with A-. From the top contact of the socket, which also connects to A+, there is a circuit up and to the left, through the r-f heater and back to the lower left contact of the socket.

Starting from the top contact of the socket again, there is a circuit up and to the right, through the detector heater, back to the common return, and down to the lower right contact of the socket. As the A+ connects to the top and left contact of the socket and the A- connects to both lower contacts, the heaters of the r-f. Det., and a-f tubes are in parallel across the A battery. The rectifier tube is not needed and therefore its heater is not connected.

The plate or "B" supply has its "+" connected to the right hand socket contact and its "-" connected to the lower contacts. Tracing from the right hand contact of the socket, there is a direct connection to the choke from which point, as already explained, current is supplied to all plate and screen circuits. These circuits are completed through the common return to the lower socket contacts and back to B-. Although not shown, a battery switch could be placed in the "A-B" wire of the battery connections.

Thus, with a 6 volt A battery and 90 volt B battery, the re-recier will operate under practically the same conditions as when connected to a 110 volt supply. It may be well to mention here that, because the maximum a-c voltage is 1.4 times the effective value, the rectified a-c when filtered, produces approximately the same d-c voltage as when a d-c power supply is used.

SIGNAL CIRCUITS

Checking briefly through the signal circuits, at the left you will find the antenna coil, T1, the tuned secondary of which is in the control grid circuit of the r-f tube. The signal is carried over to the detector grid through the r-f transformer T2, the primary of which is in the plate circuit of the r-f tube and the tuned secondary in the detector grid circuit.

The detector is Resistance-Capacity coupled to the a-f or output tube which has output transformer T3, in its plate circuit. The output transformer secondary connects to the speaker which is of the magnetic or Permanent Magnet type. In some receivers of this type, you will find the windings of a high impedance type speaker are connected in the plate circuit of the output tube thus eliminating the output transformer.

Tracing the input circuit, you will find the antenna connects directly to one end of the primary of T1 and the circuit is completed to ground through condensers C1 and C2. Condenser C1 is connected between the primary and the common return while C2 is connected between the chassis, or common return, and the external or actual ground.

As you perhaps already know, the Electrical Code requires that lighting circuits be grounded on one side so that the voltage between the line and ground can never exceed the circuit voltage. In Figure 4, one side of the 110 volt supply connects directly to the chassis, or common return, and we will assume the plug has been inserted in the outlet so that this is the ungrounded or "hot" side of the supply circuit.

With an external ground properly made, there would thus be a short across the supply circuit unless condenser C2 was in place. Also, it is quite common practice to use steam radiators and other similar grounded metal objects as an antenna and, unless C1 were in place, again there would be a short across the power supply.

Equipment of this general type must always be arranged so that there is no direct connection between either of the power supl ply circuit wires and any external connection which may be grounded.

SIX TUBE SUPERHETERODYNE

To give you a further application of the a-c/d-c type of unit, for Figure 5 we show a 6 tube superheterodyne receiver which includes several features not included in the simpler trf type, receiver of Figure 4.

Checking on the tubes, you will find the first, or left hand one is a pentagrid converter which acts as a first detector and oscillator. This is followed by a pentode which acts as an i-f amplifier, its output feeding into the diode plates of a duo-diode-triode.

This tube acts as the second detector, automatic volume control, and its triode section is the first audio amplifier. At the right there is a power pentode tube, and at the bottom the rectifier and ballast tubes.

You can trace the filament or heater circuit by starting at the upper wire of the power supply and passing through the "Ballast", "Rect." "Output", "I.F.", "1st Det.", "2nd Det." tubes and back down to the lower power supply wire.

HIGH VOLTAGE CIRCUITS

For the high voltage, plate and screen circuits, you can start again at the upper wire of the power supply, go over to the right to the rectifier tube plates, across to the cathodes and up to the horizontal connections. To the right there is a direct path to the screen of the output tube and another path through the primary of the output transformer to the plate.

To the left, there is a path to the plate of the a-f tube through R10 and through R6 to the screen of the i-f tube and also through the primary of i-f T2 to the plate. Also through the primary of i-f T1 to the plate of the first detector, through R2 to the screen grid and through the primary of the oscillator coil to grid No. 2

All of these circuits are completed to ground through the cathodes of the various tubes and, from ground, the combined currents pass through R4, R9 and speaker field to the lower power supply wire of our circuit. Here, the speaker field acts as the filter choke and together with condensers C13 and C8, forms a condenser input filter. Condenser C16 is the line filter condenser which helps to reduce hum and by-passes high frequency noise voltage.

SECOND DETECTOR

The second detector is of the diode type and its circuit is from theupper end of the secondary of i-f T2 to the upper diode of Figure 5, across to the cathode and back through the

volume control to the lower end of the secondary. The rectified signal voltage thus appears across the volume control potentiometer and is coupled to the grid of the a-f tube through condenser C10. By adjusting the movable contact of this control, any desired part of the signal voltage may be applied to the a-f grid, thus regulating the volume.

AUTOMATIC VOLUME CONTROL

To maintain a more uniform output with various carrier voltages, there is an automatic volume control circuit through condenser C15 to the lower diode plate of the tube. The circuit here is from the diode plate to the cathode, to ground and back through R4 and R5 to the diode plate.

Like the control grids of the first detector and i-f Amplifier tubes, the lower diode plate will be negatively biased by the drop across R4 and thus, with no signal, there will be no current in R5. However, when the signal voltage becomes greater than this bias, the diode will become conductive and rectified current will exist in R5.

The direction of this current will be from ground to the diode and the voltage drop across R5, caused by this current, will be positive at the grounded end and negative at the diode end. Checking back, you will find that R5 is also in the control grid circuits of the first two tubes and any voltage drop across R5 will be added to the bias voltage across R4.

Thus, an increase of signal strength causes an increase of voltage across R5 which, in turn, increases the bias on the control grids of the first two tubes. The action here is the same as explained for the volume control of Figure 3 but the bias is regulated by the signal strength and thus we have automatic volume control.

Remember here, the avc acts to maintain a constant signal level across the volume control which can be manually adjusted to allow any desired part of this voltage to reach the control grid circuit of the a-f tube.

As we have already explained, the avc circuit will not operate until the signal voltage is greater than the bias voltage on the diode plate and, therefore, the arrangement is known as "Delayed avc".

Resistance R3 and condensers C2 and C7 act as a filter to prevent any signal frequencies from reaching the controlled grid circuits the same as R7 and C11 in the grid circuit of the a-f tube.

The explanations of this Lesson complete the common type of Radio Receivers and we want you to notice particularly that about the only difference between the types is the matter of power supply. Practically all new sets employ the superheterodyne circuit and, if you understand its operation, and the various supplies we have explained, you are well on your way toward a good understanding of radio receivers.

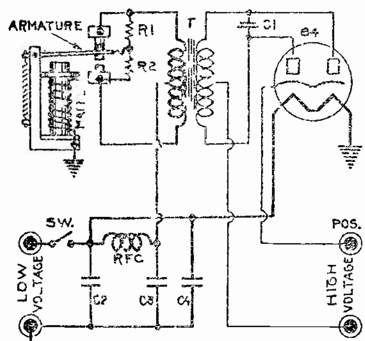


FIGURE 1

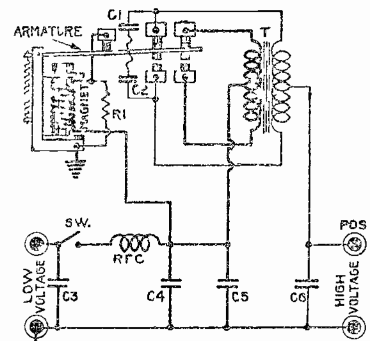


FIGURE 2

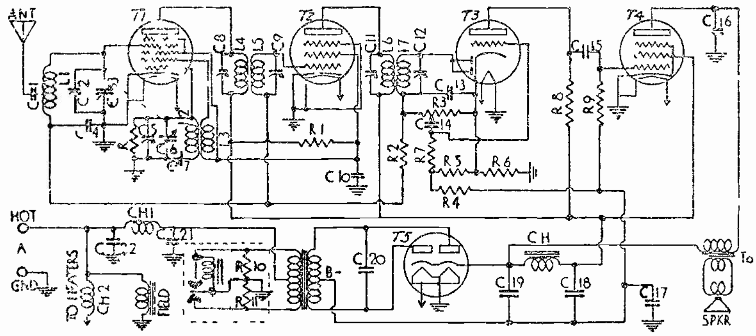


FIGURE 3

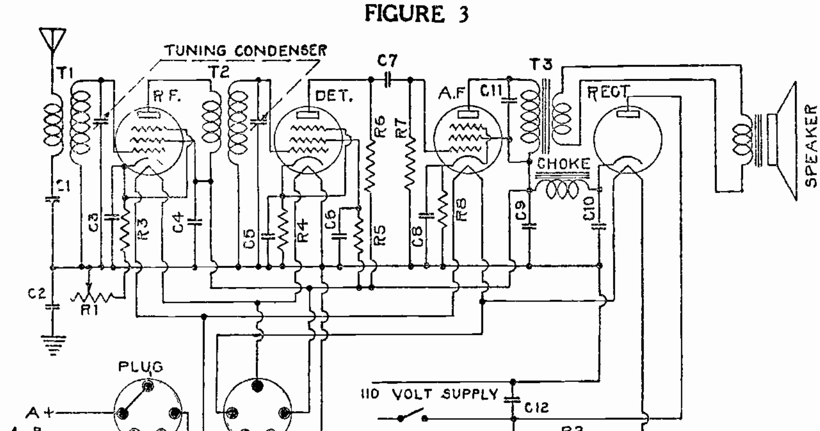
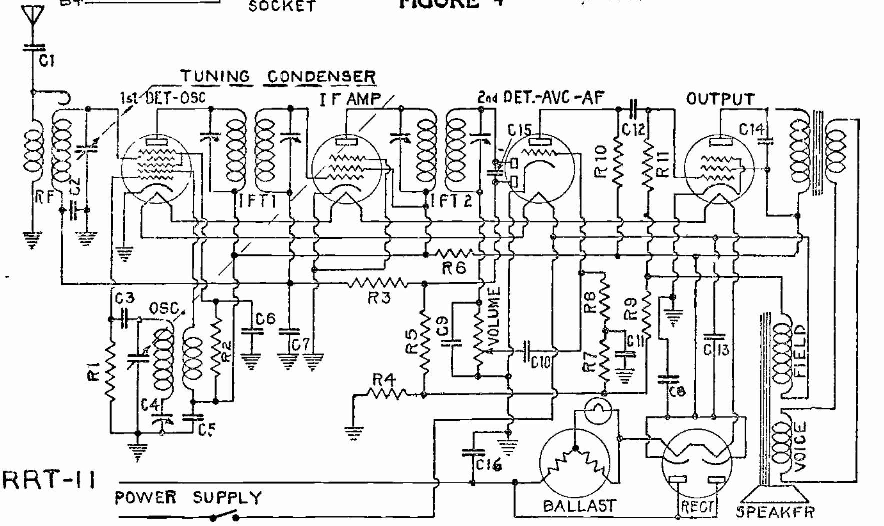
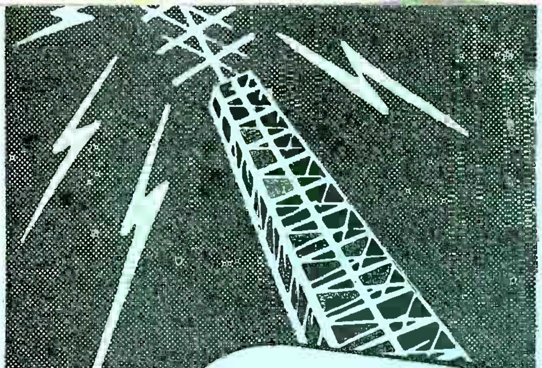


FIGURE 4



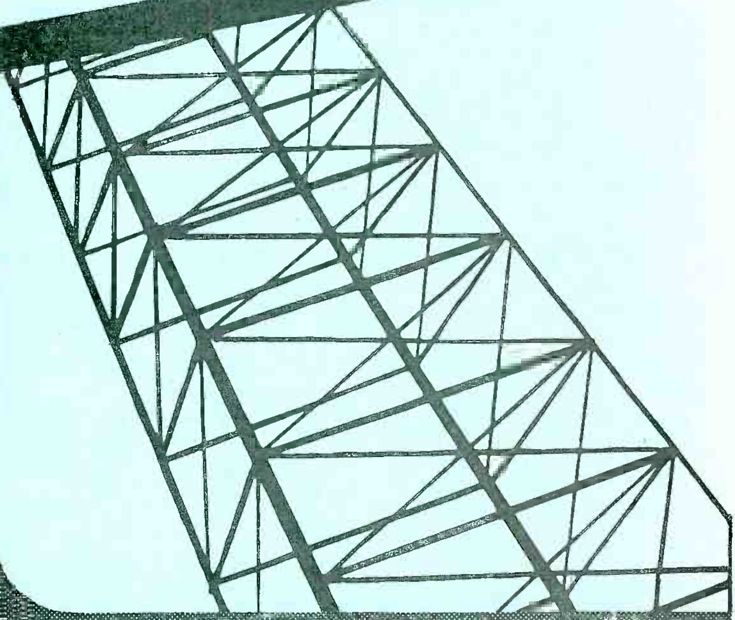
RRT-11

FIGURE 5



LESSON RRT-12

THE CATHODE RAY TUBE



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LESSON RRT-12

THE CATHODE RAY TUBE

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RADIO RECEPTION AND TRANSMISSION

LESSON RRT-12

CATHODE-RAY TUBE

* * * * *

Learning without thought is labor lost. Thought without learning is intellectual death.

---Confucius, 550 B.C.

Contrary to ordinary belief, the cathode ray tube is not new but has been employed in laboratories for a number of years. However, it has been removed from the laboratory class and is now considered as almost a necessary piece of test equipment in the Radio and Electronic industry.

For this reason, a complete understanding of its operation is essential for anyone interested in electronics and therefore, we are going to spend this Lesson explaining its action and some of its application.

THE CATHODE RAY TUBE

The cathode-ray tube is a form of vacuum tube in which the electrons are concentrated into a beam, caused to move at high velocity and strike a specially treated face, or "Screen" as it is called, which produces a spot of light. Deflection of the beam, which causes motion of the spot, is controlled by means of an electrostatic or magnetic field. Due to the persistance of vision of the human eye, when the spot is caused to move rapidly over the face of the tube, instead of a spot, a line or trace is seen. The trace presents a pattern or image which can be interpreted in terms of the voltage or current causing the motion of the electron beam.

Like the common types of vacuum tubes used as an amplifier, the cathode-ray tube contains a cathode, a grid to control the intensity of the electrons, and a plate or anode to attract them. Instead of the usual amplifying action, these elements serve to produce an electron beam of controlled diameter and velocity. One commonly used method for producing the beam is shown in Figure 1, where the electrons, that leave the cathode, are attracted to the anode A1 which is held at a positive potential. To reach the anode they must pass through the grid which consists of a metal plate with a small hole or aperture in it.

This aperture produces a beam, from the cloud of electrons that are emitted from the cathode, as only those passing through the opening reach the anode A1. The grid is maintained at a negative potential; hence, by varying its potential, it can be made to permit more or less electrons to pass. Since the object of this arrangement is to have the electrons strike the face or screen of the tube, and not remain at anode A1, it also has an aperture which further reduces the beam diameter. This combination of electrodes is commonly known as an "Electron Gun".

In order that the electrons strike the coated face of the tube or screen with sufficient force to produce a spot of light, it is necessary to increase their velocity. This is

accomplished by means of anode A2, which is maintained at a positive potential three or four times that of Anode A1, and further concentrates the beam so that a small spot is produced on the screen. The screen is made of a coating of willemite, cadmium tungstate, or other fluorescent materials which have the property of giving off light when bombarded by electrons. Different chemical coatings produce different colors, such as blue, green, yellow or white. The green being more useful for visual observation since the eye is most sensitive to this color, the blue being more satisfactory for photographic purposes, and the white for Television applications.

The intensity of the spot of light is determined by the number of electrons in the beam and the velocity at which they strike the screen. One method of controlling the number of electrons is by changing the cathode temperature; however, a better method, which is more convenient, more sensitive, and provides longer tube life, it to vary the grid potential.

The size of the spot is determined by the ratio of the voltages on A1 and A2. The voltage on A2 is usually kept constant and that of A1 is adjusted for proper focusing. If the voltage on A1 is too low, an inadequate number of electrons will reach it; hence, the number reaching the screen will be too small and result in a dim spot. If the voltage on A1 is too high, more than the required number of electrons will reach the screen and the spot will become enlarged. A careful adjustment, of the grid and anode A1 voltages, is therefore necessary to produce a spot of the correct size and intensity.

There are other methods of focusing the electron beam and one, as shown in Figure 2, is by means of the magnetic field produced by a coil placed so that the electrons pass through its core. Although the magnetic field set up by the coil does not influence those electrons traveling parallel to the flux lines, it does exert a force on those electrons which tend to diverge and move across the flux lines. The electrons are thus kept moving in one direction.

A third method of focusing, developed by the Western Electric Company, makes use of an ionized gas and the tube has the general construction shown in Figure 3.

The cathode is made part of the filament and the grid is electrically connected to it. The number of electrons passing through the grid is controlled only by the cathode temperature since the grid is always at a constant potential with respect to the cathode.

The anode A1 attracts the electrons and gives them the velocity necessary to reach the screen but, in passing through the inert gas, the electrons strike molecules of the gas and knock out some electrons which leaves the molecules with an excess positive charge. These positively charged bodies, called ions, are much heavier and move slowly compared to the electrons; hence, they are displaced very little by the impact and tend to remain in the path of the beam. Since they are positively charged, they attract electrons, thereby preventing the electrons from diverging from the path of the beam. In reality then, there exists a beam of both electroms and ions. While the ions are continually neutralizing electrons, an excess of electrons is maintained by the cathode.

Since the movement of an electron can be controlled electrostatically or magnetically, motion of the beam, which consists of a stream of electrons, can likewise be controlled. Deflection is produced electrostatically by passing the beam between two charged plates as shown in Figure 4.

By making plate A positive with respect to plate B, the beam of electrons, which are minute negative charges, will be attracted by A and repelled by B. The spot, which is normally at P_0, will then move to P1. If the polarity of the two plates is reversed, the beam will be attracted by B and repelled by A and the spot will move to point P2.

The distance that the spot moves from its normal position will be proportional to the charge or voltage on the plates. If the voltage on plate A is increased slowly from zero to the value which deflects the spot to P1, the spot will be seen to move gradually from P_0 to P1; however, if the increase in voltage is rapid enough, the spot will be seen as a straight line extending from P_0 to P1. This results from the inability of the eye to follow changes beyond a certain rate. As we have told you before, this characteristic of human eyesight is known as persistance of vision and is made use of in motion pictures. In seeing a line, the eye sees at one time every position that the spot occupied during its deflection.

By using two pair of plates, one deflecting the beam vertically and the other horizontally, the resulting pattern can be interpreted in terms of the voltages applied to the pairs of plates. In reality, this arrangement forms an electrical graph, with vertical and horizontal coordinates, and the motion of the spot, when influenced by two pairs of charged plates, is shown in Figure 5.

Assuming that plate V2 is made positive with respect to V1, the spot will move from P_o, the normal position, to P1. If plate H2 is then made positive with respect to plate H1, the spot will move to P2. If instead of applying the voltages individually, they are both applied at the same time, the spot will move diagonally from P_o to P2; since for each short distance it moves up, it will also move a short distance to the right. If the applied voltages are increased from zero to their final value at the right speed, a diagonal line extending from P_o to P2 will be seen.

Plates H1 and H2 are known as the horizontal deflecting plates or merely "Horizontal plates" and V1 and V2 are the vertical deflecting plates or "vertical plates". These names result from the direction in which they cause the beam or spot to move and not from their physical position in the tube.

Similar deflection of the beam can also be produced magnetically, as shown in Figure 6. However, this method is not commonly used for measurement work since considerable energy is required to energize the coils, whereas, practically no energy is absorbed in electrostatic deflection of Figure 5. Coils L1 and L2, mounted vertically, deflect the beam horizontally and coils L3 and L4 deflect the beam vertically.

PRODUCTION OF PATTERNS

The pattern, produced by the voltages applied to the deflecting plates of the cathode-ray tube, can be determined beforehand by graphical construction. For example, assume that two a-c voltages of the same frequency and zero phase relation are applied to the deflecting plates of the tube, as shown in Figure 7. The voltage EV is applied to the vertical plates V1 and V2 and the voltage EH is placed on the horizontal plates H1 and H2.

At zero voltage, the spot is at P_o. After a time t_1 has elapsed, the voltage between the vertical plates has increased to the value e_1 and between the horizontal plates to e_2. The spot then has moved to P1 which is located by projecting horizontally from e_1 and vertically from e_2 to locate point "P1". When a time equal to one fourth of the cycle has passed, the voltage between the horizontal plates is e_4 and between the vertical plates is e_3. By projection, the spot is now P2. As this point is passed, the voltage starts to decrease and the spot moves down the diagonal to P3, which is reached at the negative peaks of the applied voltages, and then moves back to P_o as the cycle is completed.

Thus the pattern of two sine voltages, of the same frequency and zero phase relation, is a straight line. The angle of inclination "α", that the line makes with the horizontal, is determined by the ratio of the magnitudes of the two voltages, and when they are equal, the angle is 45°.

LISSAJOU'S FIGURES

By similar construction, it can be shown that if the two voltages are sine waves of equal magnitudes and frequency but with a phase difference, the following will be true:

1. For a phase angle greater than 0 and less than 90°, the pattern will be an ellipse, with its major axis making an angle of 45° with the horizontal.

2. For a phase angle of 90° the pattern will be a circle.

3. For a phase angle greater than 90° and less than 180°, the pattern will also be an ellipse but its major axis will make an angle of 135° with the horizontal.

4. For a phase angle of 180°, the pattern will be a straight line whole angle "α" is 135°.

5. For angles between 180° and 360° these patterns will be duplicated.

These patterns, knows as Lissajous figures, produced for the various phase relations, are shown in sketches (A) through (E) in Figure 8.

If the two voltages are of the same frequency but of unequal magnitudes and 90° out of phase, instead of a circle, an ellipse will be produced, however, it cannot be confused with an ellipse produced for phase angles of less than 90° because its axes are in the vertical and horizontal plane as shown in Figure 9.

The patterns resulting from two voltages of different frequencies and of different phase relation are shown in the Lissajous figures (A) through (D) in Figure 10. All these patterns are for a frequency ratio of 3 to 1, the frequency on the horizontal plates being three times that on the vertical plates. Figure (A) is for a 0° phase angle, (B) for a phase angle less than 90°, (C) is for a 90° phase angle, and (D) is for a phase angle greater then 90° and less than 180°.

Notice that the patterns consist of double traces, which coincide for a phase angle of 0^o and become displaced from each other for other angles. Up to 90^o one trace appears to lag the other and after 90^o, it leads the other.

The Lissajous figures produced are determined by the ratio of the two frequencies, hence, if one is known, the other can be determined. As shown in Figure 11, the frequency ratio can be found by drawing a vertical line and a horizontal line tangent to the peaks of the waves produced. The frequency ratio is equal to the ratio of the number of peaks touching the vertical line to the number touching the horizontal line, and these patterns are the same regardless of the frequencies involved. For example, the left hand sketch of Figure 11 would be the same if the frequencies were 30 and 10 or 300 and 100 cps.

MEASUREMENTS

From the properties so far discussed, it can be seen that the cathode-ray tube may be used for the measurement of frequency and phase relationships.

As a d-c voltmeter, the deflection of the spot, from its original position, can be used as a measure of the voltage applied to the plates. A transparent screen, with parallel lines, placed over the face of the tube will afford a means of calibration. The tube is valuable as a voltmeter because of its extremely high internal resistance, therefore, it will not alter the circuit on which measurements are made.

As a voltmeter, the sensitivity of the tube is expressed in volts per inch or per millimeter of deflection. Stated another way, deflection sensitivity is the distance the beam will move across the screen in millimeters (one millimeter= one thousandth meter) at a difference of potential of one volt between a pair of deflecting plates. Once the sensitivity is determined, voltages can be determined from the length of the deflection.

On a-c voltage measurement, the cathode-ray tube acts as a peak voltmeter because it produces a line whose length represents twice the peak value of the wave. For example, if the vertical deflection sensitivity of a cathode-ray tube is .8 volts (rms) per inch, a vertical line trace of 3 inches on the screen would represent a value of 1/2 x 3 x .8 or 1.2 volts (rms). The peak value of the applied a-c voltage would be 1.2 x 1.41 (peak value = rms x 1.41) or 1.69+ volts.

Another valuable characteristic of the tube as an a-c voltmeter is that the deflection is independent of frequency and therefore, it can be used for measuring voltages of zero frequency, or d-c, to very high radio frequencies.

To further increase the sensitivity of the a-c measurement, an amplifier can be used in conjunction with the cathode-ray tube but, the amplifier frequency response will limit the frequencies which can be measured. The greatest drawback, to the use of the tube as a voltmeter, rises from its change in sensitivity with a change in anode potentials.

Current readings are made by measuring the potential drop across a resistor of known value, and then using Ohms law, to calculate the required value.

For frequency measurement, the output of a calibrated a-f signal generator is applied to one set of plates and the unknown frequency to the other. The ratio is then determined from the patterns as shown earlier in this Lesson.

SWEEP CIRCUITS

When an a-c voltage is applied to the vertical plates of a cathode-ray tube, a vertical trace appears on the face of the screen. As shown in Figure 12 (B), the line represents twice the peak voltage and, in a sense, the observer is looking in the direction of motion of the wave and sees an end view.

To obtain a true picture of the wave, such as shown in Figure 12)A), the beam must be moved horizontally at the same time that it is moved vertically. In order to produce this waveform, while moving vertically from A to B Figure 12A, the spot must also travel the horizontal distance AM. When the beam has moved vertically through one cycle, it will have moved horizontally a distance equal to AZ, and one cycle of the wave will be traced on the tube face.

Notice here, to produce a trace of one cycle it is necessary that the beam move horizontally from A to Z in exactly the same time required for the voltage on the vertical plates to complete one cycle.

Suppose the speed of the horizontal motion were cut in half and the beam moved only from A to Y in the time required for one cycle of the voltage on the vertical plates. Under these conditions, the complete wave of Figure 12 (A), would be compressed into the horizontal distance A-Y and a second complete cycle would appear in the space Y-Z.

The horizontal speed or velocity of the beam thus controls the number of cycles traced on the screen, and while a decrease in velocity will increase the number of cycles, an increase of horizontal velocity will reduce the number of cycles traced on the screen.

From a practical standpoint, the trace should appear to be stationary and, therefore, the horizontal velocity must be maintained in a definite proportion to the frequency of the voltage on the vertical plates.

Since the width of the screen determines the maximum horizontal distance that the beam can move, to produce a continual picture of the wave on the face of the tube, the beam must be returned instantly to its original starting point or else a double trace will appear.

The deflection of the beam is proportional to the voltage on the plates and in order that it moves horizontally at a constant velocity, the "sweep" voltage, applied to the horizontal plates, must increase directly with time. At the end of the horizontal displacement of the spot, the voltage will be miximum and then must instantly drop to zero in order that the spot be returned to the origin.

To produce this action, the waveform of the sweep voltage would be that shown in Figure 13 which, because of its shape, is called a "saw-tooth" wave. Checking the curve, you will find that the voltage builds up uniformly with time, reaching a peak value E and then drops instantly to zero.

To produce a voltage wave of this shape, it is customary to use what is known as a "relaxation oscillator" which functions on the electrical characteristics of charging condenser through a resistance. When such a condenser is being charged, the voltage across its terminals varies with time, and its voltage characteristic is similar in shape to the line OE of Figure 13 but with a certain amount of curvature which predominates as the peak voltage is approached. However, when this peak voltage is reached, some means of shorting the condenser must be provided in order to return the spot to its original position.

A motor driven switch could be used but, as it would be expensive and cumbersome, a better method, as shown in Figure 14, is to obtain the same action electrically by means of a gas filled vacuum tube shunted across the condenser. This tube, which contains two plates, has the property of being conductive only when the voltage across the plates is high enough to cause the gas to break up into negative and positive particles. This condition is known as "ionization" and when it occurs, a very low resistance path exists between the two plates. The resulting high current will stop only when the voltage on the plates is reduced to a value much lower than that required for ionization.

A tube of this type is ideally suited for the automatic shorting switch in the sweep circuit, because while the voltage is forming across the condenser, the tube acts as an infinite resistance but, after the condenser voltage reaches the ionizing potential, it acts as a low resistance or short. As the condenser discharges, the voltage drop across it is reduced and when the de-ionizing potential of the tube is reached, the current stops as abruptly as it started and the condenser again starts to charge.

The time for one cycle, or the frequency of the sweep voltage, will be determined by the difference in the ionizing and de-ionizing potentials, the value of the resistor "R", and the value of the condenser, C. The sweep voltage will be equal to the difference of the ionizing and de-ionizing voltages. In commercial circuits, the size of the condenser is changed to obtain large changes in frequency, and the voltage, or resistance, is changed for small frequency variations.

The grid controlled gaseous discharge tube has replaced the two element tube for use in sweep circuits, because of the need for synchronization of the sweep frequency with that of the voltage being analyzed. If the frequency of the signal voltage and that of the sweep circuit do not maintain a constant ratio to each other, the image will move back and forth across the screen making the analysis of the waveform difficult.

To provide a stationary pattern, the frequencies must be kept in step and synchronization is achieved by feeding a portion of the voltage being analyzed into the grid of the discharge tube, and using it to control the ionizing potential of the tube. As a result, the discharge tube will ionize at the same instant on each cycle of the signal voltage, thereby providing the necessary synchronization.

A simplified circuit using a triode of this type is shown in Figure 15 and while the grid controls the ionizing potential, it has no control over the de-ionizing potential. After ionization occurs, the grid loses control and only by dropping the plate voltage can de-ionization be brought about.

The circuit of Figure 15 functions in the same manner as that described in Figure 14 and the resistor R1 is used to limit the dischrage current to a safe value after ionization occurs while the variable bias arrangement is for small frequency adjustment.

As mentioned in the earlier part of this lesson, the sweep voltage should increase uniformly but the complete voltage characteristic of a condenser would cause a saw tooth wave with considerable curvature and a sweep voltage of this shape

would produce a distorted picture. However, the voltage characteristic curve of a condenser is almost straight-line near the start and becomes increasingly non-linear as the condenser voltage approaches that of the supply. By limiting the magnitude of the sweep voltage to a value on the lower part of the curve, a wave form closely approaching the ideal is obtained. However, by operating on the lower part of the curve, a higher supply voltage will be needed for the same ionizing potential.

The curvature in the charging voltage curve of a condenser is caused by the charging current not being constant in value but if the current could be kept constant, the condenser voltage would vary directly with time. This can be shown from the expression for the voltage on a condenser which is.

$$e = \frac{q}{C}$$

where q is the charge in coulombs and C the capacity in farads. Since the charge is equal to the product of the current and the time, that is

$$q = It$$

by substituting this equivalent of q in the voltage expression, in terms of the current and time, the voltage becomes

$$e = \frac{It}{C}$$

which shows the straight-line relation between the voltage and time when the current and capacity remain constant.

By utilizing the fact that, for a wide range of plate voltages, the plate current of a pentode tube is practically independent of the plate voltage, a method of keeping the condenser charging current constant is available and a sweep circuit, employing a pentode as a current limiting device, is shown in Figure 16.

When the supply voltage is applied to this circuit, the charging current of condenser C will be the plate current of the pentode tube which is determined by its grid and screen voltages. With time, the voltage across the condenser will build up and thereby decrease the plate voltage on the pentode, however, since the plate current is independent of this change in plate voltage, the current in the circuit remains constant.

When the voltage across the condenser becomes sufficient to ionize the triode, the condenser discharges through the tube until the voltage on the condenser drops to the de-ionizing

potential. When this occurs, the condenser discharge through the triode stops, the plate voltage of the pentode rises and the condenser starts to charge again. Although the circuit current remains constant during the condenser discharge the current through the gaseous triode becomes so large that a limiting resistor R1 must still be used.

For this circuit, the frequency of the sweep voltage can be determined from the expression

$$e = \frac{It}{C}$$

The equation for the time taken for the condenser to charge to a voltage "e" is

$$t = \frac{Ce}{I}$$

Since the frequency is the reciprocal of the time, that is

$$f = \frac{1}{t}$$

then, by substitution,

$$f = \frac{I}{Ce}$$

Since the voltage on the condenser does not drop to zero when the deionizing potential is reached, the voltage "e", across the discharge tube, commonly known as a thyration, will be the difference of the ionizing and de-ionizing potentials.

THE OSCILLOGRAPH

The cathode ray tube, in combination with auxilliary equipment such as amplifiers, positioning controls and sweep voltage generator, when used for measurement work, is known as an oscillograph or oscilloscope. Although we have explained the various actions of each of the separate circuits, it may be rather difficult for you to visualize just how they would be connected together and, therefore, in Figure 17, we show a complete circuit diagram of a typical cathode ray oscilloscope.

The controls, found on most oscilloscopes, are the intensity, focusing, positioning, amplifier gain, synchronizing and sweep frequency. All of these are shown in the circuit of Figure 17 and we are going to go through and point them out to you.

Intensity control: From our former explanations, you will remember that the bias voltage on the control grid of the cathode ray tube determined the intensity of the electron beam. Thus, in Figure 17, R25 is the intensity control because it provides a means of varying the bias on the control grid.

Focusing Control: In the tube, the focusing element is the anode the potential of which is varies by means of potentiometer R23.

Positioning Control: The positioning control consists of a potentiometer which applies a d-c voltage of the proper polarity and magnitude to the deflecting plates so that the normal position of the electron beam can be adjusted. It thus affords a means of moving the position of the pattern on the screen. There are two positioning controls, one R14, to move the spot up or down, and the other, R16, to move the spot to the right or left.

Amplifier Gain Controls: The amplifier gain controls adjust the voltage input to the amplifiers and so determine the voltage applied to the deflecting plates. In most oscilloscopes, two amplifiers are incorporated, one for the horizontal plates and the other for the vertical plates. In Figure 17, tube T1 with its circuit is the vertical amplifier and potentiometer R is its gain control.

The horizontal amplifier consists of tube T2 and its circuits, the gain control being potentiometer R2. A switch is incorporated at the input of the horizontal amplifier so that the internal sweep or an external voltage may be applied.

Synchronizing Control: To provide a stationary pattern, the sweep voltage must be kept in step with the voltage to the analyzed. To do this, a portion of the voltage being analyzed is fed into the grid circuit of the discharge tube and used to control its ionizing potential. In Figure 17, this is achieved by providing an a-c path from the plate of T1, through R7, C2 and R5 to the grid of the discharge tube T3. As the amount of the feedback voltage can be controlled by R5, it functions as the synchronizing control.

Sweep Frequency Control: For large changes of sweep frequencies, in commercial oscillographs, different capacities are substituted in the plate circuit of the discharge tube. In Figure 17 this is accomplished by switch "S" and the six different capacities. For finer adjustments or small frequency changes, the plate voltage on the sweep tube is varied by changing the position of the movable contact of R9, thus increasing or decreasing the resistance, or load, of the plate circuit.

Like the majority of vacuum tubes used in Electronic services, the cathode ray tube is identified by a specific RMA numbering system. For example, the tube used in Figure 17 could be a 3AP1. The first figure (3) indicated the approximate diameter of the face of the tube in inches, the letter (A) represents the manner of obtaining the deflecting potentials, the letter (P) indicates the screen material is some phosphor compound, and the last figure (1) represents the general persistency of the screen. The larger the number, the longer the persistence. A tube identified as 3AP5 would have a longer persistence than the tube indicated above.

Now that we have explained the fundamental actions and the controls of the oscilloscope in Figure 17, we will show you how it can be employed for checking distortion in an audio amplifier. To do this, it is necessary to use a calibrated a-f signal generator which we will assume to have a sine wave output. That is, when the output of a-f oscillator is applied to the vertical plates of the oscilloscope, and its controls properly set, an undistorted sine wave will appear on the screen of the cathode ray tube.

To start this check, the power cord of the oscilloscope is plugged into a suitable supply and the power switch turned "On". After allowing time for the tubes to heat, and with the positioning controls at their mid point of rotation, the intensity control is advanced until a spot appears on the screen. The focusing and intensity controls are then adjusted simultaneously until the smallest sharply defined spot is obtained. By the use of the positioning controls, the spot is moved until it comes to rest in the approximate center of the screen.

Once the spot is properly centered and focused, the intensity should immediately be decreased until the spot is just barely visible because an intense electron beam, allowed to remain stationary on the screen for any length of time, may burn the flourescent material and thereby decrease its ability to give off light.

As we are interested in the over-all distortion of the a-f amplifier, the vertical plates of the oscilloscope should be connected across the secondary of the amplifier output transformer and the output terminals of the a-f signal generator connected to the amplifier input terminals. The dial of the signal generator is set to a frequency of 50 cycles and, with the switches of the oscilloscope in a position to employ its internal synchronizing and sweep voltages, the main sweep frequency control, switch "S", in Figure 17, is set to a position which covers 50 cycles. The synchronizing control should be set for zero voltage.

With the connections and adjustments properly made, both the amplifier and signal generator are turned "On". After allowing time for their tubes to heat, the intensity control of the oscillograph should be advanced until a pattern is seen.

The horizontal and vertical amplitude controls, R2 and R of Figure 17, are then adjusted until the pattern just covers the screen. Due to the fact that the sweep frequency is not the same as that of the applied voltage the pattern may be complex and to remedy this, the sweep frequency venier, R3, should be adjusted until a single trace pattern is obtained.

If the amplifier has perfect fidelity, the pattern on the screen will be an undistorted sine wave, the same as the output of the generator. However, if the amplifier is not perfect at this frequency, the pattern will be a distroted sine wave.

When making tests of this kind, the gain control of the audio amplifier should be rotated from minimum to maximum so that any distortion, at the various volume levels, will be shown on the oscilloscope

After the tests have been made at 50 cycles, both the signal generator and sweep oscillator should be set to 100 cycles and the above procedure followed. Like tests should be made at frequencies of 200, 300, 400, 500, 1000, 2000, 3000, 4000, 5000, 6000, 7000, 8000, 9000 and 10,000 cycles so that the entire audio spectrum may be covered.

The reason for repeating the tests is that the amplifier may distort at some frequencies and not others. For our explanation, however, we will assume that with the gain control at the half way position, there was no distortion at any frequency but, with maximum gain, distortion occurred at all frequencies.

In order to determine in which amplifier stage or circuit, this distortion is originating, the signal generator and sweep oscillator should be set at some audio frequency, the exact value of which is not important and with the amplifier gain control at maximum, the distorted wave will appear on the screen of the oscilloscope. The vertical plates of the oscillograph should then be disconnected from the secondary of the output transformer and placed across the primary. Should this change of connection cause an undistorted pattern to appear, the output tr nsformer is at fault.

If the pattern remains distorted, the vertical plates of the oscilloscope should ge connected across the grid, or grids, of the output stage and the pattern checked again to see if the distortion is eliminated. By following the same plan, each stage of the amplifier can be checked and the source of

the distortion determined. When the stage, in which this distortion occurs, has been located, it is necessary to check the design and component parts of its circuits in order to determine what changes must be made to improve the fidelity and reduce or eliminate the distortion

When making tests of this kind, the input signal voltage from the test oscillator should not be greater than that normally applied to the amplifier in actual operation, With a strong input signal, a distorted wave may result, because of overloading, and not be due to defective parts or poor design in the amplfiier.

The above tests are only a few of the applications of the cathode ray oscilloscope and, in the later Lessons, we are going to take up many more. However, before going ahead, we want you to make a very careful study of this Lesson in order that you may completely understand the fundamental actions.

Without this knowledge, you will be unable to obtain full benefit from the more complicated applications of the cathode ray tube, as used in the Television, Sound, Radio and other Electronic fields.

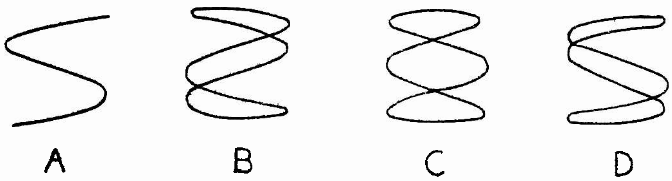


FIGURE 10

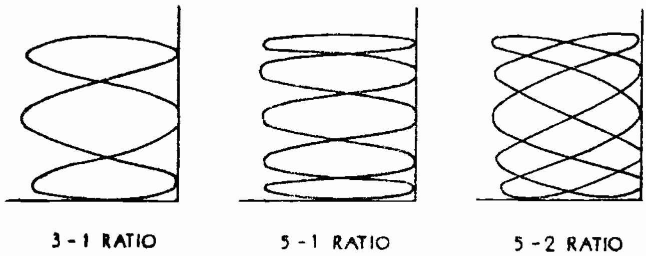


FIGURE 11

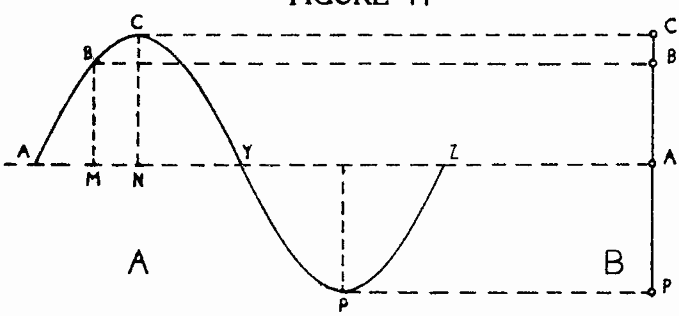


FIGURE 12

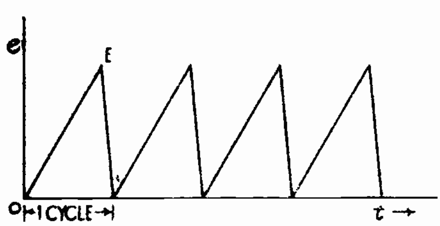


FIGURE 13

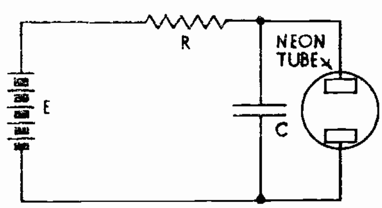


FIGURE 14

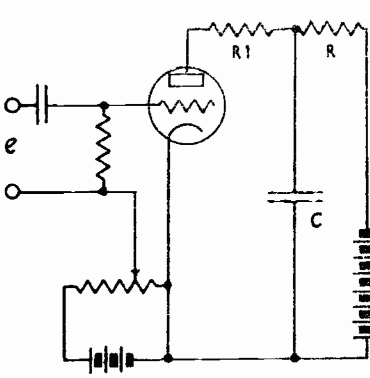


FIGURE 15

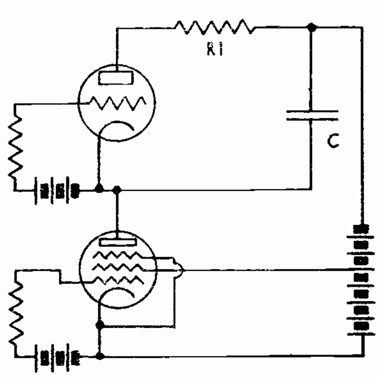


FIGURE 16

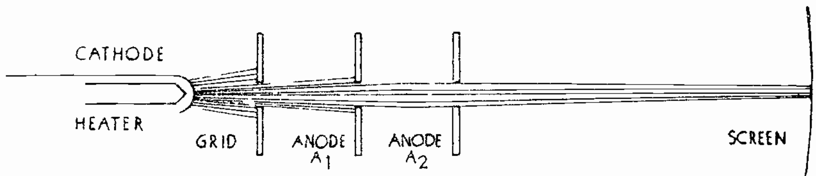


FIGURE 1

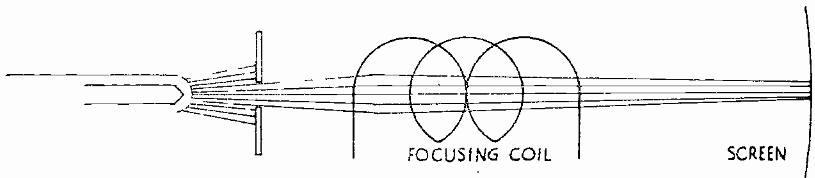


FIGURE 2

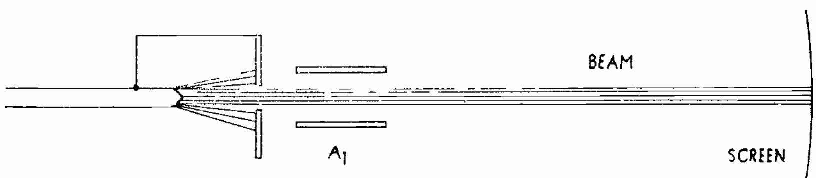


FIGURE 3

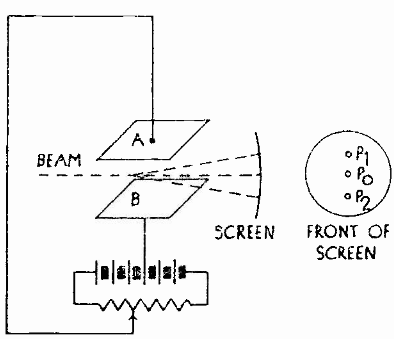


FIGURE 4

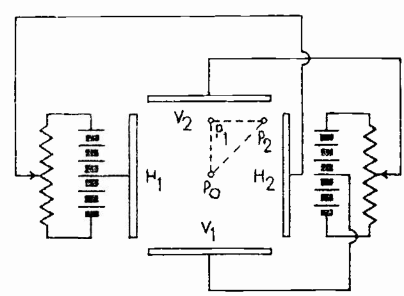


FIGURE 5

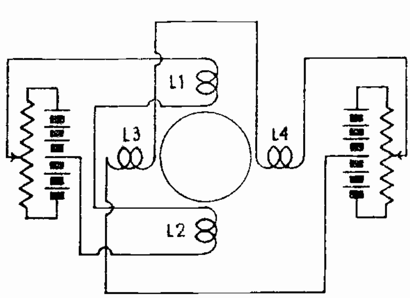


FIGURE 6

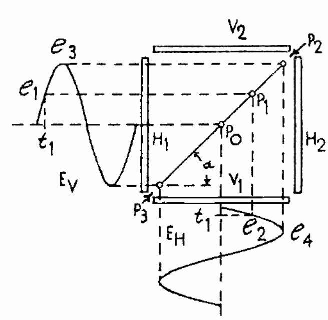


FIGURE 7

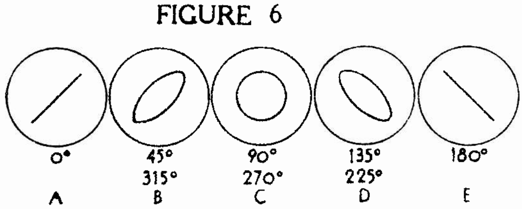


FIGURE 8

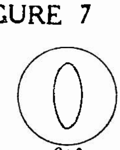
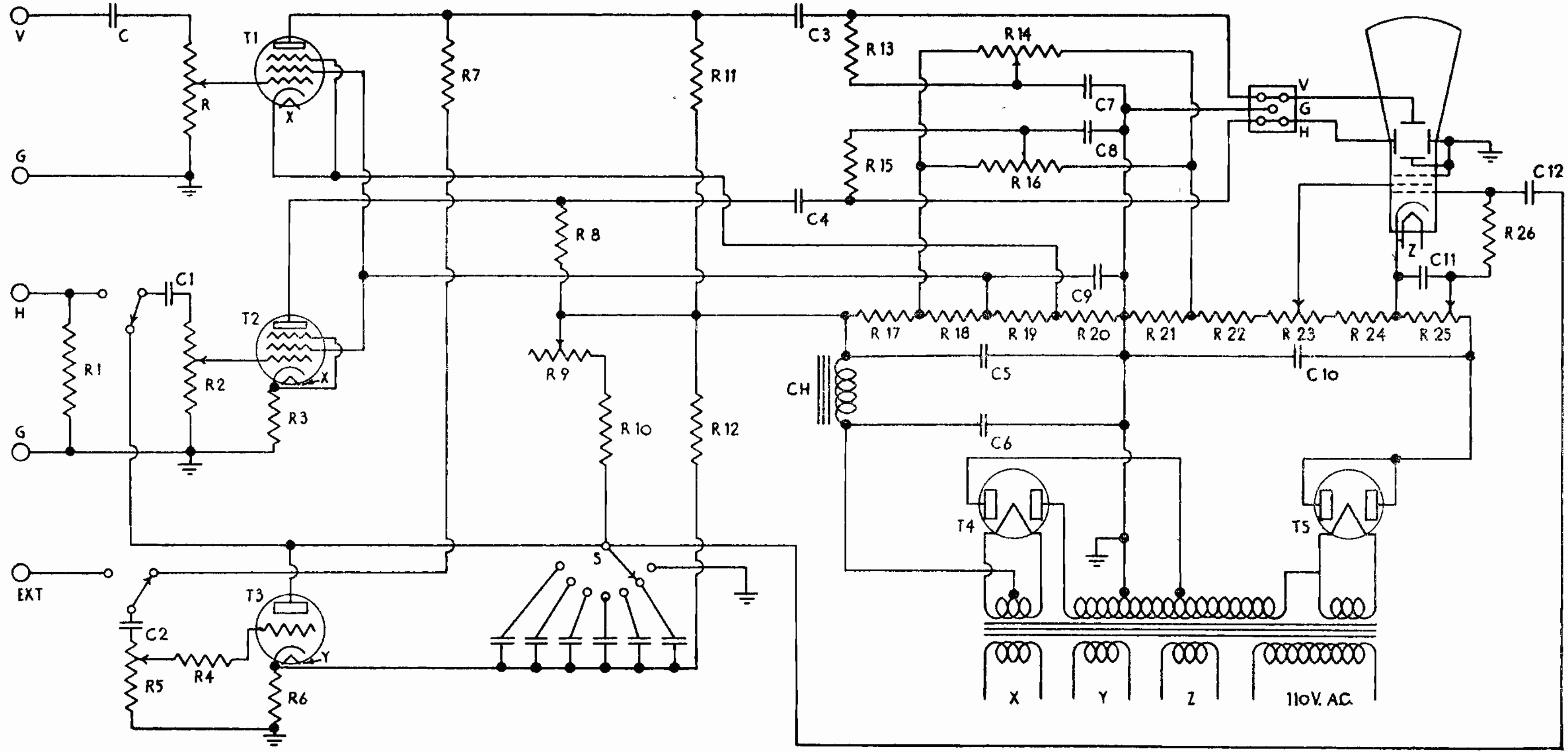


FIGURE 9



V
C
T1
R
X
R7
R11
C3
R13
R14
C7
C8
R15
R16
C4
V
G
H
G
R8
C12
R26
C11
Z
C9
H
C1
T2
R2
X
R3
R1
G
R9
R10
R12
R 17
R 18
R 19
R 20
R 21
R 22
R 23
R 24
R 25
C5
C10
CH
C6
T4
T5
EXT
S
T3
C2
R4
R5
Y
R6
X
Y
Z
110V. AC.

FIGURE 17

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LESSON RRT-13

FREQUENCY MODULATION TRANSMITTERS

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DE FOREST'S

TRAINING, Inc.

LESSON RRT-13

FREQUENCY MODULATION TRANSMITTERS

Founded 1931 by

RADIO RECEPTION AND TRANSMISSION

LESSON RRT-13

FREQUENCY MODULATION TRANSMITTERS

# # # #

The secret of happiness is not in doing what one likes, but in liking what one has to do.

James M. Barrie

MODULATION

In our early explanations of Radio we told you that a frequency of 10,000 cycles per second was often considered as the dividing line between the Audio and Radio regions of energy. Thus, in general, the frequencies which we can hear, can not be transmitted directly through space, while those which can be transmitted will not affect our ears.

To be of practical benefit, the radiated or transmitted frequencies must be made to carry intelligence so that, at the receiver, they will produce an action which affects at least one of our senses. Due perhaps to its comparative simplicity, or similarity to the Telegraph, the early Radio systems were arranged to produce audible code signals and were known as a Wireless Telegraph.

In these early systems, the higher transmitted Radio frequencies had to carry lower or audio frequencies, and this was accomplished by starting and stopping the high frequencies according to a pre-arranged code. At the receiver, the reception of the high frequencies would cause a local circuit to be energized and thus a telegraph sounder could be operated.

Later, after vacuum tubes came into use, the heterodyne principle became popular and the generated frequency of an oscillator in the receiver, mixed with the incoming signal frequency, produced a beat note at an audible frequency. This principle is still used for code reception and the audible beat frequency operates head phones or loud speakers. However, the code is transmitted by starting and stopping the radiated high frequency at the desired intervals.

