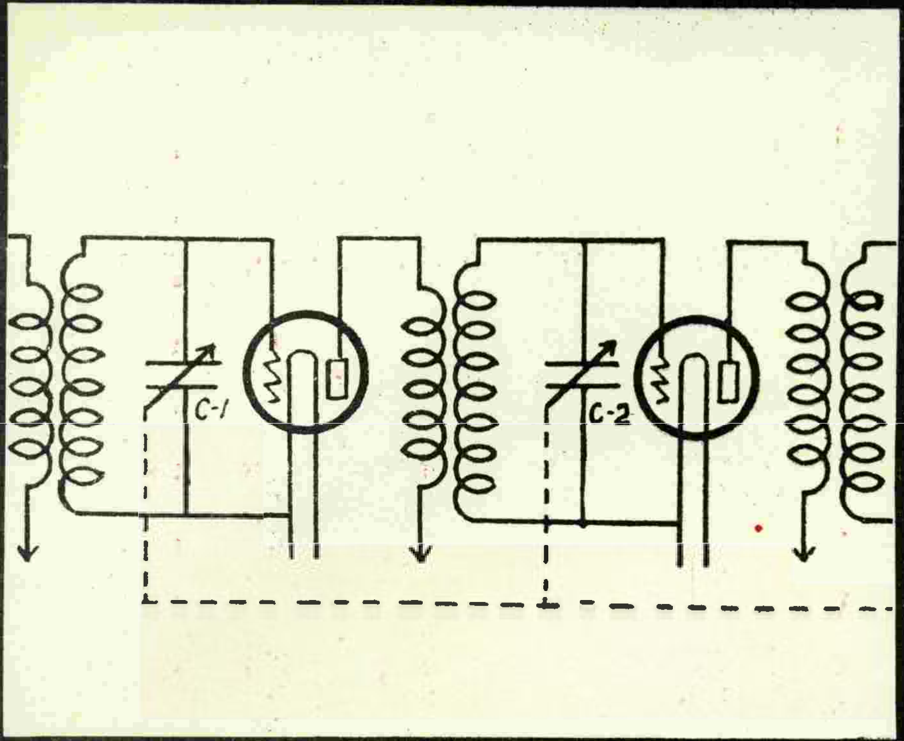

LESSON
21 RA

TUNED RADIO FREQUENCY RECEIVERS
LAYOUT OF TRF RECEIVER

ESTABLISHED 1922

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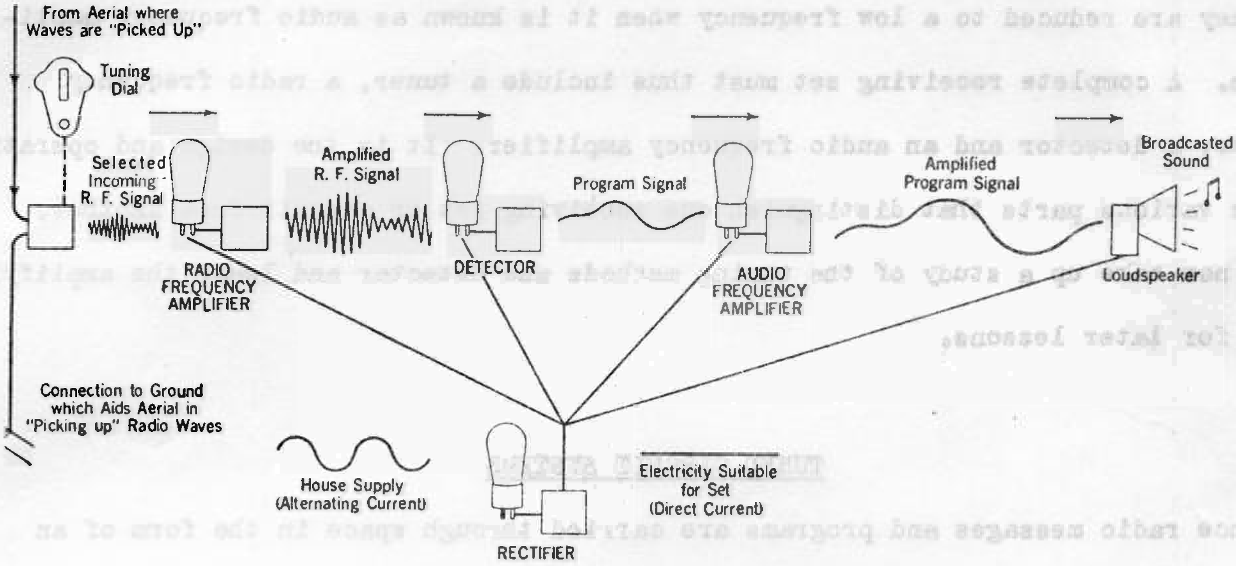


Various functions performed by the different tubes in the successive stages of a radio receiving circuit.

In a previous lesson we learned that when a radio wave was sent out from an antenna, it consisted of two component parts - the radio frequency carrier and the audio frequency. The audio frequency was impressed upon the carrier and the amplitude of the carrier or"RF"wave was modulated by the audio signal impressed upon it. This constituted a modulated wave.