In general, the control of the radiated energy, enabling it to carry signals, is known as "modulation". Thus we have the control or "modulation" frequency and the radiated or "Carrier" frequency.

By the general methods first mentioned, a "Wireless" system can transmit messages similar to those of the wired Telegraph systems but Radio enjoys its present popularity because it can transmit messages of the same type as the Telephone.

For this type of signal, the high frequency carrier must be modulated by the audio frequency of the signal and thus, the original method of stopping and starting the carrier is not practical. Instead, the carrier is made to vary at the rate of the modulating frequency and present day systems can be classed according to the type of variation.

To explain the modulation methods of the older and more common systems, for Figure 1 we have drawn a simplified circuit of a Radio Frequency oscillator of the Electron Coupled Type.

As explained in the lesson on Oscillators, the values of condenser C and Inductance L control the frequency at which the oscillator operates. The tuned circuit, commonly known as a "tank" circuit made up of C_1 and L_1 in the plate circuit of the screen grid tube, may be adjusted to the same frequency as C-L or one of its harmonics. Coil L_2, inductively coupled to coil L_1, will contain a constant frequency which may be radiated or braodcast when properly connected to an antenna.

The basic principle of operation of Figure 1 is very similar to circuits previously explained. However, we want to offer greater detail with regard to the variations in order that you clearly understand the action of a simple transmitter.

Considering only the cathode, control grid and screen grid circuits of the tube, we have the basic arrangement of a triode Hartley Oscillator. In this instance, the screen grid serves as the plate.

As the instant power is supplied there will be a surge of screen grid (plate) current to the cathode, through the lower portion of L and back to B-. Acting as an auto-transformer, this change of current through a part of L induces an emf in the entire winding.

The polarity of this emf is such that the grid, coupled to the upper end of the coil through condenser C_g, becomes more positive in respect to the cathode and causes a further increase of screen grid current. However, as soon as the grid becomes positive, there will be grid current which carried by resistor R_g produces a voltage drop that tends to make the grid negative in respect to the cathode.

This action continues until the opposing voltages become balanced at which point there is no further change of grid potential, the screen grid current does not vary and the induction in coil L dies out. With no induced emf to maintain the positive grid potential it diminishes in value, the grid becomes less positive or more negative, and causes a reduction of screen grid current.

During the period of increasing screen grid current, condenser C is charged to the voltage across the entire coil L and, as the emf dies out, the condenser discharges through the coil causing a reduction of tank circuit voltage. As mentioned above, this reducing voltage lowers the positive grid potential to cause a reduction of screen grid current.

With reducing screen grid current, the magnetic flux around coil L becomes weaker or collapses and reverses the direction of induction, thereby aiding the discharge of the condenser. Thus, the grid becomes more negative, the reduction of screen grid current continues and the resulting induction not only discharges the condenser completely but charges it with a voltage of opposite polarity.

This action continues until the grid potential is sufficiently negative to cut off the screen grid current and the magentic flux, set up by coil L, is reduced to zero. With zero flux, the induction dies out, the condenser starts to discharge and the grid potential becomes less negative, thereby, allowing the re-establishment and increase of screen grid current. With increasing screen grid current, the action is as previously explained and the complete cycle is repeated.

The speed at which the changes occur depends upon the values of coil inductance and the condenser capacity which thereby regulates the rate at which the complete changes take place and control the frequency of the oscillator.

As shown in Figure 1, the plate of the tube connects to a separate supply terminal usually of higher voltage than that of the screen grid. Therefore, many of the emitted electrons will pass through the screen grid mesh and reach the plate, but the previously explained action of the control grid voltage will vary the stream of electrons at the frequency of the oscillator.

Because of this action, the plate current will vary or pulsate at the oscillator frequency and develop a-c power in the plate tank circuit which, in Figure 1, consists of coil L1 and condenser C1. This circuit may be tuned to the fundamental or some harmonic of the frequency to which the grid tank circuit L-C is tuned.

Through the inductive coupling between the coils, power in the plate tank circuit L1-C1 is carried over to coil L2 and radiated into space when the coil is connected in a suitable antenna system.

Notice in our explanation so far, there is nothing to cause a change in either the frequency or amplitude of the output. However, should we connect a telegraph key in the cathode circuit of the tube, the oscillator could be stopped and started at will to provide code transmission. We mention that action mainly to show that the high frequency output must be modulated in order to carry intelligible signals.

Going back of Figure 1, the greater the magnitude of the current changes in the load circuit, the greater the a-c power available for radiation of intelligence. In order to obtain greater power output, greater plate voltage changes are required. Consequently, the power output of this transmitter is controlled fundamentally by the magnitude of plate voltage changes.

Between the "B+" supply and the tuned plate circuit, "C1-L1" you will find the coil TS which is the secondary of an audio frequency transformer. Because of its series connection, any voltage developed in this winding will be impressed on the plate circuit of the oscillator tube.

For simplicity, we have shown the transformer primary winding, "TP" connected in series with a carbon microphone and a battery. When sound waves strike the microphone diaphragm, they cause it to vibrate and this movement produces a corresponding change in the resistance of the carbon button. As a result, the current in the circuit will vary at the frequency of the sound waves which strike the microphone diaphragm and the amount of this variation will be proportional to the strength of the sound.

The current changes in the primary of "TP" will cause corresponding charges of voltage across the secondary TS. Considerint this voltage as a-c, during one alternation it will aid the d-c supply, causing the total plate voltage to increase and during the following alternation, it will oppose the d-c supply, causing the total plate voltage to decrease.

Because of this action, the strength, or amplitude of the oscillator output will vary with the sound waves which strike the microphone diaphragm, to produce what is known as amplitude modulation.

As explained in the lesson on resonant frequency circuits, the basic expression for resonance is $f = \frac{1}{2\pi\sqrt{LC}}$. Since there is no indication of "R" in the formula, changing the resistance of the circuit, containing an L-C tank, does not change the value of the resonant frequency, but rather changes the magnitude of the current in the circuit.

It is customary to represent the output of an amplitude modulated wave by the plan of Figure 2-B, and we want you to study it carefully in order to be familiar with two important characteristics.

First, as indicated by the light, broken vertical lines, the frequency of the oscillator remains constant as each cycle occupies the same horizontal distance on the curve.

Second, the height or amplitude of the cycles vary and, by drawing a light line across the tops or bottoms of each of the peaks of the cycles of Figure 2-B, the resulting curve would represent the modulation frequency or signal.

Thus, for amplitude modulation, the carrier has a constant frequency the amplitude of which varies as the signal or modulation frequency. Looking at Figure 1 again, you can see that the stronger the audio signal at the microphone, the greater the voltage across "TS". This, in turn, means a greater variation in the amplitude of the cycles of Figure 2-B.

At the left of Figure 2-B we show a few cycles of unmodulated output and you will notice both the frequency and output are constant. The heavy line directly above the left part of Figure 2-B labeled "no sound" (Figure 2-A) indicates further that no intelligence is carried by the wave. The curve at the right of Figure 2-A is the wave form of the modulating signal, and is a loud note of rather low frequency. The wave is really a projection of the variation in amplitude of Figure 2-B. Horizontal line "A" of Figure 2-B represents the axis or line of zero output and thus, the distance between lines A and B represents the value of the unmodulated output.

Following the peaks of the modulated cycles, you will find they drop from line B to line C and then rise from C to B to D. Thus, line B becomes the axis of the modulation frequency and the distance between lines C and B or D and B represents the amplitude of the signal frequency.

When the value of BD is equal to that of AB, the amplitude of the carrier will vary from zero to twice its unmodulated value and we say there is 100% modulation. For other values, the percentage of modulation is the ratio between the peak of the modulating frequency and the peak of the unmodulated carrier. Using the letters of Figure 2-B as an equation

$$\% \text{ modulation} = \frac{BD}{AB} \times 100$$

Figures 1 and 2 represent the common system of amplitude modulation and, as the action of receivers designed for this type of signal has already been explained in detail, we will not repeat.

FREQUENCY MODULATION

Earlier in this lesson we said that, "In general, the control of the radiated energy, enabling it to carry signals, is known as Modulation", but nothing was said in respect to the type of control. For code transmission, the carrier frequency is simply stopped and started at the desired instants, while for amplitude modulation, the strength of the carrier frequency is varied at the rate of the signal frequency.

To illustrate another method of modulation, for the circuit of Figure 3 we have the oscillator of Figure 1, but, instead of the carbon microphone and transformer in the plate circuit, have connected a condenser type microphone across the tuning condenser of the oscillator tank circuit.

However, as we mentioned for the circuit of Figure 1, the oscillator frequency is controlled by the values of C and L in the tank circuit. As L represents a coil of fixed inductance, the frequency can be adjusted by changing the capacity of the variable condenser "C".

Referring again to the familar resonant frequency formula,

$$f = \frac{1}{2\pi\sqrt{LC}}$$

a change of the capacity "C" will change the value of the resonant frequency. As a matter of fact, increasing the value of C decreases the value of the resonant frequency, whereas decreasing "C" increases the frequency.

From the explanations of the earlier Lessons, you will remember that the diaphragm of a condenser type microphone is in effect, the movable plate of a two plate variable condenser. The sound waves, which strike the diaphragm, cause it to deflect and this movement produces a corresponding change of capacity.

In the simplified arrangement of Figure 3, these variations of capacity in the microphone will cause a change in the total capacity across the tank coil L and thus produce corresponding change of oscillator frequency. With this arrangement, the audio or signal frequencies will control the oscillator or carrier frequency and thus we have Frequency Modulation.

The curve of Figure 4-B represents the modulated output of the oscillator of Figure 3, the same as the curve of Figure 2-B conforms to Figure 1. By comparing these two curves carefully, you will notice, in Figure 4-B the amplitude remains constant but the frequency, shown by the horizontal distance between adjacent peaks, has quite a wide variation.

In Figure 4-A the curve again shows the wave form of the audio modulating signal, and we will assume that it represents a note of low audio frequency of medium loudness.

As already explained, when no modulation exists a definite frequency will be generated as determined by the values of L-C in Figure 3. Under this condition the condenser microphone, will have a fixed value and added to C, will cause the oscillator will, have a fixed value and added to C, will cause the oscillator to generate a "mean" frequency, sometimes called

the "center" frequency. Checking Figures 4-A and B, the mean frequency occurs when the a-c audio wave corsses its reference axis.

The curve of Figure 2-B represents a carrier of constant frequency with varying amplitude while the curve of Figure 4-B represents a carrier of constant amplitude with varying frequency. Keep this fundamental difference in mind because it is important.

Going back to the microphone of Figure 3, the diaphragm will vibrate at the frequency of the sound waves which strike it and its movement varies the oscillator frequency. Therefore, the oscillator frequency will vary at the rate of the signal frequency.

To keep the illustration simple we will assume that with no action of the microphone, the oscillator opperates at a frequency of 1000 kc. Then, as sound waves of some fixed amplitude strike the microphone diaphragm, its movement one way increases the total capacity of the circuit just enough to reduce the oscillator frequency to 995 kc. At the other end of its travel, the diaphragm reduces the total capacity of the circuit by a similar amount and increases the oscillator frequency to 1005 kc.

Thus, each complete vibration of the diaphragm will cause the oscillator frequency to shift from 1000 kc to 995 kc, back through 1000 kc, up to 1005 kc and back to 1000 kc. From these values, you can see that each cycle of diaphragm movement causes one cycle of frequency changes in the oscillator, and the band width required for transmission is 1005-995 or 10 kc

For example, a 400 cycle sound wave will vibrate the diaphragm 400 times a second, therefore, the above frequency changes occur 400 times per second. A 1000 cycle sound wave will vibrate the diaphragm 1000 times a second, therefore, the frequency changes given above will occur again but, at the rate of 1000 times per second.

The important point to remember here is that each vibration of the diaphragm causes the same changes of oscillator frequency. Different signal frequencies produce different rates of diaphragm vibration and therefore, cause different rates at which the changes of oscillator frequency take place.

As we will explain later, the amount of frequency change, or deviation swing, is important but, at this time we want to emphasize only that the signal frequencies are transmitted by changing the rate at which the oscillator or carrier frequency is varied.

Going back to Figure 3, we will assume that a high amplitude sound wave strikes the microphone diaphragm, forcing it to move a greater distance. This will produce a greater change of microphone capacity which, in turn, will cause a greater change of oscillator frequency.

Continuing our former illustration, we will assume now that each complete vibration of the diaphragm will cause the oscillator frequency to shift from 1000 kc to 990 kc, back to 1000 kc, up to 1010 kc and back to 1000 kc. This is the same as the former cycle of frequency changes but, the greater movement of the diaphragm has caused a frequency shift of 1010-990 kc. Thus the carrier occupies a 20 kc band instead of the 10 kc band of our former explanation.

To illustrate this difference you can imagine that the curve of Figure 4-B represents the 10 kc band width transmission while that of Figure 5-B represents the 20 kc band. The curve Figure 5-A represents twice the amplitude of the curve of Figure 4-A yet the audio signal has the same frequency because the audio variations provide the same variations of carrier frequency in the same length of elapsed time. Therefore, the only difference between Figures 4B and 5B is the deviation from the mean carrier, and 5B has twice the deviation of 4B. Remember for both of these curves, the frequency of the signal determines the rate at which the oscillator, or carrier frequency, swings through the band. In both cases, the oscillator putput has constant amplitude.

For the curve of Figure 2-B the strength of the signal determines the percentage of modulation which is a ratio between the peak value of the modulating frequency and the peak value of the non-modulated carrier.

For the curves of Figures 4B and 5B, the strength of the audio signal controls the amount of frequency variation and the extent of modulation must be described in terms other than those of the amplitude modulated wave.

In general, when referring to a class of stations operating in the same service, a certain maximum frequency swing may be agreed upon as representing 100% modulation. In the case of f-m Boradcast stations, a frequency swing of plus or minus 75 kc from the unmodulated center frequency is commonly considered as being 100% modulation.

MODULATION INDEX

However, a recent adoption of describing the extent of modulation lies in stating the value of the "modulation index" (M). This index is simply the ratio of the amount by which the transmitted frequency swings from its average frequency to the value of the modulating frequency.

For example, if the modulating frequency swings the transmitted frequency over the range of ∓ 5 kc, and the audio modulating frequency is 5000 cycles, the modulation index M_f is 5000/5000 or 1. Similarly, should the modulating frequency be 10,000 cycles, the index M is 5,000/10,000 or .5.

Note carefully that in describing the extent of frequency modulation, the modulation percentage and modulation index are defined in a different manner. Summarizing these points, the greater the magnitude of the modulating signal the greater the frequency swing, which means that the modulation percentage is directly proportional to the frequency swing.

If a frequency swing of ∓ 75 kc is considered 100% modulation, then a modulated carrier having a frequency swing of ∓ 37.5 kc would be modulated 50%.

The modulation index M is inversely proportional to the highest modulating frequency because, using the example cited above, the increase from 5000 to 10,000 cycles as the modulating frequency caused a reduction of the index M from 1. to .5.

As was explained in the lesson on Superheterodyne Receivers, it is possible to generate an output voltage which contains the sum and difference frequencies, as well as the original frequencies, when two different frequencies are combined. By higher mathematics it can be shown that the frequency modulated output is the sum of a center frequency and numerous pairs of sideband frequency components. The center frequency then is, really the unmodulated carrier, and the two components of the first sideband pair have frequencies respectively higher and lower than the center frequency by the value of the modulating frequency, just as in amplitude modulation.

In frequency modulation, however, there are additional pairs of sideband components which have amplitudes great enough to be important

For example, there may be a second pair of sideband frequencies which have values higher and lower than the center frequency by twice the value of the modulating frequency. Likewise, a third pair of sideband frequencies may exist which are removed from the center frequency by three times the modulating frequency. Sideband frequencies of higher orders may be important too, but under certain conditions which will be explained, these frequencies may be neglected.

BESSEL FACTORS

Convenient tables have been compiled for determining the important sideband frequencies, and in table 1, at the end of the lesson, we show Bessel Factors for finding the amplitudes of center and sideband frequency components.

Column one represents the modulation Index (M) from 0 to 6, the second column, J_0 (M) with F just below, shows the relative value of the amplitude of the components of the f-m wave compared to an unmodulated carrier of 1, where F, the carrier frequency is designated. The columns J_1 (M) to J_9 (M) can best be explained by referring to an example.

Considering the case of modulating frequency of 10,000 cycles with a frequency swing of ∓ 5000 cycles, the modulating index (M) is 5,000/10,000 or .5. For an M of .5, J_0 (M) is .9385, indicating the amplitude of the center frequency component is roughly 94% of the amplitude of the unmodulated carrier. The first pair of sidebands represented by column J_1 (M), with the frequencies being F + 10,000 cycles and F-10,000 cycles, have an amplitude of .2423 or 24% of the carrier wave. The second pair of sidebands (J_2 (M) /F ∓ 2 F_M) as read opposite .5 in the M column is .0306 or approximately 3% of the amplitude of the f-m carrier. Notice here, F ∓ $2F_M$ is the frequency of the carrier ∓ 2 (10,000) or F ∓ 20,000 cycles.

The values for the third pair of sedbbands (J_3 (M)) are not shown and the actual value is less than .005 or .5% of the amplitude of the carrier, and thus the sideband pair is not important.

F-M BAND WIDTH

The band width of an f-m wave depends upon the number of important sidebands as well as the modulating frequency. In the example just cited, two pairs of sidebands were important. The frequencies of the second pair differ from the center frequency by the greatest amount and hence determine what the band width will be. One of the sideband frequencies is higher than the center frequency by two times the modulating frequency of 10,000 cycles, and the other sideband frequency is lower by the same amount. 20,000 cycles above and 20,000 cycles below the center frequency gives an over-all frequency change of 20,000+20,000 or 40,000 cycles. Thus, 40 kc is the required band width.

To determine the band width required for an f-m transmission under other conditions, let's assume we desire to learn the band width of an f-m wave when the audio modulating frequency is 2000 cycles and the strength of modulation provides a frequency swing of ∓ 8 kc.

The modulation index (M) is 8000/2000 or 4. From table 1, under M = 4, read to the right and find .0152 under column J7(M). This data tells that seven sidebands are important, the seventh sideband having 1.5% of the amplitude of the center frequency. The band width, however, is determined from

$F \pm 7F_M$, and as $F_M = 2000$ cycles, $7 F_M = 7 \times 2000 = 14{,}000$ cycles. Therefore, the upper sideband limit is 14 kc and the lower sideband limit is also 14 kc. The over-all deviation or band width is 2 x 14 kc or 28,000 cycles.

From the explanations given, and the examples shown, you can see that the band width of a f-m wave varies, and the accepted maximum limit of the sideband deviation is +75 kc, or a band width of 150 kc, as stated in a previous section of this lesson.

The reason for the limit is not because of the nature of the radiated wave, but rather to characteristics of the transmitter.

F-M vs A-M RADIATED POWER

You have already learned that the amplitude of an f-m wave is constant, and only the frequency varies with elapsed time. However, the average power during any r-f cycle is the same as for any other cycle in the transmission. Therefore, in order to maintain a constant power output when sideband currents appear, the amplitude of the center frequency must decrease sufficiently to keep the total "I^2R" product of all the components equal to the power of the unmodulated carrier.

The above action is in direct contrast with the condition in a-m waves. As you will learn in later lessons, the radiated power from a carrier having amplitude modulation varies with the magnitude of the modulation. In other words, the power output of the circuit of Figure 1 varies with the audio modulating signal, whereas the power output of the circuit of Figure 3 remains constant and under conditions of f-m the amplitude of the center or carrier frequency varies with modulation.

Generally speaking, the power required for radiating an f-m wave is less than the power for the radiation of the same intelligence in an a-m wave. Such a feature is important from the standpoint of transmitter operation costs and efficiencies.

FREQUENCY MODULATION METHODS

The circuits of Figures 1 and 3 have been simplified, for sake of illustration and cannot be considered suitable for practical operation. In the circuit of Figure 1 for example, audio modulation of the oscillator is not satisfactory as the changes of plate voltage causes undesired changes of carrier frequency.

For the circuit of Figure 3, as frequency changes are desired, it is necessary to modulate the oscillator, but the frequency variation of the oscillator output would not be sufficient for satisfactory reception.

There are numerous methods of obtaining the amplitude modulated carrier of Figure 2-B, and in the same way, there are various methods of obtaining the frequency modulated carrier of Figures 4-B and 5-B. The simplified arrangement of Figure 3 illustrates what is known as "pure" frequency modulation and it is only the strength or amplitude of the signal which controls the swing or deviation of the oscillator frequency.

Another system makes use of the elements found in the Automatic Frequency control circuits used in some superheterodyne Radio receivers. For frequency modulation, however, the control tube is made to work in reverse and vary the oscillator frequency according to the signal.

The method invented by Major Edwin Armstrong operates on a somewhat different principle, known as "Phase Modulation" to produce the variations of carrier frequency, and for the following explanation, we will assume that "Phase Modulation" is a form or method of Frequency Modulation. The over-all principle of operation is the generation of a fixed frequency carrier which provides frequency modulation when combined with an "out of phase" modulating signal.

PHASE MODULATION

Before trying to follow the action and purpose of the various units of a system of this kind, it will be well to review a few a-c principles and the methods of illustrating them.

Starting at the left of Figure 6, we have drawn the line "O-A" of a length to represent the maximum value of the a-c voltage of some circuit. This line is called a vector and may represent either current or voltage values.

However, a-c values are continually changing and therefore, we rotate the vector O-A, around the center O and consider each complete revolution as one cycle. It is customary to consider the rotation in an anti-clockwise direction and thus, the horizontal, right hand position of the vector is considered as 0° or the beginning of the cycle.

Following around the circle from this point, we show 12 successive positions of the vector and have marked them in degrees as measured from the starting point. Adding 30° to the 330° position, you will see that the 360° and 0° positions are the same and, if the rotation is continued, the same variations will be repeated.

Also, you will remember that at 0° of a cycle, the a-c values are usually taken as zero, therefore, we extend the position of the 0° vector over to the right and consider it as a zero axis. If the vector rotates at a uniform speed it will move each 30° in equal time and, therefore, we divide the zero axis into twelve equal parts to represent this time.

Knowing that a-c values are zero at 0° or 180° and maximum at 90° or 270°, we let the vertical distance, between the outer end of the vector and the 0° or base line, represent the a-c value for that particular point or phase of the cycle.

FREQUENCY MODULATION TRANSMITTERS

To plot a curve of these changing a-c values, we first extend horizontal lines, from the outer end of the vector, in the various positions. Lines are then drawn vertically, from the divisions of the axis, and the points at which corresponding lines intersect, are points on the curve.

For example, from the end of the 30° position, a horizontal line is drawn to the right while a vertical line is drawn up from the 30° division of the axis. The point at which these lines cross, or intersect, is a point on the curve. Following this plan for all twelve divisions, we have 12 points and, joining them with a line, have a curve for one cycle. This, by the way, is what we call a sine curve or sine wave.

The point we want to bring out at this time is the relationship between the vector and the curve. If we are concerned only with conditions at some particular instant or phase of a cycle, a vector, drawn of proper length and at the correct angle, will provide as much information as the curve. This is important because, when more than one a-c value is under consideration, complete curves become rather complicated while vectors, drawn properly as to length and position, can be made to serve the same purpose.

In Figure 7-A, for example, we show an oscillator and modulator voltage, both of the same frequency, but 90° out of phase. A modulator is essentially an a-f amplifier, but the name given it is more descriptive of its service. The oscillator vector is drawn vertically and the modulator vector drawn horizontally to provide the 90° angle between them. As both have the same strength or amplitude, both vectors are of equal length.

In order to add vectors, we simply complete a parallelogram, of which the vectors form two sides, and then draw in a diagonal. In Figure 7-A, the vectors are at an angle of 90° and

of equal amplitude, therefore, the parallelogram is a square and the diagonal, marked "Carrier", is a vector which represents the strength and phase angle of the combination of the original two. The original voltages were 90° out of phase but, being of equal amplitude, the resultant voltage is 45° out of phase with both.

For Figure 7-B, we again have the arrangement of Figure 7-A, except that the amplitude of the modulator has been reduced to 1/2 of its former value. Following the former plan, the resultant "Carrier" vector has been drawn in but it does not lie midway between the original vectors. Instead, it has shifted in phase by the angle "b".

For Figure 7-C, the modulator vector has been drawn to represent a value 1 1/2 times that of the oscillator. Following the former plan, we find the resultant vector has shifted in phase by the angle "C", compared to that of Figure 7-A.

Checking the three conditions of Figure 7, you can see that when two like frequencies are combined at a constant phase difference, a change of amplitude in one will cause a phase shift of the resulting voltage.

As shown in Figure 8, a similar phase shift is obtained when two like frequencies, of equal amplitude, are combined at different phase angles and Figure 8-A duplicates the conditions of Figure 7-A.

For Figure 8-B, the amplitude of the "Mod". vector remains equal to that of the oscillator but the angle between them is less than 90°. As a result, the carrier is shifted by angle "b" as compared to that of Figure 8-A.

By increasing the angle, between the "Osc" and "Mod" of Figure 8-C, to more than 90°, the phase shift through angle "C" is produced.

In general, therefore, we can state that two like frequencies of equal amplitude, when combined at a varying phase angle, cause a phase shift of the resulting voltage.

To show the action in a different way, for Figure 9 we have followed the plan of Figure 6 and rotated the "Carrier" vector of Figure 7-A through several cycles. The resulting curve is shown by the broken line which is marked "Unmodulated Carrier".

To reproduce the conditions of "B" and "C", Figure 7, we have drawn the "Modulated Carrier" curve of Figure 9 but, for simplicity have assumed both curves to have equal amplitude.

Starting over on the left, at point "A" we have the conditions of Figure 7-A and then, moving to the right, the modulated carrier curve falls behind until at point "B", we have the conditions of Figure 7-B.

Continuing to the right of Figure 9, we pass through another point A and then to point "C" where the conditions are those of Figure 7-C. In effect, therefore, the phase shift causes the modulated carrier to lag or lead the unmodulated carrier.

Starting at the left again, between points A and B, Figure 9, you will notice that a cycle of the modulated carrier occurs in a shorter horizontal distance than a cycle of the unmodulated carrier. As explained for Figure 6, the horizontal distance represents elapsed time and thus the modulated carrier cycle occurs in a shorter time than the unmodulated carrier cycle.

In electronics, frequency means the number of cycles per second or, as an equation

$$f = \frac{1}{t}$$

when

f = frequency in cycles per second
t = time of one cycle, in seconds

Going back to Figure 9, and keeping this equation in mind, if one cycle of the modulated carrier occurs in a shorter time, its frequency must be higher than that of the unmodulated carrier.

Between points B and C of Figure 9, the modulated carrier cycles require a greater time and thus the frequency is lower than that of the unmodulated carrier. Notice also, at points "A" which can be thought of as zero modulation, there is zero phase shift and the frequency of both curves is the same.

Thus, a change of amplitude or phase, of the modulation, as shown in Figures 7 and 8, causes a phase shift in the resultant carrier and in Figure 9, you can see that this phase shift corresponds to a change of frequency. The final result therefore is similar to that explained for the simplified circuit of Figure 3.

GENERAL REQUIREMENTS

Major Armstrong lists two basic requirements of a Frequency Modulated Transmitter as,

1. "The frequency transmitted by an f-m system should vary alternately above and below a fixed frequency which is the assigned carrier. These variations should be symmetrical with respect to the said frequency, pass through it and return exactly to this carrier when modulation stops."

2. "In the transmitter, the frequency deviation of the f-m wave at any instant must be directly proportional to the intensity of the modulating current resulting from the program. This deviation in frequency, however, must be independent of the frequency of this modulating current."

MAJOR ARMSTRONG'S SYSTEM

To meet the requirement of a fixed carrier frequency, Major Armstrong employs a crystal controlled oscillator of the type commonly used by amplitude modulation systems. However, this frequency must be varied according to the signal and, for Figure 10, we have a simplified sketch of Major Armstrong's system.

Starting at the left, the crystal controlled oscillator output is divided into two parts, one of which passes into the upper amplifier and the other into the balanced modulator.

The audio signal is picked up in the usual way, by means of a microphone, the output of which passes through a correction network so that the signal voltage is inversely proportional to its frequency. In any system of Radio Transmission, the high frequencies are attenuated most and by making the proper correction at this point, it is possible for the receiver to reproduce all signal frequencies with more uniform amplitude.

The corrected signal frequencies, marked "Audio Input" on Figure 10, are also fed into the balanced modulator and mixed with the oscillator frequency. Because of its balanced circuit, the modulator output does not contain the oscillator frequency but only the combinations of oscillator and signal frequencies which are considered as the "sidebands" of the carrier. In the hetrodyne principle, combining two waves produces sum and difference frequencies. The removal of the carrier of a modulated wave leaves the sum of the sideband components which are sometimes called the double sidebands. These sideband frequencies are then shifted in phase by 90° and mixed with the output of the oscillator amplifier, to provide frequency modulation.

Thinking of the oscillator and phase shifter outputs as being of equal amplitude, the conditions of Figure 8 are present in effect because the varying frequencies of the side bands will cause a variation in the 90° angle between them and the oscillator frequency.

The action here, as already explained, will cause a phase shift and frequency change of the resulting voltage. At this point, however, the actual frequency change is quite small and for a 200 kc oscillator, the deviation is about 15 to 20 cycles.

Going back to Figures 3,4 and 5, the deviation in frequency is proportional to the amplitude of the signal while in the f-m receiver the deviation in frequency is converted into corresponding changes of amplitude. To provide proper receiver operation and satisfactory signal to noise ratio , the deviation of Figure 10 must be greatly increased.

Yet it is not practical to provide an initial frequency deviation such that the sideband amplitude is made greater than about 1/5 the amplitude of the carrier. To exceed this value introduces amplitude variations which are undesirable, and the phase deviation will no longer be proportional as determined by the amplitude of the modulating voltage. Thus only a slight frequency shift should be produced in the phase shift modulator.

FREQUENCY DEVIATION MULTIPLICATION

To overcome these limitations and gain the desired frequency deviation, it is common practice to employ a low frequency, crystal controlled oscillator and, by means of doubler, increase the frequency to the desired value.

Most oscillators produce harmonic frequencies, in addition to the one to which they are tuned. The tuned frequency is the "Fundamental" and two times the Fundamental is the "Second Harmonic", three times the fundamental, the "Third Harmonic" and so on.

A simple Frequency Doubler is usually a stage or arrangement in which the input circuit of a tube is tuned to the fundamental frequency while the output circuit is tuned to the second harmonic. For a "Tripler", the output circuit is tuned to the third harmonic.

Compared to the earlier experiments in Frequency Modulation in which an effort was made to reduce the band width, Major Armstrong's system employs a band width of approximately 150 kc. This, you will notice is very wide in respect to the 10 kc band of the amplitude modulated Broadcast signal.

DOUBLER STAGES

To obtain this broad band, from the small frequency deviation explained for Figure 10, the signal is passed through a number of doubler stages. You can think of these as stages which amplify the frequency deviation

For example, if the output of Figure 10, with a 20 cycle deviation, is passed through 13 doubler stages, the final output will have a deviation of over 160 kc. As the operation of a doubler stage is not critical, the f-m transmitter includes a sufficient number to provide the necessary deviation.

In order to obtain distortionless modulation from a phase shift modulator, the maximum phase deviation of the f-m voltage at the output should not exceed .2 radian. The term "radian" is really another method of measuring angles, and turning to Figure 6, the 360° of the circle form 2π radians. Dividing 360° by 2π (6.28) results in a value of about 57° for each radian. Therefore, .2 of a radian is .2 x 57° or about 11.4°.

In Figure 9 we have indicated the radian displacement of the modulated and unmodulated carrier although the drawn displacement of these two waves is greater than allowable in actual circuits.

It may be believed that multiplication of the deviation could go on and on, but there is a practical limit and the accepted ratio of the maximum frequency deviation of the transmitter output wave to the highest modulating frequency is 5 to 1.

For example, in f-m broadcast service, the maximum frequency deviation is 75 kc for the highest a-f modulating frequency or 15,000 cycles, and this is equivalent to a modulation index of 75,000/15,000 or 5. or a maximum phase deviation of 5 radians.

If the lowest modulating frequency is 50, the modulation index is 75,000/50 = 1500, equivalent to a phase deviation of 1500 radians. From this data, it can be shown that the required frequency deviation multiplication, in order to raise the .2 radian phase shift at the phase-shifter to 1500 radians at the output of the transmitter, is 1500/.2 or 7500.

Here again, using doublers, 13 doubler stages would be required because 2^{13} (2 x 2 x 2 -- thirteen times) results in 8,192. Of course, other arrangements or doubler and tripler stages could be employed to achieve the desired multiplication.

F-M PROPAGATION

The present f-m station channel width is 200 kc, while the a-m broadcast station occupies a band width of 10 kc. It is easy to see that but few 200 kc channels could be allocated in the standard Broadcast band, therefore, the f-m station is assigned transmitting frequencies above 40 mc.

As both a-m and f-m propagation require the same medium, it would be well to review the Lesson on Antennas in order to recall the behavior of electromagnetic waves in space. It is known the ionized layer (E, F_1 and F_2) contain comparatively large numbers of free electrons and thus have the property of refracting radio waves. Whether or not the wave will be bent back to the earth depends on the frequency of the wave, the height of the refracting layer, and its density of ionization.

In general, the waves of a-m stations in the Broadcast band are reflected, whereas the f-m waves above 30 - 40 mc penetrate the ionized layers and are not returned to earth.

As previously stated, the sky wave of a-m broadcast stations is predominate at night, and considering only the ground wave, the field strength at a receiving point remote from the transmitter depends upon the loss sustained by the wave. The amount of this loss depends upon the distance traveled, the conductivity of the earth, and the frequency of the transmitted wave. Of these factors, we are primarily concerned with the frequency of the wave, and field tests have indicated that the strength of the a-m wave decreases as the frequency increases. Therefore, the higher frequency of an f-m wave will have less "coverage"!

High frequency waves have the property of traveling in straight lines, much like light, and therefore, are often called "Quasi Optical". In general, a receiver should be within the "line of sight" coverage of a transmitter for satisfactory reception of f-m signals, although tests have shown it is possible to provide good signal strength at distances greater than twice the "line of sight" when the radiation power of the f-m station is relatively great. This is possible partly due to the wave following the curvature of the earth.

A condition which very often occurs, particularly at high frequencies, is the creation of a "shadow" area. This is the reduction of signal strength behind an object which is large enough to reflect the initial wave. Shadow areas become more noticeable as the frequency of the wave is increased. However, such conditions are partially corrected by erecting the f-m transmitter antenna relatively high and designing the antenna array for the purpose of concentrating the radiated power toward the horizon.

INTERFERENCE CONSIDERATIONS

Satisfactory reception not only depends upon sufficient signal strength but also on the exclusion of signals which spoil the program of the desired station. In a-m transmission of the Broadcast band, the ratio of the desired signal to the

undesired signal must be about 100 to 1 for good reception, whereas a ratio of 2 to 1 is adequate in an f-m system. As the maximum range of f-m stations is approximately the same during daytime and nighttime, it is possible to operate many more f-m stations on the same frequency with less geographical separation between stations than in the case of a-m stations.

The use of f-m at very high frequencies offers a solution fort the serious interference problem encountered in a-m broadcasting. Even the reduction of a-m power at sunset, 40 kc separation of local stations, and the use of directional antennas does not reduce the a-m interference conditions to a satisfactory level.

FREQUENCY ALLOCATIONS

It is indeed fortunate that we have such a body as the Federal Communication Commission to regulate the charactdr of radio communication. There are many "classes of transmission" such as — "Transoceanic", 'Ship to Shore", "Ship to Ship", "Navigation", "Government", "Aircraft", "Broadcasting", "Television", "Amateur", "Meteorological", "Non-Government and Government fixed and mobile transmissions", as well as experimental services.

It has been quite a task for the FCC to allocate suitable frequencies for all these services in the Radio Spectrum. For the present, new f-m transmission will be located in the band of frequencies extending from — 88 to 108 megacycles.

The term f-m broadcast "channel" means a band of frequencies 200 kc wide and is designated by its center frequency. Channels for f-m broadcast stations begin at 88.1 mc and continue in successive steps of 200 kc to and including 107.9 mc.

The "term service" area as applied to f-m broadcasting means that service resulting from and assigned effective radiated power and antenna height above average terrain.

Although some service is provided by reflected waves, the service area is considered to be only that served by the ground wave. The extent of the service is determined by the point at which the ground wave is no longer of sufficient intensity to provide satisfactory broadcast service. For city business or factory areas, the field intensity should be 1,000 microvolts per meter. For rural areas the field intensity considered necessary for service should be 50 microvolts per meter.

The Federal Communication Commission have set up certain standards of good engineering practice and these will necessarily be revised from time to time as progress is made in the art. The commission will accumulate and analyze engineering data available as to the progress of the art so that those standards may be kept current with technical developments.

The assignment on Frequency Modulation Receivers will explain the basic fundamentals involved in the reception of signals using f-m systems of transmission.

TABLE 1

BESSEL FACTORS FOR FINDING AMPLITUDES OF CENTER AND SIDEBAND FREQUENCY COMPONENTS

M	J_0 (M) F	J_1 (M) F ± F_M	J_2 (M) F ± $2F_M$	J_3 (M) F ± $3F_M$	J_4 (M) F ± $4F_M$	J_5 (M) F ± $5F_M$	J_6 (M) F ± $6F_M$	J_7 (M) F ± $7F_M$	J_8 (M) F ± $8F_M$	J_9 (M) F ± $9F_M$
0.0	1.000									
0.1	.9975	.0499								
0.2	.99	.0995								
0.3	.9776	.1483	.0112							
0.4	.9604	.196	.0197							
0.5	.9385	.2423	.0306							
0.6	.912	.2867	.0437							
0.7	.8312	.329	.0589	.0069						
0.8	.8463	.3688	.0758	.0102						
0.9	.8075	.4059	.0946	.0144						
1.0	.7652	.4401	.1149	.0196						
1.2	.6711	.4983	.1593	.0329	.005					
1.4	.5669	.5419	.2073	.0505	.0091					
1.6	.4554	.5699	.257	.0725	.0150					
1.8	.3400	.5815	.3061	.0988	.0232					
2.0	.2239	.5767	.3528	.1289	.034	.007				
3.0	-.2601	.3391	.4861	.3091	.1320	.0430	.0114			
4.0	-.3971	-.066	.3641	.4302	.2811	.1321	.0491	.0152		
5.0	-.1776	-.3276	.0466	.3648	.3912	.2611	.131	.0534	.0184	
6.0	.1506	-.2767	-.2429	.1148	.3576	.3621	.2458	.1296	.0565	.0212

F represents the carrier or mean frequency
F_M represents the audio frequency

To find the amplitude of any sideband pair, enter the table with the modulation index M, read the amplitude factor for the sideband pair and multiply the factor by the amplitude of the unmodulated carrier. The amplitude of the center frequency component is found in the same manner, taking the factor from the $J_0(M)$ column.

Where no value is given, the actual value is less than .005 and the sideband pair is not important.

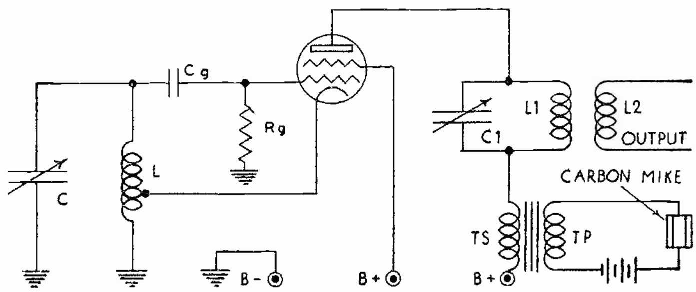

FIGURE 1

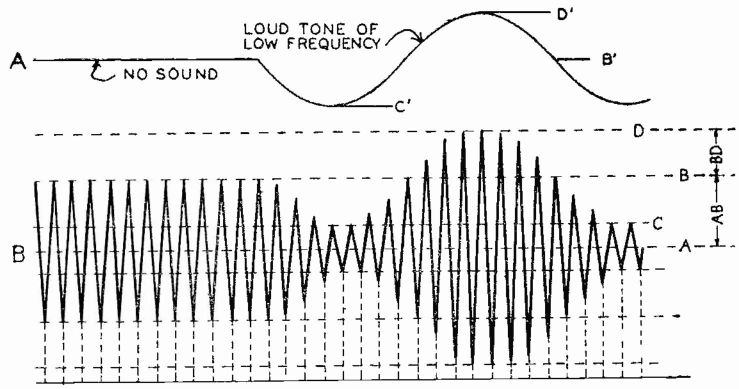

FIGURE 2

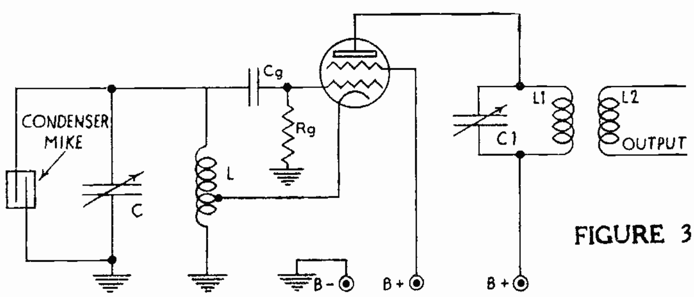

FIGURE 3

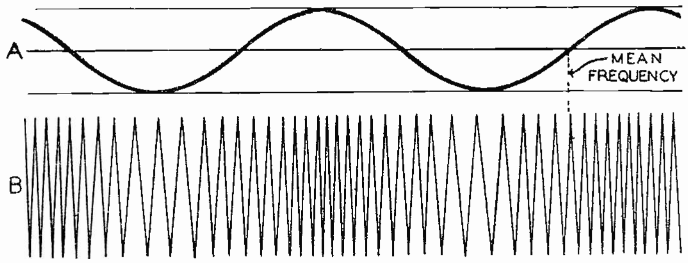

FIGURE 4

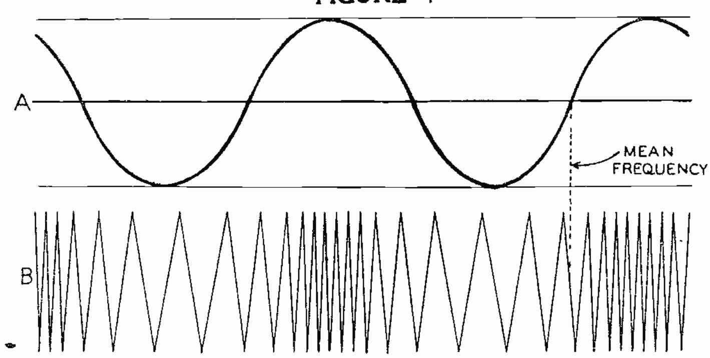

FIGURE 5

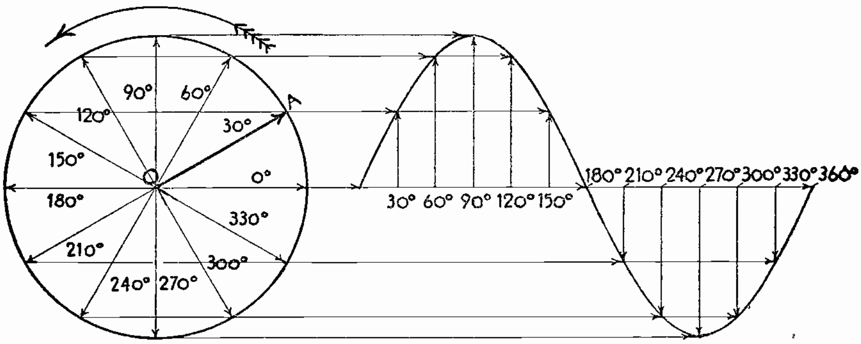

FIGURE 6

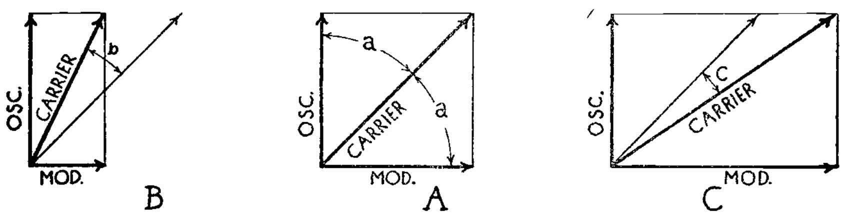

FIGURE 7

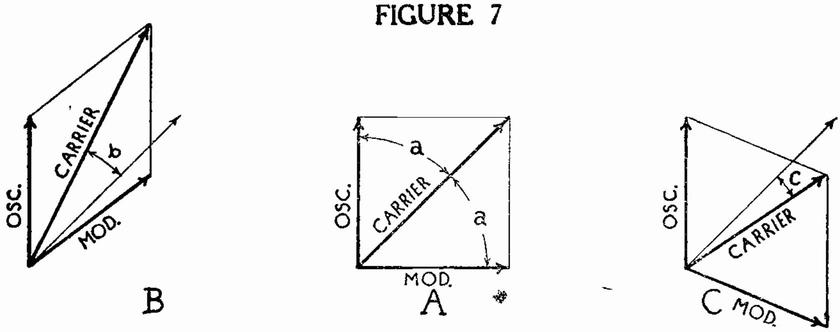

FIGURE 8

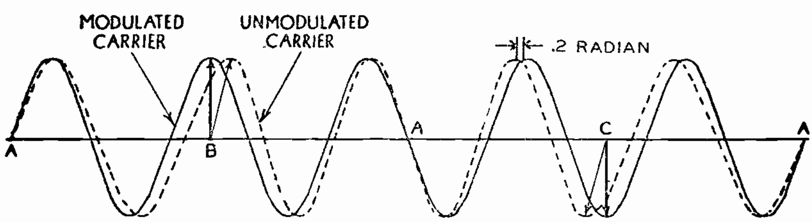

FIGURE 9

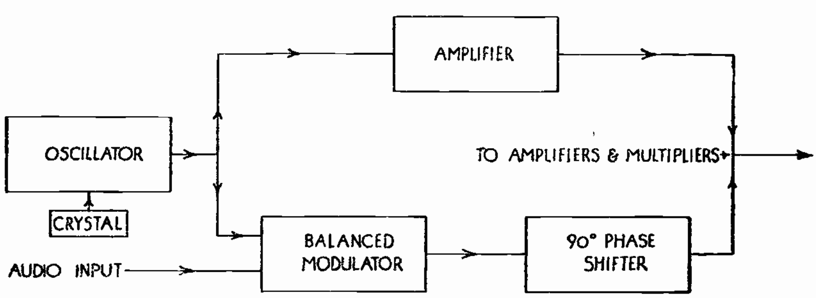

FIGURE 10

DE FOREST'S
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LESSON RRT-14

FREQUENCY MODULATION RECEIVERS

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DE FOREST'S

TRAINING, Inc.

LESSON RRT-14

FREQUENCY MODULATION RECEIVERS

Founded 1931 by

H. A. DeVRY

A PIONEER AND LEADER OF VISUAL EDUCATION

RADIO RECEPTION AND TRANSMISSION

LESSON RRT-14

FREQUENCY MODULATION RECEIVERS

* * * * * *

Luck is usually with a man who doesn't count on it.

* * * *

Taking things easy ultimately makes life hard.

* *

The largest room in the world is the room for self-improvement.

-Selected-

In our explanation of Frequency Modulation as a method of Radio Transmission, we made frequent comparisons to the common Amplitude Modulation methods in order to bring out both the similarities and differences of the two systems. For this Lesson, we will follow the same plan in respect to Receivers because, while there are many similarities, the few differences are extremely important.

You may find it necessary to completely revise a few of your present ideas, in respect to the reception of Radio signals, because in some ways, the action of the two systems are in almost direct contradiction. Keeping this fact in mind, may make it easier to understand some of the following explanations.

Later in this Lesson we will show you that, in general, the input stage, mixer, i-f amplifier and audio amplifier are about the same for superheterodyne receivers of either the a-m or f-m type. The main difference occurs at the output of the i-f amplifier and, therefore, that is where we want to start.

RECEPTION OF a-m SIGNALS

As a brief review, the curve of Figure 1-A represents an a-m carrier which we will consider as the output of an i-f amplifier or as the voltage which is impressed on the input circuit of the second detector.

Thinking of a diode detector, which acts as a rectifier, with an input as shown by curve A, the output will be as indicated by curve B of Figure 1. Notice here, we still have the carrier frequency but, instead of complete cycles, it has become a series of pulses, all of which are above the a-c axis and therefore, commonly considered as pulsating d-c.

By placing a small capacity across the output circuit, the peaks of these pulses will cause it to charge, in proportion to their amplitude while, between peaks, the condenser will discharge. As a result, the current in the circuit will be about the average of the peak amplitudes and, for the curve of B, will have the general shape of the curve C, Figure 1. Notice the resultant signal wave has a reference axis shown by the horizontal line.

Thus, we say the carrier, shown at A, has been demodulated and the modulating Frequency, shown at C, is carried over to the audio frequency circuits where it is amplified to the desired level.

SOURCES OF INTERFERENCE

In comparison to the curve of Figure 1A, for Figure 2, we have a curve which represents the output voltage of an f-m intermediate frequency amplifier. Notice here, the curve shows both frequency and amplitude modulation and we want you to think of the signal as Frequency Modulation while the changes of amplitude represent interference or noise.

As a radio listener, you are probably familiar with various things which tend to spoil the reception of radio signals. However, we want to list a number of interfering sources without offering detail concerning their characteristics.

In general, the principal disturbances to a-m reception can be classified as follows: (1) Man-made interferences, which occur when there are irregular radiations from such sources as electrical power equipment and auto ignition systems. (2) Static arising from electrical discharges in the atmosphere. (3) Thermal agitation noise, which is generally caused by small potentials set up in the conductors of the first stages of a receiver by random motions of electrons. (4) Interference resulting from the reception of signals from stations other than the desired station. (5) Tube noise, caused by random fluctuations in the rate at which electrons reach the plates of vacuum tubes. (6) Hum modulation of the signal, which can take place in an a-c receiver where a-c is sued to heat the cathodes of the tubes, and when the d-c power supply is not adequately filtered.

It is a well established fact that the greater part of the unwanted noise which accompanies a radio signal is due to changes of amplitude in the carrier. Thus, for the a-m systems, in which the desired signal also causes changes of carrier amplitude, it is difficult to reduce the noise without causing a similar effect on the signal.

For the f-m carrier of Figure 2, however, the signal modulation causes changes of frequency while the noise causes changes of amplitude. Therefore, if the changes of amplitude can be eliminated, the noise will be removed without affecting the signal. This particular condition is one of the important advantages of frequency modulation.

LIMITER

To eliminate the changes of amplitude a "Limiter" stage, with a circuit on the order of Figure 3, is employed. The tube is a pentode of the sharp cut-off type with its cathode grounded, and as far as the power supply is concerned, the tube operates a zero grid bias.

However, the grid circuit is connected across the tuned secondary of the last i-f transformer so that the curve of Figure 2 represents the signal voltage at this point. The resistance R, by-passed by condenser "C", is placed in series with the complete grid circuit.

The positive alternations of the Carrier will cause the grid to become positive, in respect to the cathode and, therefore, during these periods, there will be current in the grid circuit. Passing through resistance R, this current will produce a voltage drop the polarity of which tends to make the grid more negative. Also, the voltage across R will charge condenser C, and this d-c voltage will be very nearly equal to the amplitude of the i-f voltage across the tuned circuit condenser.

During the negative alternations of the carrier, the grid will be negative, in respect to the cathode, and there will be no grid current. Under this condition, the reduced voltage drop across R will allow condenser C to discharge through it and thus momentarily maintain the voltage. As the polarity of the voltage drop does not change, in effect there is a d-c bias on the grid.

You can readily see that the greater the amplitude of the carrier, the greater the positive voltage on the grid and thus the greater the grid current. This greater current will cause a larger drop across R and charge the condenser to a higher voltage. Thus, the grid bias will vary with the carrier amplitude much the same as in the common avc systems and, in some f-m receivers, the voltage across R is used to provide Automatic Volume Control.

To provide the limiting action, the tube is operated at comparatively low plate and screen voltages and, during the positive alternations of the carrier, the positive grid voltage causes the plate current to quickly reach a point of saturation. During the negative alternations of the carrier, the signal voltage plus that across R, quickly reaches a value which causes plate current cut-off.

The time constant "RC" is important in the suppression of impulse noises, such as ignition radiation and sparking brushes of electric motors. In general, the time constant should not exceed 10 microseconds, and more conventional values range from 1.25 to 4 microseconds.

Short time constants make it possible for the grid bias voltage, developed across R, to follow almost instantaneously an impulse which would remove the signal voltage from the grid of the limiter tube. The short time constant permits

recovery of the bias voltage in less than the time of one cycle at the highest audio frequency used, and the bias system then does not prolong the effect of an individual interferring pulse.

Thus, with properly chosen values in the limiter stage, the lowest carrier amplitude will cause saturation and greater amplitudes of carrier can not cause greater changes of plate current. Therefore, with the voltage of Figure 2 applied on the grid circuit of Figure 3, the plate circuit will carry all the changes of frequency but, due to the limiting action, the amplitude will be constant.

To realize the full advantage of this noise reducing feature, the signal reaching the limiter grid must be of such strength that the minimum amplitudes will produce limiter saturation. Then, any increase of carrier amplitude will not cause an increase of the limiter output.

In some respects, the circuit of Figure 3 resembles a grid leak type of detector which has the bad fault of cutting off high amplitude signal peaks and causing distortion. Here, such tube action is an advantage as we want to cut-off the variations of amplitude in order to eliminate the noise which accompanies the signal.

From the standpoint of the reduction of noise and interference, the limiter stage is the most important component of the f-m receiver, because f-m detectors respond to amplitude as well as frequency variations of the detector input voltage.

Although we show a single stage limiter in Figure 3, some f-m receivers employ 2 stages, the second for the purpose of removing any small amplitude variations in the output of the first limiter, and to flatten the over-all characteristic curve after the point of tube saturation is reached.

I-F AMPLIFIERS

In amplitude modulation receivers, the i-f transformers are usually peaked to pass a band of approximately 10 kc. The narrower this band is made, the greater the selectivity of the receiver but, for good reproduction, the band must be twice as great as the highest signal frequency it is desired to reproduce. Theoretically at least, a 10 kc pass band i-f can handle signal frequencies only up to 5 kc or 5000 cycles.

For f-m systems, the pass band of the i-f amplifier has nothing to do with the signal frequencies as they merely control the rate at which the carrier frequency changes. However, as we have previously explained, the relative value of the signal is in proportion to the change of carrier frequency.

Therefore, by increasing the band width, the relative strength of the signal is increased and the signal to noise ratio is improved. Or, saying it the other way, the greater the frequency deviation the better the noise suppression.

As already mentioned, for present f-m Broadcast practice, the ratio of Frequency Deviation to Maximum signal Frequency is about 5 to 1. As 15,000 cycles is considered necessary for good fidelity, the deviation is 5 times 15,000 cycles or 75,000 cycles which is equal to 75 kc. Then, as deviation means the frequency change on one side of the carrier, the total swing, equal to twice the deviation, is 2 x 75 = 150 kc.

Because of this condition, the Federal Communications Commission have allocated 200 kc bands for the f-m transmitters now in operation and most i-f amplifiers are considered as having this value of pass band.

The intermediate frequency of early receivers had a value of 2.1 mc which has been increased through values of 4.3 mc, and the post war trend is toward the use of still higher intermediate frequencies. The use of the "odd Tenths" in the value of the i-f's is for the purpose of minimizing the image frequency. It is desirable that such interference lie outside the f-m band.

The transformers are of the usual type with a tuned primary and secondary and, to provide the required band width, the coils are tightly coupled and usually loaded by a resistance connected across them which acts to broaden the response characteristics. Depending on the design and requirements, the broading resistors vary from about 10,000 to 100,000 ohms.

In other receivers, the characteristic response of the i-f amplifier does not differ greatly from that of an a-m type of receiver, the broad band, flat top response being obtained by the action of the limiter.

To illustrate, for Figure 4, we have drawn three curves, representing the relative response of an i-m amplifier at different carrier levels. You can imagine these various levels as being obtained by increasing either the signal strength at the antenna or the gain of the amplifier itself.

The vertical scale at the left indicates the relative voltage of the output measured at different frequencies as marked along the bottom, horizontal scale. Checking this scale, you can see the amplifier is tuned to 2100 kc or 2.1 mc, because the output is maximum at that frequency.

Starting with curve "A", the output at 2100 kc is approximately 4, on the voltage scale, but, as the frequency is varied above and below resonance, the voltage drops quite rapidly

For curve "B", the resonant voltage is 50% greater than that of curve A but as the amplifier circuits have not been changed, both curves have the same general shape.

For curve "C", with a still higher resonant voltage, the general shape remains the same as shown by "A" and "B" but the curve is higher and broader.

From our explanation of the limiter, you know it is arranged to have a comparatively low saturation point which we have indicated as "3" on the voltage scale of Figure 4. Thus the complete curves represent the voltage on the limiter input circuit while the lower, heavier portions, represent the limiter output.

Checking across the "3" line, you will find curve "A" is "flat-topped" for 25 kc each side of the resonant frequency and thus the limiter action would be effective for a frequency swing of 50 kc.

Curve "B" is flat-topped for 50 kc each side of resonance and, with an input voltage of this amplitude, the limiter action would be effective for a frequency swing of 100 kc Curve "C", flat-topped for 75 kc each side of resonance, would provide limiter action for the 150 kc swing of present broadcast practice.

From these curves, you can readily see that it is desirable to provide a relatively strong signal at the input of the limiter in order that the minimum amplitude be sufficient to operate it, and at the same time allow adequate band pass.

The main purpose of the Limiter is to remove the amplitude modulation from the carrier and thus remove the noise, static or other interference without affecting the signal. Remember however, some interference is frequency modulated and therefore, even though the limiter is operating properly, some noise may be heard in the speaker.

Assuming perfect Limiter action, its output will have a constant amplitude and the modulation will appear only as a variation of frequency.

DISCRIMINATOR

To produce audible signals of the desired volume, the usual types of audio amplifiers and speakers are employed and therefore, the frequency changes of the limiter output must be converted into corresponding changes of voltage or amplitude.

The circuit arrangement, used for this purpose, is similar to the "Discriminator" which was developed as a part of the Automatic Frequency Control (afc) systems found in some superheterodyne Radio Receivers, and it would be well to review the explanations should you have forgotten some of them.

A simplified circuit of this stage is shown in Figure 5 and you can imagine tube T1 is the Limiter of Figure 3, with the tuned primary, L1-C1 of the i-f transformer, in its plate circuit.

The tuned secondary, L2-C2, is center tapped and connected to the double diode, T2, in a full wave rectifier arrangement. Two resistors of equal value, R3 and R4, each bypassed with a condenser, are connected in series across the cathodes to form the output load.

Notice also, that while the lower end of R4 is grounded, the center tap between R3 and R4 connects to the center tap of L2 through the "R.F.C." which is a radio frequency choke. In addition, the center tap of L2 is coupled to the plate of T1 through condenser C.

With this arrangement, the total voltage, applied across the load resistors R3 and R4 can be thought of as consisting of two separate parts. To follow these paths, you must remember we are considering the comparatively high intermediate frequency value and thus a condenser acts as a capacity reactance allowing us to trace an a-c path through it.

Under these conditions, we can start at the plate end of L1-C1 and follow a path through coupling condenser C and through the Radio Frequency choke, (R.F.C.) to the junction between R3 and R4. From this point, there are two paths to ground, one through R4 and one through C4.

At the comparatively high intermediate frequency, the reactance of the condenser is so low, compared to the resistance, that it shorts it out and the path is through C4 to ground and back through C6 to the lower end of L1-C1.

The voltage across L2-C2 rectified by tube T2, has two d-c paths, one from the upper cathode through R3 and RFC to the center tap of L2 and the other from the lower cathode through R4 and R.F.C. to the center tap of L2.

Checking back, you will find that the paths we have traced across L2-C2 are such that the voltages will cause current in one direction through R3 and in the opposite direction through R4. Thus, any voltage drop developed across these resistances will be of opposite polarity and tend to reduce the total voltage across both of them in series.

Going back to the i-f transformer, the desired action depends upon a number of phase relations which we want to explain with the aid of the vectors of Figure 6.

In any inductance, such as L1, the current lags the voltage by an angle which we can assume to be 90°. To represent this condition, in Figure 6A the vertical vector "Ep" represents the voltage and the horizontal vector "Ip", the current. The comparative lengths of these vectors have been chosen arbitrarily as we are interested mainly in phase angles rather than actual values.

The current in L1 will induce a counter emf but, as the greatest induction occurs when the current is changing value at the greatest speed, which is at zero value, the induced emf will lag the current by 90°. This value is represented by the vector "Ec", and you will find it is 180° out of phase with the impressed voltage Ep. Remember, the flux which induces the primary counter emf also cuts the secondary and thus Ec represents the induced emf in the secondary.

When the secondary circuit, L2-C2, is tuned to resonance, its reactance is zero and thus its current will be in phase with the induced voltage "Ec" as shown by vector "Is". However, L2 is an inductance and therefore, as explained for L1, the voltage across the coil will lead the current in the coil by 90°.

To illustrate this action, we have drawn vector "E1" of Figure 6A, 90° ahead of "Is" which brings it in phase with "Ip". However, in the circuit of Figure 5, L2 is center tapped and each end is connected to a rectifier plate with the center tap as a common return.

In respect to this common return, the voltage E2 across one half of the winding will be of opposite polarity or 180° out of phase with the voltage E1, across the other half of the winding. For this reason, vectors E1 and E2 of Figure 6A are drawn of equal length but extended in opposite directions from the vector "Is".

Going back to Figure 5, you will remember that the RFC was in the path of the voltage developed across L1-C1. Current in this path will therefore, develop a drop across the choke and this voltage can be considered the same as that across L1-C1, the vector for which is shown as "Ep" in Figure 6A.

With this in mind, you will find the voltage "Ep" is in series with voltages E1 and E2, the circuits for which are completed through the rectifier and resistances R3 and R4. Thus, the total voltage across R3 will be proportional to the sum of Ep and E1 while the voltage across R4 will be proportional to the sum of Ep and E2.

Adding these vectors by the usual plan of completing the parallelogram and drawing the diagonal, we have vector ER3 as representing the voltage across R3 and ER4 as representing the voltage across R4.

Notice here, the current in the resistances is the result of rectification by T2 and, with a condenser across each of them, we can consider the voltage drop as d-c. Because of the direction of current, the upper end of R3 and the lower end of R4, Figure 5, will both be positive, in respect to the center tap. This will cause an opposing action and the total voltage across both of them will be equal to their arithmetical difference or algebraic sum.

We need consider only the length or value of vectors, ER3 and ER4 of Figure 6A and, as the diagram is symmetrical, both have the same length. Therefore, as the voltages across R3 and R4 are of equal value and opposite polarity, the total voltage, across both of them, is zero.

In the complete f-m receiver, the vectors of Figure 6A represent the condition at the exact intermediate frequency which is present when there is no modulation and the carrier frequency has its mean or center value.

Suppose now, the carrier frequency changes and causes a deviation from the i-f value. As far as the diagrams of Figure 6 are concerned, this will not cause any change in the phase relations of "Ep", "Ip" or "Ec". At a higher frequency, however, the capacity reactance of C2 will reduce while the inductive reactance of L2 will increase.

This increase of inductive reactance will cause the secondary current "Is" to lag the voltage "Ec" as shown in Figure 6B. As explained for Figure 6A, the induced voltages, E1 and E2 are 90° out of phase with Is and, therefore, are drawn at this angle in Figure 6B.

Completing the parallelogram and drawing in the diagonals under these conditions, we see that vector ER4 is longer than vector ER3 and, therefore, know the voltage across R4 is greater than that across R3.

The total voltage, across the resistors in series, will be equal to their difference and have the polarity of the larger voltage drop. Thus, as R4 is positive at the grounded end, the upper end of R3 will be negative in respect to ground. The greater the change of frequency, the greater the difference between the respective voltage drops and thus, the value of the negative voltage, between the upper end of R3 and ground, Figure 5, will increase with the increase of frequency above the resonant frequency of L2-C2.

When the intermediate frequency drops below the resonant value, the capacity reactance of C2 increases and the inductive reactance of L2 decreases. As a result, the tuned circuit becomes capacitive and the secondary current "Is" leads the induced voltage "Ec" as shown in Figure 6C.

Following the former plans, vectors E1 and E2 are again drawn at 90° angles to Is, the parallelograms completed and the diagonals, ER3 and ER4 drawn in.

Here, you can see that conditions are opposite to those of Figure 6B and ER3 is longer than ER4. Going back to Figure 5, this means that the voltage across R3 is greater than that across R4 and therefore, the upper end of R3 will be positive in respect to ground.

To check the entire action, we could connect a sensitive voltmeter from the upper end of R3 to ground and then take readings as the frequency was varied above and below the value to which the i-f transformer was tuned.

The results of such a test, when plotted in the form of a graph, produce a curve on the order of Figure 7 where we have a frequency scale across the bottom and a center zero voltage scale at the left.

The intermediate frequency is assumed to be 2100 kc and, as already explained, the total voltage is zero at this point. As the frequency is reduced, the voltage rises in "+" value and, as the frequency is increased, the voltage increases in a negative direction. Thus, variations of frequency are converted to changes of amplitude and the output of the discriminator can be considered the same as the output of the second detector of an a-m superheterodyne receiver.

Looking at Figure 7 again, you will notice the curve is almost a straight line for a distance on each side of the resonant frequency, after which it starts to curve and then falls back toward zero.

The straight line section, as shown by the vertical broken lines, is the valuable range of the action because, between these limits the output voltage will vary in direct proportion to the frequency changes. As drawn in Figure 7, the frequency deviation is 75 kc for a swing or band width of 150 kc.

In Figure 5, the voltage of Figure 7 is impressed on the network, made up of R1, C5 and the volume control R2 while the grid circuit of the following tube is connected across the "Output" terminals. The stages following the discriminator are those of the ordinary type of audio amplifier.

COMPLETE RECEIVER

To show how the various stages are inter-connected, for Figure 8 we show a circuit diagram of the General Electric Model HM-50 Frequency Modulation Receiver.

Checking the action briefly, the antenna transformer, L1, has a center tapped primary for use with a dipole antenna and balanced transmission line. The secondary, tuned to the mean carrier frequency, connects across the control grid circuit of the 6K8 converter tube. The oscillator coil, L2, is connected to the proper grid and plate elements of the 6K8 and tuned to a frequency which heterodynes the carrier to produce an i-f of 2100 kc or 2.1 mc.

The output circuit of the 6K8 is carried through the first i-f transformer L3 which drives the grid circuit of the 6SK7, first i-f tube. A second i-f stage, consisting of transformer L-4 and the second i-f 6SK7 amplifier tube follows.

The third i-f transformer, L-5, drives the grid circuit of the 6SJ7 Limiter tube, the circuit of which is similar to that shown in Figure 3. Its action, of course, is as previously explained.

Transformer, L-6, corresponds to the i-f transformer of Figure 5 and the tube marked "6H6 Detector" is the discriminator. The signal voltage appears across the two "100M" resistors and the greater portion of this signal is fed from the midpoint of the 100 M - 220 M voltage divider networks to Switch S-2 and through the .005 mfd coupling condenser to the "2 megohm" volume control. In effect, the 100 M resistor, operating in conjunction with the condensers controlled by switch S-1, serve as a "De-emphasis" network. That is, if the f-m transmitter employs a pre-emphasis circuit which, in the modulator circuit, provides a grester amplitude of the high frequencies, then it is necessary to reduce the emphasis of the high audio frequencies in the receiver. Of course, the basic circuit arrangement here is that of the high frequency tone control.

With pre-emphasis at the transmitter, it is necessary to have de-emphasis at the receiver for the purpose of bringing the high frequencies down to the same proportion with respect to the low frequencies that exist at the studio microphone. The use of the de-emphasis network will reduce the high frequency noise picked up by the receiver antenna or from thermal agitation and "shot effect" to inaudibility.

The signals continue from the moveable arm of the volume control through the "P-A" terminals and through another .005 microfarad coupling condenser to the grid of the 6SF5 a-f amplifier tube.

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The signals continue from the moveable arm of the volume control through the "P-A" terminals and through another .005 microfarad coupling condenser to the grid of the 6SF5 a-f amplifier tube.

The plate circuit of the 6SF5 is resistance coupled to the grid circuit of the 6Y6G output tube which, in turn, is coupled to the speaker by transformer T1.

The power supply is conventional and consists of the usual type of power transformer with a 5Y3G full wave rectifier. The filter however, differs from the common type in that no iron core chokes are employed.

The rectifier filament connects directly to the primary of the output transformer with a 40 mfd condenser to ground. For the other plate circuits, the supply is through two resistors with a 20 mfd condenser to ground at the load end of each.

AUDIO AMPLIFIER

Switch S2 makes it possible to connect a phonograph pick-up across the grid, or input circuit of the first audio amplifier tube through the regular volume control.

The "P-A. Terminals" make it possible to use the receiver as an f-m tuner and feed the audio signals into a PA system or other audio amplifier. When the terminals are shorted, the incoming signal is fed to the grid circuit of the "6SF5 a-f Amp." to operate the audio amplifier and its speaker. The signal is also available between the PA Terminal connected to the volume control and ground.

Checking the values in the 6SF5 stage you will find a plate load of 220 M ohms, a grid load of 15 megohms and a cathode resistor of 82 ohms. As this is a high mu triode with a normal plate current of less than 1 ma, the voltage drop caused by plate current in the 82 ohm resistor will be negligible.

Therefore, we consider the tube as operating under conditions of "zero bias", an arrangement which has been found to provide high gain and low distortion with a minimum of parts. This method is particularly adapted to high mu triodes and in general consists of eliminating the cathode resistor while the value of the grid resistor is greatly increased.

For most purposes, we consider that, for Class A operation of an amplifier tube, the grid current is zero. That is not strictly true because, even with a negative bias, there is s small grid current which varies with the grid voltage.

By greatly increasing the usual value of the grid resistance, this small grid current will cause a voltage drop sufficient to properly bias the grid circuit. For example, in the circuit of Figure 8, a grid current of .1 microampere in the 15

megohm grid resistor will cause a drop of 1.5 volts and the normal rating of the 6SF5 is -2 volts on the grid. Therefore, the 82 ohm cathode resistor does not provide the grid bias voltage in the usual way but, tracing from the cathode, you will find a circuit through the 220 ohm resistor, by-passed with a .1 mfd condenser, and through the secondary of output transformer T1 to ground.

For this circuit, the output transformer supplies the voltage and thus inverse feedback is provided as part of the speaker voice coil voltage is fed back to the cathode of the first audio amplifier tube.

The current caused by that voltage, in passing through the 82 ohm resistor, produces sufficient voltage drop to bias the grid. Due to the relative value of the 220 ohm and 82 ohm resistors, slightly more than 25% of the voice coil voltage will be fed back to the cathode circuit.

The .1 mfd condenser, connected across the 220 ohm resistance acts as a sort of auxiliary tone control because, at higher frequencies, it becomes a partial short across the resistance. With a reduction of effective resistance, feed back voltage across the cathode resistance will be greater and thus the higher frequencies will be attenuated to a greater degree to cause an apparent bass boost.

It is interesting to note that this audio amplifier really has three tone controls. 1. The bass compensated volume control, 2. The switch type shunt capacity tone control and 3. Inverse feed back compensated for high frequency attenuation.

ALIGNMENT

As previously explained, the i-f amplifier must pass a 150 kc to 200 kc band, the exact width depending on the manufacturer's specifications. The i-f amplifier output is measured by meaas of a micro-ammeter connected in the limiter grid circuit or a vacuum tube voltmeter connected across the limiter grid bias resistor.

Some manufacturers recommend a 300 kc frequency modulated oscillator, as a signal source of i-f amplifier adjustment, with an oscilloscope as the indicating instrument. The actual response curve of the amplifier can thus be seen and corrected by proper adjustment.

Other manufacturers suggest the use of a good signal generator of the usual Radio type, output readings to be taken at the intermediate frequency and also at points 75 kc to 100 kc above and below. Comparison of these three output readings indicates the shape and band width of the amplifier response.

For either method, the output indicator is connected in the grid circuit of the Limiter and the usual plan is to increase the signal input to a point at which no further increase of output is noted. This assures correct Limiter action and proper operation.

The adjustment of the Discriminator, or second detector input circuits is quite critical becuase, for best results, its output voltage must be symmetrical in respect to the intermediate frequency. Using a frequency modulated oscillator and oscilloscope, and referring to the diagram of Figure 5, the vertical plates of the scope are connected across the load resistors which correspond to R3 and R4. The Discriminator transformer trimmers are then adjusted to produce a curve like that of Figure 7, care being taken to have the cross over point in the proper position with an approximately straight line, as far as possible, on both sides of it.

To make the same adjustment, using an ordinary oscillator and micro-ammeter, the meter is connected across the load resistors but in such a position so as to be in series with a resistance such as R1 of Figure 5. When aligning with a vacuum tube voltmeter, it can be connected across the load resistors the same as the vertical plates of the oscilloscope

To obtain maximum output reading, the primary is tuned to the signal frequency but the secondary must be detuned because when it is resonant, the total output voltage is zero.

The test oscillator is then set at 75 kc to 100 kc below the i-f and, as the polarity of the output voltage will be reversed, it will be necessary to reverse the test meter connections. For this particular job a meter scale with a center zero is convenient as it eliminates the need for reversing connections.

The output voltage should be checked again and a peak value obtained by a slight readjustment of the trimmers if necessary. After this has been done, the oscillator frequency should be tuned to the exact value of the i-f at which point the output should have decreased. The secondary trimmer is then carefully adjusted until the output is zero.

This is an extremely important adjustment and, if there appears to be more than one setting for zero output, the position of greatest sensitivity is the proper one.

The oscillator frequency should then be changed slowly to values above and below the i-f, one way causing a positive output and the other way a negative output. The primary trimmer adjustment can then be checked to make sure the output is of approximately the same value at equal frequencies above and below the i-f.

The alignment and tracking of the converter and oscillator stage is usually somewhat simpler as a low frequency oscillator padding condenser is seldom needed. It is usually sufficient to simply adjust the trimmer condensers for maximum output at the high frequency end of the tuning range.

ADVANTAGES OF F-M

While there have been many claims and counter claims in respect to f-m vs a-m, it seems to generally conceded that, for transmission at equal power levels, the f-m signals are received with much lower noise levels.

For amplitude modulation, the noise levels are in proportion to the band width but, for frequency modulation, the reverse is true. Checking back on the action of the limiter and second detector, you will remember that the amplitude of the signal is proportional to the frequency deviation while the noise or amplitude modulation, remains the same. Thus, the wider the band the better the signal to noise ratio.

Another advantage of frequency modulation is that of less interference between two stations transmitting on the same carrier frequency. In effect, therefore, although the f-m stations require a wider band, more of them can operate on the same carrier frequency without interference. This is due to the reduced interference and also because the high carrier frequencies, used for f-m Transmission, limit the service area of the Broadcast stations somewhat as compared to those operating on lower carrier frequencies.

TECHNICAL AND ECONOMIC PROBLEMS

From a technical standpoint, there has been a great deal of discussion as to the methods of comparing a-m and f-m systems. It is quite well known that certain forms of interference, troublesome in the present Broadcast band, are greatly reduced or disappear entirely at the high carrier frequencies used for f-m. However, f-m seems to have a distinct advantage in respect to "made made Static" which can cause trouble at most frequencies.

Two technical problems which must be solved are the band width which will allow good f-m reception with minimum noise and whether the public will be served better by allocating more frequencies for f-m, or by allowing more a-m stations to transmit on the ultra high frequencies.

From an economic standpoint, there is a wide difference of opinion as to whether or not the public will appreciate the reduced noise and higher fidelity f-m programs to the extent of buying new receivers. In this country, practically all Broadcast stations are supported by the sale of time to advertisers. The prices paid depend greatly on the estimated size of the listening audience and, unless assured of such an audience, the advertiser would not buy time of an f-m station.

Under this condition, the burden on the station would be heavy because, even though the public appreciated the advantages of f-m, they would not purchase receivers unless assured of good programs.

FUTURE POSSIBILITIES

With all of these conditions in mind, many predictions have been made regarding the future of Frequency Modulation. One quite plausible forecast is that the larger cities and other densely populated areas will be serviced by broad band, high frequency f-m stations while the more sparsely populated areas will be served, as now, with lower frequency a-m stations.

The wide band f-m system is sufficiently flexible to permit multiplex operation on the same channel. This would allow the transmission of two simultaneous programs such as one for sound and one for facsimile.

Frequency modulation has been called a "Revolution in Radio Broadcasting" and we have tried to indicate briefly, a few of the more important problems which it has brought up. The entire science of Radio is comparatively young, it is only natural that many improvements will have to be made. It is but a few years ago that there was ample space on the air for every active station and the amateurs were assigned all the frequency bands below 200 meters or above 1500 kc.

Today the entire Radio spectrum from 10 kc to 300,000 kc or 300 m-c has been definitely allocated for specific services and the present trend is toward higher and still higher frequencies because that appears to be the only direction in which additional space is available.

Frequency modulation seems to be well adapted for the higher frequency carriers and its demonstrated advantages seem to assure it quite an important place in the radio Broadcast systems of the near future.

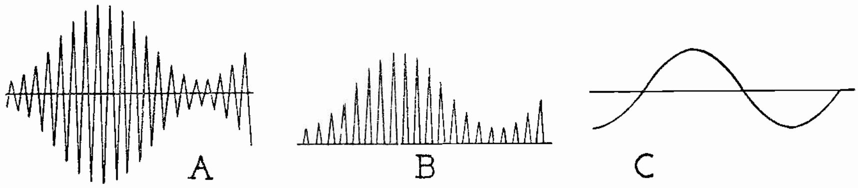


FIGURE 1

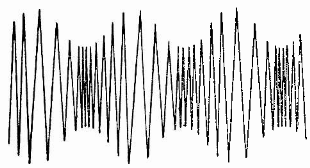


FIGURE 2

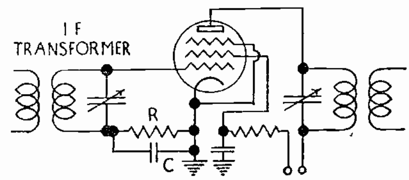


FIGURE 3

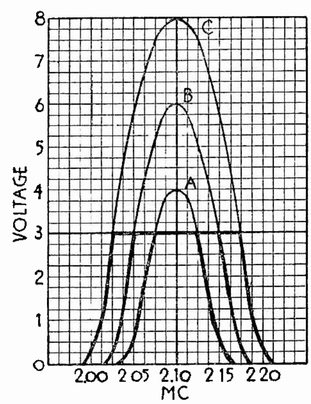


FIGURE 4

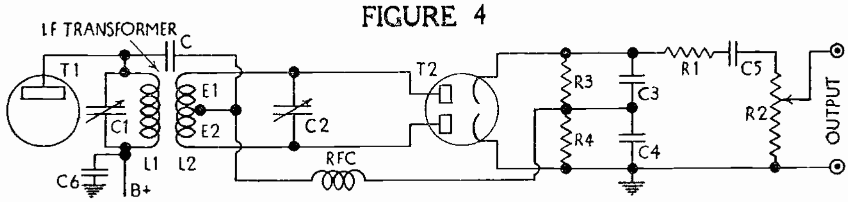


FIGURE 5

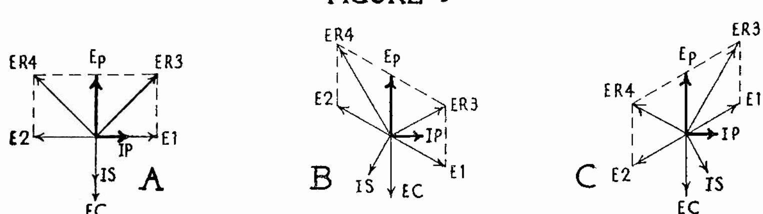


FIGURE 6

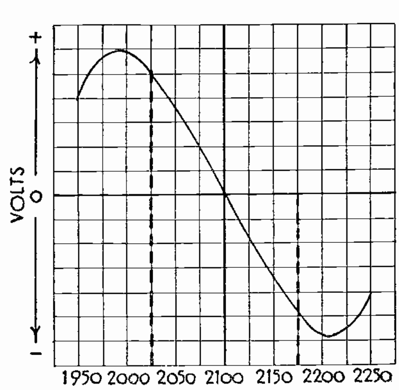
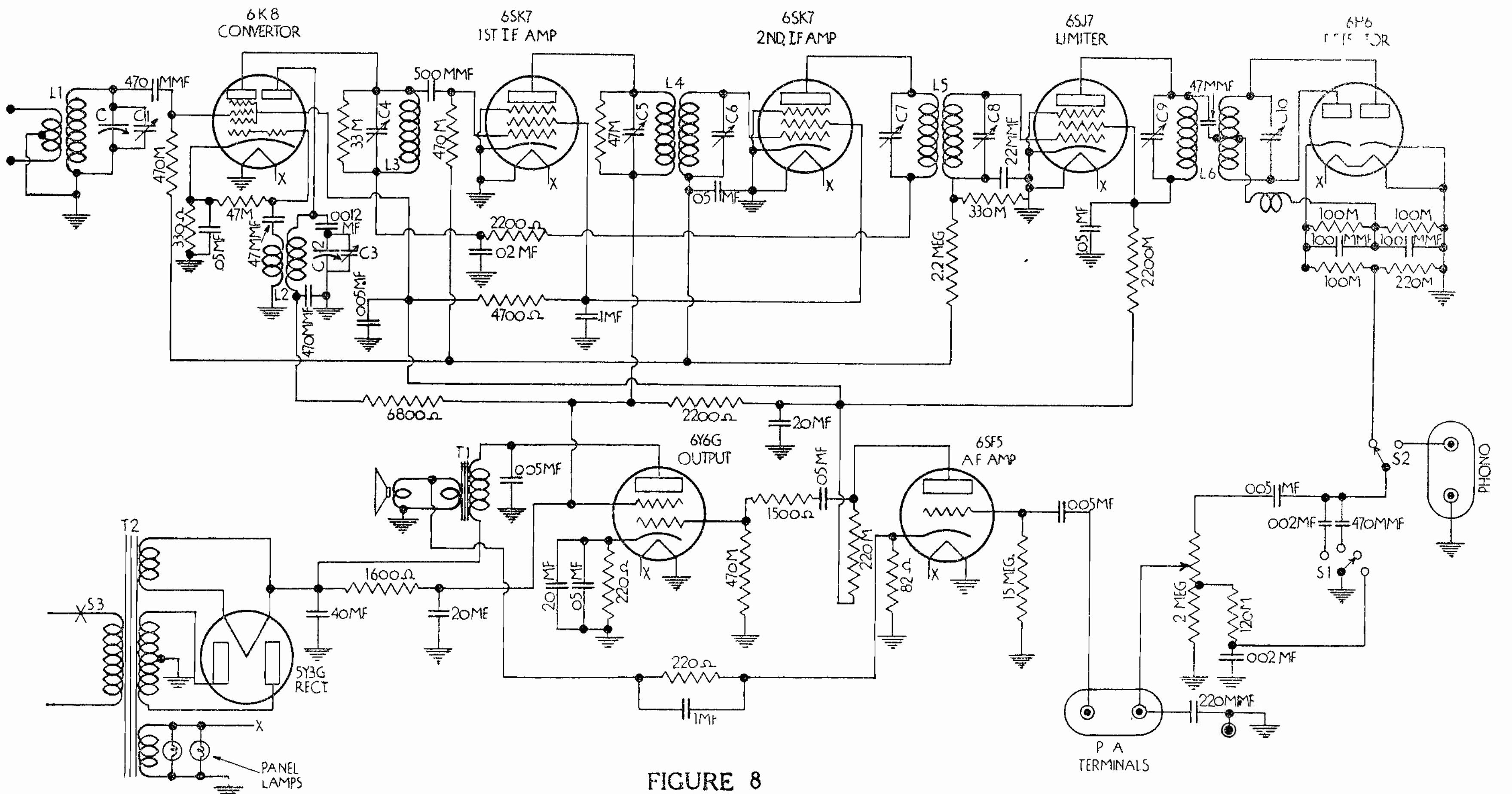


FIGURE 7



6K8
CONVERTOR
6SK7
1ST I.F. AMP
6SK7
2ND I.F. AMP
6SJ7
LIMITER
6Y6G
OUTPUT
6SF5
A.F. AMP
5Y3G
RECT
PANEL
LAMPS
PHONO
P A
TERMINALS
L1
L2
L3
L4
L5
L6
T1
T2
S1
S2
S3
C1
C2
C3
C4
C5
C6
C7
C8
C9
C10
470 MMF
500 MMF
47 MMF
.0012 MF
.05 MF
.005 MF
470 MMF
.02 MF
.1 MF
22 MMF
20 MF
.005 MF
.05 MF
1 MF
40 MF
100 MMF
.005 MF
.002 MF
220 MMF
470M
330Ω
47M
33M
470M
2200Ω
4700Ω
6800Ω
2.2 MEG
330M
2200M
100M
220M
1500Ω
220M
82Ω
15 MEG.
470M
220Ω
1600Ω
2 MEG
120M

FIGURE 8

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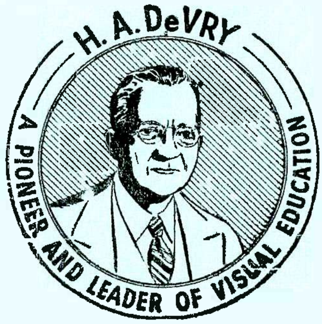
LESSON RRT-15
OSCILLATOR CIRCUITS

• • Founded 1931 by • •



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OSCILLATOR CIRCUITS

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DE FOREST'S TRAINING, INC.

LESSON RRT-15

OSCILLATOR CIRCUITS

* * * * * * * * * *

We cannot grow unless we know. Here are some suggestions on knowing and growing: (1) Ask questions. Don't be ashamed to say "I don't know", (2) Adapt yourself. Learn to fit in. (3) Set a goal. Have an aim in life. (4) Co-operate. Play fair with everybody. (5) Have faith. Believe in yourself. (6) Make your work your life. Don't postpone happiness.

Dr. Frank Crane

We have already explained the basic principles of Oscillators, and now want to offer greater details as to the general characteristics of oscillating circuits. As you probably know, a vacuum tube oscillator is really the heart of a Radio Transmitter. It generates or originates the carrier frequency radiated, and the constants of its circuit largely determine the stability of that frequency.

Before going further, we want to remind you that all radiated Radio signals exceeding the legal range as determined by --

$$\frac{157,000}{KC} \text{ ft.}$$

from their source, come under the jurisdiction of the Federal Communications Commission, (FCC) and it is illegal to put any signal on the air unless and until a proper License has been obtained.

Each station must obtain a License, the terms of which contain the allowable Power, Transmission Frequency, Hours of Operation and other similar details. The operation of the station is under the direct supervision of someone who has passed the necessary examinations and obtained an "Operator's License".

There are various classes of station Licenses, various types of Transmission and various grades of Operator's Licenses, each of which have definite privileges and limitations and all of which are under the direct supervision of the FCC. As the various rules and regulations are subject to change, we will not attempt to include them as a part of our explanations.

However, to facilitate the jurisdiction of Radio Transmission, the United States has been divided into 22 Inspection districts, each with a "Radio-Inspector in Charge". You will find these districts and the Inspector's addresses listed at the end of this Lesson and, if you are interested in obtaining a License of any kind, we suggest you write to the "Radio Inspector in Charge" of the district in which you live. He can send you full details in respect to the requirements, time and place of examinations and all other necessary information.

The circuits we are going to explain in this and following Lessons are comparatively simple to construct and capable of producing signals which come under the jurisdiction of the FCC. There is no charge made for an Operator's License but there are heavy fines and jail sentences for operating without a license.

We want to emphasize these facts as many persons are not aware of them and we feel that an essential part of Transmitting Circuit knowledge is the regulations which must be observed in respect to their use.

SIMPLE REGENERATIVE OSCILLATOR

In several of the earlier Lessons, we explained the circuits and operation of various types of oscillators, used in some Radio Receivers and certain types of test equipment but, as similar circuits are used for Transmission, we feel that a brief review of the subject will be of benefit at this time.

Starting with Figure 1, we show a circuit, the major part of which was previously described as a Regenerative Detector used in a Radio receiver. Upon connecting the load coil "L" between an antenna and ground and inserting a pair of headphones in series with the "B+" lead, the arrangement would operate as a one tube receiver.

Plate coil "L_2", known as a "Tickler", is inductively coupled to the grid coil of "L_1" so that some energy from the plate circuit is fed back to the grid circuit, causing an increase of signal strength. However, if the feed back is increased sufficiently, the tube oscillates and prevents proper operation as a detector.

We are interested in the oscillating condition of the tube because it acts as an r-f generator, and "L" becomes the load coil instead of a primary or input coil as explained for the detector action.

To follow the action, we will assume the tube of Figure 1 is in operating condition but the "B" or plate circuit is open and there is no action. When the "B" circuit switch is closed, there is a surge of plate current through coil L_2, causing a voltage drop across it. Because of the coupling, the transformer action induces an emf in coil L_1 which is connected across the grid circuit.

Thus, the original surge of plate current causes a voltage pulse on the grid and the amplifying action of the tube causes a large pulse of plate current. The original action is then repeated except that the voltage pulses across the grid circuit continue to increase for each cycle until the grid is driven positive in respect to the cathode.

When this condition occurs, there is grid current which must be supplied by energy from the plate circuit. This is known as the "driving power" and the more positive the grid is driven, the larger the required driving power.

When the a-c power generated in the plate circuit is just sufficient to supply that required by the grid circuit, the

tuned circuit, the plate resistance and other losses, a state of equilibrium is reached and the values of a-c plate voltage, grid voltage, plate current and grid current become fixed and constant.

As explained in the earlier Lessons, grid current in resistance R of Figure 1 will produce the necessary grid bias voltage for the tube and, by selecting the proper values for R and C_1, the tube can be made to operate on the desired portion of its characteristic curve.

Condenser C is connected across the plate supply to provide a low impedance path for the r-f so that, in effect, the power supply is not in the high frequency circuit.

Thinking of coils L, L_1 and L_2 as a transformer, the plate coil L_2 is the primary while L and L_1 are secondaries. Thus, energy taken by the grid circuit of the load circuit will, as mentioned above, be supplied by the plate circuit.

The entire action of the circuit of Figure 1 can be thought of as self excited amplifier in which, by means of a feed back arrangement, energy from the output circuit is impressed on the input circuit. Keep this action in mind as it applies to most transmitting type oscillators.

TUNED PLATE-TUNED GRID

Another basic type of oscillator circuit is shown in Figure 2 and you will find the tuned circuit L_1-C connected to the grid while another tuned circuit, L_2-C_3 is connected to the plate. Therefore, the arrangement is commonly known as a "Tuned Plate Tuned Grid", (TPTG) type of oscillator.

Compared to the circuit of Figure 1, there is no apparent coupling between the plate coil L_2 and the grid coil L_1 of Figure 2. However there must be a "feed back" from the plate to the grid circuit in order to maintain the conditions required for oscillation and here, the coupling is the grid-plate capacity of the tube itself as indicated by C_4.

From our earlier explanations, you know that a-c signal circuits may be coupled inductively or by capacity. Comparing Figures 1 and 2, you will find the grid circuits are the same, but in Figure 1 the energy from the plate circuit is fed back to the grid circuit through the inductive coupling between L_2 and L_1.

In Figure 2, there is no inductive coupling between L_1 and L_2 but the energy of the plate circuit is fed back to the

grid circuit through the grid plate capacity of the tube, shown as C_4.

As we explained for Figure 1, the plate circuit energy must be fed back in proper phase and with sufficient amplitude to sustain the oscillations. Thus, although the grid-plate capacity of the tube is present in Figure 1, the untuned plate circuit does not provide sufficient feed back voltage. The frequency of oscillation of this circuit is determined by the LC combination which has the higher "Q".

In Figure 2, you will notice the plate coil L_2 is tuned by condenser C_3 and, by tuning this circuit to a frequency slightly above the resonant frequency of the grid circuit, it becomes inductive, causes a lagging plate current and produces the proper phase relationship.

The other circuit components of Figure 2 are the same as explained for Figure 1 but you will notice the load coil "L" is now coupled inductively to the plate coil L_2. Perhaps it would be simpler to state that in Figure 2, the grid coil is not inductively coupled to either the plate or load coils.

In this type of equipment, tuned circuits, such as L_1-C and L_2-C_3 are known as "Tank" circuits and to distinguish them, in Figure 2, L_1-C is the "Grid Tank" and L_2-C_3 is the "Plate Tank".

THE HARTLEY OSCILLATOR

From the standpoint of the required number of parts, the Hartley Oscillator of Figure 3 is one of the simplest types. The tank circuit consists of the tapped coil, shown as L_1-L_2 and the tuning condenser C. Although shown as a single coil, L_1 and L_2 need not be wound on the same form or be inductively coupled because, connected in series, the circulating current of the tank circuit passes through both.

One end of this coil is coupled to the plate, through the blocking condenser C_2, the other end is connected to the grid through the C_1-R combination and the tap, which can be thought of as a common return for both circuits, connects to the cathode of the tube and B-. Oscillation is maintained because the circulating current in the tank circuit produces voltage drops across L_1 and L_2, which are 180° out of phase in respect to the common return or tap.

There are a number of variations of this circuit but the principle of operation is the same for all. The load coil L is inductively coupled to the tank coil, while R and C_1 in the grid circuit serve the same purpose as similar units in Figures 1 and 2.

The Radio Frequency Choke, (R F C), connected between "B+" and the plate, must have a high reactance, compared to that of condenser C_2, at the oscillation frequency, in order that sufficient r-f voltage will be impressed on the L_1 part of the coil.

COLPITTS OSCILLATOR

The Colpitts Oscillator of Figure 4 is quite similar to the Hartley of Figure 3 and the principles of operation are the same for both. For the Hartley, the tank coil is tapped while for the Colpitts, in effect, the tank capacity is tapped.

From a practical standpoint, the tank capacity is in two parts, C and C_1, the grid circuit across C_1, the plate circuit across C and the coil L_1, across both. Here, the amount of feed back is controlled by changing the relative values of C and C_1. The smaller the capacity of C_1, the higher its reactance and the greater the difference of potential across it.

While quite similar in operation, both the Hartley and Colpitts oscillators claim certain advantages. For example, the Hartley is simpler to tune but the adjustment of the feed back, or tap on the coil is more inconvenient. For the Colpitts, the feed back voltage ratio can be easily adjusted by employing variable condensers. With fixed condensers, the inductance of the coil may be varied, or plug in coils, covering a wide range of frequencies, can be used without disturbing the feed back voltage ratio.

THE ULTRAUDION

For the circuit of Figure 5, we show one of the oldest types of tube oscillators, known as the ultraudion. While oscillators of this type are not particularly stable at the lower radio frequencies, they have proven quite satisfactory in some ultra high frequency applications. Checking up here, you will find the circuit resembles both the Hartley and Colpitts but there are some important differences.

To follow the circuit action, we will assume the tube is operating so that when the plate circuit is closed there is a rush of current in it. The resulting change of voltage, across the plate circuit of the tube is impressed on the parallel circuit made up of L_1-C, and series C_1.

The portion of this drop, which appears across C_1 is impressed on the grid circuit, R F C and R, through a low reactance condenser C_2. This is the grid excitation voltage, which causes the tube to oscillate and, as explained for Figure 4, its value can be controlled by varying the capacity of condenser C_1.

In our explanations so far, we have assumed the frequency at which the oscillator operates to be controlled by the values of inductance and capacity in the tank circuit. However, the inter-element capacities of the tube may resonate with the grid and plate circuit leads, which can be thought of as one turn inductances, to produce oscillations at a frequency much higher than the resonant frequency of the tank circuit.

This action is known as "Parasitic Oscillation" and is undesirable because it absorbs power, acts as a power loss and therefore reduces the available power output. The R F C in the grid circuit of Figure 5 is a common arrangement to prevent "Parasitics".

The inductance of the choke offers a much higher impedance to the higher Parasitic frequency, detunes the circuit and prevents Parasitic oscillation. You will find r-f chokes inserted in the grid circuit, plate circuit, or both, to prevent the generation of parasitics.

Low frequency parasitics sometimes occur when r-f chokes, in both the grid and plate circuits, resonate at about the same frequency because of coupling through circuit condensers. As the inductance value of these chokes is not critical, one common plan is to use units of different inductance so that their resonant frequencies will be sufficiently different to avoid the action of Figure 2.

ELECTRON COUPLED OSCILLATOR

All of the oscillators, explained so far, are fundamental types and have little practical value as far as present day transmitting is concerned. They are known as "Self Excited" because of the feed back from the plate to the grid and any changes in the plate circuit have a tendency to cause a variation of the generated frequency.

With the present crowded radio frequency spectrum and definite allocations, a variation of Transmitter frequency will cause interference between stations and may prevent the reception of important signals. To give you an idea of the importance of this condition, all present Broadcast Stations must not vary more than 50 cycles from their frequency allocations.

New Broadcast Stations must not vary more than 20 cycles from their frequency allocations and, in the near future, the older stations must meet the new requirement. For a station operating with a 1000 KC carrier, this means an accuracy of 20 parts in a million which is .002%.

Because of its frequency stability and ease of tuning, the Electron Coupled Oscillator, (eco) of Figure 6 is used in many Amateur Transmitters. One common form of its circuit is shown in Figure 6 and, like other oscillators, its frequency is determined by the values of inductance and capacity in the grid tank circuit LC. The circuit differs from the conventional oscillator in that no capacitive, inductive or direct coupling exists between the grid and plate circuits. Here, the load on the oscillator is coupled to the tank circuit by means of the electron stream.

To fully understand its operation, let us consider the arrangement of Figure 6 and, for the time being, neglect the tube plate circuit. When a positive voltage is first applied to the screen grid, there will be a surge of screen current to the cathode and through the lower part of coil L. This coil acts as an auto transformer and with a changing current in the lower portion, a voltage will be induced in the complete winding. As the grid circuit is connected across the upper portion of the coil, the induced voltage will cause a further change of screen current. This action continues until a state of equilibrium is reached, and the a-c values of voltage and current become fixed.

As stated above, the frequency of this oscillation is determined by the inductive and capacitive values in the tank circuit. The action of condenser C_1 and resistance R is to provide a d-c bias so the tube will operate on the desired portion of its characteristic curve.

So far then, we have nothing but a simple regenerative type of oscillator, similar to that of Figure 1 except that, in effect, the plate coil is connected between cathode and "B-". However, the screen grid of a tube is made of a mesh material and by operating it at a lower potential than the plate, only a small number of the electrons will be attracted to the screen while the rest will go to the plate. Only enough electrons, to supply the driving power for the oscillator, need be taken by the screen grid.

The electrons pass through the screen in pulses, the frequency of which is determined by the oscillation of the inner elements, and this pulsating current develops power in the plate circuit load. Thus, the only coupling between the oscillator and the load is the electron stream which passes through the screen and thereby we derive the name "electron coupled oscillator".

It has been found that increasing the plate voltage will shift the frequency of the electron coupled oscillator in one direction while increasing the screen voltage will shift it in the

opposite direction. Thus, by supplying the screen voltage through a voltage divider arrangement in the plate supply, the screen voltage can be adjusted to a value which will make the frequency independent of the plate supply voltage. This is because any change in frequency, due to a slight change in plate voltage, will be neutralized by an opposite change in frequency due to the change in screen grid voltage. In general, the stability will be best when the ratio of the plate to screen grid voltage is about three to one.

In Figure 6, condenser C_2 places the screen grid at ground r-f potential and causes it to act as an electrostatic shield between the output or load circuit and the oscillating circuit. This arrangement prevents variations in the output circuit from affecting the frequency determined by the L-C tank circuit.

Pentodes can be used in the eco's but it is preferable to connect the suppressor grid to the screen grid rather than the cathode, in order to obtain additional internal sheilding of the load circuit from the oscillator circuit.

It is difficult to obtain good frequency stability as well as high power output from oscillators of this type. Therefore, instead of attempting to obtain both of these desirable characteristics from one unit, an oscillator and power amplifier arrangement is most frequently employed. A low power oscillator is used to provide good frequency stability and its output is fed to a power amplifier where large power output is obtained. This arrangement is known as a "Master Oscillator Power Amplifier", commonly abbreviated, "MOPA".

QUARTZ CRYSTALS

There are several crystalline materials which possess piezo-electric properties, although quartz is most commonly employed for frequency control apparatus.

Figure 7 shows a whole, or parent, crystal and the dashed lines represent three major axes. The letter X is used to denote the electrical axis, Y the mechanical axis and Z the optical axis. The raw crystal is usually first cut into rods, some having the hexagon shape illustrated by Figure 8. These rods are then cut down to desirable "plates" or crystals for a definite service.

Crystals cut from a quartz rod have good mechanical strength, small charge in vibration frequency with temperature and comparatively low cost.

Perhaps you are wondering just what the term "vibration frequency" means but every object has a natural period of vibration or what might be called the mechanical resonant frequency at which it will vibrate when subjected to a sudden force. A good example of this is the sound produced by a drinking glass when struck by a knife or fork. The frequency of this sound is the "vibration frequency" of the glass. The natural vibration frequency of any object will be determined by its size or shape and the elasticity or give of the material from which it is made. Also, if the object is to be maintained in a state of continuous vibration, energy must be supplied periodically to take care of the frictional losses.

As a quartz crystal comes under the heading "any object" it also has a natural period of vibration and if a force is applied to it and suddenly removed, the crystal will vibrate at its natural frequency. A vibrating crystal however, due to its piezo-electric properties, produces an electrical voltage of the same frequency as the mechanical vibration, hence the vibrating crystal becomes a voltage generator. This action also works in reverse and an electrical force will cause the crystal to vibrate mechanically so that the initial vibration in a crystal can be produced by an emf.

TEMPERATURE COEFFICIENT OF FREQUENCY

Although the piece of quartz used as a resonator in Figure 9 is generally called a "crystal", it is not a whole crystal but only a section of one cut to certain dimensions and specifications. The frequency at which the crystal vibrates depends mainly on the thickness of the cut, being inversely proportional to the thickness. That is, the thinner the cut, the higher the generated frequency.

There are several different cuts which can be made from a parent crystal and the main difference between plates cut in different ways is the temperature coefficient of frequency, that is, how much the frequency changes for every degree change in crystal temperature.

For example, as shown by Figure 8, a plate cut with its major surfaces perpendicular to an X axis is known as an X cut plate and it has a negative temperature coefficient. That is, when the temperature increases, the frequency decreases. For a Y cut crystal, the plate is cut from the parent so that its major surfaces are parallel to the X axis and it has a positive temperature coefficient.

Using some definite values, the temperature coefficient of frequency of a good X cut crystal is about .0022 per cent per degree centigrade while that of a good Y cut is about .007 per cent per degree centigrade. To compare these two cuts, let us assume a transmitter operating on an assigned carrier of 1000 kc and that for some reason, the temperature of the crystal has increased 10 degrees Centigrade.

Under these conditions, for an X crystal, the frequency would decrease by 1000000 x .000022 x 10 or 220 cycles. With these same conditions, for a Y cut, the frequency would increase by 1000000 x .00007 x 10 or 700 cycles. Thus, it can be seen that the X cut is superior for frequency stability but, in both cases, the deviation is considerably greater than that allowed by the FCC.

The fact that the temperature coefficient of X and Y cuts are opposite led to the belief that it might be possible to cut a crystal somewhere between them with a zero temperature coefficient. This would mean that temperature would not have any effect on its frequency.

Working along this line, the Bell Telephone Laboratories developed an AT cut shown by Figure 8 to be at an angle with the Z axis, while RCA developed a V cut both of which have temperature coefficients of 2 parts per million per degree Centigrade. This is the same as saying .0022 per cent per degree Centigrade. Using one of these crystals, in our former example, the frequency change would be only 1000000 x .000002 x 10 or 20 cycles, which is within the FCC requirements.

However, in the transmitting room, the temperature may vary considerably more than the 10° Centigrade change used in our example and therefore precautions must be taken to hold the crystal temperature constant.

CONSTANT TEMPERATURE OVENS

In order to maintain the frequency of the crystal well within the limits allowed by the Federal Communications Commission, the temperature of the crystal must be maintained approximately constant. This is accomplished by placing the crystal in a constant temperature oven which is nothing but a well constructed, air tight box, having heat insulated walls and containing a thermostat and a small heater. The thermostat is quite commonly a bimetallic snap action automatic switch while the heater may be simply a coil of resistance wire through which an electric current is passed.

When placed in operation, the thermostat is adjusted so that its contacts are opened when a certain temperature is reached. Obviously, the contacts should be set to open at a temperature exceeding that which may be reached outside of the oven because the apparatus in the oven heats it but no provision is made for cooling.

When the temperature in the oven falls below that for which the thermostat is adjusted, the contacts close and allow current in the heater element. When the proper temperature is reached, the contacts open and the heater is made inoperative. As the oven is now at a higher temperature than the room, the heat gradually leaks out until the temperature is again of such value to operate the thermostat and the above cycle is repeated. Thus, the temperature variation of the crystal is dependent only upon the sensitivity of the thermostat.

For broadcast stations, the FCC requires that for ordinary crystals the temperature be maintained within 0.1° Centigrade while for low coefficient crystals, the temperature must be maintained within only 1° C. In order to maintain the temperature within the .1° C limits, costly and elaborate control apparatus is required and even then, many stations have had difficulty. For this reason the low coefficient crystal, even though it is more expensive than others, is being used more and more because it is comparatively easy to keep its temperature within the 1° C tolerance.