In a receiving set just the reverse operation takes place. The radio wave in traveling through space collects upon the antenna and by induction causes high frequency alternating currents to flow in the antenna that are in every respect similar to those which originally flowed in the transmitting antenna. The receiver set must then accept these reduced currents and demodulate them; that is, to separate the radio frequency from the audio frequency so that only the audio frequency may be reproduced as sound in the loud speaker or headphones whichever may be in use.

In addition to performing the preceding operations, some receiving sets are provided with additional parts so as to be able to alter or increase the strength of the receiving signals. The amplification can be effected either while the signals are still at a high frequency when it is known as radio frequency amplification, or after they are reduced to a low frequency when it is known as audio frequency amplification. A complete receiving set must thus include a tuner, a radio frequency amplifier, a detector and an audio frequency amplifier. It is the design and operation of these various parts that distinguish one receiving set or circuit from another. We will now take up a study of the tuning methods and detector and leave the amplifying systems for later lessons.

TUNED CIRCUIT SYSTEMS

Since radio messages and programs are carried through space in the form of an electric wave motion, a receiving station in order to be able to reproduce the signals must be arranged to intercept these waves and absorb some of their energy. Also, as the various transmitters send out their signals on waves of different frequencies, the receiver must have adjustable selectivity so that it can respond to waves of only one frequency at a time.

Such response selectivity is obtained through the use of tuned circuit systems, and since the current in such a tuned circuit circulates back and forth at high frequencies, the circuit is often referred to as an oscillating circuit. Briefly, the entire action is as follows: As the waves advancing through space are intercepted by the receiving antenna, voltages are induced in it and conducted to the receiver itself via the lead-in. In the receiver these signal voltages come upon a tuned circuit that is adjusted to respond only to a certain frequency. A voltage of this frequency will cause a current to circulate, and this current builds up a voltage that is then sent through a number of stages of amplification and finally reproduced in the speaker as audible sounds.

A tuned circuit consists essentially of an inductance coil and a condenser, either one or both of which are variable. Common practice is to use a fixed inductance coil and a variable condenser. The relative size of the coil and condenser determines the rate at which the current can circulate and the response frequency of the circuit. It is the inductive effect of the coil and the capacity of the condenser that regulate the rate at which the current can vary in the circuit. Generally the circuit is thought of as oscillating at a certain frequency.

HOW A CIRCUIT OSCILLATES

The electrical actions going on within an oscillating circuit while a high frequency current is flowing back and forth in it, are most interesting. In Fig. 1 are illustrated the successive conditions as they take place. The condenser "C" is connected across coil "L" with a switch "S" for opening and closing the circuit.

At "A" the condenser is in a charged condition, that is, electrical energy (known as the charge) is stored up between its plates. The upper plate is at a high or positive potential (pressure), and the lower at a similar low or negative potential. In this condition the condenser is in a very unstable condition; and as soon as a chance is given it, the electrical charge tries to redistribute itself so that both plates will be at the same potential or pressure. As soon as the switch "S" is closed, this redistribution begins to take place, and the oscillating action commences.

Since an electric current always flows from a region of high pressure to one of low pressure, a current flow takes place in the direction indicated by the arrows in "B". This current flows through the coil "L", and as it does so it builds up a magnetic field (lines of force) around the turns of the coil. When the redistribution is completed and both condenser plates are at the same potential, there is no longer any force to keep the current flowing, and for an instant all action ceases. At this stage all the electrical energy which was at first stored up in the condenser as an electrostatic field between the plates, is now found as magnetic energy in the form of a magnetic field around the coil.