Ovens, not much larger than a regular mounted crystal, are now available with plug-in connections so that a defective unit can be replaced in a few seconds. However, for this service, spare units should be connected to a proper heater supply so that the crystal will be held at the proper temperature and placed in operation, without a "warm up" period, when a change is made.

For transmitters, other than broadcast, the temperature control ovens are not required by the FCC. However, whenever it is practical, they should be included as part of the installation so that the frequency deviation is kept at a minimum. For aircraft, where weight is a factor in the safety of the plane, and for police cars where interference from other stations is not a serious problem, the use of oven temperature control is considered impractical. Transmitters of this type, therefore, employ low temperature coefficient crystals so that their frequency deviation does not become too great.

THE CRYSTAL OSCILLATOR

In order to stay within the allowable carrier frequency deviation, practically all commercial transmitters use a

crystal controlled master oscillator and in Figure 9, a simplified arrangement of such a circuit is shown. You may recognize this as being very similar to a crystal controlled oscillator circuit explained in an earlier Lesson and will remember that its operation is dependent on the remarkable piezo-electric properties of certain crystals.

If the crystal is to generate a continuous or undamped voltage wave, enough energy must be supplied periodically to overcome its frictional losses. The circuit of Figure 9 is arranged to supply these losses and with the above explanations you should not have any difficulty in following its action.

The initial impulse of energy, which causes the crystal to start vibrating, is obtained when the plate voltage is first applied and there is a surge of current across the grid-plate capacity of the tube. This current also passes through the crystal and causes it to vibrate at its natural or resonant frequency. As a result of the vibration, a voltage is produced across the two plates, between which the crystal is mounted. Due to the electrical connections, this voltage is applied to the grid, is amplified by the tube and appears as a much larger voltage in the plate circuit. Enough energy is then fed back through the grid plate capacity of the tube to keep the crystal vibrating and the remainder of the plate circuit energy goes into the load and plate circuit losses.

It is sometimes convenient to explain the operation of a crystal-oscillator by replacing the crystal with its equivalent electrical circuit. This circuit is considered as being made up of a resistance, inductance, and capacity connected in series, the combination shunted by a second capacity. The resistance is the electrical equivalent of the give or elasticity of the material. The shunt capacity is formed by the two metal plates of the crystal holder and is very large compared to the series capacity- hence the frequency of resonance, which is the mechanical resonant frequency of the crystal, is determined primarily by the values of the series inductance and capacitance.

In this equivalent circuit, the L/C ratio is very high and the resistance small so that the Q or ratio of reactance to resistance is very high. In fact, it is much higher than can ordinarily be obtained by means of coils and condensers and therefore very little energy is required to keep the crystal oscillating.

We want you to notice also that if this equivalent circuit were placed in the grid circuit of Figure 9, the arrangement

and action would be very similar to that explained for the TPTG of Figure 2. Also, like Figure 2, the plate tank circuit, LC of Figure 9, should be tuned to a frequency slightly higher than the crystal frequency so as to reflect the proper impedance into the grid circuit.

Like the other circuits we have explained, the RFC is to prevent parasitic oscillation while the voltage drop across resistance R provides the desired grid bias.

POWER OUTPUT AND EFFICIENCY

An oscillator, of any type, is a generator and as such must be capable of supplying more power than that necessary to keep it operating. If it would only maintain itself, it would have as little value as an automobile engine which could run but could not deliver power to turn the wheels of the car. To be of practical value, an oscillator must deliver enough power to take care of its own losses, and supply additional power to some external load which may be the grid circuit resistance of an amplifier tube or the resistance of an antenna.

The efficiency of an oscillator will therefore be determined by how small the losses can be kept in comparison to the power delivered to the load. The losses in an oscillator consist of the power consumed in heating the tuned circuit resistance, the grid to cathode resistance and the plate to cathode resistance. As the power taken by the oscillator comes from the B supply, excluding the power taken by the filament of the tube, the power input will be the product of the B supply current and the B supply voltage, that is:

1. $P_I = E_B I_B$

This is often referred to as the plate power input.

Since the current taken from the B supply is the plate current of the tube, the power input to the oscillator can be expressed as

2. $P_I = E_B I_P$

If there is no appreciable d-c voltage drop in the plate coil and no cathode biasing resistor, the d-c plate voltage on the tube will equal the B supply; and the power input can then be expressed by

3. $P_I = E_P I_P$

As the a-c power output can be found by measuring the current or voltage in the load, the power output will be given by

$$4. \quad P_o = I_L{}^2 R_L$$

or

$$5. \quad P_o = \frac{E_L{}^2}{R_L}$$

The efficiency of the oscillator will then be expressed by

$$6. \quad \text{eff} = \frac{P_o}{P_I} = \frac{I_L{}^2 R_L}{E_p I_p}$$

and thus represents the degree to which the d-c power of the B supply is converted into useable a-c power.

In the above formulas,

P_I = Power Input
P_o = Power Output
E_B = B supply voltage
I_B = B supply current
E_p = Plate voltage
I_p = Plate current
E_L = Voltage across the load
I_L = a-c current in the load
Eff = Efficiency
R_L = Load Impedance

When used in an oscillating circuit, the power output of a tube will depend largely on the class of operation. If the tube is operated in Class A, the maximum power output will be that obtained for a load equal to its plate resistance.

If the tube is operated in Class B or C, the power output will be determined by the load and how hard the tube is driven. In any type of operation the maximum heat dissipation of the plate should not be exceeded. The plate power dissipation for a tube used as an oscillator, under any operating conditions, can be found by subtracting the power output, plus the power consumed in the grid circuit, from the power input.

UNITED STATES RADIO DISTRICTS

District	Territory	Address, Radio Inspector-in-Charge
No. 1	The States of Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island and Vermont	Customhouse, Boston, Mass.
No. 2	The counties of Albany, Bronx, Columbia, Delaware, Dutchess, Greene, Kings, Nassau, New York, Orange, Putnam, Queens, Rensselaer, Richmond, Rockland, Schenectady, Suffolk, Sullivan, Ulster and Westchester of the State of New York; and the counties of Bergen, Essex, Hudson, Hunterdom, Mercer, Middlesex, Monmouth, Morris, Passaic, Somerset, Sussex, Union and Warren of the State of New Jersey.	Federal Building, 641 Washington St., New York, N.Y.
No. 3	The counties of Adams, Berks, Bucks, Carbon, Chester, Cumberland, Dauphin, Delaware, Lancaster, Lebanon, Lehigh, Monroe, Montgomery, Northampton, Perry, Philadelphia, Schuylkill and York of the State of Pennsylvania; and the counties of Atlantic, Burlington, Camden, Cape May, Cumberland, Gloucester, Ocean and Salem of the State of New Jersey; and the county of Newcastle of the State of Delaware	Room 1200, U. S. Customhouse, Second and Chestnut Sts., Philadelphia, Pa.
No.4	The State of Maryland; the District of Columbia; the counties of Arlington, Clark, Fairfax, Fauquier, Frederick, Loudoun, Page, Prince, William, Rappahannock, Shenandoah and Warren of the State of Virginia; and the counties of Kent and Sussex of the State of Delaware.	Fort McHenry, Baltimore, Md.
No. 5	The State of Virginia except the part lying in District 4, and the State of North Carolina except that part lying in District 6.	402 New Post Office Bldg. Norfolk, Va.

UNITED STATES RADIO DISTRICTS

District	Territory	Address, Radio Inspector-in-Charge
No. 6	The States of Alabama, Georgia, South Carolina and Tennessee; and the counties of Ashe, Avery, Buncombe, Burke, Caldwell, Cherokee, Clay, Cleveland, Graham, Haywood, Henderson, Jackson, McDowell, Macon, Madison, Mitchell, Polk, Rutherford, Swain, Transylvania, Watauga and Yancey of the State of North Carolina.	411 Federal Annex, Altanta, Ga.
No. 7	The State of Florida.	312 Federal Bldg., Miami, Fla.
No. 8	The States of Arkansas, Louisiana and Mississippi; and the city of Texarkana in the State of Texas.	326 Customhouse, New Orleans, La.
No. 9	The counties of Arkansas, Brazoria, Brooks, Calhoun, Cameron, Chambers, Fort Bend, Galveston, Goliad, Harris, Hidalgo, Jackson, Jefferson, Jim Wells, Kenedy, Kleberg, Matagorda, Nueces, Refugio, San Patricio, Victoria, Wharton and Willacy of the State of Texas.	404-406 Federal Bldg., Galveston, Texas
No. 10	The State of Texas except that part lying in District 9 and in the city of Texarkana; and the States of Oklahoma and New Mexico.	302 U.S. Terminal Annex Bldg., Dallas, Texas.
No. 11	The State of Arizona; the county of Clarke in the State of Nevada; and the counties of Imperial, Inyo, Kern, Los Angeles, Orange, Riverside, San Bernardino, San Diego, San Luis Obispo, Santa Barbara and Ventura of the State of California.	1105 Rives-Strong Bldg., Los Angeles, Calif.
No. 12	The State of California except that part lying in District 11; the State of Nevada except the county of Clarke.	328 Customhouse, San Francisco, Calif.
No. 13	The State of Oregon; and the State of Idaho except that part lying in District 14.	207 New U.S. Courthouse Bldg., Portland, Ore.

UNITED STATES RADIO DISTRICTS

District	Territory	Address Radio Inspector-in-Charge
No. 14	The Territory of Alaska; the State of Washington; the counties of Benewah, Bonner, Boundary, Clearwater, Idaho, Kootenai, Latah, Lewis, Nez Perce and Shoshone of the State of Idaho; the counties of Beaverhead, Broadwater, Cascade, Deerlodge, Flatheat, Gallatin, Glacier, Granite, Jefferson, Lake, Lewis and Clark, Lincoln, Madison, Meagher, Mineral, Missoula, Pondera, Powell, Ravalli, Sanders, Silver Bow, Teton and Toole of the State of Montana.	808 Federal Office Bldg., Seattle, Washington
No. 15	The States of Colorado, Utah and Wyoming; and the State of Montana except that part lying in District 14.	504 Customhouse, Denver, Colo.
No. 16	The States of North Dakota, South Dakota and Minnesota; the counties of Alger, Baraga, Chippewa, Delta, Dickinson, Gogebic, Houghton, Iron, Keweenaw, Luce, Mackinac, Marquette, Menominee, Ontonagon and Schoolcraft of the State of Michigan; and the State of Wisconsin except that part lying in District 18.	927 New P. O. Bldg., St. Paul, Minnesota
No. 17	The States of Nebraska, Kansas and Missouri; and the State of Iowa except that part lying in District 18.	609 Pickwick Bldg., 903 McGee Street, Kansas City, Mo.
No. 18	The States of Indiana and Illinois; the counties of Allamakee, Buchanan, Cedar, Clayton, Clinton, Delaware, Des Moines, Dubuque, Fayette, Henry, Jackson, Johnson, Jones, Lee, Linn, Louisa, Muscatine, Scott, Washington, and Winneshiek of the State of Iowa; the counties of Columbia, Crawford, Dane, Dodge, Grant, Green, Iowa, Jefferson, Kenosha, Lafayette, Milwaukee, Ozaukee, Racine, Richland, Rock, Sauk, Walworth, Washington and Waukesha of the State of Wisconsin.	246 U.S. Courthouse Bldg., Chicago, Ill.

UNITED STATES RADIO DISTRICTS

District	Territory	Address, Radio Inspector-in-Charge
No. 19	The State of Michigan except that part lying in District 16; the State of Ohio, Kentucky and West Virginia.	1025 New Federal Bldg., Detroit, Michigan
No. 20	The State of New York except that part lying in District 2, and the State of Pennsylvania except that part lying in District 3.	514 Federal Bldg., Buffalo, N. Y.
No. 21	The Territory of Hawaii, Guam and American Samoa.	Aloha Tower, Honolulu, T.H.
No. 22	Puerto Rico and Virgin Islands	303 Ochoa Bldg., San Juan, P.R.

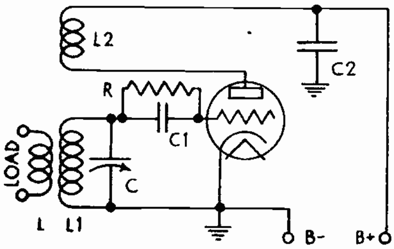

FIGURE 1

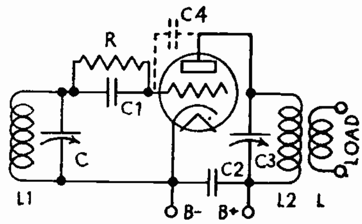

FIGURE 2

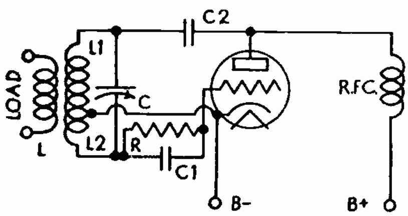

FIGURE 3

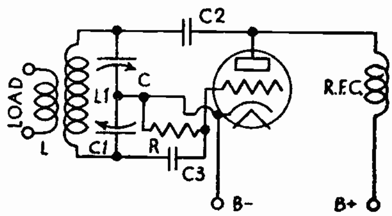

FIGURE 4

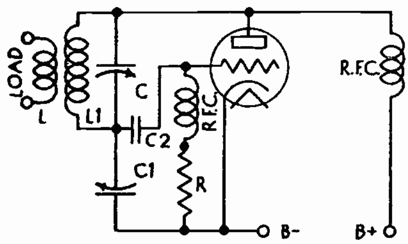

FIGURE 5

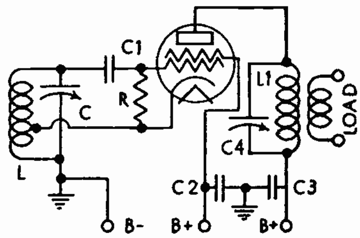

FIGURE 6

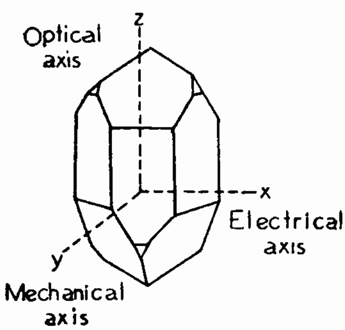

FIGURE 7

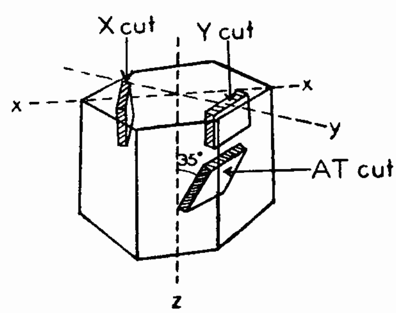

FIGURE 8

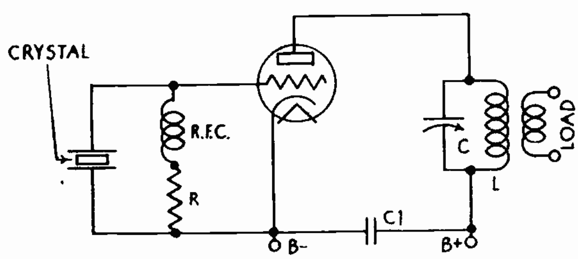

FIGURE 9

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LESSON RRT-16

R-F AMPLIFIERS

* * * * * * * *

What ever you do, try to do it better than anyone else can do it, and nothing can prevent you from coming to the top.

Dr. Frank Crane

VOLTAGE AMPLIFIERS

The subject of Radio Frequency amplifiers should not be strange to you because they are used in very nearly all of the modern receivers explained in the earlier Lessons. This may seem contradictory but you must remember that all frequencies above audibility are classed as r-f and therefore the i-f amplifiers of superheterodyne receivers fall into the general classification of "R. F. Amplifiers".

In receivers, the purpose of these amplifiers is to increase the amplitude of the modulated carrier so that it will be of sufficient amplitude to operate the demodulator and no thought is given as to the power output of the tubes. In other words, their purpose is to increase the signal voltage and thus they are classed as "voltage amplifiers".

In order to obtain a linear output with high amplification, the tubes used in the r-f and i-f sections of Radio receivers are designed for an output of but a fraction of a watt and are operated in Class A. For the r-f amplifiers used in transmitters, however, the power outputs are rated in watts and kilowatts therefore, in order to obtain this power with good efficiency, the tubes are operated in Class B and C. Thus, for this Lesson, we want to explain the various classes of r-f amplification and show where they are used in transmitters.

R-F AMPLIFIER CIRCUIT

In the circuit of Figure 1, we show the simplified arrangement of a typical r-f amplifier stage as used in transmitters. There is nothing complicated about its action and the r-f input is coupled to the grid of the tube by condenser C and the radio frequency choke coil, R.F.C. As fixed bias is common for this type of circuit, we have indicated that it should be applied across C- and C+ with the negative of the supply connected to the grid circuit.

The plate circuit is conventional, being made up of the tank L-C_1 which is inductively coupled to L_1. The resistance R thus acts as the load on the plate circuit and can be considered as the grid resistance of a following stage or the resistance of an antenna. It might be well to mention here that, when working with transmitters, one has to think in reverse as compared to receivers, because the antenna now becomes a part of the output circuit, or load, on the final amplifier while with receivers, it is a part of the input circuit.

Going back to Figure 1, the high voltage is applied across B+ and B- while condenser C_2 is an r-f by-pass which permits

the r-f currents to complete their circuit to the cathode without passing through the power supply. As you will learn in a later Lesson, when using triodes for r-f amplification, it is necessary to use some method of neutralize the effects of the grid-plate capacity, but, for simplicity, this is not shown here. Also, in order to be operative, there would have to be a heater circuit for the tube and the proper voltage applied across it.

CLASS A AMPLIFICATION

The various types of r-f amplifiers used in Radio receivers and other Electronic equipment all operate in what is known as Class A. Although this type of operation was completely explained in the earlier Lessons, we feel that a brief review will be of benefit. As you will remember, a tube operating in Class A, has a negative d-c bias voltage of a value equal to or greater than the maximum signal voltage. Operating under these conditions, the straight part of the characteristic curve is utilized and linear amplification results.

In order that you may have a little better picture of what takes place, in Figure 2, we show the graphical representation of Class A operation. Here, we have the characteristic I_p-E_g curve with the plate current scale running vertically at the left and the grid voltage scale horizontally across the bottom. The a-c signal voltage, impressed on the grid of the tube, is represented by the small sine curve near the top of the Figure while the resulting plate current curve, shown at the right, has the same general shape but greater amplitude than the input signal.

As mentioned above, in order to obtain this linear relationship between the a-c signal input and plate current, it is necessary that the negative d-c grid bias voltage of the tube be properly chosen. From the I_p-E_g curve of Figure 2, is can be readily seen that this bias voltage should be of such value that the input voltage swing will always be on the straight part of the curve. This particular value of bias is indicated as "O.P." on the curve and represents the operating point of the tube.

Although no values are given in Figure 2, we will assume that the operating point (O.P.), shown on the curve, is obtained with a negative grid bias of 2 volts. Thus, in order to remain in Class A operation, the maximum grid input signal cannot exceed this value. When the positive swing of the input signal is equal to the bias voltage, the resultant grid voltage will be zero and on the negative alternation, the total grid voltage will be -4. Thus, the grid voltage swings between 0 and -4 volts causing a corresponding change in plate current.

Another point we want to bring up here is that for Class A operation, the grid bias is of such value as to allow plate current during each complete cycle of input voltage. That is, there are 360° in every electrical cycle and, in order for a tube to operate in Class A, there must be plate current during every electrical degree of each input cycle.

Thus, summing up, the complete and correct definition of a tube operating in Class A, is one whose negative d-c bias voltage is equal to, or greater than the maximum input signal voltage and with plate current existing during the complete 360 electrical degrees of each input cycle.

Assuming the curve of Figure 2 is the operating characteristic for the tube of Figure 1, a 2 volt supply, properly connected between C- and C+ of Figure 1, would allow the circuit to operate as a Class A, r-f amplifier. With high power tubes, this type of amplifier can be made to give fairly high power output, but its plate efficiency, which is the ratio between power input and output, is low and therefore it finds little use in the r-f power amplifier circuits of transmitters.

CLASS B AMPLIFIERS

From your earlier study of audio amplifiers, you will remember that when a tube operates in Class B, it is biased to plate current cut-off and therefore plate current exists only during the positive alternations of input signal.

To compare this condition, with that explained in Figure 2, we have drawn the curve of Figure 3 and you will find that about the only difference between them is in the position of the operating point "O.P." which is determined by the amount of negative grid bias applied to the grid of the tube. Notice also, that the plate current pulses occur only during the positive alternations of signal input and thus the tube action is similar to that of a half wave rectifier. It is because of this action that two tubes, operating in Class "B" push-pull, are required for audio work.

For r-f work however, a single tube Class B amplifier can be employed to amplify a modulated carrier wave, without appreciable distortion of the signal, because of the "fly-wheel" action that takes place in the plate tank circuit. This action is very important and, in our explanations, we will assume that the circuit of Figure 1 is now biased so that it now operates as a Class B amplifier. Before going ahead however, we want to explain an analogy which is quite similar to the action which takes place in the tank circuit L-C1 of Figure 1.

No doubt you are familiar with the usual type of play ground swing and, at some time or other, have been the one to supply the energy or "push" to some friend who desired to swing. Whether you have noticed it or not, the swing moved back and forth at some definite rate which depended on the length of the rope. To use technical terms, the movement of the swing, from start to the other side and back to the start position, is a cycle, the rate at which it makes the cycle is its frequency and the height it swings above the ground is its amplitude. Thus, a single swing has frequency and amplitude analogous to an a-c wave.

As stated above, the length of the rope controls the frequency which can be considered as the natural resonant frequency of the swing. The amplitude of each cycle, will, of course, depend on the applied energy or "push" but, regardless of the amount of energy applied, the frequency remains constant. If one "push" were given and the swing then left alone, it would oscillate back and forth with diminishing amplitudes to produce an effect analogous to a damped electrical wave.

However, you have probably found that if you pushed at just the right instant, it was quite easy to keep the swing going at the same amplitude. In other words, if you supply energy periodically, and at the right instant, both the amplitude and frequency of the swing remain constant. Therefore, because it is necessary to supply energy for only a small portion of the time, in order to maintain complete and uniform cycles, we way the swing has a fly-wheel effect.

Now here are the points we want you to establish firmly in your mind. The swing has a natural frequency which is determined by its physical arrangement; the amplitude of each cycle depends on the input energy and, with equal energy pulses applied at the proper time, both the amplitude and frequency can be kept constant.

Let's go back to Figure 1, which you will remember is now operating as a Class B amplifier, and compare its action to that of the swing. Here, the tank circuit $L-C_1$ is comparable to the swing and its natural resonant or vibration frequency will depend on the values of the inductance L and the capacity C_1. When a single pulse of energy is applied to this circuit, it will cause a circulating current at the resonant frequency, but, unless additional energy is supplied the current will die out in the form of a damped wave.

If additional energy is supplied periodically and at the proper instant, the circulating current can be maintained at all times and, if these energy pulses are of equal value, the amplitude of the circulating current will be constant. Thus we can say that, when a tube is operating on the linear part of its curve, the circulating current in the tank circuit of a Class B amplifier is proportional to the a-c voltage applied on the grid.

Checking back on our analogy, the swing can be compared to the tank circuit L-C1; the movement of the swing to the circulating tank current and the amplitude of the swing to the amplitude of the circulating current so that the "fly wheel" action of both is similar.

Summing up the electrical action, when an amplitude modulated carrier wave is impressed on the grid circuit of Figure 1, the amplitude of the pulses of current in the plate circuit will be proportional, within certain limits, to the amplitude of the a-c grid voltage. These plate current pulses charge condenser C_1 and set up a circulating tank circuit current which is proportional to the magnitude of the pulses. Thus, due to the "fly wheel" effect, the modulated carrier frequency is amplified with but negligible distortion of the modulating frequencies.

DRIVING POWER REQUIREMENT OF CLASS B AMPLIFIER

In our foregoing explanations of Class B amplifiers, we have not mentioned that, on signals of high amplitude, the grid is driven positive, causes current in its circuit and thus introduces a power loss in the stage. In order to prevent an exceedingly high distortion level, it is necessary that the grid power be supplied by the preceding stage.

As the peak plate current of a Class B amplifier tube occurs at the instant of peak grid voltage, its power output will be determined largely by the amount the grid is driven positive. However, there are certain limitations as to how far positive the grid can be driven. First, the grid current causes grid power dissipation in the form of heat and therefore the maximum positive grid voltage is determined by the safe heat dissipation limit of the tube.

Another limiting factor is that minimum plate voltage occurs at maximum grid voltage. If this is a little hard for you to see, just remember that the plate of the tube and its load are in series with the plate supply voltage. Thus, when the grid is driven positive, the plate current increases and causes a larger drop across the load which, in turn, reduces the plate voltage. Physically, the grid is closer to the cathode and if the minimum plate voltage approaches the

maximum positive grid voltage, the grid tends to take current which would normally go to the plate. This action results in a distorted plate current wave form and overheating of the grid.

Still another factor to be considered is that when grid current exists, power is absorbed in the grid circuit. As mentioned above, this power must come from the preceding stage and therefore the further the grid is driven positive, the more power the driver stage must be capable of supplying. Thus, it follows that in the design of a Class B, r-f stage, the driving power requirements must not be made excessive.

PLATE EFFICIENCY

As you perhaps know, the purpose of a tube and its circuits, operating as a power amplifier, is to change the direct current power available at the supply into a-c power in the tank circuit. Of course, the more efficiently this conversion is made, without objectionable distortion, the greater its usefulness.

The plate efficiency may be expressed as a percentage according to the following general formula:

$$\% \text{ Efficiency} = \frac{P_o}{P_{in}} \times 100$$

Where P_o is the a-c power output and P_{in} is the d-c power input. You will recognize this expression as the efficiency of an oscillator given in a former Lesson.

For example, let us assume a certain transmitting tube has a safe plate dissipation of 1000 watts and consider only the efficiency of the plate circuit. If the plate efficiency is 90%, the circuit could handle an input of 10,000 watts from the plate supply because 9000 would be dissipated in the load leaving the 1000 watts for the tube.

However, if the plate efficiency were 70%, the circuit output power would be determined as follows:

$$70 = \frac{P_o}{P_{in}} \times 100; \text{ but as } P_{in} = P_o + P_{tube},\ P_{in} = P_o + 1000$$

Substituting for "P_{in}",

$$70 = \frac{P_o \times 100}{P_o + 1000} \text{ and rearranging, } 70\,P_o + 70000 = 100\,P_o$$

Collecting, $30\,P_o = 70000$ the power output $P_o = \frac{70000}{30} = 2333$ watts.
The power input (P_{in}) equals 2333 + 1000 = 3333 watts.

Thus, a reduction in the plate efficiency from 90% to 70% would cause the power output to the load to reduce from 9000 watts to 2333 watts or by approximately (6667/9000) 75%.

In radio- telephone transmitters, Class B radio frequency power amplifiers are generally used to amplify the modulated carrier wave, and are called "post modulated" stages. Unfortunately, the plate efficiency of these stages is far below the values given above, usually being between 25 and 33 per cent. Thus, there is always the desire to increase the output efficiency but, when this is done, the adjustments generally result in a distorted modulation envelope which means that the audio signal will not be amplified with good fidelity.

There are various circuits which have been developed to overcome this fault but, in every case, they require additional equipment. One circuit arrangement has been developed by W. H. Doherty of the Bell System Laboratories.

DOHERTY TYPE HIGH EFFICIENCY CLASS B R-F AMPLIFIER

In the high efficiency Doherty type of Class B, r-f amplifier, two tubes are employed. One, called the "carrier tube" is operated at or very near its plate current saturation point when the unmodulated carrier wave only is impressed on its grid circuit. Thus, with a modulated carrier applied, it is possible for it to follow only the negative swings of the modulation. The other, called the "peak tube", is operated so that it draws approximately no plate current when the unmodulated carrier only is applied to its grid circuit. However, when the carrier is modulated, the peak tube delivers power on the positive swings of the modulation. Consequently, when the tubes function, they deliver a larger proportion of their rating with an increased efficiency.

At first thought, it may seem that this could easily be accomplished by connecting two tubes in parallel and operating their grids at different bias voltages. However, this is not true because, under these conditions, the output of the carrier tube would be applied to the peak tube, preventing its output from being in proportion to the positive input swings of the modulation, and resulting in a distorted envelope. In the Doherty system, this "mixing" action is obtained by the use of an impedance inverting network between the carrier tube and the load, or output.

Checking through the "carrier tube" circuits, the r-f input is applied across the inductance L and because of the inductive coupling is carried over to L_1 which is tuned to resonance by condensers C and C_1. The voltage drop across this tuned circuit is applied to the grid of Tube T_1 through the coupling

condenser C_2 and rfc_1. As previously explained, this tube is biased so that it operates at the plate saturation point.

Going ahead with the signal, it will appear across the plate load rfc_2 which is coupled to the tank circuit L_5-C_{11} through condenser C_{10}. This tank circuit is tuned to resonance by condenser C_{11} and because of the inductive coupling, the signal appears across L6. The load, R_1, is connected across L6 through the "impedance inverting" network, made of of L7, C_{12} and C_{13}.

The path of the signal through the "peak tube" circuits is the same as explained above except that the impedance inverting network, made up of L_2, C_3 and C_4, is placed in the input circuit. The tube T_2, is biased so that it will deliver power only on the positive swings of the modulation and its output signal voltage appears across L_9.

Checking back on these explanations, with a modulated carrier as the "R-F" input" in the circuits of Figure 4, the negative swings of the modulation will produce a voltage across L_6 while the positive swings will produce a voltage across L_9. As the load connects across L_6 and L_9, which are in paralled to each other, R_1 will carry the complete modulated carrier made up of the outputs of both tubes.

IMPEDANCE INVERTING NETWORK

So far in our explanation, we have just mentioned the impedance inverting networks but, as the operation of the system depends on them, we want you to have a good understanding of their action. Fundamentally, these networks are equivalent to a quarter-wave transmission line and, as such, have the characteristic that their impedance, as measured at one end of the network is inversely proportional to an impedance connected across the other terminals. That is, in Figure 4, the impedance, as measured across C_{12}, increases if the load R_1 is decreased and decreases if the load is increased.

Stating the same facts a little differently, tube T_2 works into Load R_1 directly, whereas the carrier tube T_1 "sees" a load of 1/R ohms, and thus its load will vary inversely as the load resistance R_1. Read this statement over several times because it describes the action which allows the circuit to perform satisfactorily.

The network, shown as C_{12}-L_7-C_{13} in Figure 4 is designed to present an impedance of such value that tube T_1 must operate at nearly its maximum possible radio frequency plate voltage swing in order to deliver the carrier power. You will also

remember that tube T_2 is operated so that it will deliver power only on the positive swings of the modulation therefore, at all other times, the carrier tube is the only one delivering power.

During the positive alternations of the modulation, the peak tube delivers power to the load R_1 which, in effect, increases the load resistance. However, due to the inverse characteristic of the network, this results in a decrease of the impedance presented to the carrier tube T_1. With a decreased impedance, its plate current will increase, without an increase of the alternating plate voltage, which is already at maximum, and result in an increase of its power output.

When the peak of the modulation envelope is applied to the grid of the peak tube, it is delivering its maximum power output which is half of the power in the load R_1. Under these conditions, the effective resistance of R_1 has increased to twice its original value and because of the action of the network the impedance presented to T_1 has decreased to half of its original value. Thus, the carrier tube can deliver twice its original output power with no increase in its output voltage. The total power in the load, at peak modulation input, is thus equal to four times the carrier power which corresponds to increasing the current in the load to twice its carrier value.

As indicated previously, the inverting network may be considered a quarter wave transmission line and, from a previous lesson, the characteristic impedance of such a line is given by: $Z = \sqrt{L/C}$. Removing the square root sign, $Z^2 = L/C$. It can be shown that $Z_o^2 = Z_{in} \times Z_L$, where Z_o is the characteriastic impedance of the line, Z_{in} the input impedance and Z_L the load impedance. If, in Figure 4, we let R_1 represent Z_L and L_2 represent Z_{in}, then the product of $R_1 \times L_2 = Z_o^2$. When the peak tube starts to deliver power to R_1 the effect is to increase the impedance of R_1. In order for Z_o^2 to remain constant, the impedance of the input circuit L_2 must decrease. Therefore, the property of the impedance inverting network has permitted the load on the carrier tube to decrease when the peak tube starts to deliver power to the load.

From the above explanations, you can easily see the necessity for the impedance inverting network because if it were not used, when the peak tube started delivering power, the effective impedance presented to the carrier tube would increase and, as its alternating plate voltage is at maximum, the current would decrease and result in a decrease of out-out power instead.

In addition to the action already explained, the impedance inverting network has the characteristic of shifting the phase of the signal by 90° and thus, to keep the output of both tubes in phase, a similar network is placed in the output circuit of the peak tube. In Figure 4, this is represented by the combination of L_2, C_3 and C_4 while resistance R is the load on the input network. Also, in Figure 4, the capacities C_8 and C_9 are neutralizing condensers, the adjustment of which will be explained in a later Lesson.

The complete Doherty Class B radio frequency amplifier will give good linear operation with a very high efficiency, compared to the ordinary type of post-modulated Class B r-f amplifier, and therefore it is quite extensively employed in modern radio broadcast transmitters.

CLASS C R-F AMPLIFICATION

From the earlier explanations of this Lesson, you can see that the shorter the plate current pulses, or the fewer the electrical degrees they exist, the smaller the amount of power absorbed at the plate of the tube and the higher the plate efficiency. This is true because, with shorter plate current pulses, the average current drawn from the supply is reduced and therefore, in modern transmitting design, it is common practice to bias the tube beyond cut off so that plate current exists for less than 180 electrical degrees. Operating in this way, the tube is said to be working as a Class C amplifier.

In Figure 5, we show curves of a tube operating as a Class C amplifier and want you to notice that the operating point, "O.P.", is now at a point beyond plate current cut off. As a matter of fact, this tube is biased so that plate current exists for only about 120 electrical degrees of each complete input cycle.

Due to the short period of plate current for each complete input cycle, the distortion in a Class C amplifier is very great. However, this is not detrimental when an unmodulated carrier only is to be amplified and, as will be explained in a later Lesson, a Class C amplifier can be modulated without serious distortion of the modulating signal. For post modulation stages, however, the Class C amplifier cannot be used without greatly distorting the modulated carrier envelope.

As we pointed out above, the shorter the period of plate current for each complete input cycle, the greater the plate efficiency. In fact, by making the current pulses extremely short, the efficiency can be made to approach 100% but, by

going to this extreme, the input is reduced with a resulting decrease of power output. Therefore, in practical work, it is necessary to make a compromise between high efficiency and power output. Under the usual operating conditions for Class C, r-f amplifiers, the plate current pulses exist for about 120 to 150 electrical degress to produce practical efficiencies somewhere between 60 and 80 per cent.

Due to this comparatively high efficiency, Class C operation is employed in transmitters wherever it is possible. For example, in a radio telegraph transmitter all stages, including the master oscillator may be operated in Class C with a resulting high efficiency system. In a radio telephone transmitter, when the final stage is modulated, all the r-f section may be operated in Class C. However, as pointed out above, when an amplifier follows the modulated stage, it must be operated in Class B so as to prevent distortion of the modulated carrier envelope.

CLASS C GRID BIAS

In our definition of Class C operation, we said that the grid bias could be of any value beyond plate current cut off but, experience has shown that, for amplifiers working with an unmodulated carrier such as in a telegraph transmitter, a negative bias of about twice plate current cut off is recommended. That is, if a bias of -30 volts produces cut-off, for the service just mentioned, the bias should be increased to -60 volts. In the case of a modulated stage however, a bias of approximately three times cut-off for the normal plate voltage is recommended but the bias voltage is not very critical in either case and good results can be obtained with different values.

Earlier in this Lesson we assumed the amplifiers to be operating with fixed bias but it is entirely practical to obtain the complete bias by placing a resistance in series with the grid circuit. Under these conditions, the grid current through the resistance produces a voltage drop which biases the grid. This system however, has the bad fault that when anything happens to reduce the exciting voltage, the bias is also reduced and the plate current rises to a value which may be high enough to damage or completely ruin the tube.

Therefore, it is considered as good engineering practice to use a combination of fixed and self bias with a value of fixed bias just large enough to hold the plate current to a safe value in case the excitation voltage is lost.

PUSH-PULL R-F AMPLIFIERS

Although our explanations in this Lesson have been based mainly on single tube amplifier circuits, r-f amplifiers for transmitting purposes can be operated in push-pull. Like an audio amplifier, this results in twice the power output of one tube and a reduction of second harmonic voltages.

This last feature of push-pull operation is perhaps the most important from a transmitting angle because it helps the station keep within the law on this subject, as found in the Madrid Treaty of 1932. This law is very general and, in part, requires that all stations reduce their harmonics as much as the state of art permits. From a practical standpoint, this is interpreted to require well designed output circuits in keeping with the power employed and the class of service.

However, the Institute of Radio Engineers standardization committee suggests that, for broadcast stations, the harmonic field strength be limited to .02 percent of the fundamental field strength. In order to operate within this limit, the system must be well designed and a push-pull output stage is of considerable benefit.

In operation, a push-pull r-f amplifier is much the same as a push-pull audio amplifier, working in the same Class. However, in the tank circuit of an r-f amplifier, the tuning condenser is divided, the center tap being connected back to the reference point of the tube in order to provide a low impedance path for the harmonic currents. If this is not done, considerable harmonic voltages may appear between the tank and ground.

Also, for equal output per tube, the total r-f voltage input to the grids of a push-pull stage must be twice as high as for single tube operation. Likewise, in order to keep the circuit balanced, the d-c grid current for each tube should be the same and the total equal to twice the value for single tube operation. With these exceptions, the values of voltage and current, for the Class of push-pull operation desired, are the same as for a single tube.

R-F TRANSMITTING TUBES

In general, the tubes used for transmitting are very similar to those used in ordinary receivers, about the only difference being in their size, wattage rating, etc. As a matter of fact, when a transmitter output is to be limited to only a few watts, ordinary receiving tubes can be employed. However, where large power outputs are required, special transmitting tubes must be used.

The power a tube can handle is determined by the plate voltage that may be applied safely, by the electron emission of the cathode and by the amount of power which can be dissipated, inside the tube, without overheating.

It follows then, that in the design of a tube, its cathode should be capable of emitting enough electrons so that the peak current can be maintained for the entire life of the tube. The voltage which can be applied safely to the plate is dependent on the plate-cathode insulation and the degree of vacuum inside the tube. Depending on the tube, this value may range between 1000 and 20,000 volts.

As power is the product of voltage and current, the amount of power absorbed at the plate of a tube is equal to the d-c plate voltage times the average value of plate current. In addition to this, there is the power at the grid plus that used in heating the cathode, all of which must be dissipated in the form of heat through the tube's envelope.

In general, tubes generating less than 1000 watts of alternating current power, can pass this heat to the surrounding air through comparatively small glass walls, without danger. However, glass softens at a comparatively low temperature so that the amount of energy, radiated per unit area, is quite low and makes it necessary to use very large envelopes for larger power. The cooling of these tubes is ordinarily obtained by allowing the free circulation of air although in the larger sizes, it is sometimes necessary to employ a forced draft supplied by a fan.

For transmitting tubes which have ratings of 1000 watts or more, it is common practice to cool the plate with circulating water. In one water cooled type, the plate is made of a seamless copper tube welded into a glass base so as to form a part of the complete envelope. This leaves the outside of the plate exposed while the grid and filament assembly are placed inside. Then, in order to cool the plate, it is immersed in a container through which cooling water is circulated.

Being in contact with the plate, the water is at a very high potential and is carried by rubber hose connections of sufficient length to prevent a high order of leakage current. The inlet and outlet hose connections are usually coiled together on a circular form located beneath the tube and provide two parallel leakage paths, of about 20 to 30 ft., depending on the value of plate potential.

Even though the water columns are quite long, comparatively pure water is necessary and for this reason it is quite common practice to circulate distilled water in a closed cooling system.

Also, some provision should be made to immediately remove the plate voltage from the tube in the event of failure of the cooling system. Unless such a provision is made, a failure of the cooling system would allow the temperature inside the tube to rise quickly to a value high enough to liberate gas or even melt the copper anode.

We have mentioned these various facts about transmitting tubes merely to point out their differences in respect to the ordinary receiving tube. Remember however, their action is the same and the main differences are the high plate voltage they can withstand safely, the large currents they are capable of producing and their ability to dissipate large amounts of power.

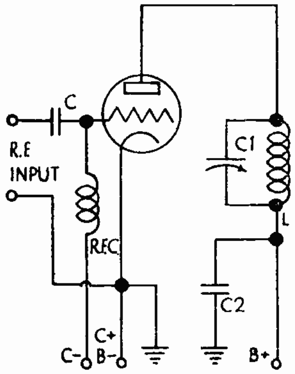

FIGURE 1

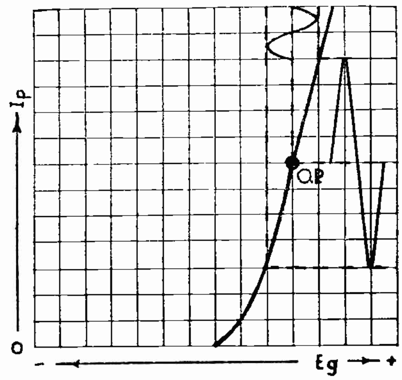

FIGURE 2

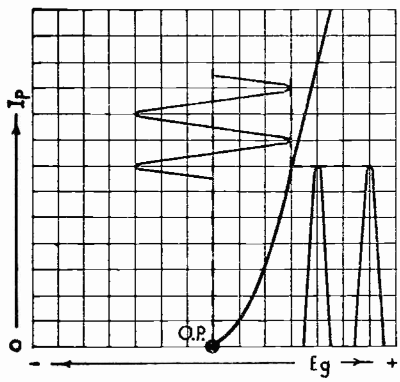

FIGURE 3

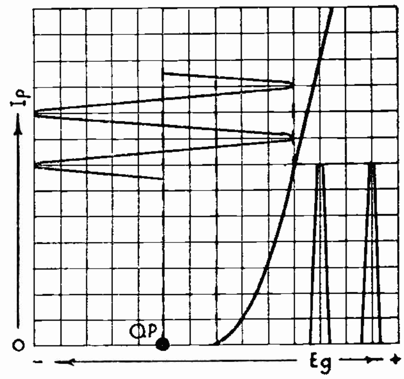

FIGURE 5

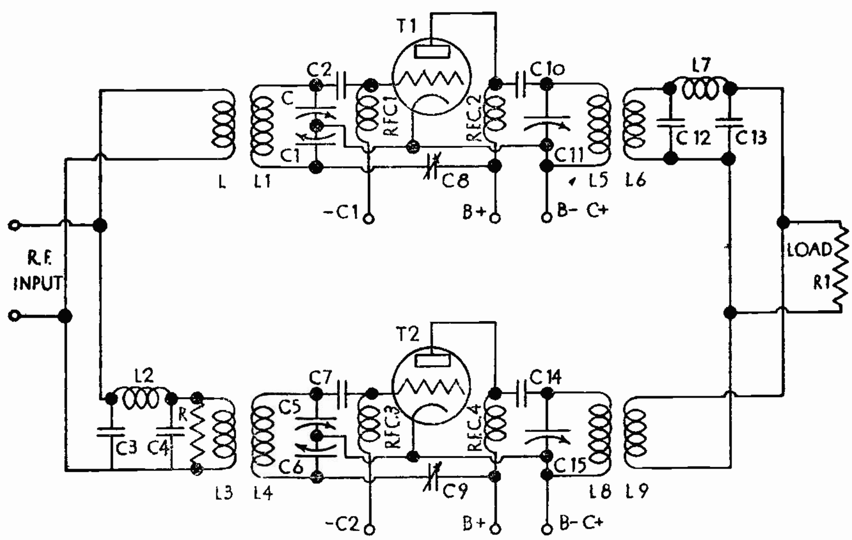

FIGURE 4

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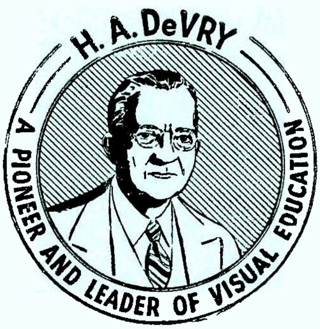

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LESSON RRT-17

R.F. COUPLING CIRCUITS

* * * * * * * * * *

The man with the most efficient education is not the one who knows things; he is the one who knows where to go to find out about them.

Dr. Frank Crane

Like all the other multi-stage electronic units explained in the earlier Lessons, a radio transmitter requires some method by thich the signal energy may be carried over or "coupled" from one stage to the next. Therefore, for this Lesson, we want to explain some of the various methods or types of coupling.

In general, these methods can be divided into the three main classifications, of capacitive, inductive and link. As you will learn later, the "link" is really a form of inductive coupling but, its extensive use has brought forth its own classification.

INTERSTAGE R-F COUPLING CIRCUIT

In our following explanations, we want you to remember that the general types of r-f coupling can be used to couple a single tube to a single tube, a single tube to push-pull tubes, push-pull tubes to a single tube or push-pull tubes to push-pull tubes. For parallel operates tubes, it is customary to employ the same general method of coupling as used for single tubes.

The requirements for an interstage r-f coupling unit are not many in number but sometimes prove quite difficult to meet. First, the unit must be capable of delivering the desired excitation from the driver tube to the following stage without over-loading the driven grid circuit. Second, there must be no coupling between the interstage circuit and any other electrical networks of the transmitter. The effect of this r-f feedback may cause the transmitter to be unstable.

The third requirement is a low impedance high frequency path from the grid to the cathode. If this is not provided, the circuit will have a tendency to favor parasitic oscillations which cause erratic operation of the system, and incur additional power losses.

With these general requirements of an r-f coupling device in mind, lets look at Figure 1 where we show a simple type of capacitive coupling circuit of which the plate of the driver tube obtains its d-c energy through the inductance of the L-C tank and is known as a series feed arrangement. The r-f excitation is developed across the plate tank L-C which is coupled to the grid of the following tube through condenser C_2 and the RFC. The capacity C_1 acts as a bypass condenser and provides a low reactance r-f path to ground.

The first requirement, concerning the excitation, is quite easily met because, by varying the position of the tap on coil L, any degree of the full excitation can be applied to the grid of the following tube.

The second requirement can also be met by this circuit but there are several precautions which must be observed. As you know, in ordinary receivers and amplifiers, it is common practice to run ground wires to the most convenient point on the chassis. For r-f work with transmitters, this is not considered good practice as it may provide coupling between the ground returns of several stages, thus introducing regeneration and instability.

Instead, all ground leads of each stage should be run separately to a common ground connection which is placed so as to make the leads as short as possible. By this arrangement, all the ground leads are kept at the same r-f potential, and thus the tendency toward coupling is minimized. Also, as a further protection against coupling, the magnetic flux which is set up in the coils and other units should be kept in its proper circuit by means of suitable shielding.

Should the voltage output of the driver, Figure 1, be greater than that required for the proper excitation of the following grid, the tap on the coil can be moved down but, under these conditions, the circuit would not meet the third requirement. That is, with the tap in the position shown, part of the tank coil inductance is in series with C_2 and C_1, which are in the r-f path from grid to ground. As the reactance of a coil increases with frequency, the impedance of this circuit will also increase, thus making it favorable for parasitic oscillation.

By moving the tap to the upper end of coil L in Figure 1, there would be a path from grid through C_2, C and C_1, to ground and, with nothing but capacity reactance, its impedance will decrease with an increase of frequency. However, under this condition, maximum output is available and therefore, the tubes in the circuit must be selected so that the voltage output of the driver is equal to the desired excitation voltage of the following tube.

For Figure 2, we show a modification of the circuit of Figure 1 and, checking through the plate circuit here, you will find a parallel feed arrangement with the d-c plate voltage supplied through the RFC and the r-f voltage coupled to the tank circuit, L-C_1-C_2, through condenser C. From the junction between C_1 and C_2, the signal is coupled to the grid of the following tube through C_3 and RFC_1. Notice here also, condenser C blocks d-c

plate potential, and condenser C_3 serves as a coupling unit. There is no d-c potential applied to the tuning condensers.

A circuit of this type meets all three of the above requirements and the excitation applied to the grid can be varied by changing the relative capacities of C_1 and C_2. Also, there will always be a low impedance r-f path to ground through C_3 and C_2. Of course, the precautions for grounding and shielding, explained for Figure 1, must again be observed.

In order to give you a little variation from single tube arrangements, in Figure 3 we show the driver feeding a pair of tubes connected in push-pull. Checking the circuit, the driver plate voltage is shunt-fed as energy is applied through the RFC, and the r-f voltage is coupled to the plate tank $L-C_1$ through condenser C much the same as the parallel feed arrangement of Figure 2. Here however, coil L is inductively coupled to L_1, which is tuned by condensers C_2 and C_3, and the voltage drop across it is applied to the grids of the push-pull connected tubes.

Neglecting the tuning condensers, C_1, C_2 and C_3, the circuit is very similar to that of the ordinary push-pull input stage of an audio amplifier and the action is about the same. The voltages at the opposite ends of coil L_1 are 180° out of phase with respect to the center tap and thus the voltages on the push-pull grids are in their proper relation to each other. However, with the tuning condensers C_2 and C_3 in place, their capacities must be equal in order to keep the necessary balanced condition of the circuit.

Compared to the circuits of Figures 1 and 2, where the signal energy is carried over or "coupled" by means of capacity, here in Figure 3, coils L and L_1 are placed to provide an inductive coupling. As the signal is carried over by this arrangement, we say the circuit is "Inductively coupled".

In an inductive circuit of this kind, the excitation voltage applied to the grids is controlled by varying the coupling between the two tank coils. In Figure 3, this variable coupling is indicated by the arrow which is drawn through coils L and L_1. Notice also, that this circuit will meet the three requirements listed earlier in this Lesson provided the precaution regarding shielding is properly observed.

Inductive coupling provides for a smooth adjustment of excitation voltage and is generally preferable to capacitive coupling. The main disadvantage of this form of coupling is the mechanical difficulty in arranging for some means to vary the coupling between the tank coils.

By means of a transmission line to transfer the energy from the plate tank to the grid tank circuit, the advantages of inductive coupling, with its separately tuned circuits, can be retained without the necessity for a direct inductive coupling between the two tank coils. An arrangement of this kind, commonly called a "link" coupled circuit, is shown in Figure 4 where we have a push-pull driver exciting the grids of two tubes connected in push-pull.

Here, the plate voltage for the driver is supplied through the RFC to the center tap of coil L which is tuned by condensers C and C_1. The r-f voltage across L is transferred inductively to coil L_1 and, because of the connections between them, appears across L_2. As coil L_2 is inductively coupled to L_3, which is tuned by condensers C_2 and C_3, the signal energy is transferred to the grids of the following tubes.

The inductances, L_1 and L_2, commonly called "links", are usually one or two turn coils connected together by ordinary twisted pair. The assembly results in a fairly low impedance line which may be of any convenient length, from several inches to a few feet, without an appreciable loss of power in the transfer. With this type of coupling, the proper excitation voltage can be secured by changing the position of either coupling coil, in respect to its tank circuit, or by changing the number of link coil turns.

Link coupling between shielded stages is very adaptable because the transmission line may be run through a small hole in the shield can without appreciable loss. Perhaps its principal advantage is in making extremely short connections possible without crowding the stages together. Also, if one side of the transmission line is grounded, it acts as an effective electrostatic shield between stages and greatly reduces the transfer of signal frequencies other than the fundamental. This is of great benefit because it prevents the transfer of any parasitic energy from stage to stage and thus improves the stability of the transmitter. As a matter of fact, many amateurs employ link coupling between all the stages of their transmitter even when the transmission lines are only a few inches long.

NEUTRALIZATION CIRCUITS FOR TRANSMITTERS

From your earlier lessons, you will remember that a three element tube can be made to oscillate, because of the feed back through the grid-plate capacity, and some types of oscillators depend on this action for their operation. However, oscillation is not desired in amplifiers, and therefore some means of overcoming the feed-back voltage must be employed.

In receiving circuits, this was accomplished by using tetrode and pentode tubes with a small grid-plate capacity but, as triodes are still common in the transmitting field, special circuits are employed to neutralize this feedback voltage.

In general, this undesirable voltage is overcome by taking some of the radio frequency voltage from the input or output of the amplifier and introducing it into the other circuit in such a way that it opposes the grid-plate feedback voltage. This outside voltage is applied to the circuit 180° out of phase with the grid-plate voltage and when both are of equal amplitude, the resultant voltage is zero and we say the grid-plate feedback voltage is completely "neutralized".

There are many ways in which this neutralizing voltage can be obtained but, in general, they may be put into two main classifications. When the neutralizing voltage is obtained from the plate circuit and fed back to the grid, we call it a "plate neutralized" stage, and when the neutralizing voltage is obtained from the grid and fed back to the plate, it is a "grid neutralized" stage.

For Figure 5, we show the circuit of one form of a plate neutralized stage and want you to notice that the plate voltage is applied to the tube through a tap on the coil L instead of at the end. By doing this, the r-f voltages at the opposite ends of the coil are 180° out of phase with each other, in respect to the tap. Thus, voltages fed to the grid through the grid-plate capacity of the tube from the upper end of coil L are 180° out of phase with those fed to the grid through C_3 from the lower end of coil L.

This condition meets the phase requirements for neutralization and all that remains is for the neutralizing voltage to equal the feed-back voltage. For this purpose, condenser C_3 is made variable and, as it controls the amplitude of the neutralizing voltage, it is called a "neutralizing condenser".

A method of plate neutralization for a push-pull stage is shown in Figure 6, but here the problem is quite simple because, in push-pull operation, the voltages on the respective grids and plates are already 180° out of phase. Therefore, it is necessary only for the plate of one tube to connect to the grid of the other through the neutralizing condenser C_2 while the other plate and grid are connected by the neutralizing condenser C_3. In operation, condensers C_2 and C_3 are adjusted until the neutralizing voltage equals that fed back by the grid-plate capacity of the tubes.

For the circuit of Figure 7, we have shown a method of grid neutralization and you will notice that the neutralizing circuits are very similar to those of Figure 5, except that they are now in the grid instead of the plate circuit. Here, the voltages fed back through the grid-plate capacity of the tube are applied to one end of coil L while similar voltages are applied to the other end through condenser C_2. When these voltages are made equal, by an adjustment of condenser C_2, their effects on coil L will cancel and the stage will be neutralized.

NEUTRALIZING ADJUSTMENTS

Regardless of the type of tube or the circuit employed, the procedure for neutralizing is the same and some form of sensitive r-f indicator is needed for proper adjustment. The indication may be obtained by means of a neon bulb, a flash light bulb, or thermo-galvanometer connected to a loop of wire or a d-c milliammeter connected to read the rectified grid current.

In order to make our explanation more specific, we will assume that you are going to neutralize an r-f stage, and that you have inserted a d-c meter in the grid circuit to serve as an indicator. You then disconnect the plate voltage supply from the tube being neutralized, but its filament voltage should be applied as in normal operation, and normal, or perhaps a bit greater, excitation from the preceding stage should be fed to the grid circuit at the stage being neutralized.

Under these conditions, the grid current meter usually shows quite a high reading and you rotate the tuning condenser, in the plate circuit of the stage being neutralized, until a noticeable dip in the grid current reading indicates the plate circuit is tuned to resonance. Next, you adjust the neutralizing condenser, while slightly rocking the plate tuning condenser, until the grid current dip becomes less and less pronounced. When perfect neutralization is secured, rotating the plate tuning condenser will have no effect on the grid current reading.

When using the flashlight bulb, thermo-galvanometer or neon bulb as r-f indicators, the same procedure is followed, but instead of being placed in the grid circuit, they are coupled to the plate tank. In the case of the flash-light bulb or thermo-galvanometer, coupling is made by placing the wire loop close to, or around, the plate tank coil while the neon bulb is placed close to, or on the tank coil. Plate circuit resonance is indicated by maximum light, or reading, depending on the indicator, and the neutralizing condenser is adjusted until this is zero.

The disadvantage of using a neon bulb is that the operator's hand may disturb the conditions of the circuit so that exact neutralization cannot be obtained. That is, the circuit may be neutralized while the operator's hand is near the coil but, as soon as he removes it, the balance may not be maintained. Of course, as soon as the hand is removed, the neon bulb is also removed and this condition will not be detected.

As you can see from the above explanation, the purpose of the neutralizing adjustment is to find the setting of the neutralizing condenser which eliminates r-f in the plate circuit when it is tuned to resonance. After a few trials, it is not at all difficult to neutralize a stage, provided the circuit is properly laid out and the neutralizing condenser has the correct capacity range.

However, it sometimes happens that the neutralizing condenser can be adjusted to give minimum, but not zero, R.F. in the plate circuit. Such a condition indicates the presence of stray coupling between the amplifier and driver tank coils or stray capacities between various parts of the amplifier circuit, each of which have a tendency to upset the voltage balance. This condition can usually be eliminated by a better layout of the parts, with short, widely spaced leads and by placing the coils so that the coupling between them is minimized. This position of minimum coupling between coils is usually found when their axes are at right angles to each other.

L/C RATIOS OF TANK CIRCUITS

In our explanation of radio receiving vacuum tubes, we told you that the load into which a tube operates has a big effect on its efficiency. This is also true for transmitting tubes and, within practical limits, the higher the impedance of the plate tank circuit, the greater its efficiency.

From your study of the earlier Lessons, you will remember that, at resonance, the impedance of a parallel circuit is high and its current is at minimum value. Under the conditions of parallel resonance, the formula for the impedance is generally given as,

$$Z = \frac{L}{CR}$$

Where

Z = impedance in ohms

L = the inductance in henrys

C = the capacity in farads

R = effective resistance of the circuit

In order that you may understand just how this formula may be used, we will assume that you desire to know the resonant frequency impedance of the tank circuit LC, Figure 1, when L = 200 microhenries, C = 100 micromicrofarads and the effective resistance is 10 ohms.

Substituting in the formula,

$$Z = \frac{.0002}{.0000000001 \times 10} = \frac{.0002}{.000000001} = 200{,}000 \text{ ohms}$$

Now, suppose that you want to increase the impedance of this tank circuit without changing its resonant frequency. Analyzing the formula, you can see that the value of "Z" may be increased by increasing L and by decreasing C or R. As the coils are usually of low loss construction, not much can be done about R, which leaves only L and C to vary. However, to keep the resonant frequency the same, if L is increased, C must be decreased in the same proportion so that the produce of L and C will always remain the same.

Going ahead, we will assume the inductance has been doubled and the capacity cut in half, while the effective resistance remains the same. Under these conditions,

$$Z = \frac{.0004}{.00000000005 \times 10} = \frac{.0004}{.0000000005} = 800{,}000 \text{ ohms}$$

Thus, by varying the L/C ratio from "2 to 1" to "8 to 1" we have increased the tank impedance 4 times. As we pointed out previously, the higher this impedance, the higher the plate efficiency and therefore we can say that the plate efficiency will be increased with an increase of the L/C ratio.

However, by using a high L/C ratio, the distortion and harmonic content of the amplifier are increased also but, in order to minimize this action, you will recall that the fly wheel effect of the tuned circuit was utilized. If the fly wheel effect increased with an increase of the L/C ratio, the problem would be quite simple but the reverse is true. That is, in order to reduce harmonics and the resultant distortion, considerable fly wheel effect is necessary and this calls for a fairly high C/L ratio.

Therefore, in practice, the design of the tank circuit must be a compromise between high plate efficiency and the required amount of fly wheel effect.

FREQUENCY MULTIPLIERS

In our earlier explanations of a class C amplifier, we told you that the harmonic output increased as the plate current pulses became shorter. Due to this action, it is possible to tune the plate tank circuit to one of the harmonics and thus obtain an output frequency which will be a multiple of the fundamental or input frequency.

Operating in this way, an r-f amplifier stage is called a "Frequency Multiplier" and, while the third and fourth harmonics are occasionally employed, it is customary to operate on the second. With its output frequency equal to twice the fundamental or input frequency, an amplifier stage is commonly known as a "Doubler" and its use has already been referred to in the Lesson on f-m Transmitters.

In order to provide a frequency multiplier with a sufficiently strong harmonic output, it is usually necessary to operate with a negative grid bias considerably higher than for straight Class C amplification. Due to the higher grid bias, the driving power required for good doubler efficiency should be at least two or three times greater than that used for efficient straight amplification. To keep the driving power requirement as low as possible, a tube with a high amplification factor and low bias voltage is recommended while a tank circuit with a high L/C ratio is desirable.

Almost any Class C amplifier, with a single tube or tubes in parallel, can be used for a frequency multiplier provided the driving power and grid bias requirements are met. Push pull amplifiers, because of their cancellation of second harmonic voltages, cannot be used as doublers but may be tuned to the third harmonic to operate as triplers.

The principle advantage of frequency multipliers is found in their application to short wave transmission where a more stable, lower frequency crystal oscillator may be employed and its output frequency multiplied until the desired carrier frequency is reached. This arrangement eliminates the need of a more expensive high frequency crystal and, because the plate circuit is not tuned closely to the grid input frequency, it is seldom necessary to provide neutralizing circuits.

ANTENNA COUPLING CIRCUITS

Some method of coupling is needed to transfer the energy from the final amplifier to the antenna, where it is radiated. As you already know, all tubes operate at their best when they have their proper load and, as the plate impedance of the tube

is comparatively high, while that of the antenna input is low, the coupling unit must also act as an impedance matching device. Thus, the antenna coupler performs the same general function as the output transformer of an audio amplifier which transfers the energy from the high impedance plate circuit of the output tube to the low impedance voice coil of the speaker and at the same time provides for a proper impedance match.

In a transmitter, the final amplifier may be coupled directly to the antenna or by means of capacitive, inductive and link coupling as already explained. With certain exceptions, direct or capacitive coupling to the antenna is forbidden by the FCC because such arrangements favor harmonic radiation which would cause interference, and therefore the following explanations will cover only inductive and link coupling.

Starting with the circuit of Figure 8A, we show a simplified form of an inductive coupled network and have indicated the tuned circuit LC as being the plate tank of the final amplifier. Coil L is inductively coupled to L_1, tuned by condensers C_1 and C_2, which, in turn, are connected to the feeders or transmission line that carries the energy to the antenna. The coupling between L and L_1 is made variable so that the amount of "loading" can be adjusted to the desired value. Because coil L_1 and condensers C_1 and C_2 are all in series with the antenna, at resonance, the current in the circuit will be maximum and therefore this arrangement is known as a "series tuning" or "current feed" system.

In Figure 8B, we show a similar circuit but coil L_1 is now tuned by a single condenser C_1 , connected in parallel, while the feeders are connected across the tuned circuit L_1C_1. With an arrangement of this kind, at resonance, the voltage will be maximum and the current minimum, therefore it is known as a "parallel tuning" or "voltage feed" system. As explained for the circuit of Figure 8A, the coupling between L and L_1 is made variable so that the desired amount of loading can be secured.

For the third or "link" form of coupling, we have drawn the circuit of Figure 8C which is exactly the same as 8B with the exception that coils L and L_1 are now coupled by the link. As explained for the interstage coupling methods, the amount of coupling is varied by changing the position of each link in respect to its tank. Although we show a voltage feed arrangement in Figure 8C, current feed could be used just as well.

In the above circuits, the choice of the voltage or current feed arrangement depends on the length of the feeders and the antenna itself. From the explanations of an earlier Lesson, you will remember that for a half wave length doublet type of antenna, the current was greatest at its midpoint and minimum at the ends. Therefore, if the energy from the final amplifier is fed at the midpoint of the antenna, the coupling device must be of such design that the current will be maximum when it reaches the antenna proper.

One method of providing this condition is shown in the circuit of Figure 9A where we have a half wavelength antenna which is connected to a parallel tuned coupler by feeders which are each 1/4 wavelength long. The amplitude of the antenna current is represented by the curved lines X-X' while that of the feeders is represented by Y-Y'. Notice, that although each feeder is 1/4 wavelength, their combined length is the same as that of the flat top, so that their current is minimum at the ends and maximum at the midpoint. Thus, a parallel tuned coupler meets the requirements because it allows minimum current with maximum voltage at the input to the line.

You can easily see that if a series tuned coupler were employed with these dimensions, the current would be maximum at the transmission line input and minimum at the antenna. Should such an arrangement be tried, the combination would not tune properly and the antenna would not take power from the transmitter.

In order to satisfactorily employ series tuning, it is necessary to increase the length of each feeder, as shown in Figure 9B. The terminology used here is the same as in Figure 9A but notice each feeder is now 1/2 wavelength resulting in a total of one wavelength and causing the current to be maximum at the antenna. From these two examples, you can see that when tuned feeders are employed, their length is quite critical in respect to the type of tuning employed in coupling networks.

To "tune up" an antenna coupling circuit employing series tuning, the condensers are set at minimum capacity, the antenna coil is loosely coupled to the plate tank of the final amplifier in the transmitter and the plate current reading is observed. Then the two antenna condensers are adjusted simultaneously until a maximum plate current reading is obtained. This indicates that the antenna is now in resonance with the transmitter frequency and the plate tank condenser is then tuned for minimum current. This last step is necessary because the antenna adjustment will have an affect on the tuning of the plate tank.

Although this minimum value of plate current will be higher than that obtained before the antenna circuit was tuned, it should be considerably lower than that for which the tube is rated.

Next, the coupling between the antenna and tank coils is increased by a small amount, the antenna condensers are readjusted for maximum plate current and again, the plate tank condenser is set for minimum current. This procedure is then repeated until the minimum plate current reading is equal to the rated value of plate current for the tube.

When making adjustments of this kind, always use the lowest amount of coupling, between the antenna and plate coils, which will bring the amplifier plate current up to its rated value when the antenna condensers are tuned through resonance.

For parallel tuning, a similar procedure is followed except that there is but one antenna condenser to adjust. Again it is proper to find the lowest value of coupling, between the antenna and plate coils, which will bring the plate current to the desired value as the antenna condenser is rotated through resonance. Like series tuning, a slight readjustment of the plate tank may be necessary to compensate for the effect of changing the coupling.

TRANSMISSION LINES

In the earlier explanations of this Lesson we mentioned feeders, or transmission lines but now we want to give you a little more information in regard to them. As you know, their purpose is to transfer energy, from the source to some other unit, with as little loss as possible. When a transmission line carries r-f current, as in transmitters, it tends to radiate energy and to minimize this action as much as possible, special design is necessary.

The amount of radiation can be decreased by using a line with a comparatively high impedance and a resulting low current or by using two conductors arranged so that the current in them is in opposite directions and of equal amplitude. By this latter method, the fields set up by the conductors are 180° out of phase with each other and being of equal amplitude they cancel.

There are several common types of transmission lines and perhaps the simplest is made up of a pair of insulated wires twisted much like the old style lamp cord. Because of its arrangement, this is known as a "twisted pair" line.

Another type, quite popular with amateurs, is made up of two parallel wires, held two or six inches apart by means of insulation strips called "spacers". Here again, the construction indicates its common name of "open wire" line.

A third type, quite commonly used in commercial installations, is made up of a relatively small diameter conductor placed centrally inside an outer tubular conductor. The inner conductor is held in its central or axial position by means of "coaxial cable" or "concentric" line.

Still another type of line, known as a "single wire feeder" uses only a single wire, and radiation is minimized by keeping the line current low.

TRANSMITTER ADJUSTMENT

Now that we have explained a number of the various components which go to make up an unmodulated transmitter, we want to combine them in a complete unit and explain the adjustments which are necessary for satisfactory operation. We will therefore assume a transmitter consisting of a master crystal oscillator, a first amplifier and final amplifier all operated in Class C. This arrangement is quite commonly used by amateurs and the first amplifier stage is commonly referred to as a "buffer stage".

In tuning up the transmitter, the first step is to remove the load from the oscillator and connect a current meter in its plate circuit. With the amplifier tubes' plate voltage off, the oscillator tank condenser is rotated from its minimum capacity setting, until a dip in its plate current is observed. While making this adjustment, it will be noted that, as the condenser is rotated toward its maximum capacity, the plate current will gradually decrease after oscillations commence. Turning the condenser past the peak dip will result in a sharp increase of plate current and indicate that oscillations have ceased. For stable operation, it is considered good practice to adjust the oscillator to a point just before the maximum dip in the plate current occurs.

The next step is to load the oscillator, by increasing the coupling to the following stage, until the tube is delivering its rated output. When making this adjustment, it will be noted that the dip in the oscillator plate current is less pronounced.

This completes the oscillator tuning and moving to the next stage, it must be "neutralized", in case a triode tube is used.

As this process has been previously explained we will not repeat. After neutralizing, plate voltage is applied to the buffer tube but, for the preliminary adjustments, it is advisable to use a low value. This is due to the excessive plate current which may be drawn by the tube before the plate tank is tuned to resonance. With low plate voltage, the tank condenser is adjusted for minimum plate current, which indicates resonance, and then the normal plate voltage can be applied to the tube.

As these adjustments have been made without a load, the minimum plate current will be quite small in respect to the normal loaded current. To continue with the procedure, the load is increased by increasing the coupling between the buffer plate tank and final amplifier grid circuit. Keeping the plate tank at resonance, the coupling is increased until the tube is drawing its rated plate current.

The final amplifier stage is adjusted on the same plan as the buffer stage and is properly loaded by following the procedure outlined in our former explanation on antenna tuning. To avoid radiation while adjustments are being made, it is good practice to replace the regular antenna with a "dummy" of equal impedance. Then, after the transmitter is all "tuned up", the dummy is replaced by the regular antenna and the transmitter is ready for operation.

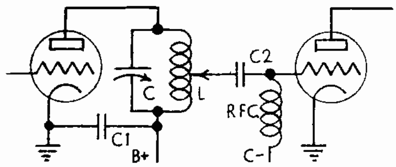

FIGURE 1

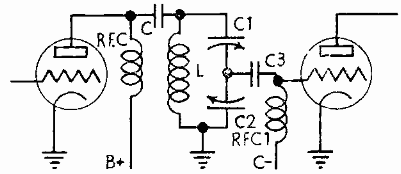

FIGURE 2

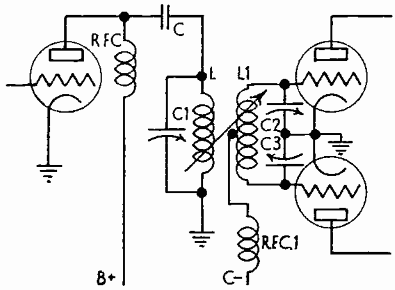

FIGURE 3

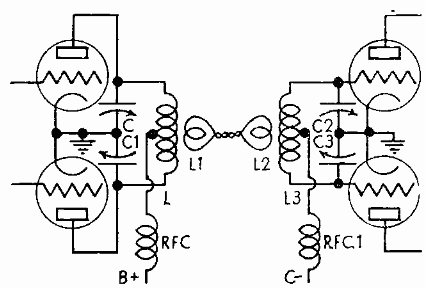

FIGURE 4

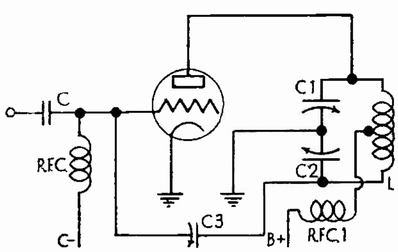

FIGURE 5

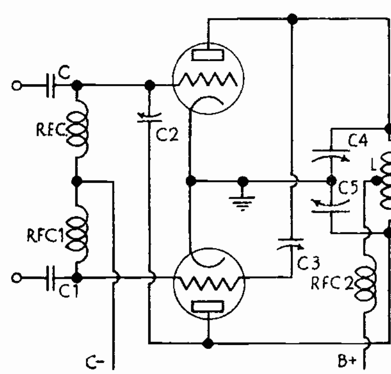

FIGURE 6

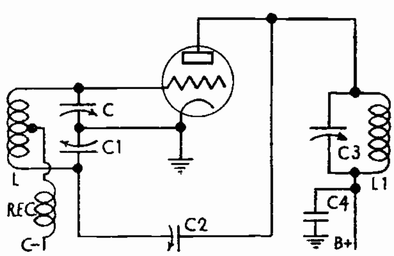

FIGURE 7

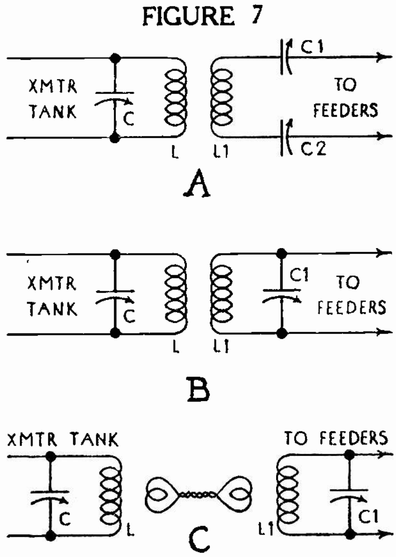

FIGURE 8

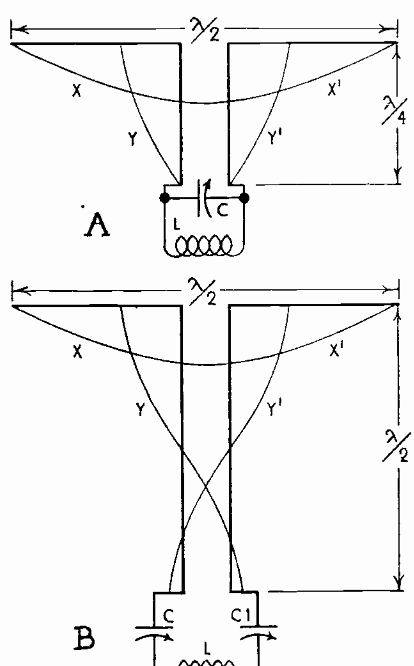

FIGURE 9

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MODULATION

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RADIO RECEPTION AND TRANSMISSION

LESSON RRT-18

MODULATION

# # # # # # # # # # # # # # #

Courage and perseverance have a magical talisman, before which difficulties disappear and obstacles vanish into air.

John Quincy Adams

In our earlier Lessons on transmitters we have explained how a high frequency signal is generated by oscillators and then showed you how it can be amplified until the desired power level is reached. However, this r-f energy is of no practical value for the transmission of intelligence until some method of control is employed. In general, any means of controlling the r-f carrier, for the transmission of intelligence is known as modulation and, as many methods are in use, we want to explain the more common types.

KEYING

One of the first methods of conveying a message through space, from one point to another, was to interrupt the generation of the continuous carrier of the radio transmitter. Today, this method is called "Keying" and is used for all telegraph radio transmission. There are many ways by which keying can be accomplished and, for Figure 1, we have drawn a simple system.

Here, we show the final stage of a transmitter with its input or grid tank LC, blocking condenser C_1 and bias resistor R_1. In the plate circuit we have the tank L_1-C_2 which is inductively coupled to the antenna coil L_2, while the key is connected between cathode and ground, placing it in series with both the grid and plate circuits. In operation, the key is really nothing but a single pole, single throw switch which, when closed, allows the stage to operate continuously and transmit power to the antenna where it is radiated in the form of radio waves.

However, if the key is open as shown, the plate circuit will be broken, there will be no circulating current in the plate tank L_1-C_2 and thus no power to the antenna. Of course this is strictly true only when the stage is properly neutralized but, for simplicity, we assume this has been done.

Thus, by closing and opening the key in the circuit of Figure 1, it is possible to start and stop, or interrupt, the carrier and, if this is done according to some prearranged code, a message can be transmitted from one point to another. It may be well to mention here that the carrier frequency is too high to operate 'phones or speaker, therefore, at the receiver, the output of a beat frequency oscillator, (BFO) is combined with the incoming carrier to produce a beat note of audio frequency.

In addition to the arrangement of Figure 1, there are many other methods of keying but all you need to remember at this time is that they are all used to interrupt the carrier current to the antenna.

SIMPLE ABSORPTION MODULATION

Although the circuit of Figure 1 is satisfactory for the transmission of code, it does not allow the transmission of speech or music which requires a variation of either the amplitude or frequency of the r-f carrier at the audio frequency of the speech or music. At first, this may seem rather difficult to accomplish but, as you will learn, it is comparatively easy to do.

One of the simplest methods of this type of modulation is shown in Figure 2 and we want you to think of the inductance L as being the tank coil of an oscillator which is inductively coupled to the antenna coil L_1. A third coil is tightly coupled to L_1 and connected to a carbon microphone.

With no sound entering the microphone, its resistance is fixed and can be considered as a part of the load on the oscillator. Thus, with a constant load, the amplitude of the carrier in the antenna will be constant and the circuit operates like that of Figure 1 when the key is closed.

From your earlier Lessons, you know that the internal resistance of a carbon microphone varies at the frequency of sound waves which strike its diaphragm. Also, you will remember that a change of load, on an oscillator, will cause a variation in the amplitude of its output.

With these two actions in mind let us examine the circuit of Figure 2 at an instant when a sound wave strikes the microphone diaphragm. We will assume the resulting movement of the diaphragm causes a reduction of microphone resistance which permits an increase in current. In effect, this increases the load on the oscillator and causes a reduction of carrier amplitude. Of course, the same action is true the other way around and if the resistance of the "mike" increases, the load on the oscillator decreases and the amplitude of the carrier increases.

The amplitude and frequency of the diaphragm movements correspond to those of the sound waves which strike it. The variation of microphone resistance corresponds to the movements of the diaphragm and therefore the amplitude of the oscillator output, or carrier, will vary according to the amplitude and frequency of the sound waves.

Because the amplitude of the carrier is varied, all arrangements of this type produce what is known as "Amplitude Modulation".

Although the arrangement shown in Figure 2 will operate, in practice it is not considered as a very satisfactory method. It is limited to small transmitters because of the low power absorbing qualities of the microphone which result in its being heated to the point where it is no longer operative.

Another big disadvantage is that the modulation system operates on the power output of the oscillator and causes its load to vary. This has a tendency to cause the oscillator frequency to shift sufficiently to violate the rules of the FCC. Therefore, in commercial transmitters, the oscillator functions normally and modulation takes place in one of the amplifier tubes. The output, or amplitude of an r-f amplifier can be changed in accordance to the modulation, without causing an appreciable change of carrier frequency.

PLATE MODULATION

Perhaps the most common form of amplitude modulation is known as the "Plate" or "Heising" method, a simplified arrangement of which is shown in Figure 3. Checking through the r-f circuit, you will find the grid tank LC, blocking condenser C_1 and the bias resistor R. In the plate circuit of T_1, we have the tank L_1-C_2 and, tracing down to B+, go through the RFC resistor R_1 shunted by condenser C_3 and the iron core choke L_3. The plate of T_2 receives its voltage from the junction between R_1 and L_3. In this circuit T_1 functions as an r-f amplifier while T_2 is the output tube of an audio amplifier which, in this arrangement, is known as the modulator.

The operation of this circuit depends on the action of the choke coil L_3 which is designed to present a very high reactance to both the audio and radio frequencies. In fact, the reactance is of such value that the total current through it, or that drawn from the B supply, is held at an approximately constant value although the plate currents drawn by T_1 and T_2 may vary.

This constant current from the supply will divide between the T_1 and T_2 branches in proportion to their resistances. That is, if the resistance of the plate circuit of T_2 is decreased, it will carry more current and thus there will be less in the plate circuit of T_1. Of course, this is also true the other way around and if the resistance of T_2 increases, the current through T_1 increases. Thus, in the circuit of Figure 3, we can say that the current in the plate circuit of T_1 varies in proportion to the resistance of the plate circuit of T_2. The power output of T_1 depends on its plate current and therefore the amplitude of the carrier will vary in proportion to the resistance of T_2.

Now, here is the point. When an audio signal is impressed on the grid of T_2, in effect, its plate resistance varies in proportion to and at the same frequency as the signal voltage. Therefore, from the above explanation, you can see how the carrier amplitude is varied in proportion to and at the same frequency as the incoming audio signal.

Another way of explaining this same action is in terms of voltage, instead of current. Checking the circuit of Figure 3, you will see that the choke L_3 is common to the plate circuits of both T_1 and T_2. Also, the total voltage of the plate of T_1 will be the sum of the plate supply and audio voltage developed across the choke. As the output of an r-f amplifier is dependent on its plate voltage, part of which is made up of the audio voltage in this case, the amplitude of the carrier will be made to vary in proportion to the incoming audio signal.

When the process of modulation causes the peak amplitude of a carrier to rise to twice its original value we say it is 100°/o modulated and for this condition, the peak amplitude of the audio signal will be equal to the plate supply voltage, E_b. The peak a-c plate current of the modulator will be equal to the d-c plate current, Ib, taken by the r-f amplifier when it is unmodulated. As effective value is equal to peak value divided by the $\sqrt{2}$, the power output of the modulator will be equal to -

$$P = \frac{E_b}{\sqrt{2}} \times \frac{I_b}{\sqrt{2}} = \frac{E_b I_b}{2} \qquad (1)$$

For the unmodulated condition the power input to the r-f amplifier is equal to the supply voltage times the supply current. As an equation,

$$P = E_b I_b \qquad (2)$$

By comparing expressions (1) and (2) you can see that, for 100 per cent modulation, the power delivered by the modulator to the r-f amplifier is 50 per cent of the power input required by the r-f amplifier for the carrier power.

The load current, which is the antenna current in Figure 3, is dependent on the modulation ratio and is expressed by

$$I_L = I_o \sqrt{1 + \frac{m^2}{2}}$$

where

I_o = unmodulated load current
m = modulation ratio.

For 100 per cent modulation, m = 1, and the load current becomes

$$I_L = I_o \sqrt{1 + \frac{1}{2}} = 1.225\ I_o$$

which shows that the load current increases 22.5 per cent. Since the power output varies as the square of the current, the power output will be incbeased by 50 percent.

Because the modulator stage works at audio frequencies, the single tube, T_2 of Figure 3, must be operated in Class A in order to prevent serious distortion. For 100°/o modulation in a circuit of this kind, the d-c plate voltage on the r-f amplifier should be lower than that on the modulator. This is necessary because, for Class A operation, the peak a-c voltage is from 60 to 80 per cent of the plate supply voltage while the peak modulating voltage must equal the plate supply voltage of the oscillator. In Figure 3, therefore, the plate supply voltage of T_1 is made lower by the dropping resistor R_1, bypassed by condenser C_3 which has sufficient capacity to present a low reactance to audio frequencies.

Because of the direct coupling between the plates of the tubes, push-pull operation of the modulator is not applicable to the circuit of Figure 3. Thinking back over the earlier explanations, the total plate current of a push-pull Class A stage remains practically constant and does not vary in proportion to the signal voltage.

For Class B push-pull stages, the plate currents occur in alternate pulses one for the positive and one for the negative alternation of each cycle of signal voltage.

Connected in the circuit of Figure 3, a Class A push-pull modulator stage would produce little or no modulation while with a Class B push-pull stage, modulation would occur at twice the signal frequency.

This is a big disadvantage because about the highest practical efficiency attainable for a single tube modulator, operating in Class A, is 30°/o while for Class B it may run as high as 60°/o. This may not seem like such a big item but when you consider modulating a high power amplifier it becomes important.

For example, if a 21,000 watt, or 21 kilowatt, carrier is to be modulated 100 per cent and the plate efficiency is 70 per cent, the direct current plate power required is (100/70) x 21,000 or 30,000 watts and the modulator output is one half of this or 15,000 watts. Thus, it is quite evident the requirements of the modulator become important and with the higher efficiency, obtainable in Class B operation, it is possible

to use lower voltages, resulting in longer tube life, than for the same tubes operating in Class A.

Perhaps you are wondering how a push-pull Class B modulator can be connected for plate modulation but it is quite simple. In fact, you need imagine only that L_3 of Figure 3 is the secondary of a push-pull output transformer, the primary of which connects to the plates of the Class B modulator tubes while its center tap connects to B+. Do not confuse this with the ordinary output transformer because the secondary must be wound with wire of sufficient size to carry the current for the r-f amplifier plate circuit in addition to the modulation of audio current. Also, as we will explain in a later Lesson, the impedance ratio between the primary and secondary must be of the proper value and the assembly is known as a "Modulation" transformer.

To differentiate this arrangement from the direct coupling of Figure 3, it is known as inductive coupling and, as the action in the complete circuit is similar to that already explained, we will not repeat. With inductive coupling however, the dropping resistor and its bypass condenser may be eliminated as the required peak modulating voltage can be obtained by the proper turn ratio between the primary and secondary of the modulation transformer.

In the above explanations, we have considered only a single ended r-f amplifier which may be a single tube or tubes operated in parallel but we want to point out that a push-pull operated stage can be modulated just as well; in fact, push-pull operation is a more common arrangement. The triode tubes used for a plate modulated amplifier are the same as those of a regular unmodulated triode amplifier. You must keep in mind, however, that the power requirements are greater at the peak or crest of modulation than at the carrier level and therefore the tubes must be operated accordingly. Pentode and screen grid tubes are sometimes plate modulated although the linearity of operation tends to be poor. For such tubes, it has been found advantageous to modulate the screen voltage as well as the plate voltage.

GRID MODULATION

For plate modulation, the plate voltage of the r-f amplifier is made to vary at an audio rate while for grid modulation, a somewhat similar plan is used but the grid bias voltage is made to vary in proportion to the modulating signal.

An arrangement for grid modulation is shown in Figure 4 and, checking through the circuit, you will find the grid tank LC is coupled to the grid through condenser C_1. From the grid,

there is a path through the RFC, the secondary of the modulation transformer L_4 and the "C" supply to ground while condenser C_3 is a bypass for r-f currents. In the plate circuit, the tank L_1C_2 is inductively coupled to coil L_2.

Now notice, the secondary L_4 is directly in series with the "C" supply and thus, with an a-c signal across L_4, its voltage will add to or subtract from the "C" supply voltage, depending on its polarity at any given instant. With suitable audio power applied to the primary L_3, the grid bias voltage of the tube can be made to vary in proportion to the amplitude and frequency of the audio input. As you already know, this variation of bias voltage will cause the plate current to vary also and thus the amplitude of the carrier will change in accordance to the incoming audio frequency.

For the proper operation of a grid-modulated amplifier, the conditions at the peak of the modulation are very similar to ordinary Class C operation. The main differences are that the minimum instantaneous plate voltage be somewhat smaller and that the grid current be less than with customary Class C operation. Grid current has a tendency to flatten or distort the positive peaks of the a-c modulating voltage and also tends to make the r-f exciting voltage drop off at the modulation peaks. These actions flatten the positive peaks of modulation and are the principal cause of distortion, provided the conditions at the crest of the modulation cycle make the instantaneous minimum plate voltage small.

In broadcast transmitters, where low distortion is of very great importance, the stage is sometimes operated so that the grid is never driven positive and thus there is no grid current. With this arrangement, the linearity of modulation is greatly improved but, in comparison with a stage where the grid is driven moderately positive, the power output is very low.

The advantage of grid modulation is that very little modulation power is required but, it has the disadvantage of low average plate efficiency. Also, unless very little power output is obtained, the linearity of a grid modulated Class "C" stage is not as good as a Class C plate modulated amplifier.

SUPPRESSOR GRID MODULATION

For Figure 5, we have drawn a simplified circuit of another form of modulation in which the amplifier tube is a pentode and modulation is performed by varying the voltage on the suppressor grid. The fundamental amplifier is the same as those previously explained therefore we will not repeat our explanations of its operation. Here, the suppressor grid is connected to ground through the RFC, the modulation secondary

L_4 in parallel to R_1, and the voltage supply while condenser C_2, acts as an r-f bypass.

The action in this circuit is very similar to that explained for grid-modulation because the audio signal, supplied to the primary L_3, appears across L_4 and R_1 where it adds to or subtracts from the normal suppressor grid voltage. In turn, this variation of suppressor grid voltage causes variations in the output of the amplifier which result in an amplitude modulated carrier.

The modulating power requirements, efficiency and power output are of the same order as explained for the grid-modulated amplifier. This arrangement has an advantage in that the modulating and excitation signals, being fed to separate grids, result in simpler operation because best adjustments for proper excitation and modulation requirements are more or less independent. Its disadvantage is that the linearity of modulation does not equal that of conventional grid modulation.

Although used but very little for commercial work, this type of modulation is employed quite frequently in amateur transmitters.

CATHODE MODULATION

Still another form of modulation is shown in the circuit of Figure 6 where we have the conventional amplifier input and output circuits but the cathode is returned to ground through L_4, the secondary of the modulation transformer, and resistor R_1 which is bypassed by condenser C_3. Due to the fact that the modulating signal is applied in the cathode circuit, this arrangement is called "cathode modulation".

From your former study of vacuum tubes, you know that the grid bias voltage is the difference of potential between the grid and cathode. Here, the plate current passes through L_4 and R_1 and causes a voltage drop across them. The direction of current is such that the cathode is made positive in respect to ground or, saying it the other way around, ground is negative in respect to the cathode. As the grid connects to ground, through resistor R, it is negative in respect to the cathode by an amount equal to the drop across L_4 and R_1.

In practice, the d-c resistance of L4 is small in comparison to R_1 and therefore practically all the voltage drop, known as the initial bias voltage, is developed across R_1. So far, we have assumed no r-f excitation on the grid, because when this occurs with no audio input to the modulation transformer, the total bias will be the sum of the voltage drops across R and R_1.

When an audio signal is impressed across the modulation transformer primary L_3, a similar voltage will be induced in the secondary L_4 which is directly in series with the cathode circuit. Depending on its polarity at any given instant, this a-c audio signal will add to or subtract from the initial bias voltage causing the total grid voltage to vary in proportion to and at the frequency of the audio signal. You will probably recognize this action as the same as that which took place during grid-modulation and, for that reason, we say that the arrangement of Figure 6 causes grid modulation.

That is not all however, because as you already know, the cathode is really the return of the plate circuit and therefore in series with it. Also, when units are connected in series, the sum of their voltage drops is equal to the impressed voltage on the circuit.

Going back to the circuit of Figure 6, and neglecting the voltage drop across R_1, the secondary L_4 is in series with the plate voltage supply, the negative terminal of which is grounded. Thus, the a-c signal voltage across L_4 will alternately aid and oppose the plate voltage supply.

This action is really the same as explained for the voltages across L_4 and R_1, which result in grid modulation and therefore, the sum of the voltages across L_4 and the plate supply, result in plate modulation. Because of this double action, cathode modulation is really a combination of plate and grid modulation and permits an efficiency part way between the two depending on the ratio of grid to plate modulation.

With normal operating conditions, about 75 per cent of the modulation is supplied by the grid bias method while the remaining 25 per cent is supplied by plate voltage variation. With this ratio, efficiencies of 40°/o or better can be obtained with relative little audio power as compared to that needed for plate modulation. With cathode modulation, the modulator should be capable of supplying audio power equal to about 10°/o of the d-c plate input to the modulated amplifier.

As we stated above, higher efficiencies are obtained when the ratio of grid to plate modulation is reduced therefore the tube used in a cathode modulated amplifier should have a low mu. Because of this requirement, the ordinary low mu transmitting triodes are adaptable for this type of work.

FREQUENCY MODULATION

So far in this Lesson, all the general methods of modulation which we have explained operate to vary the amplitude of the

carrier and all of them come under the same general head of "amplitude modulation". As you already know, intelligence can also be transmitted by varying the frequency of the carrier at an audio rate and, when this is done, we call it "frequency modulation".

Although the important details of this system of modulation have already been explained, for review purposes we show a simplified arrangement in Figure 7 where we have a conventional type of regenerative oscillator with its grid tank LC, blocking condenser C_1, and bias resistor R. In the plate circuit you will find the tank L_1-C_2 which is inductively coupled to L_2. Notice also, that we have connected a condenser microphone across the tank condenser C.

From the explanations of the earlier Lessons, you know that the frequency generated by this oscillator will depend on the value of capacity and inductance in the grid circuit. If these values are fixed, the output frequency will be practically constant but, if either is changed, a change of frequency results. In its simplest form, the diaphragm of a condenser microphone is really the moveable plate of a two plate variable condenser so that, in Figure 7, the main tuning condenser C is shunted by another variable two plate condenser. If the capacity of either one of these is changed, the oscillator frequency will also be changed.

Sound waves, striking the diaphragm of the microphone, will cause the total capacity across the tank coil L to change, and produce a corresponding change of oscillator frequency. Therefore, with this arrangement, the sound waves which strike the diaphragm of the microphone will control the oscillator or carrier frequency, and result in frequency modulation.

Going back to the diaphragm, it will vibrate at the frequency of the sound waves which strike it and, being connected across the grid coil, the oscillator frequency will vary at the same rate as the incoming audio or signal frequency.

Reviewing briefly the important principles of f-m, each complete vibration of the diaphragm will cause the oscillator frequency to shift above and below the mean or carrier frequency and the greater the amplitude of the modulating audio signal, the greater the frequency swing or deviation. Therefore a "soft" audio modulation signal will cause but slight frequency deviation.

An increase in the frequency of the audio modulating signal causes the diaphragm to complete its vibrations at a faster rate and hence the "rate of change" of the oscillator frequency varies directly with the modulating frequency.

Summing up, we can say that the band width of an f-m carrier depends on the amplitude, or intensity, of the modulating signal, and the rate at which the carrier frequency takes place depends on the frequency of the modulation.

HIGH AND LOW LEVEL MODULATION

Going back to amplitude modulation, we want to explain what is meant by the commonly used expressions "High Level" and "Low Level" modulation. From our former explanation, you know that the ordinary radio broadcast transmitter is made up of a very stable crystal controlled oscillator followed by a number of stages of r-f amplification, one of which is modulated.

Although it is possible to modulate the oscillator, we have already pointed out the disadvantages of this arrangement and need consider it no further. However, it is possible and practical to modulate any of the following r-f amplifier stages but there must always be a definite ratio between the power requirements of the modulator and the r-f power output of the stage it modulates.

In general, therefore, when the final r-f stage of a transmitter is modulated, a high level of modulator output is required and the arrangement is known as "High Level" modulation. When an intermediate r-f stage is modulated, a lower level of modulator output is sufficient and the arrangement is known as "Low Level" modulation.

With high level modulation, all the r-f stages may be operated in Class C, with the resulting high efficiencies but, this advantage is offset by the large power requirements of the modulator.

With low level modulation, all stages following the modulated stage must be operated in Class B so that linear amplification can be obtained. While this arrangement reduces the efficiency in the r-f stages, it also reduces the requirements of the modulator.

Thus, you can see that choice of system is more or less dependent on the particular installation. However, it has been found that, in high power transmitters, low level modulation is cheaper, especially when the Class B, r-f amplifiers are operated in a high-efficiency circuit, such as the Doherty system.

In this Lesson we have explained various methods of modulation but have said nothing about the modulators, speech amplifiers, and other units which are needed to produce the desired results. Therefore, in the next Lesson, we are going to take up details of the modulation or audio equipment associated with a radio telephone transmitter.

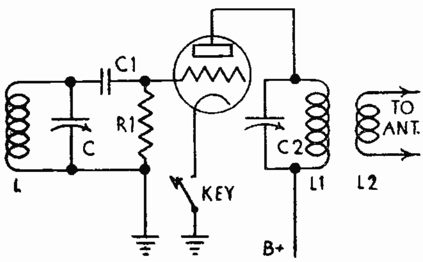

FIGURE 1

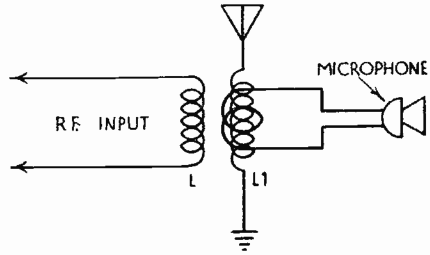

FIGURE 2

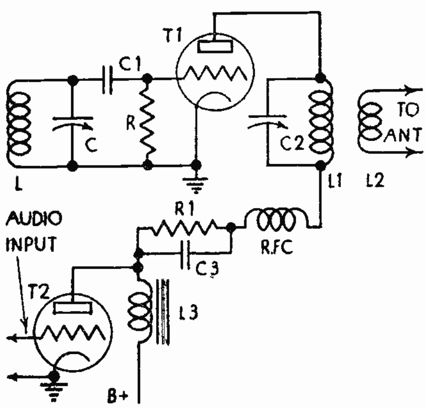

FIGURE 3

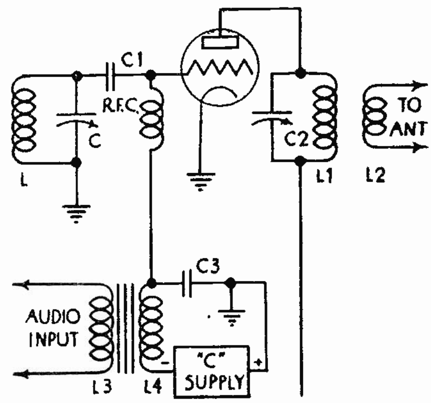

FIGURE 4

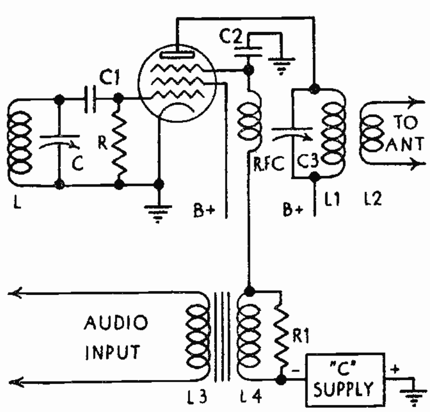

FIGURE 5

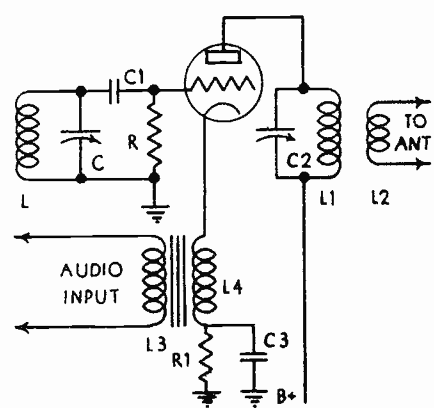

FIGURE 6

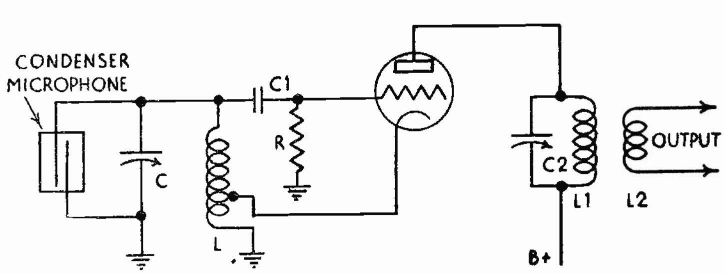

FIGURE 7

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# # # # # # # # # # # # #

The people who fail are those who become discouraged over their mistakes. They lose heart, and when you lose heart the best way to get over it is to quit doing wrong and begin to do right. We progress simply by watching our mistakes and correcting them.

Dr. Frank Crane

In the last Lesson, we explained several different methods by which an r-f carrier frequency could be modulated and now are ready to take up the modulating equipment itself. If you will remember here, that this equipment is really nothing but an audio amplifier, and review your earlier Lessons on the subject, you will find the following explanations easy to understand.

CLASS A OPERATION

In the upper right hand corner of Figure 1, we show the conventional circuit of a triode push-pull Class A amplifier, made up of the input transformer, two tubes, the output transformer and the load which we have designated as R_L. As the action in a circuit of this kind has already been explained many times, we will not repeat. Instead, we are going to show you how to make use of a family characteristic curves in order to determine the power output with different values of load resistance.

To do this, it is first necessary to plot a curve which is called a "Load Line" and represents all the values of plate voltage attained during one cycle of plate current swing. As you know, the voltage on the plate of a tube is equal to the "B" supply voltage minus the drop across the load resistance. As an equation,

$$E_p = E_b - I_p R_L \qquad (1)$$

Where

E_p = plate voltage
E_b = "B" supply voltage
I_p = plate current
R_L = load resistance

Analyzing this equation, with E_b and R_L constant, you can see that E_p will vary directly with I_p and thus the plate voltage has a linear, or straight line, relation to the plate current. To construct a straight line, only two of its points need be known and one of these can be considered as zero plate voltage. For this condition, we assume the voltage drop across the plate load just equals the plate supply voltage. That is,

$$E_b - I_p R_L = 0$$

and solving for the current, I_p, we have

$$I_p = \frac{E_b}{R_L} \qquad (2)$$

which gives us one of the points of our load line.

The second point on the load line can be considered as the plate voltage when the grid is sufficiently negative to cause plate current cut-off. Under this condition, with no plate current, there will be no drop across the load and the plate voltage will be equal to the "B" supply voltage. That is,

$$E_p = E_b - (0 \times R_L)$$
$$E_p = E_b \qquad (3)$$

A line, connecting these two points, gives the locus of the plate voltage during one cycle of plate current and, from our former definition, is a "Load Line".

To show you how a load line can be put to practical use, suppose we want to find the power output of a triode tube with a family of curves like those shown on Figure 1. The recommended operating values are 250 plate volts, 33.5 ma plate current, 48.5 volts negative grid bias and a load resistance of 3900 ohms. The first step is to determine the value of "B" supply voltage necessary to allow a plate voltage of 250 volts at a current of 33.5 ma. This can be done by substituting in formula (1) and solving for E_b.

$$E_p = E_b - I_pR_L \quad \text{or, transposing terms,}$$
$$E_b = E_p + I_pR_L = 250 + (.0335 \times 3900)$$
$$E_b = 250 + 130.65 = 380 \text{ volts. (approx.)}$$

Substituting in Equation (2), the plate current, at zero plate voltage, will be

$$I_p = \frac{E_b}{R_L} = \frac{380}{3900} = .0974 = 97.4 \text{ ma}$$

This value of plate current is now plotted on the plate current scale at zero plate volts and is shown as point A in Figure 1.

For the plate voltage at plate current cut-off, or zero plate current, $E_p = E_b = 380$ volts which is point "B" on the load line. Point A lies on the zero voltage axis at 97.4 ma and point B lies on the zero current axis at 380 volts. Joining these two points produces the load line AB, Figure 1, which must also pass through the $E_p = 250$, $E_c = -48.5$ and $I_p = 33.5$ intersection, as this was the suggested operating point.

Before we can find the power output, it will be necessary to derive a formula so that the current and voltage values of

the curves may be used. The amplitude of the a-c plate current is equal to the total current swing divided by two. As an equation,

$$I_p = \frac{I_{max} - I_{min}}{2}$$

In a like manner, the peak amplitude of the a-c plate voltage can be expressed by

$$E_p = \frac{E_{max} - E_{min}}{2}$$

Then, as power is equal to voltage times current, the peak power is equal to,

$$P_p = E_p I_p = \left(\frac{I_{max} - I_{min}}{2}\right)\left(\frac{E_{max} - E_{min}}{2}\right)$$

$$P_p = \frac{(I_{max} - I_{min})(E_{max} - E_{min})}{4}$$

To obtain the average power, the effective values of the plate current and plate voltage must be used and remembering the ratio between maximum and average a-c values, we divide both the above current and voltage values by 1.414 or $\sqrt{2}$.

$$P_{av} = \left(\frac{I_{max} - I_{min}}{2 \times \sqrt{2}}\right)\left(\frac{E_{max} - E_{min}}{2 \times \sqrt{2}}\right)$$

$$P_{av} = \frac{(I_{max} - I_{min})(E_{max} - E_{min})}{8} \qquad (4)$$

In order to keep the grid from being driven positive, the positive peak value of the a-c grid voltage must not exceed the grid bias value. When these two values are equal, the voltage on the grid will be zero and the plate current will be maximum value. From the family of curves in Figure 1, this maximum plate current is shown by the intersection of the load line AB and the $E_c = 0$ curve and has a value of approximately 68 ma.

As the a-c grid voltage swings an equal distance on either side of the fixed d-c grid bias operating voltage, at the negative peak of the signal, the voltage on the grid is twice the grid bias, or in this case, -97 volts. At this value of bias voltage, the plate current is minimum and its value of approximately 6 ma as shown by the intersection of the load line AB and the $E_c = 97$ curve. Therefore, the plate current swings from 6ma to 68 ma in one cycle of a-c grid voltage.

The plate voltage swing can be found in a similar way and, reading down from the intersection of the load line AB and $E_c = 0$ curve, the value is approximately 118 volts while at the intersection of the load line AB and $E_c = -97$ volts, the value is approximately 358 volts. Thus, the a-c plate voltage swing is from 118 to 358 volts.

Substituting these values of plate current and plate voltage in formula (4), the power output will be,

$$P_{av} = \frac{(Imax - Imin)\ (Emax - Emin)}{8}$$

$$P_{av} = \frac{(.068 - .006)\ (358 - 118)}{8} = \frac{.062 \times 240}{8}$$

$$P_{av} = 1.86 \text{ watts.}$$

As the load resistance is decreased, the value of plate current change will increase and result in a greater power output. However, any attempt to reach the maximum power output of the tube by decreasing the load resistance is limited by the allowable amount of distortion.

From your earlier Lessons, you know that for distortionless Class A operation, the average value of plate current remains constant, whether there is a signal input or not, because the positive and negative lobes of the plate current cycle are of equal amplitude. When this is not the case, the average plate current varies and results in what is called "second harmonic distortion". As this distortion is due to unsymmetrical positive and negative plate current lobes, we can set up the following expression between Imax, Imin and the current at no signal input, "I_o".

$$D = \frac{\frac{Imax + Imin}{2} - I_o}{Imax - Imin} \times 100 \qquad (5)$$

Where D is the percentage of second harmonic distortion.