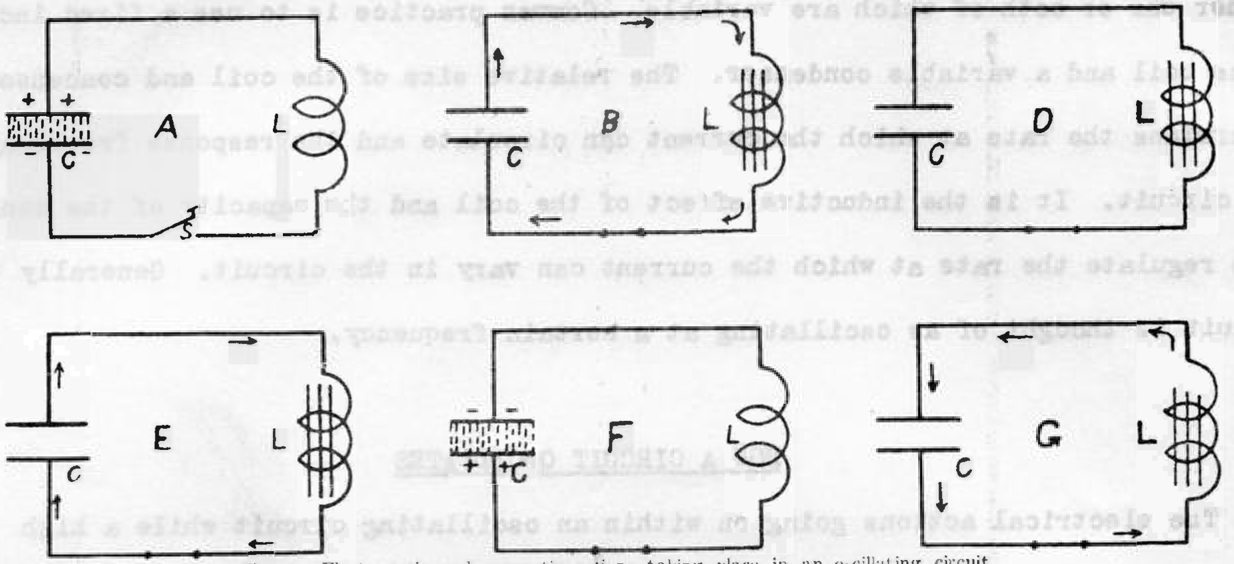


Fig. 1. Electrostatic and magnetic actions taking place in an oscillating circuit consisting of a coil and a condenser.

This is illustrated at"D". But when the current flow ceases, there is no longer any force to maintain this magnetic field, and as a result it at once begins to collapse. As these lines of force collapse or shrink, they cut all the turns of wire on the coil and induce in them a voltage which tends to keep the current flowing. Current flow thus contimues toward the lower plate of the condenser as is shown at "E". When the magnetic field has completely disappeared, all the energy is again stored up in the condenser. The condenser is again charged as it was originally, but this time in the opposite direction as illustrated at "F". The lower plate is now at high potential and the upper at low potential.

With the condenser in this charged condition, it is again very unstable or restless, and the stored up charge at once tries to redistribute itself. Current flow immediately begins again, this time from the lower plate through the coil to the upper plate as is illustrated at "G". Energy transference again takes place from the condenser into the coil and then from the coil into the condenser again until the upper plate is positive and the lower negative. When the action is completed, we are back at "A" once more, ready to start all over.

Such a complete series of actions is known as one cycle, and consists of a current surge in one direction and back again. Four transformations of energy take place: From electrostatic energy in the condenser at "A" to magnetic energy in the coil at "D", from magnetic to electrostatic energy at "F", and then in reverse from electrostatic to magnetic and lastly from magnetic to electrostatic again at "A". Of course, these actions all occur at a tremendous speed. The number of cycles that occur per second is known as the oscillation frequency of the circuit. The oscillation frequency, as we shall see later on, depends upon the size of each coil and of the condenser. In broadcasting service frequencies ranging from 545,000 to 1,500,000 cycles per second are used today. This means at the higher frequency the period of complete time required for one cycle is less than one-millionth of a second.

These oscillations do not continue indefinitely, but on account of the resistance of the wires and of the coil a certain amount of energy is dissipated during each cycle, with the result that the current surges soon die out. It is evident that the lower this resistance is, the less energy will be dissipated and the more intense will each current surge be. It is for this reason that all circuits in a Radio receiver should be made as perfect as possible so that all energy loss will be reduced to a minimum.

THE TUNED OSCILLATING CIRCUIT

Every tuned Radio circuit involves the two electrical principles, inductance and capacity. Either one or both of these elements can be variable, but it is common practice to employ a definite fixed inductance coil and a variable capacity in the form of a condenser.

A typical tuned circuit is illustrated in Fig. 2 in which we have the inductance coil "L" shunted by the variable condenser "C". An alternating current set up in this circuit will oscillate (flow back and forth) at a rate or frequency depending upon the size of the coil and the condenser. By varying the capacity of the condenser, it is possible to regulate the ability with which it can take on or give out a complete charge; and this in turn controls the frequency at which the current will oscillate in the circuit. The tuning elements of most Radio receivers consist of just such oscillation circuits, a fixed inductance coil shunted by a variable condenser, and the tuning process consists of adjusting the relative values of the inductance and capacity until the current in the tuned circuit oscillates at the same frequency as the waves coming in over the antenna. When two such circuits oscillate at the same frequency they are said to be in resonance. The word, resonance, means to be in step.

The tuned circuit can readily be compared to a wave filter, for when tuned to a particular frequency it admits waves of only that frequency and withholds or rejects all the rest. The efficiency of the tuning apparatus determines how effective the Radio receiver will be in selecting only one station at a time. The most elaborate receiver would be of little value in practice if its tuning equipment will not permit sharp and selective tuning.

MECHANICAL ANALOGY OF THE TUNED CIRCUIT

The electrical action of an oscillating circuit as was just described, can readily be compared to the up and down motion of a spiral or coiled spring at the bottom of which is suspended a weight. When the weight is once given a slight push, it will keep on bobbing up and down for some time, just as a current once set up in the electrical circuit will continue to oscillate for some time.