All of these values can be found in the curves of Figure 1 and, as previously shown, Imax = 68 ma and Imin = 6 ma. As I_o is the current at no signal input, its value is indicated by the intersection of the load line and $E_c = -48.5$ volts and is approximately 33.5 ma. Substituting these values in formula (5), the percentage of second harmonic distortion will be,

$$D = \frac{\frac{(.068 + .006)}{2} - .0335}{(.068 - .006)} \times 100 = \frac{.037 - .0335}{.062} \times 100$$

$$D = 5.64\%$$

For quality amplification, the distortion should not greatly exceed 5% and, as our example is only slightly higher, a load of 3900 ohms would be satisfactory. A higher load would result in distortion but also a lower power output, while a lower load would give higher distortion and greater power output.

Of course, there are limitations to the amount the load may be increased or decreased and they depend on the type of tube employed. However, you can see from the above explanations that the power output and distortion are dependent on the load resistance. These formulas, for power output and distortion, hold true only for Class A triode operation and, with two tubes operating in push-pull as shown in the circuit of Figure 1, the power output will be approximately twice that of one tube.

CLASS B OPERATION

In the circuit diagram of Figure 2, we show a conventional Class B audio stage which, as far as the connections are concerned, is exactly like that shown in Figure 1. In Class B, however, the grid is driven positive and the bias voltage is of such value that plate current exists only during the positive alternations of signal input. The action for this class of operation has been explained in an earlier Lesson and, if it is not clear, we suggest that you go back and review so that you will have no difficulty understanding the following explanations.

The power output of a Class B stage is determined by the value of the load and the peak or maximum plate current drawn by each tube. The peak value of plate current is determined chiefly by the amount the grid is driven positive and the minimum plate voltage, which occurs at maximum plate current, is then determined largely by the value of load resistance.

At plate current cut-off, the voltage on the plate is maximum and equal to the supply voltage E_B, therefore the peak amplitude of the load voltage is expressed by -

$$Emax = E_B - Emin.$$

As the current varies from zero to the value Imax, the peak amplitude of the load current is equal to Imax.

The peak power output then is

$$P_p = Imax\ (E_B - Emin)$$

and the effective or average power output, in terms of the peak load current and voltage is expressed by

$$P_o = \frac{(Imax)}{(\sqrt{2})}\frac{(E_B - Emin)}{(\sqrt{2})} = \frac{Imax\ (E_B - Emin)}{2} \qquad (6)$$

The plate power input is the d-c power delivered to the stage by the supply and is expressed by

$$P_I = E_B Iav$$

where E_B is the plate supply voltage and Iav is the average current taken from the supply. This average current is the average value of plate current taken by the tubes, and is expressed in terms of the maximum plate current by

$$Iav = .636\ Imax$$

The average plate power drawn from the plate supply is then

$$P_I = E_B Iav = .6366\ E_B Imax \qquad (7)$$

In percentage, the efficiency of the stage is equal to the power output divided by the power input times 100 therefore, we can write,

$$Eff = \frac{P_o}{P_I} = \frac{\frac{Imax\ (E_B - Emin)}{2}}{.6366 E_B Imax} \times 100 \text{ or}$$

$$Eff = 78.5\ \left(1 - \frac{Emin}{E_B}\right) \qquad (8)$$

Maximum efficiency will be obtained when the minimum plate voltage is zero and, by substituting in equation (8), will be found to be 78.5%.

As pointed out earlier in our explanation, peak plate current will occur at peak grid voltage therefore the power output is determined largely by the amount the grid is driven positive. However, when the grid is positive, grid current exists and causes grid power dissipation in the form of heat so that

the maximum positive grid voltage is determined by the safe heat dissipation limit of the tube.

Another factor which also limits the maximum positive grid voltage is that minimum plate voltage occurs at maximum grid voltage. If the value of minimum plate voltage approaches that of maximum positive grid voltage, the grid, being closer to the cathode, tends to take current which would normally go to the plate. This results in a distorted plate current wave form and overheating of the grid.

Still another factor to be considered is the absorption of power in the grid circuit when grid current exists. As this power must come from the driver, or stage ahead of the Class B stage, excessive grid current means that more driver power must be delivered.

Taking all of these factors into consideration, a safe rule is to hold the minimum plate voltage to a value not less than twice the maximum grid voltage. By following this rule, the maximum plate current and minimum plate voltage, for any grid voltage, can be found by means of a family of plate current-plate voltage curves. Knowing these values, it is quite simple to determine the proper load resistance into which each tubes works.

From our former explanations, you know that the drop across the load is the difference between the supply and plate voltages. The resistance of the load is equal to the voltage drop across it divided by the plate current and, if we take the conditions of peak plate current, which causes minimum plate voltage, we can write

$$R_L = \frac{E_B - E_{min}}{I_{max}} \qquad (9)$$

where R_L represents the effective load resistance of each tube in a Class B stage. In actual practice, the specifications of an output or modulation transformer of a Class B stage are given in terms of the plate to plate primary impedance, which is four times the effective plate load of each tube.

In order that you may see why this "four" relation is proper, let us consider the circuit of Figure 2 and assume that R_L is the proper effective load for each tube. In an earlier Lesson, we gave you a formula for a transformer where

$$N^2 = \frac{R_p}{R_s}$$

When,

N = turn ratio
R_p = resistance of primary
R_s = resistance of secondary

Transposing and solving for R_p, we find that

$$R_p = N^2R_s$$

which tells us that the primary impedance varies as the square of the turn ratio. In Class B operation, only one tube operates at a time therefore, in Figure 1, one half the transformer primary must have a 1:1 ratio to the secondary in order that R_L will be reflected as the proper load in the primary circuit. However, with a one to one ratio between each half of the primary to the secondary, the total primary ratio to the secondary will be 2:1. Under these conditions, the load R_L will be reflected to the total primary as

$$R_p = N^2R_s = (2)^2R_s = 4R_s$$

which shows the four to one relationship previously mentioned.

Thus, as equation (9) expressed the effective plate load of one tube, the plate to plate load can be expressed as,

$$R_{L_1} = 4\left(\frac{E_b - Emin}{Imax}\right) \qquad (10)$$

where

R_{L_1} = plate to plate load resistance.

To show you how these various formulas can be put to use, let us consider the family of plate voltage-plate current curves shown in Figure 2. For definite values we will assume that the grid is to be driven 80 volts positive, the supply develops 800 volts and the maximum plate dissipation is 26 watts.

Our first step is to determine the points for a load line and, from the former rule of minimum plate voltage equal to twice the grid voltage, we locate point "A". The second point, for the plate voltage at zero plate current, is indicated by point B. Connecting these two points gives us the load line AB.

The power output for the two tubes can be determined from equation (6) and the curves show that $Imax$ = 265 ma, E_B = 800 volts and $Emin$ = 160 volts.

Substituting in equation (6),

$$P_o = \frac{Imax\ (E_B - Emin)}{2} = \frac{.265\ (800 - 160)}{2}$$

$$P_o = \frac{.265 \times 640}{2} = 84.8 \text{ watts}$$

The proper plate to plate load to obtain this power output can be found by substituting in equation (10).

$$R_{L_1} = 4\frac{(800 - 160)}{.265} = \frac{4 \times 640}{.265}$$

$$R_{L_1} = 9660 \text{ ohms}$$

The plate power input for this load can be found by substituting in equation (7) and is

$$P_I = .6366\ E_B Imax = .6366 \times 800 \times .265$$

$$P_I = 135 \text{ watts approx.}$$

The efficiency can be found by substituting in equation (8)

$$Eff = \frac{P_o}{P_I} = \frac{84.8}{135} = .628 = 62.8\% \text{ or}$$

$$Eff = 78.5\ (1 - \frac{Emin}{E_B}) - 78.5\ (1 - \frac{160}{800}) = 62.8\%$$

The power dissipated in the plates of the tubes in the form of heat, is the difference between the power input and the power output or

$$135.0 - 84.8 = 50.2 \text{ watts}$$

The plate dissipation per tube will be half this value or 25.1 watts which is less than the maximum allowable dissipation given in our explanations and therefore satisfactory.

MATCHING MODULATOR TO AMPLIFIER

The plate to plate load impedance specified for the rated power output of a Class B modulator seldom corresponds to the modulating impedance of the Class C r-f stage, so that a match must be brought about by adjusting the turns ratio of the coupling transformer. As pointed out before, for proper impedance match, the required turns ratio should be,

$$N^2 = \frac{R_p}{R_s} \text{ or } N = \sqrt{\frac{R_p}{R_s}} \qquad (11)$$

which

N = turn ratio
R_p = primary impedance
R_s = secondary impedance

To show you how this formula is applied, we will now assume that we are to match the 9660 ohm plate to plate load of our former example to a plate modulated Class C amplifier which, when modulated, draws 300 ma, from a 1200 volt supply. From our former study of a plate modulated Class C amplifier, we know that, when properly adjusted, the plate current is almost exactly proportional to the applied plate voltage. Thus, the load presented to the modulating voltage is equal to the plate supply voltage of the amplifier divided by the unmodulated d-c current. As an equation,

$$R_s = E_b/I_b \qquad (12)$$

when

R_s = secondary impedance of modulation transformer
E_b = plate supply voltage of Class C amplifier
I_b = d-c plate current of Class C amplifier when unmodulated.

For our example,

$$R_s = E_B/I_p = \frac{1200}{.300} = 4000 \text{ ohms.}$$

The proper turn ratio of the modulation transformer is therefore,

$$N = \sqrt{R_p/R_s} = \sqrt{\frac{9660}{4000}} = \sqrt{2.415}$$

$$N = 1.55$$

which tells us that the total primary has a ratio of 1.55 more turns than the secondary.

It is commercial practice to give the specifications of Class B modulation transformers in terms of the Class B output tubes to the secondary impedance. This, however, is nothing but a short-cut method of stating the turns ratio which can be found by the proper use of equation (11). Also, many modulation transformers, known as "Universal" types, are provided with

primary and secondary taps so that various turn ratios can be obtained to meet the requirements of a large number of tube combinations. This latter type, while seldom used in commercial stations, is a big help to the amateurs who change their equipment quite often.

PER CENT OF MODULATION

As we explained in an earlier Lesson, for c.w., or radio telegraph, the amplitude of the carrier is constant while a signal is being radiated from the transmitting antenna. However, for the transmission of voice or music, the amplitude of the carrier varies in proportion to the sound or signal frequencies and we say the carrier is modulated. The ratio of the peak modulating voltage to the normal carrier amplitude is called the "percentage of modulation". As an equation,

$$M = \frac{A}{B} \times 100 \qquad (13)$$

when

M = percentage of modulation
A = peak signal voltage
B = normal carrier voltage with no modulation.

Analyzing this formula you can see that when the peak signal voltage is equal to the normal carrier voltage with no modulation, we have a condition of 100°/o modulation. Saying this in a little different way, when the carrier increases to twice its normal amplitude on one alternation of the signal frequency and then drops back to zero on the next, the carrier is 100°/o modulated.

You will recognize the general curves of Figure 3 as having been offered in a previous Lesson. However, we want to repeat at this point and at the left of Figure 3A we have drawn an unmodulated carrier and then at the right have shown the effect of a modulating signal. Notice, amplitude "B" indicates the normal carrier while "A" shows the peak amplitude of the modulating voltage. In this Figure, "A" and "B" are equal therefore 100°/o modulation results.

For Figure 3B, we have drawn another modulated carrier wave but with "A" equal to half the value of "B". Under these conditions, the modulated wave, or envelope as it is quite commonly called, represents a percentage of modulation of,

$$M = \frac{A}{B} \times 100 = \frac{1}{2} \times 100 = 50°/o$$

Going back to Figure 3A, you will notice that the carrier amplitude is the a-c axis for the modulating frequency which we have considered to be a sine wave signal and the power in this sine wave, or side band, must be supplied by the modulator stage. The average carrier power in the antenna is equal to the current squared times the resistance of the antenna divided by two. Expressed as an equation,

$$P_c = \frac{I_c^2 \times R}{2} \qquad (14)$$

when

P_o = average power in unmodulated carrier
I_o = carrier current
R = antenna resistance

The amplitude of the current in each side band is equal to the current in the carrier multiplied by one half the percentage of modulation. As an equation,

$$I_s = I_c \times \frac{M}{2} \qquad (15)$$

when

I_s = current in each side band
M = percentage of modulation.

As the average-power is equal to half the current squared times the resistance, the average power in each side band is,

$$P_s = \left(\frac{I_c \times M}{2}^2\right) \times \frac{R}{2} = \frac{I_c^2 M^2}{4} \times \frac{R}{2}$$

$$P_s = \frac{I_c^2 M^2 R}{8} \qquad (16)$$

when

P_s = power in each side band

The total power in the antenna is equal to the sum of the separate powers and, as there are two side bands, it is equal to equation (14) plus two times equation (16). As an equation,

$$P_o = \frac{I_c^2 R}{2} + 2\left(\frac{I_c^2 M^2 R}{8}\right) = \frac{I_c^2 R}{2} + \frac{I_c^2 R M^2}{4}$$

Factoring out the $(I_c^2R/2)$ terms,

$$P_o = \frac{I_c^2R}{2} \times \left(1 + \frac{M^2}{2}\right) \qquad (17)$$

when

P_o = total antenna power

Now notice, in equation (17), when the value of M is 1, or the carrier is 100% modulated, the power increases, over that with no modulation, by the factor 1.5. Considering the average unmodulated power as unity, or 1, it will represent 1/1.5 or 66.7% of the total antenna power leaving 33.3% of the power in the side bands. When M is 50%, the factor becomes 1.125 and the carrier power is 1/1.125 or 88% which leaves about 12% in the side bands.

As it is through the medium of these side bands that intelligence is transmitted, it is obvious that the most efficient use of the carrier is obtained when it is 100% modulated.

METHODS OF MODULATION MEASUREMENT

By analyzing Figure 3 and equation (13) you can easily see that the percentage of modulation can be determined if the amplitude of the carrier is measured with no modulation and then measured again when it is modulated. One of the simplest methods of making these measurements is by the use of a vacuum tube voltmeter, one arrangement of which is shown in Figure 4. You may recognize this as a slide back type of vtvm explained in an earlier Lesson but, for the present application, we have added the inductance L and condenser C so that no direct connection to the transmitter is necessary.

In using an instrument of this kind, the movable arm of R_1 is rotated to the extreme right and then R_2 is adjusted until the milliammeter in the plate circuit indicates zero current. Then, coil L is coupled to the unmodulated amplifier and the coupling and condenser C are adjusted until the plate current milliammeter reads some convenient value of at least half scale. Then, without touching R_2, R_1 is adjusted until the plate current is again zero. When this happens, the voltmeter "V", will read the peak value of the incoming carrier, which is represented by "B" in formula (13) or in Figure 3.

Without changing the coupling, a sine wave note is applied to the modulator input causing the carrier to be modulated, and the change will be indicated by current in the meter "M". R_1 is adjusted again until there is zero current in "M" and

under this condition meter "V" indicates the peak amplitude of the incoming modulated carrier which, in Figure 3, would be A + B.

To show you how this works out, we will assume that the first reading was 2 and second 3. Under these conditions, B = 2, and A = 3 - 2 or 1. From equation (13), the percentage of modulation is

$$M = \frac{A}{B} \times 100 = \frac{1}{2} = 50\%$$

Although this system does provide a means of determining the percentage of modulation, it has the disadvantage of not being direct reading and does not give any indication of the symmetry between positive and negative peaks.

Another way of determining the percentage of modulation is by the double rectifier method, a simple arrangement of which is shown in Figure 5. Checking through the circuit and starting from the left, you will find the combination LC which is coupled to the half wave rectifier T_1 through condenser C_1. A "T" type filter, made of two r-f chokes and condenser C_2, with voltmeter V_1 across its output, connects to the rectifier plate. From the upper terminal of this voltmeter there is a connection to one side of a polarity reversing switch, while from the other terminal, there is a connection to the other side of the polarity reversing switch through voltmeter V_2. Notice here, voltmeter V_2, measures the voltage drop between the movable contact of potentiometer R and its + terminal. From the reversing switch, there is another circuit made up of the capacity C_3, shunted by R_1 in series with current meter M, all of which are in series with the rectifier tube T_2.

A circuit of this kind operates on the idea that when a modulated envelope is rectified, it is made up of an a-c component which represents the modulation and a d-c component which represents the carrier.

Keeping this in mind, coil L is coupled to the r-f amplifier stage and condenser C is adjusted until the circuit is resonant at the transmitter frequency. This will cause a rectified current in the plate circuit of T_1 and V_1 will indicate the average, or d-c, voltage, which represents the carrier level. The movable contact on potentiometer R is then adjusted until V_2 reads the same as V_1. Under these conditions, and with an unmodulated carrier, there will be no difference of potential between points A and B. However, if the carrier is modulated, and the reversing switch is in the position of the broken lines, the d-c component will be cancelled and the a-c

component only will appear across A-B. Because of the rectifying action of the tubes, only the negative alternations of modulating signal voltage will cause current in the plate circuit of T_2 and meter "M". With the switch thrown in the opposite position, the positive alternations will cause current in the meter "M".

As you probably remember, with a condenser input filter across the output of a rectifier, the d-c voltage very closely approximates the peak value of the pulsations. In the cathode circuit of T_2, condenser C_3 acts as a condenser input filter while R_1 and M, which is a very sensitive current meter, measure the voltage drop across it. As pointed out above, this voltage very nearly equals the peak of the pulsations and therefore the meter M can be calibrated in "% of modulation" and read directly. Also, by changing the position of the polarity reversing switch, a check of the symmetry between the positive and negative peaks is obtained.

MODULATION PATTERNS

Due to the fact that an oscilloscope gives a visual indication of the happenings in a circuit, it can also be used to provide a check of the percentage of modulation. Although a 'scope could be connected directly to a transmitter, the high voltages encountered make it a rather dangerous procedure therefore, a circuit arrangement, similar to that of Figure 6, is more advisable. You will notice that we have a coupling coil "L" in the tuned circuit LC which, in turn, is coupled to a half wave rectifier through C_1. In the rectifier plate circuit there is a conventional r-f filter the output of which is resistance capacity coupled to the terminals H. This allows only the a-c component of the signal to appear across the "H" terminals while the "V" terminals are connected directly across the tuned circuit LC.

In operation, the vertical plates of the 'scope are connected across the V terminals and the horizontal plates across the H terminals. Then, coil L is coupled to the modulated amplifier and the condenser C adjusted until the circuit is resonant at the transmitter frequency. With these connections, the full modulated envelope will be applied to the vertical plates of the scope while only the modulation or a-c component of the signal is applied across the horizontal plates. The result is a "trapezoidal" pattern on the screen of the scope and, if the carrier is 100% modulated with negligible distortion, the pattern will be similar to Figure 7A.

If the carrier is modulated 50%, the pattern of Figure B will appear while a pattern, similar to 7C, indicates over-modulation. In Figure 7C, the over-modulation is indicated by a bright line which is pointed out at the right side of our drawing.

From such patterns, percentage of modulation, up to 100% can be quite easily determined by measuring the distances D_{max} and D_{min}, as indicated in Figure 7-B, and then substituting in the following formula -

$$M = 100 \frac{D_{max} - D_{min}}{D_{max} + D_{min}} \qquad (18)$$

As a definite example, you will find by measurement that, in Figure 7B, D_{max} is 3 times as long as D_{min}. Substituting in equation (18)

$$M = 100 \left(\frac{3 - 1}{3 + 1}\right) = 100 \times \frac{2}{4}$$

$$M = 50\%$$

Following the same plan, D_{min} is zero in Figure 7A, therefore the percentage of modulation is

$$M = 100 \left(\frac{D_{max}}{D_{min}}\right) = 100 \times 1 = 100\%$$

Another method of using the 'scope as a modulation indicator is to apply the modulated carrier to the vertical plates, by the use of a tuned circuit similar to LC, Figure 6, while the internal sweep of the 'scope is used on the horizontal plates. The carrier is then modulated by a single tone and the internal sweep is adjusted to the frequency of this tone.

With this set up, 100% modulation will produce an image on the screen similar to that shown in Figure 3A, while with 50% modulation, the image will be similar to Figure 3B. Over-modulation will be indicated by a pattern similar to Figure 7D where the bright line appears in the center of our drawing. In practical use of this method, the single cycles of carrier frequency will not stand out as shown in our drawings, but this is not detrimental as the percentage of modulation is determined by the wave form of the envelope.

Although the 'scope does show the modulation continuously, and is very valuable for this reason, it is not considered as a very accurate measuring instrument because the pattern on the screen is comparatively small and it is difficult to make accurate measurements. Therefore, the 'scope should be considered as supplementary to a more accurate modulation meter.

CARRIER SHIFT

In the operation of a transmitter, slight changes in dynamic conditions may result in carrier frequency modifications known as "carrier shift". Looking at Figure 3B, if the amplitude of "A", with respect to the dashed line representing the r-f carrier level, is greater than corresponding negative alternation of audio signal, we have a condition of positive carrier shift. In other words, the lobes representing the audio variation are not symetrical and the result is noticeable distortion and broad tuning.

Positive carrier shift may be caused by over modulation, insufficient r-f excitation in the amplifier stage, high grid bias values or poor regulation of the grid bias supply.

In contrast with the condition of positive carrier shift, excessife r-f excitation of the amplifier, mismatch between modulator and modulated stages, as well as mistuned circuits may cause negative carrier shift. In such a case, the negative lobe of the audio modulated r-f carrier is greater.

SPEECH AMPLIFIERS

So far in our explanation of modulators, we have said nothing about the sound signal before it reaches the modulator stage. However, before reaching the modulator, it must be amplified to the proper level by means of a unit which is called the "Speech amplifier". For Figure 8 we have drawn the circuit of a simple speech amplifier and you will notice that it is nothing but an audio voltage amplifier.

Following the path of the signal, it is applied across resistor R and impressed on the grid of T_1, is amplified by the tube and appears across the plate resistor R_3. From here it coupled to the grid of T_2, through condenser C_3 and the volume or gain control, R_5, is amplified by this tube and appears across R_7. It is then coupled by C_5 and R_8 to the grid of T_3 and appears finally across the secondary of the output transformer.

In case the modulator is operating in Class A, like the circuit of Figure 1, T_3 of Figure 8 need be a voltage amplifier only because no power is required. If we assume that the primary of the input transformer of Figure 1 is the primary of the output transformer of Figure 8, the speech amplifier would be properly connected to the modulator.

Should the modulator operate in Class B, which is most generally the case, then T_3 of Figure 8 would have to furnish the power to

drive the Class B grids and is commonly called the driver. In the design of a circuit of this kind, the type of tube will depend on the amount of driving power required. Where larger driving power is necessary, it is customary to use two driver tubes connected in push-pull, and because the load into which the driver works is continuously variable, low mu power triodes are most suitable for drivers. Pentode or beam power tubes can be used but, in order to prevent serious distortion, inverse feed-back should be employed to reduce their effective plate resistance and provide better voltage regulation.

MICROPHONES

Although microphones have been explained in an earlier Lesson, they are an important unit in transmitting work and therefore we want to briefly go over several of the different types.

A carbon microphone, you will remember, operates on the principle that its resistance changes when sound waves strike the diaphragm. Its a-c resistance is quite low, making an impedance matching transformer necessary when working into the grid of a tube. Compared to later types, its frequency response is not very good and it has a comparatively high background noise level which is caused by current through the carbon granules. It is non-directional and requires a voltage for operation but does have the advantage of a comparatively high output.

The condenser type of microphone, which operates on the principle of a changing capacity when sound waves strike its diaphragm, and is of the high impedance type and requires a polarizing voltage. Due to this voltage, it cannot be coupled directly to the grid of a tube, but requires some arrangement, such as a resistance capacity coupling, to block the d-c. This type of microphone is non-directional and has a good frequency response but with a low output.

In the ribbon or velocity microphone, the sound waves are changed to electrical energy by moving a conductor in a magnetic field which is set up by a permanent magnet. The conductor is a small corrugated ribbon, suspended between the pole pieces of the magnet, and when sound waves cause it to vibrate in the magnetic field, a voltage, of the same frequency and amplitude of sound, is induced in the ribbon.

The impedance of the ribbon is but a fraction of an ohm and thus its output is transferred immediately to the primary of an impedance matching transformer which is considered as an integral part of the microphone. The transformer secondary may be wound to most any desired impedance, and therefore

both low and high impedance types of velocity microphones are available. Their frequency response is excellent, they are bi-directional, transmitting sounds equally well from front and rear, require no polarizing voltage and have an output comparable to that of the condenser microphone.

The "dynamic" is another type of microphone and it operates on the same principle as the dynamic speaker. Conditions are reversed however, and an emf is induced in the moving coil of the microphone as the sound waves cause it to vibrate in a strong magnetic field. The impedance of the moving coil is low and an impedance matching transformer is quite often built in as an integral part of the complete microphone. Therefore, as explained for the velocity types, dynamic microphones may be of the low or high impedance type.

They are sensitive only to sounds striking the diaphragm at approximately right angles, and are therefore uni-directional, have a good frequency response, do not require a polarizing voltage and develop an output higher than that of the ribbon or velocity microphone.

The operation of a crystal microphone is dependent on the piezo-electric properties of certain crystals such as the commonly used Rochelle Salt. One of the exceptionally fine characteristics of this type microphone is its ability to amplify the higher spectrum of audio frequencies above 8000 cycles. It does not require a polarizing voltage, is non-directional and has an output comparable to that of the dynamic type. In general, crystal microphones are of the high impedance type and can be connected directly across the grid circuit of an amplifier tube.

Of the microphones which we have explained, the velocity or ribbon, dynamic and crystal types are the most popular at the present time. However, the particular type employed depends considerably on conditions under which the desired sound is to be picked up.

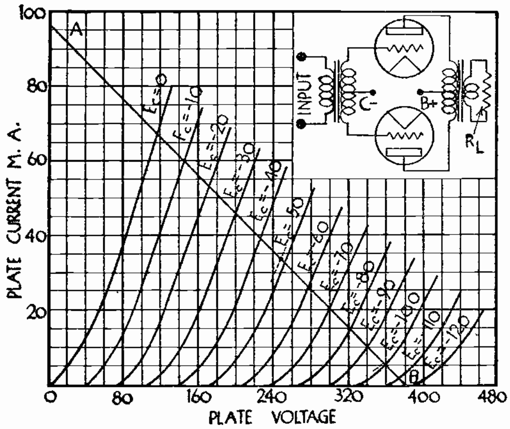


FIGURE 1

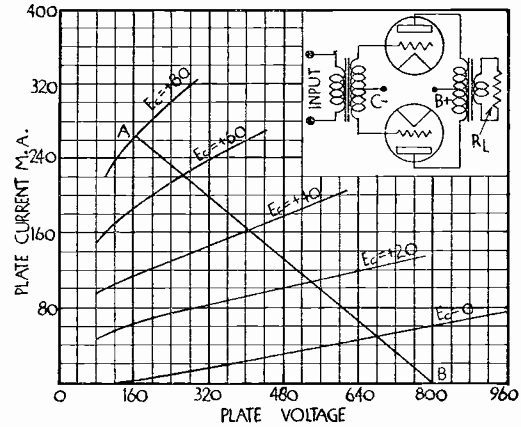


FIGURE 2

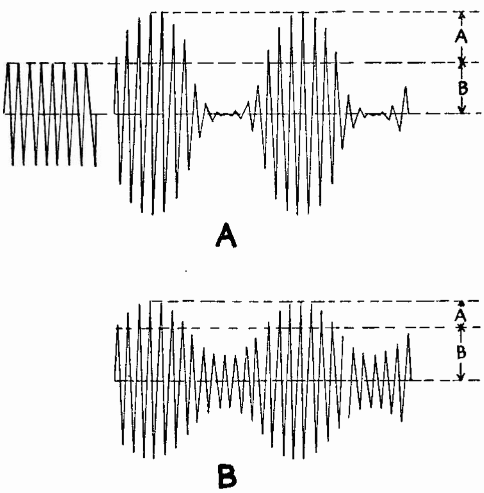


FIGURE 3

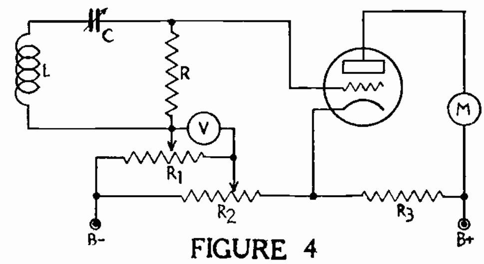


FIGURE 4

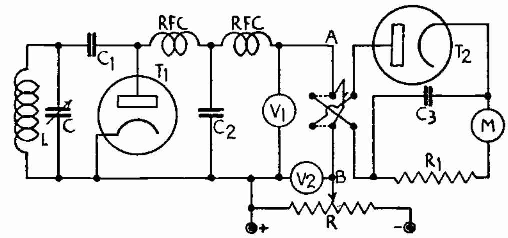


FIGURE 5

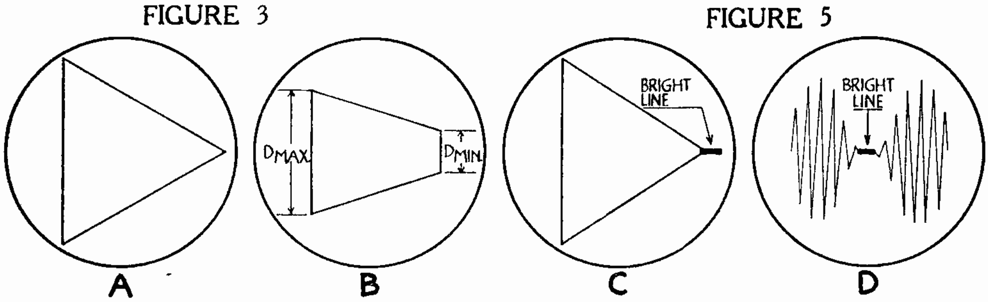


FIGURE 7

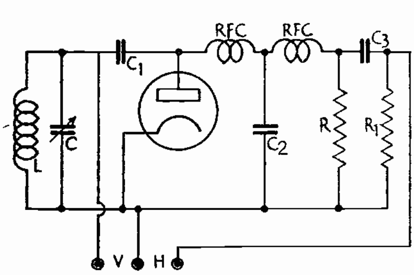


FIGURE 6

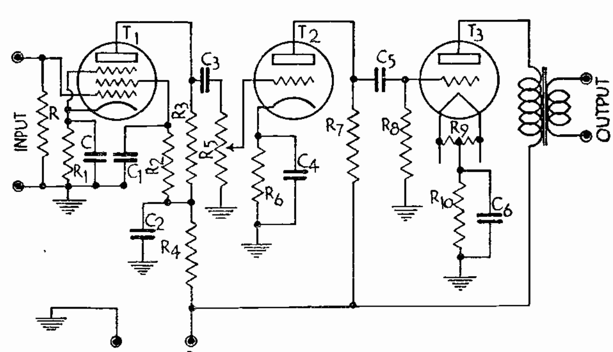


FIGURE 8

RADIO RECEPTION AND TRANSMISSION

LESSON RRT-20

AIRCRAFT RADIO

# # # # # # # # # # # #

Mental laziness is a common disease. Put in a certain amount of time every day at making your brain more efficient. Read - Study - Think. You can get used to hard study as well as hard work, and it pays. Improve yourself from the chin up.

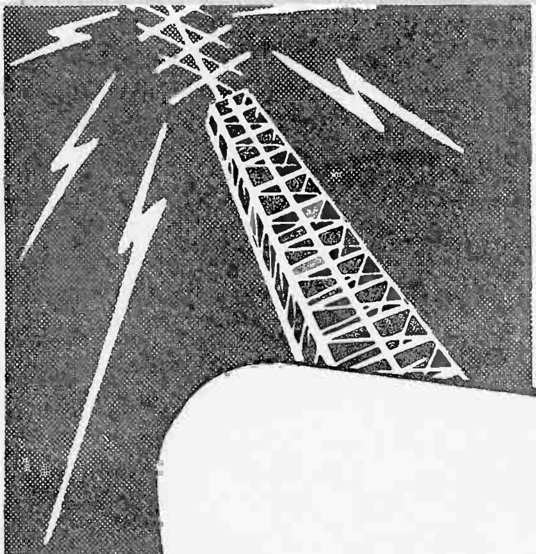
Dr. Frank Crane

LESSON RRT-20

AIRCRAFT RADIO

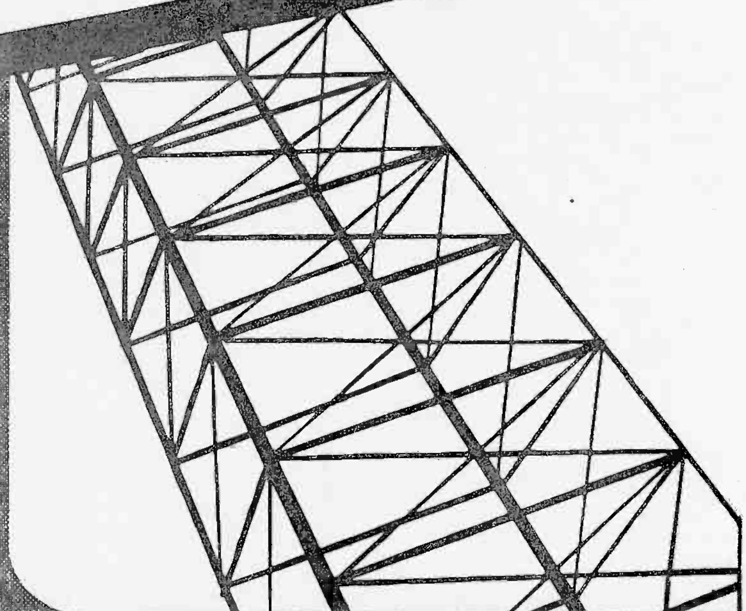
DE FOREST'S TRAINING, INC.

2533 N. Ashland Ave., Chicago 14, Illinois



LESSON RRT-20

AIRCRAFT RADIO



RADIO ELECTRONICS
DE FOREST'S TRAINING, INC.

DE FOREST'S TRAINING, INC.
2533 N. Ashland Ave., Chicago 14, Illinois

AIRCRAFT RADIO COMMUNICATIONS

The "SOS" radio distress call has been given so much publicity that everyone fully appreciates the importance of Radio communication in respect to ocean transportation. Although more or less taken for granted, the general public does not seem to appreciate that the rapid development of air transportation has been due largely to the various applications of Radio Communication.

Full credit must be given to the wonderful improvements of aircraft design as well as to the great advances which have been made in speed, reliability, safety and comfort of both the pilots and the passengers. As a transportation system however, the Radiotelephone, Radio Telegraph, Radio Beacon, Radio Direction Finder, Radio Altimeter and Radio Landing Beams have made it possible to fully utilize the capability of modern types of aircraft.

By means of these various Radio services, the airplane pilot is in constant communication with other ships in flight and also with the ground stations at the various landing fields. He receives up to the minute weather forecasts which tell him what lies ahead and enables him to pass around severe local storms.

His radio instruments tell him when he is on the proper course and show him which way to go, in case he is "off course", tell him how high above the ground his ship is and help him to land under conditions of bad weather or poor visibility.

In a Railroad system, the Train Dispatcher can send messages to any of the stations along a given route and thus periodically issue orders to the train crew. By means of Radio communication, the Airline traffic manager has continuous contact with all aircraft in flight and can thus control their movements at any time in respect to weather conditions, traffic requirements and details of landing.

To improve the safety of Air Navigation, the United States Government has developed an elaborate network of Radio stations to supplement those of the commercial systems. There are government stations which, at frequent intervals, broadcast up to the minute weather forecasts for ships in flight as well as the airports in range.

There are about 200 Radio range beacon stations which furnish special directional signals and provide charted courses which can be followed in bad weather.

Supplementing the Range Beacons there are about the same number of Radio Marker Beacons which locate the meeting points of the range beacon courses and also indicate important locations such as emergency landing fields and sudden changes in the elevation of the ground.

In addition to all of the above, there is a teletype system connecting Radio stations with government weather observation stations to provide almost instant typewritten weather forecasts at the offices of the air transport lines.

Thus, while Radio has nothing to do with the actual flying ability of a ship, it is Radio alone which makes it possible to fly the ship over given routes and maintain regular schedules.

For both Army and Navy work, Radio is even more important as it permits the pilot to maintain constant communication with Headquarters and instantly report his observations.

Even for pleasure craft, which are flown only in fair weather, Radio equipment has become almost a necessity to insure safe take-offs and landings on a busy airport as well as to provide direct courses for cross country flights. In effect therefore, the Radio equipment of modern aircraft is almost as important as the motive power which makes air transportation possible.

The total amount of Radio equipment carried on a transport aircraft has increased considerably the last 10 years and even further increases are expected in the future. The most important reason for added radio equipment is to provide facilities for operation in all conceivable flying conditions.

Radio equipment, normally employed in aircraft, can be segregated into three distinct types as follows: 1. Two way communication radio equipment; 2. Radio equipment for enroute navigation; 3. Instrument landing equipment.

Before going into greater detail as to their principles of operation, we want to offer an "overall picture" of the first of these services.

TWO WAY COMMUNICATION

As the terms imply, two way communication is the transfer of essential information between any two stations, either mobile or fixed, although the greatest amount of traffic will be exchanged between aircraft and airport stations. The latter, known as "fixed" stations, are separated, on the average, by distances of 200 miles.

At present, transport aircraft in any given area of the United states transmit on two frequencies. They are equipped to transmit on as many pairs of like frequencies as there are radio divisions on the system and the two frequencies employed in each pair are used for day or night transmission.

The frequencies for night time communications center at approximately 3 megacycles while those for day time communication center at about 5 megacycles. The information carried on these frequencies is of two kinds: (a) Important weather reports and direction given to the pilot by supervisory ground personnel. (b) Position and weather reports given by the pilot to the ground.

As you can readily appreciate, direct and positive contact must be provided between aircraft and airport stations in order to insure maximum safety of life and property. There are limitations as to the range of positive radio signals due to atmospheric conditions and unusual behavior of radio waves, therefore approved aviation transmitters have reliable transmission ranges somewhat as shown by the following table.

TABLE 1

Condition	Average Distance (Miles)
Winter	400
Summer	200
Summer Thunderstorm (scattered)	125
Summer Thunderstorm (heavy)	30

At present, many ground stations are equiped with 3000 watt transmitters, whereas the usual aircraft transmitters are 50-100 watt units. You may wonder at this difference in power of the transmitters but there are two reasons for this discrepancy. 1. There is a definite weight and power limitation in the aircraft. 2. Ground stations must communicate with one another over the full distance between such stations, which is usually twice as far as the greatest aircraft communication distance.

Experience has shown that an increase in the power of the aircraft transmitter from 50 watts to 1000 watts resulted in an effective increase of radiation from 200 to about 400 miles, but the increase in weight was from 70 lbs. to about 450 lbs. Although these figures are only approximate they show the high weight penalty paid for increased power and the relatively small increase in communication distance for this weight. Of course, recent improvements in the efficiencies of tubes and lighter associated equipment has reduced the "weight" that normally would have been required to increase the power of the transmitter.

CHOICE OF FREQUENCY

Obviously the transmission conditions over a given distance vary so greatly that small power changes are ineffective in establishing reliable communication. However, there is a partial solution to this difficulty in the choice of the proper frequencies at given distances.

Table II shows how a group of six frequencies can provide efficient transmission over various distances.

TABLE II

Local Time	Frequency in kc	Distance in Miles
Noon	6,500 8,000 10,000	0-200 100-500 400-1600
6 PM	5,000 8,000 10,000	0-200 150-800 400-1600
Midnight	4,000 5,000 6,500	0-200 150-500 400-1600
6 AM	3,000 4,000 5,000	0-200 150-500 400-1600

For example, suppose it is desired to provide not less than 250 mile transmission at any time of a 24 hour cycle. At noon and through 6 PM, 8000 kc transmission would be used. At midnight and 6 AM frequencies of 5000 and 4000 kc respectively would be used.

One factor, not considered in the above table, is that of atmospheric noise. Such disturbances decrease almost inversely with frequency and this immediately suggests the use of ultra high frequencies. At the present time a considerable amount of development work is being done using such frequencies for aviation communication. Ultra high frequencies do not follow the curvature of the earth, nor are they reflective back to earth at great distances from the Heaviside layer. Phenomenal reductions in thunder storm static are realized on these frequencies, and aircraft can work with ground stations through almost any atmospheric conditions.

Although transmission can take place over greater distances than those shown in Table II it has been found by actual tests, that these frequencies are reliable day and night and depend only upon the altitude of the plane plus the elevation of the ground station antennas.

GENERAL REQUIREMENTS

In some ways, Aircraft Radio can be compared to Auto Radio because, in both cases, the equipment must be installed on a mobile unit which is complete in itself and must operate without the benefit of a remote power supply or elaborate antenna equipment. The comparison can not be carried too far however because the safety of the aircraft may be entirely dependent on the proper operation of the Radio equipment, a condition that is seldom, if ever, true of Auto Radio.

From the standpoint of safety, Aircraft equipment must be reliable in performance and simple in operation. As already explained, it must be low in weight and occupy a minimum of space but these considerations should not be emphasized sufficiently to reduce the stability and efficient operation of the aircraft.

There are often wide differences of temperature between ground levels and the altitudes at which flights are made and the speed of the ship will expose the equipment to sudden temperature changes. Similar conditions exist in respect to the weather and thus the operation of the equipment must be continuous under all conditions, of weather and temperature, which will be encountered in flight.

Mechanically, the equipment must be built and installed to stand up under constant vibration as well as the more violent shocks which sometimes occur when landing. To sum up the requirements, the Radio equipment must operate normally under any and all conditions which may be encountered during take-off, flight and landing.

POWER SUPPLY

Like the automobile, the need for electrical power to operate the various Radio and other equipment of modern aircraft is growing steadily. Although the general conditions are much alike, the problem of minimum weight imposes additional restrictions on aircraft power supply systems.

In order to provide at least a temporary source of power to operate the Radio equipment while the plane is grounded and its engines are idle, a storage battery will be found in most

installations. Although the 12 volt battery was used, most present day aircraft operating voltages are — 24-30 volts d-c.

For Figure 1 we show the simplified circuit of any ordinary supply and you will notice first that the load is connected directly across the battery at all times. The meter, in series with the battery, will indicate both the amount and direction of current in the battery circuit.

The generator, a simple shunt wound d-c type, is mechanically connected to and driven by the main engine so that, while the plane is in flight, the generator will carry the load and also charge the battery. The cut-out or cut-out relay is essentially a check valve type of automatic switch, closing the generator battery circuit when the generator voltage is high enough to charge the battery and opening the circuit when the generator voltage drops sufficiently to allow the battery to discharge through the generator.

For the automobile generator, various forms of voltage and current regulators are installed but, for aircraft systems, the general trend is toward their elimination. Instead, a mechanical type of governor is placed in the driving connection between the engine and the generator. By means of a friction clutch, the generator speed remains practically constant, regardless of engine speed, so that the generator maintains a practically constant voltage on the system. With a constant generator voltage, the battery charging rate automatically adjusts itself according to the condition of the battery and thus the desired regulation is obtained without any electrical complications.

One quite common form of electrical voltage control, shown by the simplified circuit of Figure 2, depends upon the action of a magnetically operated switch. The unit resembles the cut-out of Figure 1 but the coil has only a voltage or shunt winding and the contacts are arranged to open as an increase of voltage causes a stronger magnetic pull on the contact arm.

The shunt field winding of the generator connects across the generator armature in series with the contact points which have a resistance, "R", connected across them. The position of the movable contact arm is balanced between an adjustable spring and the magnetic pull of the coil so that the contacts are normally closed.

With the contacts closed, the resistance is shorted out and the shunt field connects directly across the armature as shown in the circuit of Figure 1. As the generator is mechanically driven at increasing speeds, its terminal voltage rises, causes greater current in the magnet coil and increases the pull on the contact arm.

At some pre-set value of voltage, the magnetic pull overcomes that of the spring, the arm is pulled down and the contacts are opened. When this happens, the resistance "R" is in series with the shunt field winding, increasing the total resistance of the circuit and reducing the current in it.

With reduced field current, the magnetic flux cut by the armature coils will also reduce, causing a lower value of induction and a lower terminal voltage. This lower terminal voltage means a lower voltage across the regulator coil and less pull on the contact arm which the spring pulls up sufficiently to close the contacts.

When the contacts close, the resistance is shorted out, the shunt field current increases and the terminal voltage of the generator rises until the contacts are pulled apart and the entire action is repeated. With this arrangement, the generator provides its maximum voltage at low speeds and, as the speed increases, the regulator contacts open and close rapidly enough to keep the output voltage practically constant.

Within the usual working limits, the voltage of a lead acid storage cell varies from 2.1 volts at full charge to 1.8 volts at discharge. While being charged, the voltage may rise to 2.5 volts per cell but this value drops quickly to 2.1 volts as soon as the charging circuit is opened.

For example, suppose the generator regulator is adjusted to provide a 14 volt output, the resistance of the charging circuit and battery is .2 ohm and the maximum charging rate is 16 amperes. For a 12 volt, six cell battery, when discharged to 1.8 volts per cell, the total voltage will be 6 x 1.8 = 10.8 volts.

As the generator positive connects to the battery positive, the effective voltage on the circuit will be 14 - 10.8 = 3.2 volts and with a .2 ohm resistance, the charging current will be

$$I = \frac{E}{R} = \frac{3.2}{.2} = 16 \text{ amperes.}$$

As the action continues, the battery charges and we will assume the cell voltage rises to a value of 2 volts. The total for the battery is then 6 x 2 = 12 volts and the effective circuit voltage is 14 - 12 = 2 volts. At this time the charging rate will be,

$$I = \frac{E}{R} = \frac{2}{.2} = 10 \text{ amperes.}$$

At the fully charged condition of 2.1 volts per cell, the battery voltage is 6 x 2.1 = 12.6 volts for an effective value of 14 - 12.6 = 1.4 volts. The charging rate will then be

$$I = \frac{E}{R} = \frac{1.4}{.2} = 7 \text{ amperes.}$$

Should the charge still continue, by following the plan above you will find the following values.

Cell Voltage	-	Charging Rate
2.2	-	4 amps.
2.3	-	1 amp.
2.33	-	0 amps.

This constant voltage method of charging has the advantage of providing a high rate for a discharged battery and a low rate for a charged battery without danger from overcharge in case of long or continuous charging periods.

The problem of keeping the battery properly charged under the varying conditions of charging time, discharging time and load is of great importance and many arrangements have been and still are in use. The constant voltage method just explained has proven highly satisfactory but refinements have been added for some systems.

For example, by connecting the magnet winding of Figure 2 in series with the load, like the "Series" coil of the cut-out of Figure 1, the spring could be adjusted so that the contacts would be pulled apart at the desired maximum current. The regulator would then operate to limit the generator output at some safe or desired maximum current value.

As a further refinement, a series winding, like that of Figure 1, could be added to the coil of Figure 2, connected to carry the load current and arranged so that its flux would oppose that of the shunt winding. Then, as the load increased, the regulator magnet would be weakened sufficiently to allow a higher generator voltage with a resulting higher output.

With the coils properly balanced and a generator of sufficient capacity, it would be possible for the generator to carry varying loads and, at the same time, maintain the proper battery charging rate.

DYNAMOTOR

While the arrangements of Figures 1 and 2 provide a practical source of low voltage d-c, the plate circuits of the Radio tubes require a high voltage d-c. Unlike a-c, a transformer can not be used directly to alter a d-c voltage and therefore a "Dynamotor", built on the general plan of Figure 3, is sometimes employed.

A dynamotor consists of a low voltage d-c motor, shunt or compound wound (suitable arrangements of series windings), designed to operate on the low voltage supply circuit of Figure 1. The armature carries a second winding, with a comparatively large number of turns, brought out to a second commutator and set of brushes.

Revolving with the motor armature, the turns of this second winding cut the magnetic flux of the field and thus operate exactly as the armature of a generator. The commutator and brushes provide a d-c output while the large number of turns of the armature winding produce the required high voltage.

You can think of this arrangement as a low voltage d-c motor driving a high voltage d-c generator but, to save weight and space, both units operate in the same frame and magnetic circuits.

The overall effect is much like that of a step up transformer except that a low voltage d-c input provides a high voltage d-c output.

Dynamotors of this type are made in a variety of sizes with outputs, in terms of voltage and current, designed for the ordinary Radio units. The efficiency of these units is about 50°/o and one model with an input of 5 amps. at 14 volts, provides an output of .1 amp. or 100 ma at 360 volts. Thus, with a 5 x 14 = 70 watts input there is a .1 x 360 = 36 watts output.

ROTARY CONVERTERS

For most ground Radio, the problem has been to devise circuits or units which, with an a-c input, will deliver a d-c output. Thus, every common a-c unit includes a rectifier and filter in its plate supply.

In the usual type of aircraft, the primary source of electricity is low voltage d-c but there are a number of advantages to be gained by having an a-c source. With a-c, a transformer, which has no mechanically moving parts and which requires no attention, can be used to provide any a-c voltage within reasonable limits.

Also, with an a-c supply, all of the highly developed and efficient rectifier circuits will be available for aircraft radio.

One type of machine for obtaining an a-c output from a d-c supply is shown in simplified form in Figure 4. The general arrangement is much like that of Figure 3 and again there is a shunt wound d-c motor operating on the low voltage d-c supply.

The electrical circuits are different and, as shown in the circuit diagram of Figure 5, the armature has but one winding. Instead of a second commutator, this unit has a pair of slip rings, insulated from each other and each making continuous contact with a brush.

Each slip ring connects directly to a commutator bar and the angle between these bars is the same as that between the motor brushes. As shown in Figure 5, which represents a two pole, two brush motor, slip ring "A" connects to segment 9 while slip ring B connects to segment 3, directly opposite or at an angle of 180°.

To follow the action, we have shown the polarity of the d-c supply and want you to remember that the circular portion of Figure 5 revolves while the "+" and "-" brushes remain stationary. Assuming a 12 volt supply, you will notice that between the brushes there are two parallel paths through the armature winding.

As we show only a 12 coil armature and 12 segment commutator, to have a 12 volt drop across the brushes there will be a 2 volt drop between adjacent commutator bars. Tracing the paths, there is one from the "+" brush through the winding tapped at segments 7, 6, 5, 4, 3, 2 and 1 which is in contact with the "-" brush. With a 2 volt drop between segments, there will be an 8 volt drop between the "+" brush and segment 3 which is connected to collector ring "B".

Going around the other way, there is a path from the "+" brush through segments 7, 8, 9, 10, 11, 12 and 1 which is in contact with the "-" brush. In this path, there will be a 4 volt drop between the "+" brush and segment 9 which is connected to collector ring "A".

Checking back, ring B is 8 volts negative in respect to "+" while ring A is but 4 volts negative in respect to "+". A d-c voltmeter connected across the rings would therefore read 4 volts with A positive.

As the armature revolves in an anti clockwise direction, segment 8 will move under the "+" brush and segment 2 under the "-" brush. Again using the "+" brush as a reference point, in this position there is a 10 volt drop between "+" and B but only a 2 volt drop between "+" and A. A voltmeter across A-B now would read 8 volts with A positive.

In the next position, segment 9 and ring A will be in direct contact with the "+" brush while segment 3 and ring B will be in direct contact with the "-" brush. Therefore, the voltage across the rings will be the same as that across the brushes, with ring A positive.

As the armature continues to turn, the voltage across the rings will decrease until segment 12 is in contact with the "+" brush and segment 6 in contact with the "-" brush. Under these conditions segments 3 and 9 will be midway between the brushes, the voltage drops will be equalized and the drop across the ring will be zero.

From this point on, segment 3 and ring B approach the "+" brush, making B positive in respect to A until, with segment 3 under the "+" brush and segment 9 under the "-" brush, ring B will be 12 volts positive with respect to ring A.

Thus, as the armature revolves, there will be an alternating voltage across the rings and, for the arrangement of our sketch, each revoltuion of the armature will produce one a-c cycle. For 60 cycle a-c, the armature will have to revolve at 3600 rpm.

An arrangement of this kind is known as a Rotary Converter and the frequency of the a-c output depends on the number of field poles and the speed or rpm of the armature. Notice here, the function of the motor is mainly to revolve the armature so that the commutator and its brushes will act as a reversing switch between the d-c input and a-c output.

Remember here also that, ignoring any losses, the d-c input voltage equals the maximum value of a-c output voltage so that an ordinary a-c voltmeter connected across rings A to B will read the effective a-c value which is equal to .7 of the maximum. With a 12 volt d-c input the output would be 12 x .7 = 8.4 volts a-c effective, but by means of transformers, this low voltage a-c can be stepped up to the desired values.

The present trend of aircraft power supply is to use the engines of the ship to drive a generator which charges the battery. One disadvantage of this arrangement is that in case of an emergency or forced landing with a dead engine, the battery will operate the radio equipment for but a limited time.

As we stated before, in addition to the electrical energy supplied to the radio equipment, the electrical load requirements of modern aircraft are increasing steadily due to the addition of motors for starting the engines, lights, deicer equipment, motors for operating fuel and oil pumps, retractable landing gear, adjustable pitch propellors and additional current for remote controls operated by relays. Another demand for electrical power is the facilities commonly required by passengers such as reading lights, cabin ceiling lights, the heating of the cabin, food and water.

A-C AIRCRAFT EQUIPMENT

One solution to handle increased electrical loads is the use of an auxiliary gasoline engine driving an electric generator because, with this arrangement, only a small battery is needed and, as long as fuel is available, the electrical supply is independent of the main flight engines. Also, with an electrical power plant of this kind, the generator can be made to produce a-c of most any desirable frequency and voltage.

In considering the use of a-c for aircraft, an important factor is the choice of frequency. This factor has a direct bearing on the weight of transformers, and if the weight of a 60 cycle transformer is considered as 100°/o the weight of a similar transformer at 400 cycles is about 59°/o, at 800 cycles 27°/o and 1000 cycles 18°/o. Recent developments have shown that transformers can be constructed to operate at these higher frequencies with efficiencies greater than the more conventional lower frequency types.

Although frequency does not directly effect the weight of motors used in the various services in the operation and maintenance of an aircraft in flight, the greater the frequency, the greater the synchronous speed, and utilizing this factor, lighter motors for a given horsepower rating can be produced. However, in the a-c rectifier supply, higher frequencies permit the use of lighter weight chokes for adequate filtering.

In general, the weight of electric wiring is not affected by frequency, and problems of the reactance of conductors are not appreciable except at extremely high frequencies.

Another factor to be considered in selecting the best a-c power supply for use on aircraft is the phase. That is, the greater the number of phases, the greater will be the number of distribution wires, switches, fuses, conduits and installation material. Likewise, the problem of insulation must be considered.

It has been found that the weight of insulation on a 3 phase system is about 22.5% greater than that on a single phase system. This point can be more clearly appreciated because, in single phase systems, the airplane structure is used for a common ground much in the same manner as the chassis of an automobile, but the 3 phase system requires a balanced distribution line and thus dictates the use of 3 conductors.

Successful aircraft installations have been made with either a 3 phase 400 cycle supply or a single phase 800 cycle supply, both systems utilizing 120 volts.

AIRCRAFT SUPPLY VOLTAGE

As indicated in preceding sections, the supply voltage requirement, as well as power capacity has increased with electrical demands. The 12 volt system met with favor prior to the war years but now the use of the 24 volt system, considering a large range of airplane, is perhaps the optimum value. For very small private planes, it is expected that 6 volt systems will be used.

The trend is still toward higher supply voltages as the size of aircraft increases and there will be a considerable saving in wiring weight because the current requirement for a given amount of power is reduced. The idea here is not new because for many years, transmission lines have conveyed energy from one remote point to another over high voltage (tension) lines, therefore it is possible to convey this power using small sizes of wire, which is merely another way of stating that the weight of the wire can be reduced. For example, in a recent large aircraft design, an increase in the operating voltage of the electrical system makes possible a saving of more than 1 ton in wiring alone.

One of the prime requisites of the optimum voltage for an aircraft electrical system is that it provides the necessary service at the lowest possible weight. As the voltage is increased, the reduction in the size of wire may take place up to the point where it is necessary to add more insulation for safety reasons. It has been found that mechanical considerations make impractical the installation of solid wires smaller than #20. Therefore the equivalent size in stranded wire is being used because experience has shown that it is better able to withstand the vibration encounter in aircraft operation. Recently, various combinations of materials, such as artificial rubber, asbestos and spun glass are being used to fireproof the distribution wires.

Some consideration has been given to the possible use of aluminum in order to reduce wire weight and comparing their characteristics, the weight of the copper is about 3.36 times as great as that for aluminum. However, if the resistance per unit length of each conductor is to remain the same, the aluminum conductor must have about 63°/o greater area than the copper conductor or about 28°/o greater circumference. This greater circumference requires a greater weight of insulation, and therefore the use of aluminum as a reduction in weight is not a decisive factor. Another consideration is that of the difficulty of attaching terminals to the ends of aluminum conductors because this material does not solder readily.

Designers in aircraft electrical equipment have learned new methods of getting more power out of each cubic inch of electrical equipment, how to cool systems advantageously, that motor and generator brushes can be worked harder, and that new materials can stand higher temperatures. Along with all of these factors, great strides have been taken in the use of "light" materials to obtain a further reduction in weight.

ANTENNAS

The antenna equipment presents several problems because the dimensions of the aircraft limit its size while the structure offers resistance to a ship in flight and causes what is known as aerodynamic "drag". The variation in aircraft design, as well as the range of frequencies in use, make it necessary to compromise and select the type best suited to the particular aircraft and also the type of service for which it is to be used. However, all of the more common types may be divided in general classes and all antennas mounted on top of the wings of fuselage are known as "Overhead" while those mounted below are called "Belly" antennas.

For Figure 6 we show an antenna mounted on top of the upper wing of a biplane, with a support at each end and the lead is connected at the center. This is known as a "Transverse T" because the antenna wire is at right angles to the direction of flight and, with a center lead in, the system has the general shape of a letter "T".

The antenna wire should be from 6" to 12" above the surface of the wing and the lead in, made as short as possible, is brought down through a deck insulator to the receiver.

Another arrangement of a T type antenna is shown in Figure 7, the front end supported by a stub mast mounted at the forward end of the fuselage with the rear end supported by the vertical tail surface. In some cases, the rear end may be supported by a mast, about 5 ft. high, mounted forward of the tail. The antenna is usually stretched with a 100 lb. tension as provided by a spring adjacent to one insulator. This antenna, although subject to icing, presents the least drag and is one of the most efficient types.

As shown in Figure 7, the central lead in makes this a "T" and because the direction of the antenna is the same as that of the ship when in flight, it is known as a "Longitudinal" type.

There are many variations of the two installations shown and you will find one common combination which has the two wing supports of Figure 6 and the tail support of Figure 7. The antenna wire is then strung from each wing support to the tail support so that electrically it is still a "T" but, looking down on the ship, the physical shape is that of a "V". While the "T" type of antenna is used largely for Transmitting it may also be used for receiving in any frequency band.

In other installations, when the vertical stabilizer is of sufficient height, the rear support of the antenna is often made as shown in Figure 7 but the wire is carried foward and attached at a point in the approximate location of the deck insulator.

The "Mast" of "Vertical" type of antenna, shown in Figure 8, is quite similar to the "Whip" antennas used on automobiles. For aircraft installation it has the advantages of low air resistance, does not accumulate ice and is practically non-directional in operation. Masts of this type are commonly made of a hollow, streamlined metal rod and must be completely insulated from the main structure.

Ultra high frequency two way equipment usually makes use of a "whip" antenna about 40 inches in length and this part may be fastened either on top or the bottom of the airplane. This antenna is fairly free of icing but does present some drag. Its location on the bottom of the plane fuselage of transports may present difficulties in proper servicing of the airplane on the ground unless it is located where it cannot be accidentally impared by ground crews.

The arrangement we have described are known as "fixed Types" because they are mounted permanently in contrast with the "Trailing Wire" types, which consist of a wire fastened at one end in the airplane and allowed to trail behind while the ship is in flight.

The trailing wire may be released from various points along the bottom or "Belly" of the ship, may be of fixed length or may be mounted on a reel which allows certain specified lengths to be used. This latter type is known as "Retractable" and may be operated manually, when mounted in the cockpit, or operated by remote control when located near the tail.

To provide the proper electrical conditions, the length of the trailing wire antenna is made equal to some odd multiple of the transmitted wavelength or of some more convenient length with a loading coil added to provide resonance. In some retractable types, there is an indicator to show the length of wire let out and thus, by properly regulating the length, the antenna can be resonated at more than one frequency.

When the trailing wire is brought out from under the forward part of the ship, a streamlined lead weight, about the size of a large fountain pen, is attached to the end. This holds the outer end of the wire down and prevents it from whipping against the under side of the ship.

The trailing wire has some disadvantages from an operating standpoint as the reel and lead at the end of the wire have an appreciable weight (usually more than 10 lbs.). The drag is high and cannot be tolerated on modern high-speed airplanes. Some hazard is present should the pilot forget to "reel-in" his antenna just prior to landing.

When the trailing wire is brought out from the tail, the weight may be replaced by a wind sock which tends to hold the antenna taut and maintain its proper length.

The retractable types are reeled in before landing while other types are not, making them subject to excessive wear from dragging along the ground during take-offs and landings. For both types, all parts of the mounting in the ship must be completely insulated from the fuselage.

The antenna requirement of the various units on an aircraft is so different that the best solution seems to be an individual antenna for each service. For example: A Douglas DC-3 uses 5 antennas for communication and navigation purposes.

Various types of Loop antennas are also in common use but usually for the reception of various navigation signals and therefore will be described later as a part of the indicating instruments.

BONDING

In all of the various types of antennas, the necessity of complete insulation has been emphasized and, as a ship in flight has no ground connection, the need for this insulation may not be apparent. Thinking of a Ground Radio installation, you will remember that a good ground or "earth" connection is always provided, either directly or through the power supply system.

For localities with dry sandy soil, or other conditions which make it difficult to obtain a good "ground", it is customary to erect a counterpoise. In effect, this is a second antenna, mounted below the usual antenna. In theory, the antenna forms one plate and the counterpoise another plate of a condenser with the energy of the transmitted or received signal applied across them.

For aircraft, the ship itself acts as the counterpoise and therefore it must be completely insulated from the antenna proper. As the ship is thus a part of the antenna system all of its various metal parts must be connected electrically to form a single unit or conductor.

The usual mechanical connections, made by rivets or bolts are not sufficient because, although physically tight, the joint may have electrical resistance which will vary with vibration and other stress. As a result, certain parts may be at different electrical potentials and produce sparks which will cause noise in the radio receiver.

Bonding is usually done during the assembly of the plane and in general consists of electrically connecting the various parts with strips of metal having about the same electrical resistance as the parts they join. Metal braid is commonly used because, being flexible, it is readily installed and when not pulled tight, will maintain proper connection under conditions of vibration and other relative motion.

All long metal pieces, including piping, tubing, shielded cables and wire bracing are bonded at each end and at distances of not more than 36" in between. They are also bonded at points of contact where vibration or rubbing can occur. If it is not practical to bond at the point of contact, the parts should be electrically insulated at or near this point. The actual connections can be made by bolting, clamping or soldering and should be considered the same as the parts of a circuit carrying r-f.

For ships or parts of wood-wire construction, a metal strap, usually copper, is placed along each wooden spar and all wires, fittings, tubes or conduits of the part, are bonded to the metal strip. All of the various parts are then bonded to the main metal part of the ship.

Gasoline tanks are very often mounted to the airplane by means of leather straps, and bonding is necessary to prevent sparks which might "set off" the gas fumes.

If the tail surfaces are large, they have a tendancy to take on high charges and without bonding, will cause discharges to the fuselage and create interference in the radio equipment.

All water, oil and gasoline lines should be bonded to the frame at frequent intervals. When a metal line is divided by a rubber or other non-metallic joint, a copper braid bond should be soldered across the adjacent ends of the metal line.

In a similar way, the parts of metal hinges, such as those used on the rudders, ailerons, elevators and so on, should be bonded together and also bonded to the connecting control wires. In general, regardless of the actual mechanical construction, all metal parts of an airplane should be bonded so as to form one single piece electrically.

Because of the low resistance of the parts, the ordinary types of ohmmeters used in Radio work are not satisfactory for testing work of this kind. However, a similar circuit can be made up by using one cell of a storage battery, a low reading ammeter and a low resistance high current rheostat. The circuit should be made up of #14 wire and the units connected in series between the test prods.

With the test prods shorted, the rheostat is adjusted until the meter reads 1 ampere. The prods are then applied to the various parts which have been bonded, one prod to one part and the other prod to another part. Care must be taken that the prods make good contact but, after this has been done, any test which causes the meter reading to drop below .9 ampere shows the bonding between the parts is not satisfactory. In terms of resistance, the test circuit, with 1 ampere at 2 volts has a total resistance of 2 ÷ 1 or 2 ohms. A test reading of .9 amp. shows the test circuit plus the bonding has a total resistance of 2 ÷ .9 = 2.2 ohms. Therefore the resistance of the bond is about .2 ohm which is the maximum value allowed.

While these tests are being made, the adjoining parts should be strained or the control surfaces moved and a noticeable variation of meter reading indicates improper bonding.

SHIELDING

Another point in common with the automobile, is the shielding of aircraft electrical systems to prevent noise from this source to interfere with Radio reception.

As you perhaps know, whenever a spark discharge takes place in an electrical circuit, high frequency oscillations are produced. For the usual types of gasoline engines, a spark is necessary to ignite the fuel in the cylinders and while the spark itself may be well shielded by the metal parts of the engine, the high frequency oscillations are present in the entire high tension circuit.

The reason that shielding is effective in reducing noise can be understood by realizing that the undesired electromagnetic radiations set up currents in the shields. These currents in turn set up a magnetic field having a direction opposite to the field inducing the shield current. If the resistance of the shield is relatively low, the magnitude of the field set by the shield currents will very nearly equal the field set up by the disturbance and thus the resultant disturbing field is reduced to an unnoticeable level.

Oscillations may occur in the low tension circuits of the ignition system due to its connection with the high tension circuits or because of the action of the breaker or contact points. As the radio receiver is connected to the same low tension system, these oscillations can reach the receiver through the wires.

To prevent this action from taking place, r-f filters are generally used to isolate the receiver from the balance of the low tension system as far as r-f is concerned. However, the high frequency oscillations will radiate from the wires which carry them and thus, the entire system acts as a sort of transmitting antenna, radiating disturbances which are picked up by the receiving antenna and reproduced as noise in the headphones or speaker.

Therefore, it is necessary to shield all wires of the electrical systems, even those for lighting and instruments which, by themselves, would not produce interference.

The high tension ignition circuits are the chief source of radiated interference and therefore special attention must be given to this part of the work. The actual problems are somewhat simplified however as complete shielding assemblies can be purchased for most airplane engines.

The general plan of these assemblies is to use special spark plugs with an integral shield and terminals for the wire as well as a surrounding flexible metal conduit. The flexible conduit, with the wire inside, connects to a solid metal manifold of the usual type.

The metal cover, or shield is made to completely cover all wires, magnetos, switches and other parts so that direct radiation is reduced to a minimum.

LOCATION OF EQUIPMENT

As we have mentioned previously, the weight of aircraft Radio equipment is an important factor and now we can add that the distribution of the weight must also be carefully considered when the various radio units are installed. The actual details of the installation will be taken up later because, at this time, we want to bring out the arrangement or location of the various units which make up the complete system.

One common plan is shown in Figure 9 and you will notice the receiver is located close to or directly below the Mast Antenna. The main factor here is the short lead-in between the antenna and receiver which reduces the losses and allows maximum signal input.

With the receiver close to the antenna, the distance between the receiver and the pilot is greatly increased and therefore some form of remote control is usually required. This may take the form of a flexible shaft, as indicated in Figure 9, or may be a more elaborate electrical control similar to the motor driven types of push button tuners installed on Broadcast receivers.

The storage battery is frequently mounted close to the engine up near the nose of the ship and therefore a cable must be run from the battery back to the receiver. However, the battery must also supply the high voltage plate source, such as the dynamotor of Figure 9, which is often mounted close to the receiver.

Because of this condition, it is common practice to install a junction box, close to the receiver and run a cable from the battery to it. The receiver and dynamotor also connect to the junction box as well as the control unit or switch box, mounted in the cockpit.

With an arrangement of this type, all the electrical controls for both the receiver and power supply can be brought to the switch box in the cockpit. In some installations, the actual circuits are extended while in others, the switching is done by remote control and only the control circuits are extended.

In our description of the receivers themselves, we will take up further details of remote control but at this time want to give you only a general idea of possible arrangements.

For the smaller aircraft, the equipment more closely resembles auto radio and the dynamotor of Figure 7 may be replaced by a vibrator type of supply. Also, because of their smaller size and more limited range, the receiver itself may be mounted in the cockpit and connected to an antenna mounted close by.

For commercial aircraft, the general tendency has been to mount the main equipment items in portions of the baggage space. In more recent designs, an equipment rack has been provided so that all radio apparatus can be located on one shock-mounted support. This rack, which consists of several hundred of pounds of radio equipment, should be located immediately aft of the cockpit, either in the cockpit enclosure itself or in a compartment immediately behind it. There are several reasons for mounting this equipment in this position: 1. This is usually a favorable location from a center of gravity standpoint. 2. Interwiring to the cockpit and main batteries is short and light. 3. The location is convenient to all antennas. 4. The equipment is located where it can readily be serviced by a flight engineer.

The disadvantage of forward location is mainly from a maintenance standpoint since service operations for other mechanical sections of the plane are required.

In addition to the main radio equipment rack and antennas, it is important that several provisions be made in the cockpit. These are: 1. A central control unit available to both pilot and co-pilot for control of radio equipment such as selection of tuning etc. 2. Switch boxes for each individual pilot. 3. When a radio operator is carried, many of the contact functions can be given to him. A control unit and switch box unit for selection of equipment must also be available to him. 4. Interphone stations provided for pilot, co-pilot, radio operator, flight engineer, navigator, stewardess, etc.

Now that we have given you a general idea of the power supply, antenna types, placement of parts and other common features, we are ready to take up the various types of receiving and transmitting units which are required to provide two way communication.

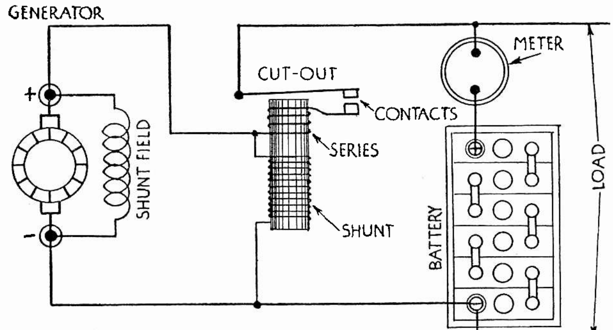


FIGURE 1

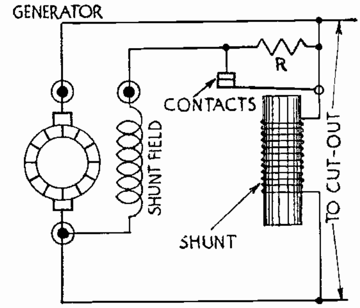


FIGURE 2

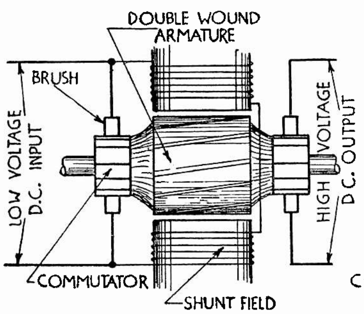


FIGURE 3

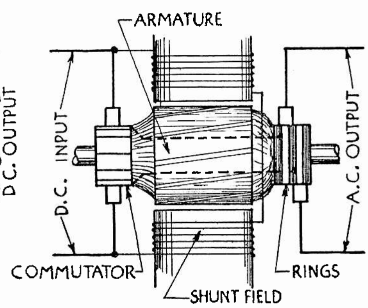


FIGURE 4

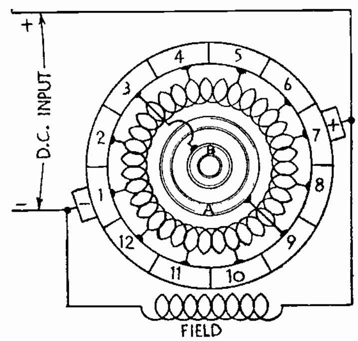


FIGURE 5

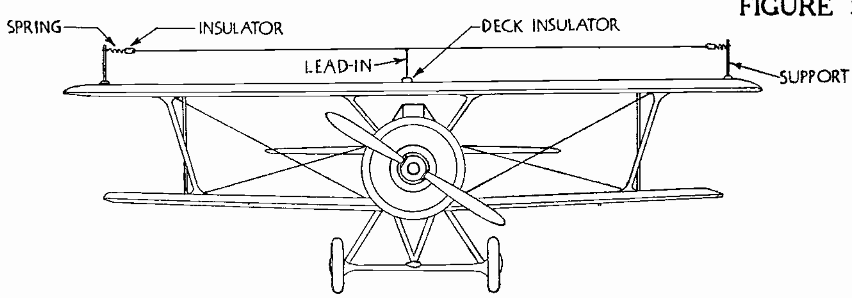


FIGURE 6

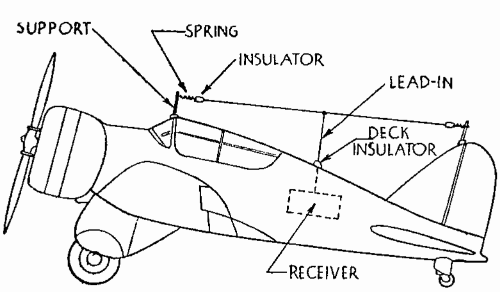


FIGURE 7

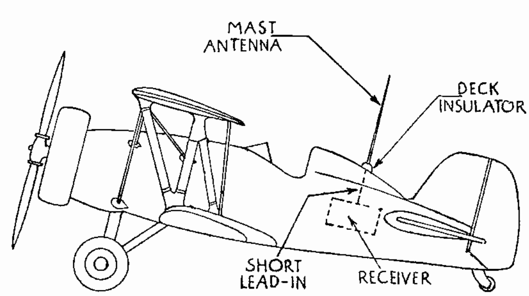


FIGURE 8

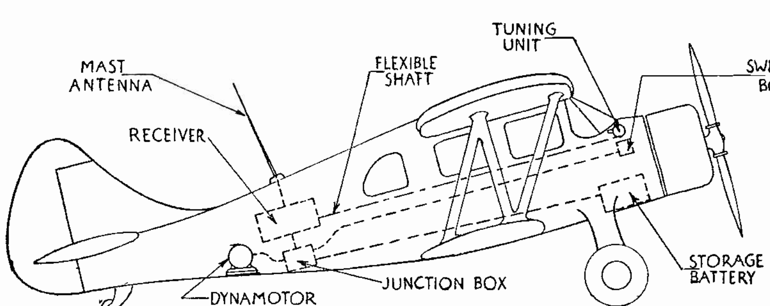


FIGURE 9

LESSON RRT-21

AIRCRAFT RECEIVERS

DE FOREST'S TRAINING, INC.
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LESSON RRT-21

AIRCRAFT RECEIVERS

DE FOREST'S TRAINING, INC.

2533 N. Ashland Ave., Chicago 14, Illinois

RADIO RECEPTION AND TRANSMISSION

LESSON RRT-21

AIRCRAFT RECEIVERS — TRANSMITTERS

# # # # # # # # # # # #

If one could learn early in life that money is of less value than his mind, he would be in possession of a priceless asset. Try filling your mind with valuable thoughts- give it an over-dose of some worthwhile subject, digest it and then begin on another subject. A right mind is of far greater value than a large bank account.

- Selected.

FREQUENCY ALLOCATIONS

In our last Lesson, we emphasized the importance of two way Radio Communication, in the operation of aircraft, and in order that it may be used to full advantage, a number of frequencies have been allocated exclusively for this purpose. These frequencies are considered as "Bands" because a number of channels may be grouped adjacent to each other.

Thinking along these lines, one of the most important is the low frequency, 200 kc - 415 kc band, which is used for the transmission of weather reports and "Range" signals by government stations. To simplify the operation of aircraft receivers, most airports have transmitters operating in this band, mainly at 278 kc, for sending "Traffic" information.

Radiotelephone communication, between aircraft and ground, usually employs a number of carrier frequencies between 2850 kc and 6600 kc. This is quite a wide band, so wide in fact, that its higher frequencies have transmission characteristics quite different from those of the lower frequencies. The differences are due mainly to the "Skip Distance" or "Skip Effect" which varies from day to night.

To obtain the most reliable transmission and reception results, this band is therefore divided roughly into two parts, 4500 kc to 6600 kc for daytime, and 2850 kc to 3330 kc for night time. Every Radio equipped plane has one day and one night frequency, the exact values of which are allocated the same as for other transmitting stations.

The commercial transport lines have definite frequencies allocated for each of their important routes while all private or "Itinerant" flyers may operate on 3105 kc during the day and 6510 kc at night. As the ground stations maintain a constant watch on these frequencies, any Radio request by a private flyer will be heard and answered. The reversal of "High-Low" frequency operation for day-night operation is for the purpose of preventing interference on frequencies which carry the greatest amount of traffic as well as to provide a clearer channel for private plane communication.

Due to the congestion of the lower frequencies and the progress being made in high frequency apparatus, the additional channels have been allocated for aircraft use. The following table lists those frequencies important in aircraft service.

Frequency Range in MC	Service
108 - 112	Air Navigation Localizers
112 - 118	Air Navigation Ranges
118 - 122	Airport Control
122 - 132	Aero Mobile, non-government
132 - 144	Aero Mobile, government
148 - 152	Mobile, government
225 - 328.6	Aviation, military and civil
328.6 - 335.4	Air Navigation Aids, Glidepath
335.4 - 400	Aviation, military and civil
420 - 460	Air Navigation
960 - 1145	Air Navigation Aids
1325 - 1375	Aero fixed-mobile, non-government
1600 - 1700	Air Navigation Aids
2700 - 3900	Air Navigation Aids
5000 - 5250	Air Navigation Aids, instrument landing

RECEIVER TUNING RANGES

Except for the smaller installations, a single receiver is seldom designed to operate on all of the available bands and, due to the importance of the signals, the simplest aircraft receiver operates only in the 200 kc - 400 kc band.

Usually a unit of this type is designed to tune continuously over the entire band and thus the pilot can receive weather reports, range signals and also traffic directions from an airport which he is passing over or on which he desires to land.

Other units of this general type are equipped so that certain preselected frequencies can be tuned instantly, the operation resembling the "push button" tuning of Broadcast receivers. This arrangement permits the pilot to shift from one service to another with a minimum of effort and time.

More complete receivers are designed to operate on two or more bands, following the general plan of the "All Wave" type of Broadcast receiver. For entertainment purposes, as well as certain forms of direction finding, other models of aircraft receivers operate over the common broadcast band.

The receiver circuits are of the usual superheterodyne type but, due to the services for which they are used, have several important differences, the most noticeable of which is the use of crystals to control the frequency of the receiver oscillator.

Going back to the earlier Lessons, which explained superheterodyne receivers, you may remember that the oscillator frequency and resonance of the input circuits were tuned by a "ganged" condenser to provide a single control. Thus, if the tuning was not done carefully, there would be a loss of sensitivity in the input circuits but, of greater importance, the intermediate frequency would not be of proper value.

As the i-f amplifier is tuned and peaked to a definite frequency, a variation from this value causes distortion and a great loss of signal strength. You may remember the automatic Frequency Control, (AFC) circuits which were developed to correct this condition.

For aircraft Radio, all of the essential services are transmitted at fixed frequencies making it possible to operate the receiver oscillator at a fixed frequency also, the value of which is equal to the transmitter carrier frequency plus the i-f of the receiver. In this way, the i-f will always have the proper value and a slight detuning of the input circuits will have but a comparatively small effect on the receiver output.

One common plan is to tune the receiver over the band in the usual way and, in addition, provide two or more crystals of the desired frequencies, which may be cut in instantly to receive the regular services. Thus, the stability of crystal control, required for the transmitter, is incorporated in the receiver to assure correct tuning and provide for positive reception.

As we explained previously, the proper location of the various pieces of Radio equipment often make it necessary to install the receiver at a distance from the controls. Thus in addition to the usual components, the receiver may contain relays and other remote control devices, but, as an added safety feature, a manually operated control is included in many remote receivers. This is known as an emergency control and can be used in case the remote control becomes inoperative.

RECEIVER TYPES

While practically all aircraft radio receivers are superheterodynes, it is common practice to classify them according to their tuning ranges. In terms of wavelength, all signals above 1500 meters are "Long Waves"; from 1500 meters to 50 meters are "Medium Waves"; and from 50 meters to 5 meters are "Short Waves" and below 5 meters are "Ultra Short Waves".

Although Radio Carriers are no longer compared in terms of wavelength, the practice has not entirely died out, and we mention the terms mainly to avoid confusion and help you understand their meaning. You need only remember that the shorter the wavelength, the higher the frequency and a conversion from one to the other can be made by this simple equation:

$$\text{Wavelength (meters)} = \frac{300{,}000}{\text{Frequency kc}} = \frac{300}{\text{Frequency mc}}$$

In some cases you will find the terms used somewhat interchangeably, as for example, the Frequency Ranges of an RCA, 4 band airport receiver are given as

Long Wave	- 150 kc - 410 kc
Standard Broadcast	- 530 kc - 1800 kc
Medium Wave	- 1800 kc - 6400 kc
Short Wave	- 6400 kc - 23000 kc

while a 3 band aircraft receiver of the same make has the following specifications

Range Band	- 195 kc - 420 kc
Broadcast	- 495 kc - 1400 kc
High Frequency	- 2300 kc - 6700 kc

In general, you will find the smaller aircraft usually employ a single receiver which may be designed to cover one, two or three bands. The large airliners however, usually have three or four receivers, each covering a specified band or serving a specific purpose.

Their average equipment includes a Range receiver, which tunes approximately from 200 kc to 415 kc, a Radio Compass receiver, often covering the 200 kc - 400 kc and broadcast bands, and a High Frequency Range receiver, covering the 108 - 118 mc bands. The fourth receiver, if used, is a part of the Radio altimeter and operates between 420 - 460 mc.

RECEIVER CIRCUIT

As a representative example of aircraft equipment, for Figure 1 we show the circuit diagram of the RCA AVR7G receiver and want you to study the various connections thoroughly and carefully.

Starting from the antenna circuit, you will find the signal passes through an r-f amplifier tube, a combination Detector and Oscillator tube, an i-f amplifier tube, a combination

second detector and first a-f tube and into the output tube, one section of which operates as a beat frequency oscillator.

This oscillator is tuned to a frequency within a few hundred cycles of the i-f and its output is fed into the second detector circuit to heterodyne with c-w Signals to produce an audible note in the phones. Therefore, it is placed in operation for c-w reception and turned off for voice or phone signals.

The power supply, similar to those of automobile receivers, is designed to operate from a 12 volt battery and, in addition to the usual chokes and filters, contains a synchronous type of vibrator. As you may remember, this type of vibrator has one set of contacts to allow current alternately in each half of the transformer primary and a second set of contacts which operate to rectify the secondary current.

The vibrator assembly is of the plug-in type and the socket is arranged with extra contacts so that a reversal of battery polarity can be compensated by lifting the vibrator assembly out of the socket, giving it a half turn and replacing it.

In order that the heaters of the tubes, designed for 6.3 volts, will operate properly on a 12 volt supply, they are connected series-parallel. One parallel group consists of the heaters of the r-f, det.-osc., and i-f tubes, while the other parallel group is made up of the heaters of the 2nd det. and output tubes together with a 21 ohm resistor. As the value of this resistor is equal to that of the tube heaters, the circuit is balanced.

CONTROL UNIT

The control unit, shown near the lower right of Figure 1 and connected to the receiver by an 8 wire shielded cable, contains the Volume Control with the main "OFF-ON" switch mounted on it, a "PHONE CW" switch, a "LIMITER-OFF" switch, a "CRYSTAL-OFF" switch and a "PHONE JACK". In addition to the cable, there is also a wire from the ungrounded battery terminal.

Checking the control unit, the battery circuit contains a fuse and the "OFF-ON" switch in series. The "PHONE-CW" switch operates to close and open the plate circuit of the triode section of the output tube which, as mentioned above, operates as a beat frequency oscillator. To receive c-w, the switch is closed and, to receive voice, the switch is opened.

The "LIMITER-OFF" switch is connected across a 3300 ohm resistor and the combination is in series with the "PHONE JACK" which means it will be in series with the headphones when they are in use. For ordinary reception, the switch is closed, the resistor is shorted out and the circuit operates normally.

When the static level is high, the switch is opened and the resistor, in series with the circuit, reduces the amount of energy in the phones. This action results in a loss of volume for both signal and static and the volume control is turned up to bring the signal level back to normal.

Under these conditions, the output tube operates at maximum so that further increases of static cause no increase of volume and, as a result, the level of the static can not exceed that of the signal and the reception is improved.

The phone jack is merely a special form of socket to hold the two contact plug connected on the end of the phone cord. As mentioned above, the phones and limiter are connected in series across the secondary of the output transformer.

The volume control is a 5000 ohm variable resistance, the moving arm of which is grounded along with one side of the phone jack through wire #8 of the cable. From the other end of the control there is a circuit, through wire #6 of the cable and up to the cathode of the i-f tube through a 220 ohm resistor. From the junction just below this resistor, there is a circuit through a 150 ohm resistor to the cathode of both the r-f amplifier and the combined "det.-osc." tubes.

The action of the volume control is to vary the resistance between these cathodes and ground so that the plate current will cause a proportional voltage drop. As the control grid circuits are grounded, the effect is to vary the grid bias voltage and provide a type of control which has been fully explained in the earlier lessons and therefore requires no further comment here.

Tracing the circuit of the "CRYSTAL" switch, you will find one terminal is grounded while the other connects to the winding of a relay through wire #5 of the cable. From this winding, the circuit is completed back to the "hot" side of the battery circuit so that the relay is in parallel to the tube heaters.

When the switch is closed, the relay winding is energized by the battery and the resultant magnetic flux attracts the armature which carries contacts and acts as a switch.

As shown in Figure 1, the crystal switch is open, the relay winding is not energized and the crystals are not in use. Closing the crystal switch, causes the relay switch contacts to connect the crystals into the plate circuit of the oscillator section of the "det-osc." tube and control the oscillator frequency.

Going back to the r-f section of the receiver, you will find three groups, each of three coils, which are necessary to permit operations on three bands.

The antenna connects to the antenna or input coils, the plate of the r-f tube connects to the r-f coils while the third group are the oscillator coils. The range switch consists of three sections, or decks, marked, S1, S2, and S3 each of which has three positions and controls two circuits. Checking the switch contacts, you will find that those coils, not in use, are shorted by having both ends connected to ground.

The general arrangement here is about the same as found in an "All Wave broadcast type of radio receiver. In the circuit of Figure 1, the upper coils are for the Range Band, the middle coils for the Broadcast Band and the lower coils for the High Frequency Band. Notice here that the crystals are operative only on the High Frequency Band.

Looking at the diagram again, you will notice the coil circuits contain the common arrangement of trimmer and coupling condensers but adjustments are made mainly by changing the inductance of the coils. This is done by means of adjustable iron dust cores as shown by the symbol of parallel lines with diagonal arrow through them.

An arrangement of this kind is often called "Permeability" tuning and here it is used in the antenna, r-f, oscillator and i-f coils. In practice, the actual adjustments are made the same as for adjustable condensers but the advantage is in increased stability.

In the alignment of the tuned circuits, the output of a signal generator is connected to the control grid of the i-f tube and the transformer is peaked at 460 kc. Using the same signal frequency, the generator is then connected to the control grid of the "det-osc" tube and the first i-f transformer is peaked, also at 460 kc.

The beat frequency oscillator (BFO) can be adjusted by turning the signal generator modulation "OFF" and throwing the receiver switch to the "c-w" position. The oscillator coil is then tuned until a beat note of about 1000 cycles is heard in the headphones.

The antenna, r-f and oscillator coil are aligned by connecting the signal generator to the antenna terminal and feeding a high and low frequency signal for each band. In general, the adjustable condensers are set for the high frequency and the coil cores for the low frequency end of each band.

Except for the Remote Control arrangement and frequencies of operation, this receiver does not differ greatly from the other types which have been explained in detail in the earlier Lessons, however, we suggest again that you study the entire circuit carefully to familiarize yourself with the various circuit details.

TRANSMITTER CIRCUIT

For Figure 2, we have drawn the circuit of an RCA, AVT12B transmitter which you can think of as a companion unit to the receiver just described. It has a power output of 50 watts phone and 90 watts c-w with a frequency range of 2600 kc to 6500 kc.

The complete unit consists of three parts, 1, the Power Supply, 2, the Transmitter Proper and 3, the Control Box.

As explained for the receiver, the power is actually supplied by a 12 volt storage battery but here, due to the higher values of plate currents, a DYNAMOTOR is used to provide the high voltage. The power unit therefore includes the dynamotor with the necessary filters and voltage dividers to properly operate the various tube circuits.

The transmitter contains three tubes, 1, a type 837 which operates as a crystal controlled oscillator, 2, a type 803 as an r-f power amplifier and 3, a type 42 as an audio amplifier modulator. Omitting the details, which will be taken up later, the circuit operates as a crystal controlled oscillator, capacity coupled to an r-f power amplifier.

For c-w transmission, the amplifier operates in Class C while, for phone operation it is suppressor grid modulated. The modulation voltage is supplied by the secondary of the transformer in the output of the type 42 modulator tube.

REMOTE CONTROL RELAYS

Complete remote control is provided by means of relays and checking through the circuit, at the upper left of Figure 2 you will find one relay which operates a switch in the crystal circuits with another in the oscillator output circuits.

At the right of the diagram a third relay is located in the anten coupling circuits of the r-f amplifier. There is also an antenna relay, to control the connections between the transmitter and antenna while a fifth relay, located in the power supply near the lower right of the figure, controls the operation of the dynamoto:

CONTROL BOX

The control box contains a four position, "Frequency Selector" switch, an "Off-On" filament switch, a "Phone-CW" switch, a Jack for microphone or telegraph key and an antenna circuit meter. The jack is of the two circuit type and carries connections for a "Press to Talk" switch mounted on the microphone.

Starting with the action of the Frequency Selector switch, in the low frequency position 1, none of the oscillator or amplifier relays are energized and the circuit connections are as shown. Under these conditions, crystals HF-3 and LF-1 are in the oscillator grid circuit of the tube while the LF or low frequency tank is in its plate circuit. The low frequency tank is in the r-f power amplifier output circuit and the tap on its coil connects to the antenna through a loading coil. As we will explain later, the antenna relay is energized at this time, moving its contacts to a position opposite to that of our drawing, and completing the antenna circuit.

With the Frequency Selector switch in position 2, the oscillator grid circuit relay is energized, operates its contacts and connects the HF-4 and LF-2 crystals in the circuit. The remaining circuits remain as explained for position 1 of the switch and thus positions 1 and 2 permit the selection of either of the low frequency crystals.

When the Frequency Selector switch is moved to position 3, the oscillator grid circuit relay is de-energized and crystals HF-3 and LF-1 are returned to their operating position. At the same time, the oscillator output relay is energized, operates its contacts and connects the High Frequency tank in the plate circuit. The relay in the amplifier output circuit is also energized and its operation connects the high frequency tank in the output circuit, also connecting the antenna directly to the tap on the tank coil.

For position 4 of the Frequency Selector switch, the oscillator grid circuit relay is energized and its operation places crystals HF-4 and LF-2 in their operating positions. The other circuit connections remain as explained for position 3 so that positions 3 and 4 make it possible to select either of the high frequency crystals.

It may be well to mention here that there is a comparatively large difference between the frequencies of the HF and LF crystals but only a comparatively small difference between those of the two HF and two LF crystals respectively. Thus, although one HF and one LF crystals are both in the oscillator circuit at the same time, the transmitter frequency will depend on whether the HF or LF tank circuits are in use.

Due to the comparatively small difference in the frequencies of either the HF or LF crystals, it is not necessary to tune the tank circuit for each of them. The HF tanks are tuned to transmit both HF crystal frequencies while the LF tanks are tuned to transmit either of the LF crystal frequencies.

The "ON-OFF" filament switch shown in the control box, serves a double purpose and when in the "ON" position it closes the heater circuits of the tubes and allows them to warm up before the plate voltage is applied. It also connects one side of all the relay windings to the battery or supply circuit.

When in the "OFF" position, this switch provides for interphone transmission by connecting the battery to the microphone through a 470 ohm resistor. This circuit is completed when the microphone "Press to Talk" switch is closed and the variations of microphone current cause an audio voltage to build up across the resistance. This voltage is carried over to the headphones by a .5 mfd coupling condenser and the "Side Tone" connection.

The "Phone-CW" switch is a double pole, double throw type and, when in the c-w position, it closes the power relay circuit, which allows the dynamotor to run continuously, and also grounds the suppressor grid of the r-f Amplifier tube.

In the "Phone" position, the power relay is energized only when the microphone "Press to Talk" switch is closed and the suppressor grid of the r-f amplifier tube is connected to the negative end of the high voltage supply. As the high voltage circuit is grounded on its voltage divider, at a point which is positive in respect to HV "-", this arrangement results in a negative bias on the suppressor grid.

The secondary of the modulation transformer is in series with the suppressor grid circuit and thus the signal voltages, alternately aiding and opposing the bias voltage, provide the desired modulation. You will find this arrangement parallels the circuit explained in an earlier Lesson on Modulation.

The resistor, connected across the secondary of the modulation transformer, provides a more constant load on the modulator tube. In case the modulation voltage drives the suppressor grid positive, the resulting current will cause a drop across this resistance and develop additional negative bias.

The antenna current meter is of the thermo-couple type, the "couple" being located in the antenna circuit with connections to the meter through a suitable filter.

As mentioned above, the phone jack is of the two circuit type and, for c-w reception accommodates a plug and carries both the microphone and "Press to Talk" switch circuits. A duplicate jack is provided on the transmitter unit and, for c-w operation, the microphone plug is removed and replaced by a "Key" properly connected to a similar plug.

AUDIO CIRCUITS

The audio circuits are quite simple and, with but one stage of amplification, a high level type of carbon microphone is used. The d-c supply for the microphone is obtained from the voltage drop across a part of the resistance in series with the Type 42 tube filament.

The microphone current passes through a choke-condenser filter, through the microphone transformer primary and through the microphone button to ground. The filter is installed to remove any voltage variations or "ripple" from the circuit.

The operation of the microphone causes variations of current in the primary and, due to the transformer action, a corresponding signal voltage appears across the secondary. This secondary voltage is impressed on the grid of the modulator, is amplified by the tube and appears in the plate circuit which includes the primary of the modulation transformer. As previously explained, the secondary of this transformer is connected in the suppressor grid circuit of the r-f amplifier tube to provide the required modulation of the carrier.

The signal voltage which appears also across the third winding of the modulation transformer, is used to provide side tone for the headphones. Tracing the circuit, of this third winding, you will find it connects to that previously explained for inter-phone operation.

ANTENNA RELAY

Looking at the antenna circuit of Figure 2, you will find the contacts of the antenna relay are arranged to operate as four

separate switches. The one shown at the top is a single pole, double throw, while the other three are single pole, single throw.

In the position of the drawing, the relay is not energized and the top switch connects the antenna to the receiver while the other three switches are open. When the relay is energized, the top switch grounds the receiver connection, the second switch connects the antenna to the transmitter output, the third switch connects the side tone winding of the modulation transformer to the side tone lead at the control box while the fourth switch connects the high voltage supply to the plate circuit of the r-f amplifier tube.

An inductance, resistance and capacity, connected in series across this plate circuit switch, make up an absorption circuit to prevent arcing at the contacts when the high voltage circuit is opened.

TRANSMITTER TUNING

In addition to the units already mentioned, you will find closed circuit type jacks in the cathode circuit of the oscillator tube and in the plate circuit of the r-f amplifier tube. An insulated case type of milliammeter is connected to a plug which, when inserted in these jacks, provides a convenient means of reading the desired currents.

The crystal frequencies are usually specified at the time of purchase and final tuning is done after the transmitter has been installed. The general procedure follows the steps explained in our earlier Lesson but, as the plate supply develops 1700 volts, care must be taken while adjustments are being made.

To tune the transmitter, the meter is plugged in the oscillator jack, the plate lead of the r-f amplifier tube is removed and, after the filaments have been on for about a minute the high voltage is applied. Starting with position 1 of the frequency selector switch, the low frequency oscillator tank circuit is tuned until a sharp drop of cathode current occurs. The condenser is then adjusted to the position of minimum current after which its capacity is reduced until there is a current increase of about 5%.

The frequency selector switch is then moved to position 2 and, with the other LF crystal in the circuit, the current should be within about 5% of the value shown for the first crystal. If this condition does not exist, the entire process is repeated until the two current readings are within 5% of each other.

The same steps are followed for positions 3 and 4 of the frequency selector switch except that the high frequency oscillator tank circuit is tuned.

To tune the r-f amplifier, the plate lead is replaced, the antenna is disconnected and the meter is plugged into the plate circuit jack.

With the frequency selector switch in position 1, the low frequency tank circuit is adjusted until the meter registers a current dip. Care must be taken here and, until the tank circuit is properly tuned, the high voltage supply must not be "ON" for more than about 10 seconds at a time.

After this first adjustment has been made, the frequency selector switch is turned to position 2 at which point the r-f plate current should remain about the same as for position 1. Slight readjustment of the oscillator circuit may be necessary to provide this condition.

The same steps are followed for positions 3 and 4 of the frequency selector switch while the high frequency tank circuit is tuned.

LOADING ADJUSTMENTS

To properly load the r-f amplifier tube, the antenna is connected to the transmitter and, while most of the adjustments can be made on the ground, the final ones are made in flight.

While a number of antenna types are in use, for this explanation we will assume a trailing type of fixed length. For the first ground adjustments the total length of the antenna should be reduced about 15% and the outer end held about 10 ft. above ground by a well insulated support.

The transmitter is then placed in operation and the r-f amplifier tank again adjusted for the dip in plate current. This adjustment will vary from that previously made and the antenna is then folded back, about a foot at a time, until the adjustment remains the same with or without the antenna.

Under this condition, the antenna presents resistance only and adjustments can then be made for the amount of power to be transferred from the transmitter to the antenna. This is commonly known as "Loading" and is done by changing the position of the tap on the tank coils.

Each time the position of the tap is changed, the tank circuit is retuned to the dip in plate current and adjustments are continued until the minimum plate current is of the desired value. In the circuit of Figure 2, the meter on the control box will indicate maximum antenna current when these adjustments have been made properly.

These adjustments are made at the higher frequencies and then repeated for the lower frequencies, the tap on the loading coil being adjusted to vary the effective length of the antenna.

The final adjustments are made in flight after the antenna length has been increased about 20% by unfolding the outer end. The antenna is shortened, while making the ground adjustments, to compensate for short distance between it and the earth.

After these adjustments are complete for c-w transmission, the modulator is placed in operation and the antenna current should show an increase of 10% to 20%. Sometimes the operation of the modulator causes a decrease of plate current or what is known as "downward" modulation.

To correct this latter condition, the loading should be readjusted for a lower value of "dip" or minimum plate current, until upward modulation is obtained.

INSTALLATION

In an actual installation, the various units are interconnected by means of specially built, shielded cables which terminate in plugs. These plugs and their respective sockets or receptacles are arranged so that there is no chance of error either in the selection of the proper cable or the proper insertion of the plug.

Going back to the circuit of Figure 2, you will find a 12 wire control cable for interconnections between the Transmitter and Control Box. At the control box, the cable terminates in a 14 wire fitting to allow for the battery and side tone leads.

A 10 wire cable is needed, for the interconnections between the transmitter and Power Unit to accommodate the various supply voltages as well as the circuits of the power relay. In addition a two wire battery cable also connects to the power unit.