The frequency or rate at which the weight will vibrate or bob up and down, will depend upon its size and upon the stiffness or elasticity of the spring. The weight corresponds to the inductance in the electric circuit and the spring corresponds to the condenser. The inductance, like the weight, acts like a load on the system; and the greater the weight, the slower it will bob up and down. Also, the larger and more elastic the spring is, the slower will be the rate of vibration; while with a finer and stiffer spring the faster will be the rate of vibration. The conditions in the electric circuit are very similar. The greater the inductance, that is, the greater the electric load on the system, the slower will be the rate of vibration or the frequency. The size of the condenser like the stiffness of the spring also affects the frequency. The larger the condenser, the longer time required for a complete charge and discharge; that is, the slower will be the rate of oscillation. By changing either the inductance or the capacity, the oscillation frequency can be varied.

COUPLED CIRCUITS

In radio practice it is common to employ a number of tuned oscillation circuits and then pass the incoming signals through each one in succession. The advantage of this arrangement is that if the first circuit is not completely effective in filtering out the undesired signals, the second one is sure to block them out; and if it is further necessary, a third and even fourth tuned or filter circuit can be used. It is through the use of such a series of tuned circuits that great selectivity is secured in our modern Radio receiving sets. By selectivity is meant the extent or degree to which a receiving circuit can select the waves of a desired frequency and exclude all the rest. A receiver that has great selectivity is said to be very sharp tuning; while a broad tuning circuit is one that is not so effective in excluding the undesired wave lengths or frequencies.

In order to transfer the energy from one circuit to the next, some form of coupling device must be used. This coupling device may be a pair of adjacent coils, a transformer, a condenser or a vacuum tube. All these various coupling methods will be taken up in later lessons in their appropriate places.

The most common system of coupling used is inductive coupling. In this system we have two adjacent coils, and the current flowing through one of them by induction causes a current to flow in the other. The relative number of turns in the two coils and their positions with respect to each other determine the tuning qualities to a great extent. In Fig. 3 are illustrated two coupled circuits "A" and "B". In circuit "A" is a generator "G" by means of which the high frequency oscillations are produced and caused to flow through the coil "P". As these current oscillations flow through "P", they set up around it a pulsating magnetic field. As this field expands and contracts with each current surge, it cuts the turns of the coil "S" in circuit "B" and causes a current to flow in it. The coil "P", through which the original current flows is known as the primary, and the coil "S" in which the induced current flows is known as the secondary coil. The current in circuit "B" is of the same nature and frequency as that in circuit "A".

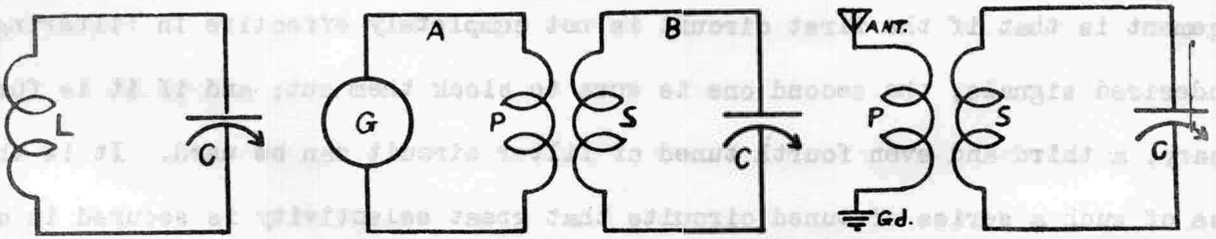


Fig. 2, 3 and 4. Illustrations of coupled oscillating circuits.

ACTION OF A CLOSED OSCILLATION CIRCUIT

Just how a tuned circuit can be made to select only one frequency and exclude all the rest is easily explained with the aid of Fig. 4. Here we have a fixed inductance coil "S" shunted by the variable condenser "C". Current waves coming down from the antenna flow through the coil "P" and by induction try to induce current waves of a similar nature and frequency in the coil "S". But the tuned circuit "SC" is very particular, and will allow current of only one frequency to flow or oscillate in it, depending upon the setting of the condenser "C".

Assume that the setting of "C" is such that the frequency of the circuit is 1,000,000 cycles per second, corresponding to a 300-meter wave length. Current of this frequency coming down from the antenna will induce a similar current in the coil "S" and this induced current will at once find free passage to flow in the circuit "SC". The nature of the current, of course, is alternating, and for the first half cycle it will flow in one direction, and then reverse and flow in the opposite direction. At the instant it is ready to start all over again, another currentwave comes down from the antenna through "P" and gives the oscillating current in "SC" another push which sends it on its way with greater strength. This process is repeated with uniform regularity, with the result that a strong oscillating current is caused to flow in the circuit "SC". The oscillation current then does the work in operating the receiving set.

It is seen that electrically the process of tuning consists of so balancing the inductance and capacity of a tuned circuit against each other that free passage is permitted a train of waves of a certain frequency and all others are excluded either entirely or nearly so. But as will be proven later, there are a number of other factors that affect the efficiency of the tuning process.