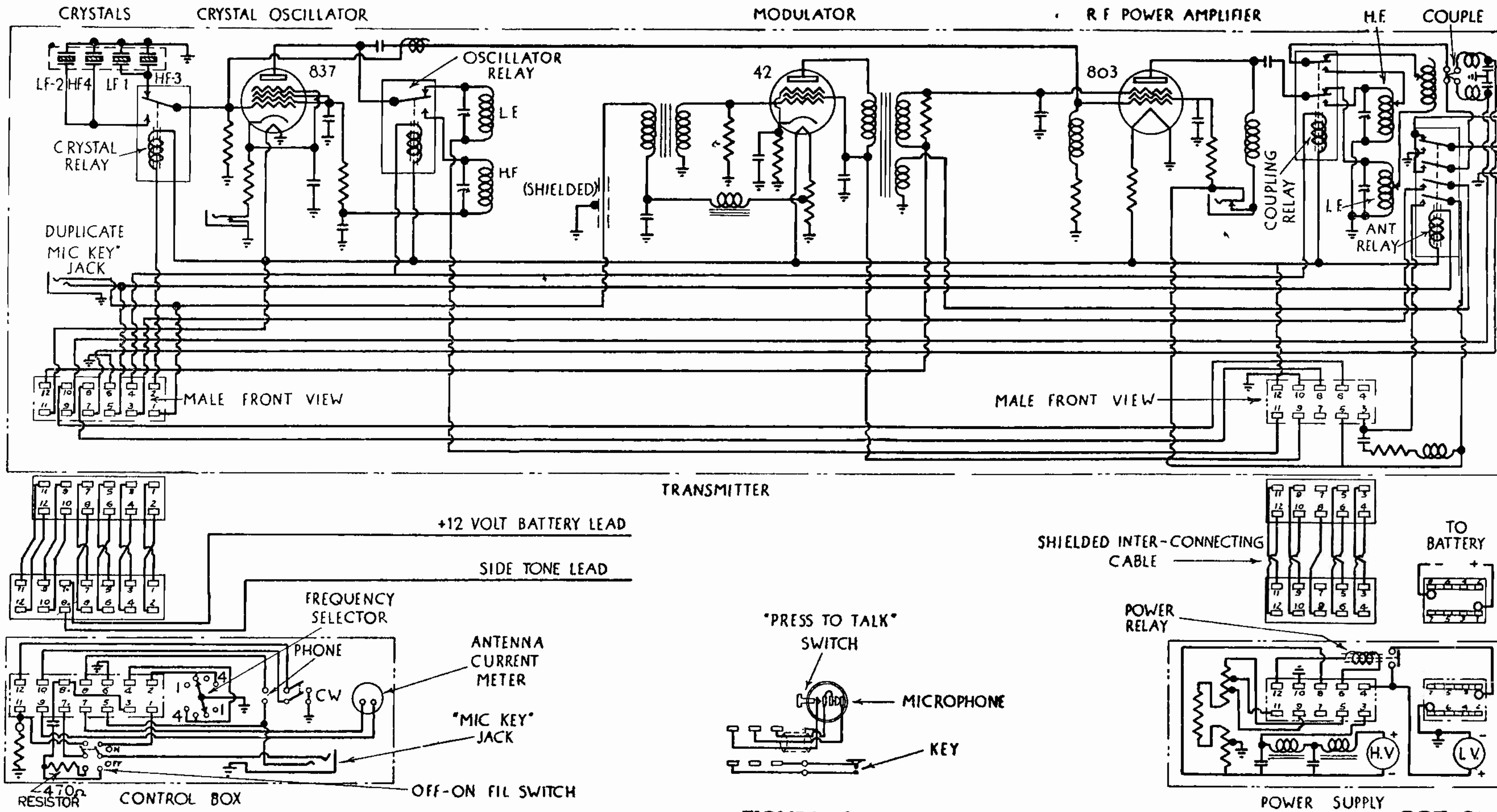


FIGURE 2

RRT-21

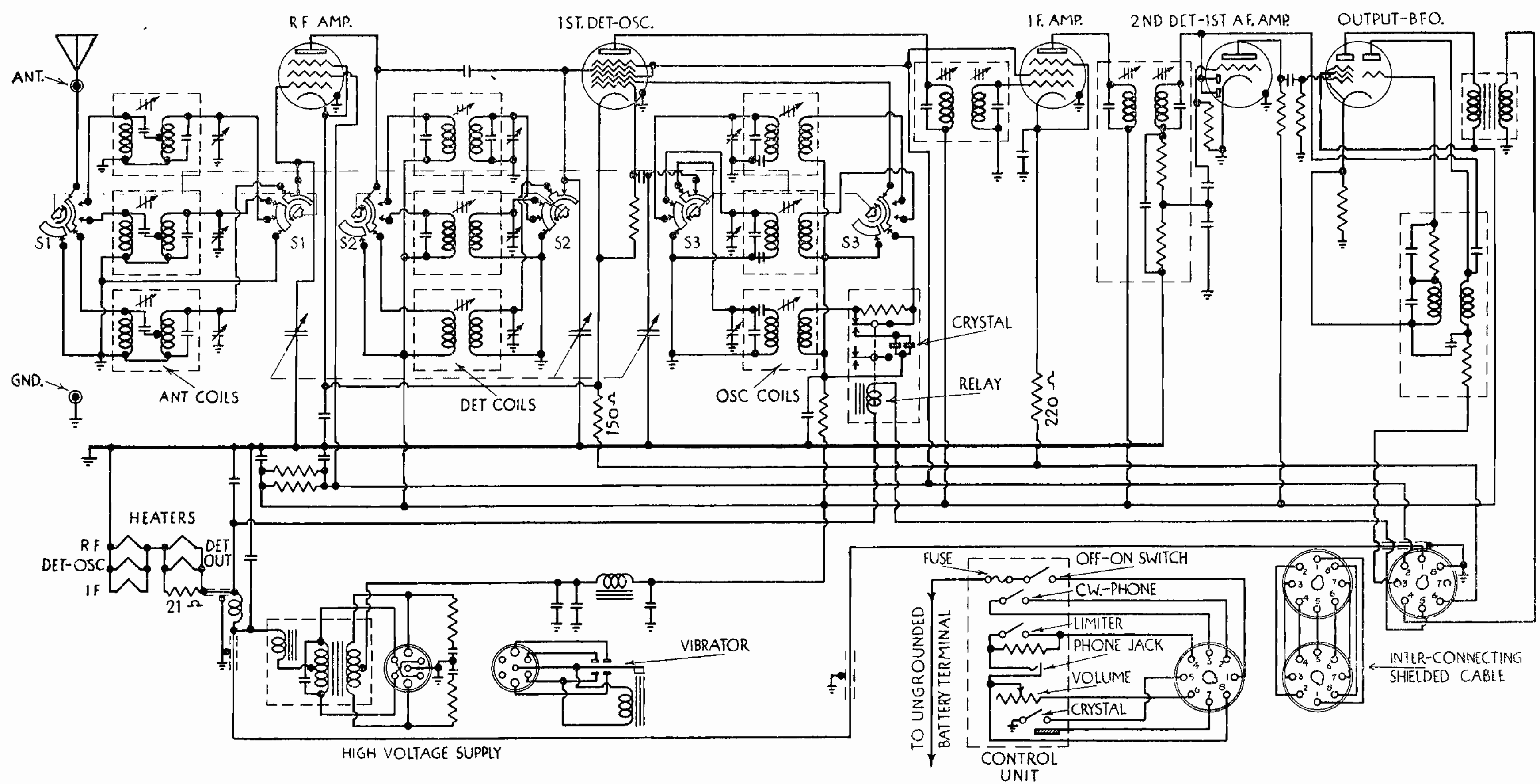
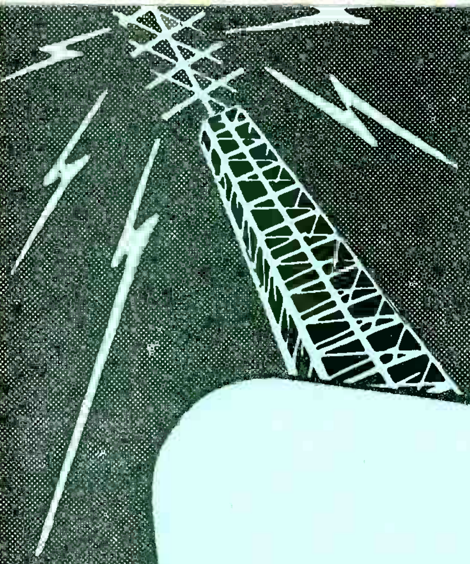
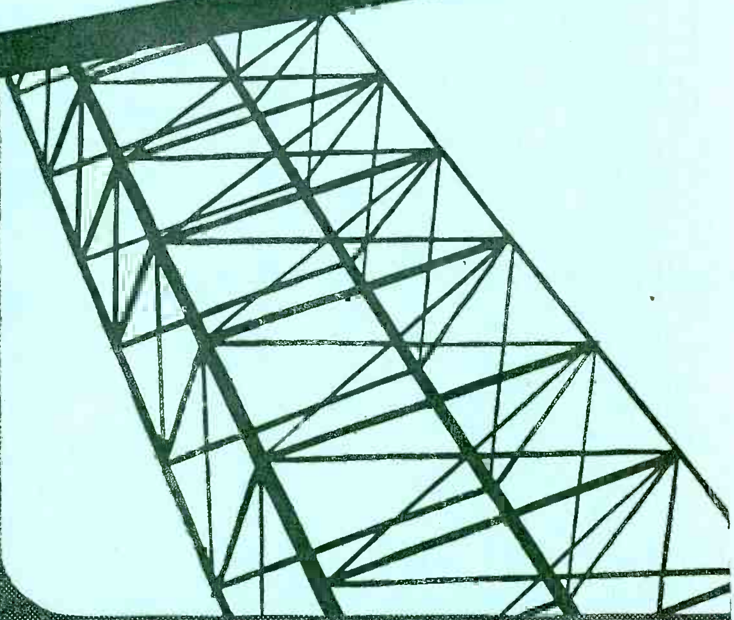

ANT.
GND.
ANT COILS
S1
R F AMP.
S2
DET COILS
1ST. DET-OSC.
S3
OSC COILS
150Ω
CRYSTAL
RELAY
I F. AMP.
220Ω
2ND DET-1ST A F. AMP.
OUTPUT-BFO.
HEATERS
R F
DET-OSC
I F
DET OUT
21Ω
HIGH VOLTAGE SUPPLY
VIBRATOR
TO UNGROUNDED BATTERY TERMINAL
FUSE
OFF-ON SWITCH
C.W.-PHONE
LIMITER
PHONE JACK
VOLUME
CRYSTAL
CONTROL UNIT
INTER-CONNECTING SHIELDED CABLE

FIGURE 1



LESSON RRT-22

RADIO AIDS TO AIR NAVIGATION



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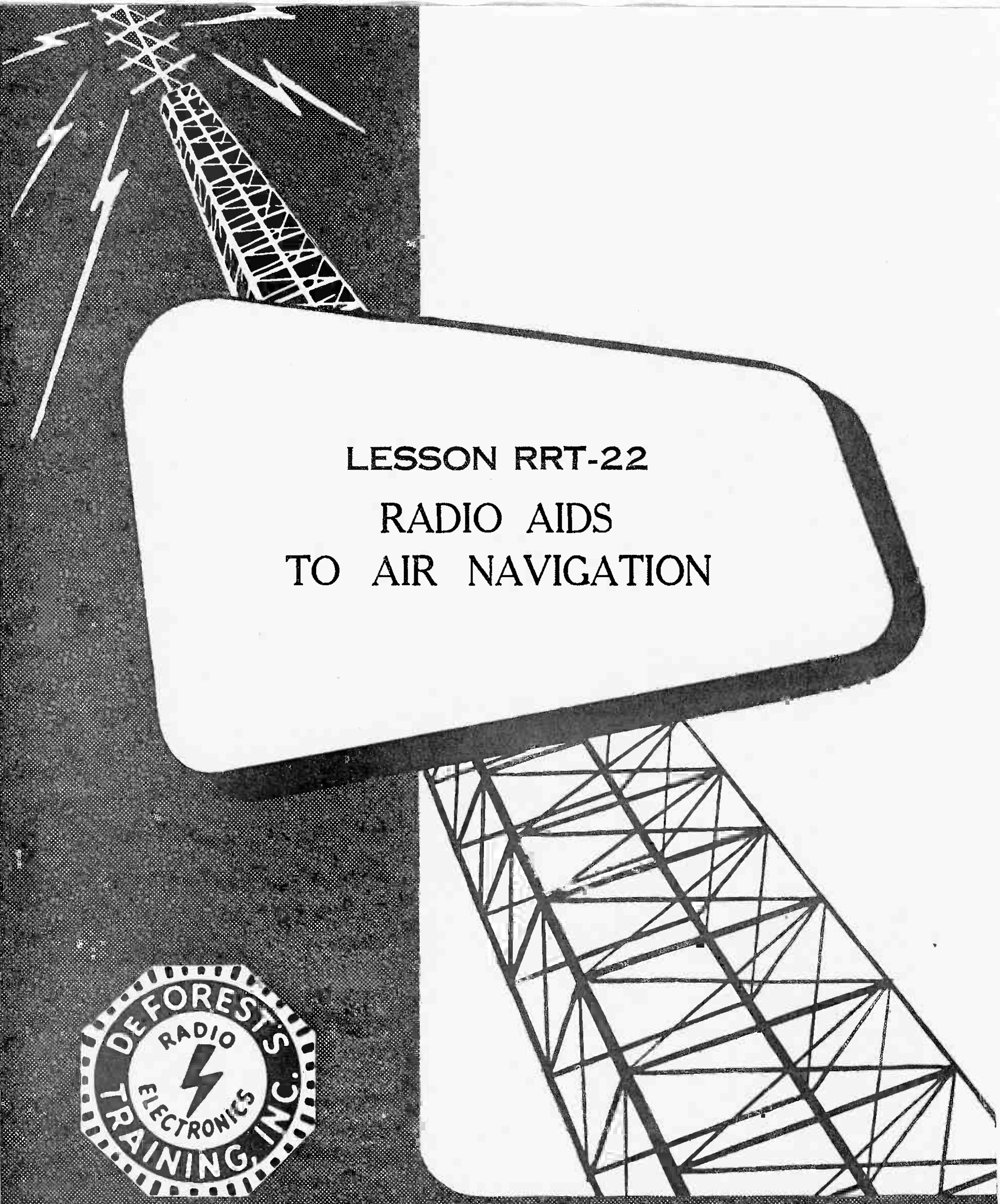
LESSON RRT-22

RADIO AIDS TO AIR NAVIGATION



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RADIO RECEPTION AND TRANSMISSION

LESSON RRT-22

RADIO AIDS TO AIR NAVIGATION

# # # # # # # # # #

When a carpenter "walks" a spike into the grainy heart of a two-by-four, he doesn't summon all his strength and with one mighty blow attempt to drive it down. It is a matter of "little by little" until the spike begins to get the bite of the grain.

Many of our problems are tough as an oak. The way of the carpenter must be the answer. Patience, plus persistence, plus understanding.

- Selected.

In an earlier Lesson on aviation radio we gave you a general explanation of a typical receiver and transmitter employed in the plane, but there are additions to this equipment which are necessary for "safe flying". All of these "additions" come under the general head of "Radio Aids to Air Navigation" and for this Lesson, we want to explain the underlying principles on which they operate.

The various "aids" generally consist of radio equipment for "en-route" navigation and, for ease of presentation we, have considered three separate major functions with explanations on supplementary services. Those divisions consist of: (1) direction finders, (2) radio ranges and (3) radio markers.

DIRECTION FINDERS ON PLANES

One of the first requirements of the pilot in a plane is to know his location and the direction the plane is traveling. Of course, this is quite a simple matter when the visibility is good, and the pilot is familiar with the route, because he can observe the country side. On the other hand, when visibility is poor and he is "flying blind", the only reliable way he can determine his location and direction of travel is by the use of a radio direction finder, commonly called a "radio compass".

A direction finder then is a device for determining the direction of the radiated energy of an electromagnetic wave. More specifically, its function is to determine the angle between the line of bearing connecting a transmitter and a receiver and a known direction in space at one or the other of these locations.

Although initial direction finding apparatus was installed on aircraft for the purpose of assisting the pilot in maintaining a designated flight course, ground direction finding equipment is being developed to a high degree of accuracy. It is now possible to "locate" the position of aircraft, from a ground station, and plot or show its position on the screen of a cathode ray tube.

In general, all direction finders make use of a loop antenna and a sensitive receiver. Refinements require the use of another antenna and on transport aircraft, these include a belly antenna and a loop enclosed in a streamlined "egg" housing which is some 8 inches in diameter and about 2 feet in length. In high speed aircraft these loops may be enclosed in a streamline "blister" or in the nose of the aircraft with a plastic skin to cover the nose.

The essential differences between the broadcast receiver and direction finder receiver lie in their basic uses. The former is for the transfer of messages whereas the latter is merely for determining the direction of radio energy radiation. However, it is true that in cases of emergency the direction finder can be used for communication purposes. Direction finders are used almost invariably where one of the stations is mobile and where its position must be determined for the purpose of navigation.

Fundamentally, the receiver action is exactly the same as those explained in the earlier Lessons therefore, we will not repeat. However, in order to understand the operation of a direction finder it is necessary to study a few antenna field patterns.

If a simple type of vertical antenna is connected to a sensitive indicator, it will be found that waves of equal amplitude, cutting it at different angles, all induce the same voltage. Thus, we say that it is non-directional and its field pattern will be a circle as indicated by the larger outer circle of Figure 1.

For receiving antennas, the field patterns are really a form of curve or graph which indicate the relative strength of the voltages induced by carrier waves arriving from all directions. The outer circle of Figure 1 therefore indicates equal induced voltages for all directions.

With a loop antenna, conditions are different and when it is subjected to the experiment just explained, it will be found that maximum voltage is induced when the waves are in the same plane as the loop. The resulting field pattern has the shape of an "8" and can be shown as the two connecting smaller circles in Figure 1.

For a pattern of this kind, the plane of the loop is along the XX' axis, and signals reaching it from this direction induce maximum voltage. Other signals, reaching the loop in the direction of the YY' axis, induce minimum voltage therefore, the loop is directional and can be used to indicate the direction from which a signal originates.

To show you how this action can be put into practical use, we will assume that the axis XX' represents the wings of a plane, while the loop, mounted as shown, is connected to a sensitive receiver. We will assume further that the plane is on a flight to Kansas City, Missouri, and visibility is so poor that the pilot has to depend on his direction finder.

Under these conditions, the pilot need only turn on his receiver, tune in some transmitting station located at his destination, and keep the plane headed in the direction which causes minimum signal volume. As explained for Figure 1, minimum signal indicates that the loop is at right angles to the direction of the signal and therefore the plane is flying in line with the transmitter.

Although the simple loop arrangement will allow the pilot to fly his plane in line with a transmitter, it does not tell whether he is flying toward his destination or away from it becaused the induced voltage in the antenna is minimum whether the signal is from "Y to Y'" or "Y' to Y" in Figure 1.

In order to correct this "180° ambiguity", as it is called, it is common practice to use two antennas, one a loop and the other a non-directional type. When the outputs of these two antennas are combined in the proper phase, the result is a heart shaped field pattern, similar to A of Figure 2. Should the phase of the loop be reversed, a similar pattern with opposite polarity results as indicated by B in Figure 2. Each of these separate patterns is called a cardioid and notice, they overlap on the axis XY. Consequently, there will be but one maximum and one minimum voltage (signal strength) induction, and such an arrangement eliminates the dual maximum and minimum positions.

Checking this Figure, and thinking of the distances, from the center "O" to the curve, as representing the relative values, a signal received from the X direction will induce equal voltages, OC, in each of the field patterns A and B. When the signal is from the X' direction, the voltage OC' induced in pattern B is much greater than the voltage OC" induced in pattern A while with signals from the X" direction, the voltage OC' induced in A is much greater than the voltage OC" induced in B.

If we assume the voltages induced in B are positive while those in A are negative, a signal from the direction X would result in zero effective voltage, with an X' signal the effective voltage would be positive while an X" signal would result in a negative effective voltage.

For a signal coming from any of the "Y" directions, the action is the same as explained for the "X" directions but the effective polarity of the induced voltage is reversed. Thus, by employing a measuring instrument to indicate the relative amplitude and polarity of the effective voltage, the 180° ambiguity is corrected. The direction of the transmitter can be located and because of the changing amplitudes of effective voltage, the "sense" of deviation from the line of flight to the transmitting station can be determined.

This is the principle employed in a large number of radio compasses which employ a left-right or zero-center type of meter as an indicator. When the received voltages are equal, the effective voltage is zero and the meter reads zero to indicate the flight of the plane is in line with the received transmitter. Should the signal be received from an angle, the meter pointer will deflect to the right or left depending on the polarity of the effective induced voltage. When the pointer deflects to the right, it indicates the line of flight is to the right of the desired course and turning the plane to the left will bring the indicator pointer back to the central or zero position.

Should the plane be traveling from the transmitter, instead of toward it, the polarity of the induced voltage will be reversed. Under these conditions, an indicated right hand deviation will be increased instead of corrected by turning the plane to the left and thus the pilot is informed of the 180° reversal in the direction of his line of flight. By properly calibrating the indicator, it becomes a "Radio Compass" and immediately shows the pilot whether he is on or off course and if "off", which way the plane should be turned in order to fly "on the course".

The left-right radio compass has not been widely adopted by commercial air-transport companies. One of the reasons is because a strong side wind blowing directly across its course could cause the path of flight to take considerable "arc" even though the nose of the ship is pointed directly toward the tranmitting station. The plane, therefore, traverses a much longer path than if following the shortest distance between the starting point and destination. Of course, if the plane has sufficient fuel and the longer path flown has no obstructions, the plane eventually reaches its destination.

Many of the Radio aids to navigation depend on "radio beams" and therefore we want to give you a general idea of just what is meant by the term and how they are produced. As its name implies, a radio beam is really a narrow path of radio energy transmitted in a fixed direction, on the same general plan as the beam of light from a searchlight. To produce a radio beam of this type, the characteristics of a loop antenna are utilized and therefore we can refer again to Figure 1.

When a loop antenna is used for transmission, the field pattern of Figure 1 represents the relative intensity of the radiation. Thus you can see that the radiation is suppressed along the YY' axis or in a direction at right angles to the loop but is at maximum along the XX' axis which is in line with the loop.

By erecting two loop antennas at right angles to each other, a field pattern like that of Figure 3is produced. One loop will have maximum radiation along the XX' axis while the other has maximum radiation along the YY' axis. However, the radiation from both loops will be of equal intensity only in the comparatively narrow zones in which the two field patterns overlap.

These zones of equal intensity are indicated by the shaded wedges of Figure 3 and represent the "Beams". In order that the airplane pilot may learn whether or not he is on the beam and if not, which way he must go to regain it, the following method is in use.

The two antennas radiate alternately, one transmitting the letter "A" which is a "dot-dash" in code, and the other transmitting the letter "N" which is a "dash-dot" in code. As long as the airplane is flying the beam, the A and N signals are received with equal intensity and timed so that the separate dots and dashes blend into a steady unbroken note or "on course" signal. In order to provide what is known as interlocking, the dash of the N is generally transmitted first, then the dot of the A, then the dot of the N, and the dash of the A.

The course signals, A and N, are broadcast for 30 seconds and then interrupted while the station identification signals are broadcast twice, once from each loop for a period of 7 seconds. This results in a complete sequence every 37 seconds and, at present, there are 12 "A's" and 12 "N's" transmitted between station identification signals.

In order to eliminate danger of mistaken identity, each transmitter is assigned an individual one or two letter station identification signal. For example "WA" (dit dah dah, dit dah) identifies a Washington, D.C. station.

Should the path of the airplane veer to one side of the beam, the two signals will not be received with equal intensity, the steady tone will be broken up and one of the signals will become louder than the other. The stronger or louder signal indicates to which side of the beam the course of the airplane has deviated.

Going back to Figure 3, each lobe of each loop antenna field pattern is known as a "Quadrant" and a single letter code signal is transmitted in each. Knowing the location of the transmitter and the orientation of the quadrants, the pilot can return to the beam without error.

Sometimes, it is desirable to lay out the beams or courses so that they are not at right angles to each other as shown in Figure 3. When this is done, and the opposite courses are in a straight line, the resulting pattern is called a "squeezed course". Should the course be laid out so that the opposite beams are not in line, the result is a "bent course". In either case, this is accomplished at the transmitter by changing the antenna and tuning arrangements so that the field pattern is altered.

If, in Figure 3, for example, the A signals were transmitted with but half the amplitude of the N signals, the upper and lower quadrants would be smaller, making the left and right angles between the beams larger while the upper and lower angles would be smaller. Thus, as previously explained, the result would be a "squeezed course".

RADIO RANGE BEACON

A radio range beacon is essentially a special radio transmitter, usually located just off the landing field at an airport and designed to radiate the course beams, such as shown in Figure 3. The actual radio range consists of two loops placed at right angles to produce the pattern indicated. As installed on the airways, the range assembly is oriented so that the courses are aligned in the direction desired. By correctly distributing the stations geographically, a system of airways can be marked out in much the same manner as the development of the modern auto highway networks.

Signals from the loop type antenna produce the pattern of Figure 3 which is satisfactory for "daytime" flying. With the advent of night flying, it was found that the "Night effect," associated with the loop type ranges, hindered a satisfactory course definition. The energy radiated from the loop type station is polarized in both the horizontal and vertical planes due to the fact that both the vertical component and horizontal top of the loop radiates energy.

The horizontally polarized energy radiates from the flat top portion of the loop antenna, travels upward at undesirable angles and is reflected back to earth by the Heaviside Layer, and interferes with the direct ground wave upon which desirable operation of the range depends. Generally, the refracted energy is out of phase with the direct ground wave and thus cancels out the desired signal. This action causes the power of one of the loop signals to be reduced, and the course will be shifted. Such phenomena accounts for the instability of courses transmitted by loop type stations during the hours of darkness.

Generally speaking, the sky wave is not reflected back to earth at distances of less than 30 miles. Therefore it is possible to use loop type radio range stations within a radius of 30 miles of the station during the hours of darkness. The loop type of station is relatively inexpensive in initial cost and maintenance and, for that reason, a great number of loop stations are operated at points where distances in excess of 30 miles are not required. Such stations are useful to fill in gaps along the airway, mark airway intersections, provide range courses to emergency fields and as localizers for low approach procedures at terminal airports.

There are several types of radio range beacons but their main difference is in the means employed for distinguishing between the two sets of signals. One, explained for Figure 3, transmits the range code characters A and N which are picked by the receiver in the plane and reproduced in headphones or speaker. When the plane is "on course" the sound is a steady note, while if "off course", the A or N code character is the louder. As the course is indicated by the sound of the note received, this method is known as an "aural type" beacon.

In the second method, the same type of transmission is used but, instead of the A and N characters, two low frequency notes, generally 65 and 86.7 cycles, are transmitted. That is, the high frequency power in opposite quadrants is modulated with 65 cycles while in the other two quadrants the high frequency is modulated with 86.7 cycles.

Two vibrating reeds, tuned to the modulating frequencies, 65 and 86.7 cycles respectively, are connected across the output of the receiver in the plane. This type of indicator is very simple and practical, being connected to the receiver in place of the headphones. The tips of the reeds are white, with a black background, and when a signal is received they vibrate at sufficient speed to appear as a vertical white line to provide a visual indication.

In practice, the reed on the pilot's left is tuned to a frequency of 86.7 cycles while the one on his right is tuned to 65 cycles and readings are taken by noting the lengths of the lines produced by their vibration. When the lines are equal, the plane is on the correct course but, if the one on the left becomes longer, the plane has drifted off the course to the left. On the other hand, if the plane has drifted to the right, the right white line will become longer than the one on the left.

In another form of indicator, designed for the same method of transmission, the vibrating reeds are placed in a position to induce voltages in two pick-up coils in much the same manner as the vibrating armature in a magnetic phono pick-up. These voltages, which are proportional to the amplitudes of the vibration of the two reeds, are rectified by cuprous oxide rectifiers and the rectified voltages are applied differentially to the terminals of a center-zero type of meter.

The meter remains at zero when "on course" because the rectified voltages are equal, and opposite. When "off course", the unequal rectified voltages from the pick-up coils result in an effective voltage which acts on the meter and causes the pointer to move. The distance and direction of this movement depends on the effective voltage and whether the plane is off the course to the right or left. As the visual indication is employed to inform the pilot of his course, this arrangement is known as a "visual type" radio beacon.

SIMULTANEOUS RANGE STATIONS

With the loop type of station, it is possible to transmit both range signals and weather broadcast reports, but not simultaneously. In order to transmit a weather report, it is necessary to discontinue the range signals and operate the entire system as a radio telephone station. The great number of requests for continuous range operation by pilots "on instrument" prompted the development of the "simultaneous" radio range stations which are capable of simultaneously broadcasting range signals and radio telephone messages on the same frequency.

In operation, the center tower radiates a carrier at the frequency assigned to the station while the N and A range signals are radiated from the diagonally opposite pairs of corner towers at a frequency of 1020 cycles higher than that of the center tower. When tuned to the assigned frequency of the station, a receiver will accept both carriers but, by itself, neither one will produce an audible note in the receiver output. However, when both carriers are received at the same time, an audible beat note of 1020 cycles is produced in the headphones or other receiver output device.

The range signals are heard because they are transmitted by the interruption of their carriers at properly timed intervals while the center tower carrier is transmitted continuously.

When voice messages are to be transmitted, the center tower carrier is modulated by the audio frequencies and thus, like Broadcast radio, these messages are heard in the receiver output in addition to the range signals. By means of a filter system, connected between the receiver output and the headphones, the two types of signals can be separated and a selector switch makes it possible to listen to, (a) Both range and voice, (b) Range only and (c) Voice only.

Electrical or mechanical breakdown of some part of the range transmitting equipment could cause complete failure, or more serious yet, a condition which might for the moment permit the pilot to receive an "on course" signal where none should exist. Every conceivable precaution is taken to prevent failure of radio ranges by frequent regular inspections, cleaning and overhauling. In addition, a monitoring system is maintained such that several receiving stations are charged with the responsibility of listening to each range for evidence of course deviation or other faults. Any departure from normal operation is investigated immediately and warnings broadcast to all concerned. For this reason, "Air lines" maintain elaborate laboratories for the purpose of testing and repairing aircraft equipment, as well as developing new aids to make flying safer.

As previously indicated, the present range stations operate in the 200 - 400 kc bands, although considerable development work is being done in the ultra high frequency regions. High frequency radio ranges have superiority over low frequency ranges for several reasons. Thunderstorm static has no effect on reception, the range "legs" are perfectly straight, whereas on the lower frequencies the legs may sometimes be bent (dog legs) because of terrain variations and also because of reflection from the Heaviside Layer.

It is very probable that radio range transmitting and receiving equipment will be operated in the ultra high frequency bands just as soon as the equipment change can be made.

INDICATING INSTRUMENTS

In the earlier sections of this Lesson, we explained the field patterns of non-directional and loop antennas and showed how, by combining these patterns in the proper phase, a cardioid pattern was produced. Also, when the polarity of the loop was reversed, the polarity of the cardioid also reversed.

By rapidly reversing the polarity of the loop antenna, the resulting pattern is similar to Figure 2 which, as you will remember, makes it possible to obtain an effective voltage determined by the direction of the signal input. At this time, we want to explain how this action is produced and, for Figure 4, have drawn a simplified circuit arrangement.

Starting at the upper left, you will find a split loop antenna, with one side of each section connected to the respective grids of tubes T_1 and T_2. The other sides of the loop connect to opposite ends of the secondary of transformer L, the center tap of which connects to the C- terminal. Notice also, that each half of this secondary is bypassed by a condenser, C_1 or C_2, with a capacity of such value as to offer a low reactance to radio frequencies but a comparatively high reactance to audio frequencies.

The cathodes of tubes T_1 and T_2 are grounded to the B-C+ terminal, while their plates, connected in parallel, receive voltage from B+, through coil L_1 which is inductively coupled to the input coil "L_3" of the receiver. The non-directional antenna is connected to coil L_2 which is also inductively coupled to the input coil L3. Because of this arrangement, the inputs from both the split loop and non-directional antennas will appear across the radio receiver input coil L3.

The action of this receiver is fundamentally the same as those explained in the earlier Lessons, and its output is fed into the primary of the transformer L4, the secondary of which connects to the moving coil, or armature, of a center-zero dynamometer type of indicating instrument. The stationary coil, or field of this indicator, is connected directly across the primary of transformer L.

The type of indicating instrument employed here is a little different than those previously mentioned therefore an explanation of its action will be of benefit. From your earlier Lessons on meters, you will remember that in the D'Arsonval moving coil type, the field is supplied by permanent magnets and the instrument is used to measure d-c voltage and current only.

When an a-c voltage is applied to an instrument of this kind, the pointer merely vibrates at the frequency of the a-c because it is first in one direction and then the other. When current is in one direction, the coil of the meter tends to turn clockwise, but this is offset by an exactly equal counter-clockwise motion when the current reverses.

In order to measure a-c with a meter of the moving coil type, the permanent magnet is replaced by an electro-magnet which is excited at the same frequency as that applied to the moving coil. Under these conditions, the flux set up by the electro-magnet reverses direction at the same frequency as the current in the moving coil and therefore the pointer moves in but one direction and can be made to measure alternating current. Indicators, employing this principle are called "dynamometer type instruments".

Going back to Figure 4, let's check the action of the circuit to see just how the polarity of the loop is reversed. In operation, the negative bias voltage on the grids of tubes T1 and T2 is of such value that, with no signal input, no plate current exists. That is, the grids of T1 and T2 are biased to plate current cut-off by a voltage applied between the C- and C+ terminals.

A low fixed frequency audio signal, called the switching frequency, is applied to the primary of transformer L, appears across the secondary and is impressed on the grids of the two tubes. As previously pointed out, these grids connect to opposite ends of the secondary therefore, in respect to the center tap, they will receive equal and opposite voltages. Saying it a little differently, the audio voltage, on the grids of T_1 and T_2 , is 180 degrees out of phase with respect to the secondary center tap of transformer L.

Under these conditions, and with the tubes biased to cut-off, T_1 will pass current during one alternation of the switching frequency while T_2 will pass current on the next alternation.

The r-f voltages, induced in the split loop antenna are also applied to the grids of T_1 and T_2 but, by themselves do not have sufficient amplitude to reduce the grid bias voltage to a value below that of plate current cut-off. As a result, the loop antenna signals will appear in the plate coil L_1 only when the switching frequency causes plate current.

As already explained, the switching frequency causes the tubes to operate alternately and, as the opposite ends of the loop are connected to the respective grids, the effective polarity of the loop is reversed at the switching frequency.

The received signal volta es in the loop antenna appear across coil L_1 and together with those appearing across coil L_2 , are inductively coupled to the receiver input coil L_3. The phase relations are such that the split loop antenna voltage alternately aids and opposes the non-directional antenna voltage.

The resultant voltage is amplified, detected and amplified again in the receiver, appears across the primary of transformer L_4, is transferred by induction to the secondary and applied to the moving coil of the dynamometer type indicator. The field coil of the indicator is connected across the primary of the transformer L and is thus excited by the switching frequency, to maintain the proper relationship between the field flux and the current in the moving coil.

By this arrangement, the pointer can be made to move, say to the left, for the aiding condition and to the right for the opposing condition of the two antenna voltages. Thus, it is readily determined whether the plane is flying away or toward the transmitting station by noting whether the pointer moves to the right or left as the heading of the plane is altered to the right or left of its course. If the pilot heads his plane to the right of the course and the indicator shows this has been done, the plane is flying toward the transmitter but, if it indicates a direction opposite that to which the plane has been headed, it is flying away from the transmitter.

As you can see, from the above explanation, this type of direction finder is quite simple and may be used with most any type of radio receiver. Also, the signals picked up need not be of any special type, even those of a broadcast station may be employed, provided of course, that the receiver tunes to these frequencies. In addition, the same receiver may be employed to receive weather broadcasts or range beacon signals.

CONE OF SILENCE

In the drawing of Figure 3, we indicate the field pattern of two loop antennas which produce the desired beam. This sketch is a plan view of the radiation but, directly over the antenna, there is an inverted cone-shaped area where the loop signals cancel each other, and comparatively little energy is radiated.

Starting from the center of the antenna system, this area projects upward and outward in the form of an inverted cone and as the beam signals in the aircraft receiver fade out when the plane passes directly through this area it is known as a "cone of silence".

As we have previously explained, a radio beam is comparatively broad at a distance from the transmitter but, as an aircraft approaches the station, the width of the beam reduces and if the course is followed, the plane will reach a definite point directly above the antennas.

As the aircraft approaches this point, the beam signals will build up rapidly, drop off suddenly for a few seconds, and then come in with still greater volume. This sudden drop in signal volume is caused by the cone of silence while the duration of the no-signal period depends upon the altitude and speed of the plane.

The action is not always perfect and unless the plane is exactly on course, the signals will not fade out completely. Also, due to the sensitivity of the receiver the signals may still be audible, even when on course, unless the volume control of the receiver is turned down.

While the approach to a cone of silence is generally made at a low altitude, there is a minimum height at which it is reasonably possible to detect the cone. Although conditions vary, depending on transmitter power and receiver sensitivity, as an example case it has been found that planes flying at a height of 3,000 feet and at a speed of 120 miles per hour received a "cone of silence" indication for approximately 7 seconds. Due to the shape of the area, the lower the aircraft, the less chance the pilot has of finding the cone of silence and it would be quite easy to pass by or around it at unduly low altitudes.

INSTRUMENT LANDING EQUIPMENT

While the various services and instruments, explained in the earlier part of this Lesson, are invaluable for cross country flying, it is generally conceded that the most difficult and dangerous part of any flight is while landing. It is only natural therefore that much research work has been done to develop a radio system which will indicate a safe and accurate landing under conditions of zero visibility.

The radio beams and range beacons make it possible to fly "blind" from one airport to another but are of no practical assistance for a successful "blind" landing. Therefore, we want you to think of a Radio landing system as something separate and distinct from all other Radio aids.

The need for such a system has been recognized almost since the beginning of commercial aviation and, as far back as 1919, an experimental system was devised by the Bureau of Standards. Since then, many systems have been developed but without going into detail in regard to them, we want to give you a brief description of the equipment and operation of one manufactured by the International Telephone Development Company.

This particular system was designed to incorporate the best features of all previous developments and will therefore serve as a model. In general, it is composed of the following elements.

1. A "Runway-Localizer" beacon which provides an indication for the proper horizontal path to follow to the particular runway being used.

2. A "Landing Beam" or glide path which will provide an indication of the proper vertical path to follow for a proper landing.

3. Two "Marker Beacons" to provide spot indications which will enable the pilot to determine his location in relation to the landing field.

For the benefit of the pilot, the first and second of these signals operate a "cross pointer" type of indicator. The vertical pointer, controlled by the Runway Localizer, will swing to the right or left of center as the plane moves to the right or left of the desired horizontal path while the horizontal pointer will swing up and down as the plane rises above or falls below the path of the landing beam.

As long as the plane remains on the proper path, the pointers will be at right angles to each other and cross exactly at a marked center on the indicator dial. The location of the "cross-over" point of the two pointers, in respect to the marked center, shows the pilot instantly whether he is to the right or left, above or below the proper landing path.

RUNWAY LOCALIZER

The localizer equipment consists of a transmitter located in line with and several hundred feet beyond the outer end of the runway. Its output is divided into two equal parts to energize two antennas which produce overlapping directive radiation fields.

Although both antennas operate at the same carrier frequency each has a separate and distinct modulation frequency. The receiver in the airplane is tuned to this carrier and its output will consist of the two modulation frequencies.

The vertical pointer of the indicating instrument is controlled by the output of this receiver and arranged so that when reception from the right hand antenna of the transmitter is stronger, the pointer will move to the right. In the same way, the pointer will move to the left when reception from the left hand transmitting antenna is stronger. The pointer assumes a

central, vertical position only when both carriers are received with equal strength.

As the transmitting antenna fields overlap, this condition of equal reception occurs only when the plane is centrally located and on the desired path of flight.

LANDING BEAM

The landing beam equipment consists of another transmitter, located near the outer end of the runway and close to the border of the field. Its carrier is modulated at a frequency of 60 cycles and operates a special "glide path" receiver installed in the airplane.

To produce the desired field pattern, the antenna system is horizontally polarized and mounted fairly close to the ground. Under these conditions, the radiated energy, which can be thought of as lines of constant field strength, start upward in space, curve back down and end on the surface of the earth close to the antenna. A few of these returning constant field strength lines are shown in Figure 5, and one of them is used for the glide path.

As the airplane approaches the field, the energy of this field operates the glide path receiver, the output of which controls the horizontal pointer of the indicating instrument. In general, the elevation of this pointer will vary with the intensity of radiated field.

Looking at Figure 5, as the airplane approaches from the right, the field intensity will be low and the horizontal pointer on the indicator will also be low. As the plane continues its flight toward the airport, the field intensity increases and the indicating pointer rises, reaching a horizontal position at a point approximately as shown by the intersection of the "Path of Plane" and glide path of our drawing.

Should the plane continue in level flight, the field intensity would increase still further, cause the indicating pointer to rise above the horizontal position and show the pilot he was above the glide path. Should the plane lose altitude too fast, the field strength would reduce, cause the indicating needle to drop below the horizontal position and show the pilot he was below the glide path.

Thus, by controlling the flight of the plane to keep the pointer in a horizontal position, the glide path would be followed to a safe landing.

MARKER BEACONS

To prevent the possibility of error in the reception of the glide path signals, the pilot should also have some definite indication in respect to his distance from the airport. The marker beacons provide this information and the "outer marker" of Figure 5 is located in line with the runway but about 2 miles beyond its outer end. The inner marker, also in line with the runway is located at the airport boundary.

The antennas of these marker transmitters are arranged to radiate a rather narrow cone shaped, vertical field of limited power. They operate at the same carrier frequency but the outer marker is modulated at 400 cycles while the inner marker is modulated at 1300 cycles.

The receivers for this service are of the usual crystal controlled superheterodyne type but have band pass filters in the audio amplifier so that each modulation frequency will operate a different indicator. For example, reception of the 400 cycle modulated carrier may flash a blue light on the control panel while the 1300 cycle modulation may flash an amber light, while both can be heard in the phones.

To make a blind landing with this system, the pilot approaches the field in the proper path indicated by the runway localizer and at the proper elevation as shown by his altimeter. Then, as he reaches the outer marker, the blue light will flash to indicate he is in position to start down the landing beam.

Following the landing beam, the flashing of the amber light will indicate a position over the boundary of the field and permit the remaining distance of the landing to be made with comparative safety.

At present, there are no standard or generally accepted blind landing systems but, because of their importance and the progress which has already been made, it seems reasonable to expect that equipment of this type will soon come into more general use.

RADIO MARKER TYPES

As aircraft traffic grew in volume, it soon became necessary to establish "radio markers" which are in the form of a miniature radio range stations and operate with low power, usually on a frequency of 278 kc. To the pilot flying a radio range course these markers indicate his position along his line of travel and so enable him to orient himself with relation to the terrain over which he is flying. Such radio markers are of the following three general types.

"M" Type Markers: "M" type markers comprise a low power, long wave radio transmitter with a non-directional antenna system. They operate on the same frequency as the range stations on whose courses they are located, and their signals are received by the pilot as an interference on the range signal without need of retuning his range receiver. Signals from these markers are received as a continuously repeated single letter of the alphabet in the Morse Code which identifies the marker.

They provide only a general check on position, since the distance over which they may be heard is comparatively small and affected by differences in antenna efficiency, night effect, and the sensitivity of the receiver used aboard the aircraft. Provision is also made for radio telephone transmission to the aircraft on a common frequency of 278 kc, the latter replying on a higher carrier frequency.

FM Type Markers (Fan Marker): The Fan Marker consists of a transmitter using a directive antenna system and operating with an output power of approximately 100 watts at a carrier frequency of 75 megacycles. Located along the airways which they serve, the radiated field pattern is in the shape of a fan extending vertically upward from the antenna with its major axis at right angles to the range course.

The carrier is modulated with an audio frequency of 3000 cycles, keyed in groups of 1, 2, 3 or 4 to identify the Fan Marker with a numbered leg of the range station. These numbers are assigned by starting from true North at the range station and, moving in a clockwise direction, the first leg is No. 1, the second leg No. 2 and so on to No. 4. The marker is given the same number as the leg on which it is located regardless of similar equipment which may or may not be installed on the other legs of the range.

To receive the Fan Marker signals the aircraft must be equipped with an ultra high frequency receiver in addition to the standard low frequency range installation. The 3000 cycle tone can be heard in the headphones but usually these signals actuate a lamp so that both aural and visual indications are given the pilot as he passes over the marker. By checking these signals, the pilot may accurately locate his position along a range course.

Z Type Markers (Zone): The Z marker consists of a transmitter using a directive antenna system and operating with an output power of approximately 5 watts at a carrier frequency of 75 megacycles. The antenna is designed to radiate a vertical, cylindrical field and is located so that this field coincides with the cone of silence of the radio range station. The

carrier is modulated continuously with an audio frequency of 3000 cycles and thus the signal can be heard in the Fan Marker receiver.

The primary function of the Z marker is to provide a positive means of identifying the true cone of silence over the radio range station. As previously explained, the range signals die out as the aircraft crosses the cone of silence to provide a "negative" station indication but similar indications may be caused by faulty receivers, momentary failure of the transmitter, fading and other conditions. Therefore, as the Z marker signal can be received only while the aircraft is in the cone of silence, it provides a "positive" identification of the true cone of silence.

Micro-Wave Markers: The micro-wave marker consists of a transmitter using a directive antenna array and operates at a frequency of about 600 megacycles. The use of micro-wave radiation results in production of a very sharp radio beam from small electro-magnetic horn radiators, and tends to correct spurious field distribution lobes which sometimes occur in the 75 megacycle marker fields. Markers using micro-waves are still in the state of development and it is anticipated that the use of two horns, each modulated with a different audio frequency, will provide a marker which has a large easy to locate field, and a centrally located pattern for positive identification.

ALTIMETERS

Unlike land and water vehicles, aircraft operate in three dimensions and therefore it is essential that some means be provided so that the pilot may know his altitude or distance above the surface of the earth. Instruments for measuring the vertical distance between an airplane and the earth are generally known as "Altimeters" the prefix "alti" referring to altitude.

The early forms of these instruments operated on the principle of a barometer and depended upon the air pressure for their readings. As you perhaps know, there is a definite relationship between air pressure and altitude, but temperature, weather and other conditions cause the actual air pressure to vary.

In fact, the relationship between air pressure and weather conditions makes the barometer a necessary instrument for the preparation of Weather Maps and forecasts. When used as an altimeter however, these variations are compensated, as far as possible, so that the readings will vary with changes of altitude only.

To be of most practical use in aircraft, an altimeter must make it possible for the pilot to know the distance between his plane and the ground below. Therefore, to use the barometer type, which indicates the altitude above sea level, it is necessary that the pilot know the altitude of the ground beneath him and subtract this value from the altimeter reading.

Knowing the exact altitude of his plane, in respect to the earth's surface beneath him, is of greatest importance during times of poor or zero visibility and, when a pilot does not know exactly where he is, the barometer type of altimeter does not supply the required information. For this reason, much research has been done to develop an "absolute altimeter" which will give an accurate reading of the actual distance between its location and the earth below without reference to any arbitrary point such as sea level.

REFLECTION ALTIMETER

One type of such an instrument makes use of the fact that high frequency radio waves are reflected quite well by the earth's surface and travel at a uniform speed. Thus, a high frequency radio wave, transmitted downward from an airplane will strike the earth's surface, be reflected upward and operate a receiver, also installed in the airplane.

To make practical use of this action, it is necessary to provide some method by which the time required for the transmitted radio wave to reach the ground and return to the plane can be converted into a measure of the distance of its travel.

To work out a relationship between these factors, we want to remind you first that the speed of transmitted radio energy is usually considered as 186,000 miles per second. With 5280 ft per mile, this means a speed of 186,000 x 5280 or 982 million feet per second.

To simplify our explanation, we will consider this value as 1000 million and, to reduce the numerical values, will take one millionth of a second, called a "microsecond" as the time unit. Thus, the speed of the signal can be stated as 1000 ft per microsecond.

Assuming a plane at an altitude of 1000 ft, the transmitted signal will travel 1000 ft to the ground and 1000 ft back up to the plane for a total distance of 2000 ft which, from the values given above, will require a time of two microseconds. When the plane is at an altitude of 500 ft, the total time required for the signal to travel to the earth's surface and back will be but one microsecond.

To convert these exceedingly small differences of time into reliable and accurate measurements of distance, two well known radio principles are employed. The first is Frequency Modulation of the Transmitted Carrier and the second is the heterodyne action of two high frequencies which produce a third frequency equal to their difference.

To explain the application of the Freuqncy Modulation principle, we will assume the transmitter is normally tuned to a frequency of 500 megacycles. In addition to the usual components, the transmitter oscillator circuits contain a tuning condenser rotated at a speed of 100 rps by a constant speed motor.

Further, we will assume the capacity of this rotating condenser is such that, at maximum capacity, it tunes the oscillator to 500 mc but, at minimum capacity, it causes the frequency to increase to 520 mc. For each revolution of this condenser, the transmitter frequency will start at 500 mc, increase to 520 mc and then reduce to 500 mc for a total change 20 + 20 or 40 mc.

As one complete revoltuion of the condenser takes place in .01 second, the frequency changes are equivalent to 4000 mc per second or 4000 cycles per microsecond.

Keeping these values in mind, the equipment is installed on the plane with the transmitting antenna mounted under one wing and the receiving antenna mounted under the other. These are both half wave antennas but, due to the high frequency, are only about one foot long, and are located approximately 20 feet apart. To provide minimum pickup between them, the antennas are mounted in line or pointed at each other.

Following the broken lines of Figure 6, you will find two signal paths between the transmitting and receiving antennas. One path is direct while the other extends from the transmitter to the ground and back to the receiving antenna.

Going back to our former explanation, if a plane is at an altitude of 1000 ft., the signal path to the ground and back will be 2000 ft. longer than the direct path between the antennas and therfore the signal will arrive after an interval of 2 microseconds.

Thus, the receiving antenna will receive two signals, one directly from the transmitter and one which left 2 microseconds earlier. As the transmitter frequency is changing at the rate of 4000 cycles per microsecond, there will be a difference of 2 x 4000 = 8000 cycles between the carrier frequencies of these two signals.

In the receiver, these two signal frequencies will heterodyne to produce a beat note of 8000 cycles which is used to operate the indicating meter.

When the plane is at an altitude of 500 feet, one signal path will be 1000 feet longer than the other to produce a time difference of one microsecond. This will cause a frequency difference of 4000 cycles and a corresponding beat note in the receiver.

In effect therefore, the indicating instrument is a form of frequency meter which can be calibrated in feet above ground. From the values of our examples, you can readily calculate that if 1000 ft. altitude causes a beat frequency of 8000 cycles and 500 ft. altitude causes a beat frequency of 4000 cycles the ratio is 8 cycles per foot of altitude.

An instrument of this type, which operates entirely on the transmission of radio energy, is practically independent of changes in temperature or air pressure and will indicate the distance above the surface directly below regardless of the altitude above sea level.

You must remember however that the energy, between the transmitting antenna and the ground, assumes the shape of a cone and, at higher altitudes, covers considerable territory. The reading will therefore represent the average altitude above the surface enclosed by the cone. As the altitude is reduced the cone area also reduces and thus, the lower the altitude, the more accurate the reading.

ULTRA-HIGH FREQUENCIES

The use of ultra-high frequencies is becoming more evident, and research into the 75 mc - 150 mc range indicates that some of the disadvantages of low (200 - 400 kc) and intermediate (2 - 6mc) aircraft frequencies can be overcome. The principle advantages anticipated are: freedom from atmospheric interference, fading and skip annoyances; reduction in aircraft installation weight, number of frequency bands required and cost of necessary equipment.

The small space requirement of the antenna for ultra-high frequency communication is well adapted to metropolitan areas where cost is an important factor, even though requiring a higher degree of care in design and adjustment.

There is a disadvantage in connection with the use of ultra-high frequencies because as we have already mentioned, such

radiations travel in straight lines and do not follow the curvature of the earth. This characteristic demands a greater number of ground installations to maintain proper radio coverage of a specified area.

However, the advantages gained far out-weigh the limited range of transmission, and we may well expect many modes of communication to exist on ultra-high frequencies.

TRANSOCEANIC COMMUNICATION FACILITIES

The Civil Aeronautics Administration (CAA) has constructed a transoceanic communication station in the New York area to serve aircraft operating to and from the United States over the North Atlantic route. All aircraft are guided constantly and their positions are reported each half hour. Routine operation of this station falls into the following five catagories: (1) Meterological (express high speed); (2) Meterological (local); (3) Aircraft-to-ground and ground-to-aircraft; (4) Point-to-point (foreign) and radio direction finding; (5) Domestic communications.

Similar stations have been constructed by the governments of Newfoundland, Ireland, Bermuda, the Azores, Portugal and France, and as additional airlines are established, such routes will be so serviced.

FUTURE REQUIREMENTS

The FCC is already faced with the problem of allocating the radio spectrum to both commercial and private aircraft, for the purpose of insuring adequate and reliable communication as well as safe navigation. Additional services, such as anti-collision devices, automatic position reporters, improved radio ranges and ground station aircraft detectors will require suitable operating frequencies. Suitable allocations will be made just as soon as improvements in equipment or new devices can be proven for the advancement of aviation.

Based on the assumption that the greatest peace-time hazard, to aircraft flying on instrument, will be collision with other aircraft, certain developments are being made, chief among these are devices that show the horizontal and vertical separation of aircraft in flight.

In view of the general trend in present day aviation, it can be said that the future of aircraft navigation will depend to a large degree upon devices controlled electronically.

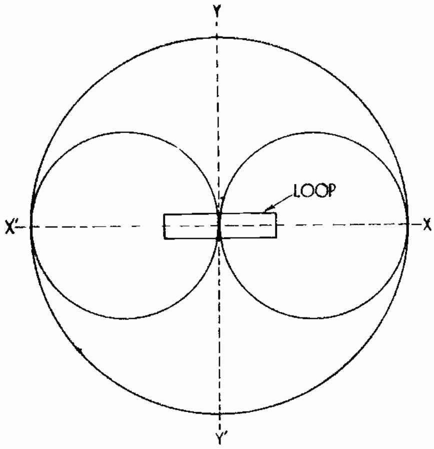

FIGURE 1

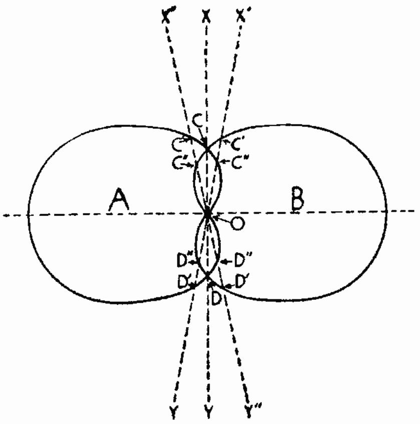

FIGURE 2

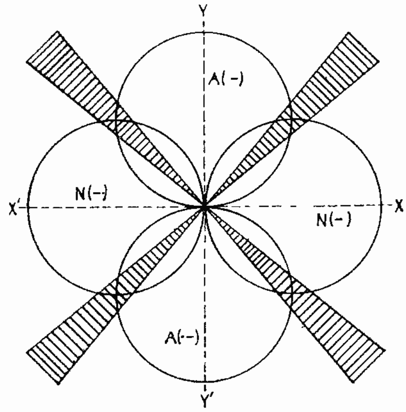

FIGURE 3

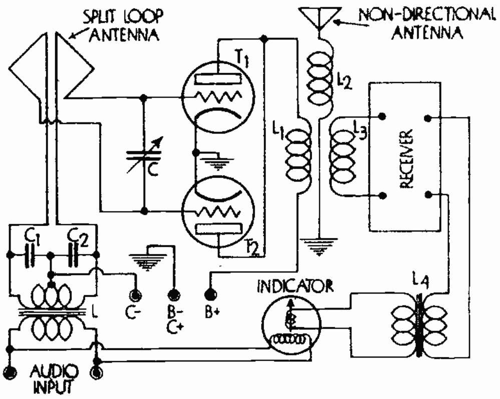

FIGURE 4

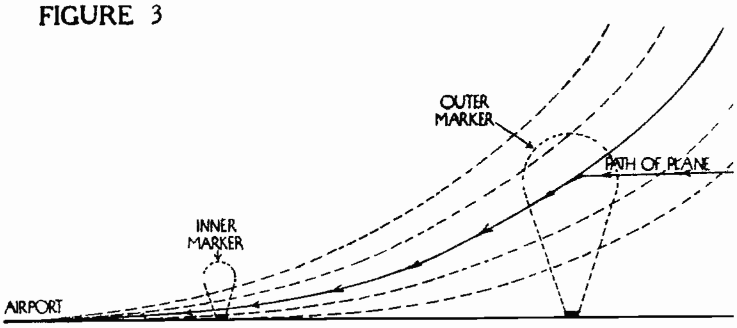

FIGURE 5

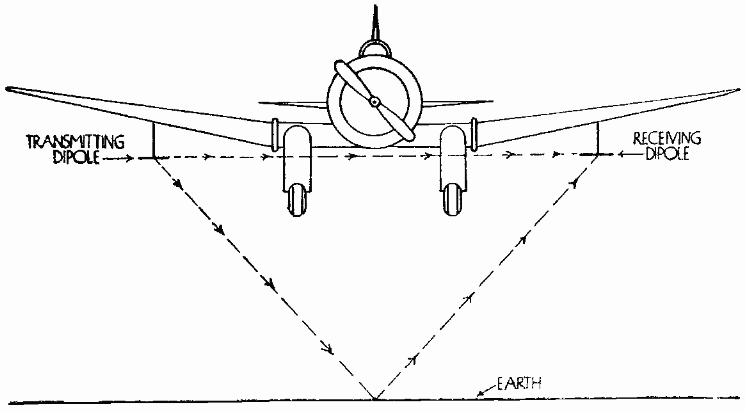

FIGURE 6