RESONANCE CURVES

A resonance curve is a chart drawn on cross-ruled paper showing the nature of the current flow in a closed oscillation circuit while it is being tuned into resonance with another circuit. For example, in Fig. 5 is the primary circuit "P", in which the generator "G" is causing a high frequency current to oscillate. Coupled to this circuit is the secondary circuit "LC", which is tuned by means of a variable condenser

"C" and into which is also connected a sensitive current indicating meter "M".

The current oscillating in the primary circuit "P" by induction tries to cause similar current to flow in the secondary circuit "LC"; but unless "L" and "C" are adjusted to the proper values, this induced current cannot get through and no appreciable result will be produced. However, as the condenser is slowly turned and the circuit brought in tune with the primary, the meter "M" will indicate a gradual increase in current flow. Suddenly the meter pointer will move far over and indicate a strong flow of current. As the condenser is turned farther, the pointer suddenly moves back again and then gradually decreases to zero. At the condenser setting at which the meter indicated maximum current flow, "L" and "C" were so balanced that the two circuits were in resonance (in step) with each other.

The above conditions can be represented graphically as is illustrated in the chart Fig. 6.

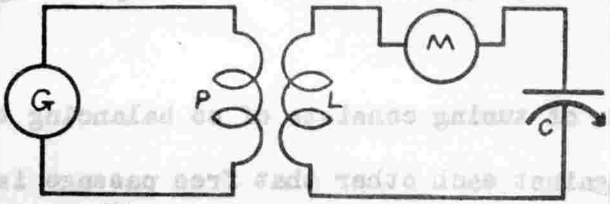


Fig. 5

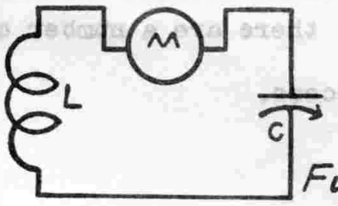
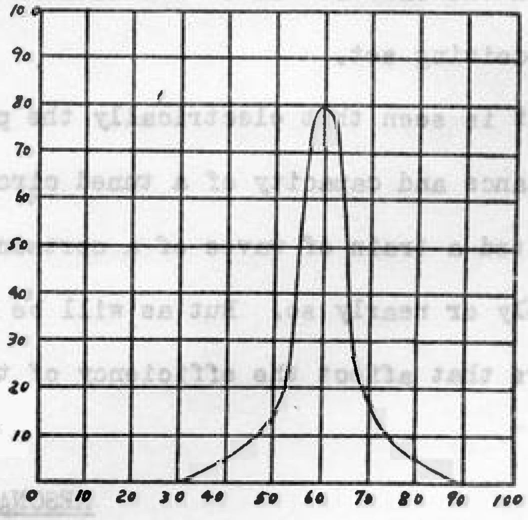


Fig. 7

Fig. 6



Horizontal distances represent dial settings and vertical distances strength of current flow. As the condenser is moved from 0 to 30, the meter indicates no current flow; but as soon as 30 is passed, the meter needle slowly moves to the right, indicating that a gradually increasing current is flowing. When 50 is passed, the needle swings to full deflection and stands at maximum when the condenser is set at 60. As soon as 60 is passed, the needle comes back to the left, and between 70 and 90 slowly returns to zero. The curve is known as a resonance curve and shows the current flow in circuit "LC" for different condenser settings. When the condenser is at 60, the current flow is maximum, and at this setting the two circuits are in resonance. It will be seen later on that if this resonance curve is very narrow and peaked, the tuning of the circuit is very sharp, while if the resonance curve is round and wide, the tuning is very broad.

THE WAVE METER

The wave meter is an important instrument used in the Radio laboratory for measuring the wave length or frequency of electric waves such as are used in Radio practice. In this instrument use is made of just such an oscillating circuit as we have been discussing. In other words, a wave meter consists of an inductance coil and shunted across the coil is a high grade variable condenser and in addition has connected in series into the circuit a delicate electric meter for indicating the strength of the current flowing. The general circuit arrangement is illustrated in Fig. 7, in which "L" is the coil, "C" is the condenser and "M" the current indicating meter.

The rate at which a current flows back and forth in an oscillating circuit, that is the frequency, depends upon the amount of inductance and capacity that is connected into the circuit. If we use a coil of the correct number of turns and a condenser of suitable size, we can arrange the oscillating circuit to cover any desired wave length range. When this circuit is then calibrated so that it is known what the wave length or frequency of the circuit is for the various condenser settings, the instrument is ready for use. This information is generally given in the form of a curved line drawn on cross-ruled paper called a calibration chart.

Suppose it is desired to measure the wave length of some unknown signals that are being received. The wave meter is then placed so that the coil "L" is near the wire that is leading down from the receiving antenna. By induction current is caused to flow in the meter coil. The variable condenser is next adjusted until the meter shows the greatest amount of current flowing through the wave meter. From this calibration chart it is then observed what the wave length for this particular condenser setting is, and this value will be the wave length of the unknown signals. Further data on the wave meter and its applications will be given later.

HOW TO CALCULATE THE WAVE LENGTH OF A CIRCUIT

The frequency at which an alternating current will oscillate (flow back and forth) in a circuit, depends upon the relative sizes of the coil and condenser. If a large coil and large condenser are used, the frequency will be low; that is, the wave length will be long; while if a small coil and condenser are used, the frequency will be high and the length of each wave very short. A definite mathematical relation exists between the inductance value of the coil and the capacity of the condenser, and this makes it possible to calculate the size of coil and condenser capacity needed in order to have the circuit cover a desired wave length range. This information is important in designing tuning units for different wave length bands.

To calculate the wave length of a circuit consisting of a coil shunted by a condenser, it is only necessary to multiply 1884 by the square root of the product of the inductance and capacity. Written in formula form this would be

$$W = 1884 \sqrt{L \times C}$$

in which "W" is the wave length measured in meters, "L" represents the inductance measured in microhenries, and "C" the capacity in microfarads. A meter is a unit of length in the metric system equal to about 3-1/3 feet (39.37 inches). The derivation of the formula is a rather complex mathematical process somewhat too difficult to be taken up at this time. The number 1884 is merely a constant numerical factor which is always used.

To illustrate the use of the formula, suppose we have a .0005-Mfd. condenser and a coil with an inductance of 73 microhenries. Multiplying 73 by .0005 we get .0365. The square root of .0365 is .191, and this multiplied by 1884 gives 359.8, or approximately 360 meters. When numerous calculations have to be performed, the above method is rather lengthy and requires too much time. A simpler method has been worked out by means of which the same results can be obtained with far less effort.

SIMPLIFIED WAVE LENGTH CALCULATIONS

From the wave length formula given in the preceding section it is evident that for any given wave length the product of the inductance and capacity under the square root sign must always be a constant quantity. For example, by working out the formula it can be shown that for a wave length of 360 meters the value of L x C under the square root sign would be .03648. If we used a large condenser, a small coil would have to be used; while if we used a small condenser, a large coil would be needed. In other words, the product of the condenser capacity and the coil inductance must always be equal to .03648.

Suppose we wanted to use a .00025-Mfd. condenser. To get the size of the coil needed, it would be necessary merely to divide .03648 by .00025, which would give as a result 146. This means that for a 360-meter wave length if a .00025-Mfd. condenser were used, a coil having an inductance of 146 microhenries would be necessary. In a similar way the necessary coil inductance could be calculated for any other size condenser.

The product of the condenser capacity and coil inductance under the square root sign is commonly called the "LC" value. These "LC" values have been worked out by means of the formula given previously and are listed in the table below for wave lengths ranging from 200 to 600 meters. This table will be found a great time saver in the design of coil and condenser combinations for various tuned oscillation circuits.

TABLE

1 Wave Length	2 Frequency	3 L C Values	4 Wave Length	5 Frequency	6 L C Values
200	1,500,000	.01129	420	714,285	.04970
220	1,363,500	.01362	440	681,880	.05446
240	1,250,000	.01623	446	652,200	.05960
260	1,153,850	.01902	480	625,000	.06480
280	1,071,300	.02209	500	600,000	.07039
300	1,000,000	.02530	520	576,900	.07604
320	937,500	.02884	540	555,600	.08210
340	882,300	.03249	560	535,715	.08836
360	833,350	.03648	580	517,200	.09467
380	789,400	.04070	600	500,000	.10140
400	750,000	.04507			

In the above table are given 6 columns of figures: Column 4 is a continuation of column 1; column 5 a continuation of 2 and column 6 a continuation of 3. Columns 1 and 4 give the wave lengths and columns 2 and 5 the corresponding frequencies. These frequencies are obtained by dividing the wave lengths into 300,000,000, the speed at which Radio waves travel. Columns 3 and 6 give the L C values obtained by solving the formula given for each wave length given.

The use of the above table will greatly simplify the work of figuring coil and condenser combinations. For instance, suppose we want to prepare a circuit that will tune up to 560 meters and that we have available condensers having a capacity of .00035 microfarads. Looking in column 6 opposite the 560-meter wave length we find that the "LC" value is .08836. The next step is to divide .08836 by .00035 and receive as a quotient 252.5, which is the necessary inductance of the coil.

It is thus evident that with this simplified method very little calculating work is necessary. It is not even necessary that the formula given be known or used. When it is known what the maximum wave length to be used is, and the capacity of the condenser has been decided upon, it is only necessary to divide the correct "LC" value by the condenser capacity to determine the inductance of the coil needed.

VARIABLE CONDENSERS

As commonly used today, the variable condenser consists of two groups of metal plates, one stationary and the other movable, so that the amount of plate surface that the two groups overlap can be varied. The plates of each group are electrically connected, and the two groups thoroughly insulated from each other. The nature of this insulating material as well as the method of interconnecting the plates of each group, determine to a great extent the quality and efficiency of a condenser.

The capacity of a condenser, it was previously stated, is measured in farads; but since this is a very large unit, the microfarad is commonly used in Radio work. A farad is equal to one million microfarads. For very small measurements a still smaller unit is used, the micromicrofarad, which is equal to one millionth of a microfarad.

The primary purpose of a condenser is to store up electrical energy. When a voltage (difference in potential) is impressed across the two sets of plates of a condenser, a current flow into the condenser will take place until the voltage across the two sets of plates is the same as the applied pressure. This current is known as the charging current, and the energy stored in the condenser is known as the charge. A measure of the amount of electricity that the condenser can hold is what is known as its capacity.

The capacity of a condenser determines the time with which it can take on and give out a complete charge. When used in conjunction with a coil, the capacity of the condenser as well as the inductance of the coil, will regulate the rate at which a current can oscillate (flow back and forth) in the circuit.

MINIMUM CAPACITY IS IMPORTANT

The wave length range of a coil tuned by means of a variable condenser, depends not only upon the maximum capacity of the condenser but also upon its minimum capacity. The maximum capacity determines the highest wave length that can be reached, while the minimum capacity determines the lowest wave length. It is therefore very important that the condenser be properly designed so that it will have a sufficiently low capacity when all the plates are withdrawn. The present broadcasting wave length is from about 200 to 600 meters, a ratio of 1 to 3. Since the wave length depends upon the square root of the condenser, according to the formula previously given, this means that the minimum capacity must be at least one-ninth or less of the maximum capacity. All of the better condensers have a range of 10 to 1 or better, and satisfy this requirement.

TYPES OF VARIABLE CONDENSERS

Variable condensers are made in three or four different types in order to secure special tuning features when they are used in connection with a fixed inductance coil. These types are: Straight line capacity, straight line wave length, straight line frequency and straight line tuning.

The term, "straight line" is used because the line which represents graphically the variation of either the capacity, wave length or frequency changes against movements of the rotor plates, is a straight line. The advantages of these different types and their applications are brought out in the following paragraphs.

The straight line capacity condensers are the old familiar ones with the semi-circular rotor and stator plates. With these, equal angles turned through by the rotor plates produce equal changes in the capacity of the condensers. This type of condenser is suitable for wave meters and other calibration work in which very accurate capacity measurements are to be made. This type of condenser is not so suitable for tuning purposes in present day Radio receiving sets, however, as the other types are, because stations separated by a certain number of meters in the lower wave length range will crowd closely together on the lower sections of the dials, while stations in the upper wave length will be widely separated on the dial settings.

A straight line wave length condenser has the plates shaped so that the wave length of a circuit using a fixed inductance coil with the condenser, changes by equal amounts when the rotor plates are tuned through equal angles as indicated by the divisions on the dial. With such a condenser stations in the lower wave lengths will be separated as much as those in the higher wave lengths. In other words, stations that are separated by an equal number of meters are spread uniformly over the tuning dial. Such a condenser is designed that its capacity increases as the square of the angular movement through which the rotor plates are turned.

With a straight line frequency condenser the frequency of a circuit into which the condenser is connected changes by equal amounts for equal variations in the dial settings of the condenser. This arrangement is of advantage because all broadcasting stations are assigned transmitting wave lengths so that stations in adjacent territories will differ by 10 kilocycles (10,000 cycles). In other words, all broadcasting stations are rated on a frequency basis instead of according to wave lengths. There is one disadvantage to this type of condenser, however, and that is that stations in the extreme upper wave length ranges are crowded considerably on the upper section of the dial.

Most condensers are designed and built so that the plates can rotate through a half circle or 180 degrees. There are a few makes of condensers, however, that are constructed so that the plates turn through 240 or 270 degrees. This is a big advantage in tuning, for it spreads the tuning range over bigger space and separates the wave length bands so much further.

For most satisfactory tuning the best condenser design to use is a combination of the straight line wave length and straight line frequency types. In other words, the condenser plates are shaped so that for the lower part of the scale the condenser tunes on the straight line frequency basis and on the upper part of the scale on the straight line wave length basis. With this arrangement there is no crowding at either end of the condenser and the stations are spread uniformly over the tuning dial. This type of condenser design is now used in practically all commercial radio receiving sets.

To obtain these various tuning characteristics different shapes of rotor plates are used. In the straight line capacity type the plates are semicircular in shape, in the straight line frequency type they have a sharp curve at one end and gradually straighten out toward the other end, while in the straight line tuning the plates are somewhat semioval in shape.

SPECIAL CONDENSER APPLICATIONS

In most modern receiving sets there is more than one tuned circuit, and each of these requires its own tuning condenser. When two such circuits are used, two tuning condensers would be needed and there would consequently be two tuning controls. If three tuned systems are used, three condensers would be required and there would be three tuning controls. Three such tuned systems are illustrated in Fig. 8, each circuit being tuned by its own individual condenser. The result of using two or more coupled tuning systems of this kind, is that much greater selectivity (sharper tuning) is had. Those undesired frequencies that succeed in passing through the first tuner are caught and held back in the following stages.

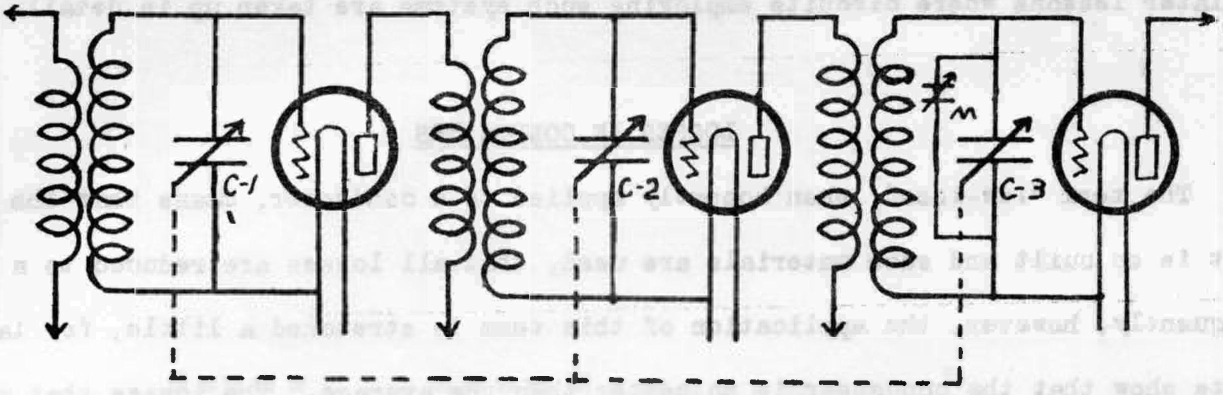


Fig. 8. Showing how a 3-gang condenser is connected into a tuned circuit system.

In case two or more tuned systems are employed, the number of tuning controls can be reduced by mounting several of the condensers on one shaft. Then as the common shaft is rotated, several of the circuits are tuned at the same time. Such condensers consisting of two, three or four sections are known as multiple or gang condensers. Many single condensers are built so that their shaft can be removed and two or more of them mounted on a single shaft. The dotted lines in Fig. 8 indicate that the three condenser sections operate as a single unit.

In order to employ such multiple tuning systems successfully with a gang condenser, it is very important that the coils and condenser sections be built with the utmost precision, for otherwise the individual circuits will not tune alike. In other words, one circuit will be tuned to a different frequency than the other, and the very purpose of using several tuned systems will be defeated. However, it is possible to overcome such difficulties by connecting across one or several of the sections of the main tuning condenser a small three or five-plate condenser. Such small condensers are known as midget condensers and serve as trimmers. Such a trimmer condenser is shown connected across the third section of the main condenser in Fig. 8. These trimmer condensers then make up for the tuning differences that may exist in the various circquits. More about the use of multiple condensers and midget condensers is given in later lessons where circuits employing such systems are taken up in detail.

LOSSES IN CONDENSERS

The term "low-loss", when honestly applied to a condenser, means that the instrument is so built and such materials are used, that all losses are reduced to a minimum. Frequently, however, the application of this termis stretched a little, for laboratory tests show that the condenser is no better than the average. The losses that may occur in a condenser are of three kinds: Resistance, dielectric, and eddy current losses.

The electricity that alternately flows into and out of a condenser encounters the resistance of the plates and all contact points. Brass plates are superior to aluminum only in that they can be soldered or welded together better. The main point to observe in a condenser is the method of assembling the plates. Good electrical contact should be established between the plates of each group so that minimum resistance is introduced at these places.

The dielectric includes all the insulating material used in the construction of the condenser. The materials commonly used are hard rubber, fibre, bakelite, glass or isolantite. Isolantite is a substance similar to porcelain but finer grained and less porous. Losses can occur in this dielectric in three ways. Surface leakage is the passing of electricity from one set of plates to the other over the surface of the dielectric, but this generally is small unless the material is covered with dust and moisture. Body leakage is the flow of electricity through the entire dielectric on account of its poor insulating qualities. Using only the best insulating material reduces this loss to a negligible amount. Absorption refers to the ability of the dielectric to absorb energy like a sponge absorbs water. With some materials this approaches quite an appreciable amount. Eddy currents are the stray electric currents that are set up in the metal framework of the condenser, especially the end plates.

Practically all of these losses increase as the frequencies become higher. At very high frequencies (short wave lengths) not too much attention can be given to some of these points, for often the efficiency of a condenser is so low, that it is useless in high frequency receivers.

HOW TO SELECT A GOOD CONDENSER

When a condenser is selected, the following points should be carefully observed: The bearings should be rugged but smooth running, the end thrust properly cared for, the plates should not be too thin but accurately spaced and rigidly clamped, and the dials should be smooth and true-running. The name of the manufacturer should carry more weight and consideration than any advertising propaganda that may be broadcast about a condenser.

WHAT CONSTITUTES A GOOD COIL

With coils also the term "low-loss", has been freely used. Numerous types and shapes of coils have been available on the market, with special and exaggerated claims for each. The question naturally arises, what constitutes a good coil and what factors tend toward coil efficiency.

Practically all coils in a Radio receiver are used in connection with vacuum tubes; and as we shall see in a later lesson, greater signal strength is obtained from these tubes when higher voltages are delivered to them. Since the primary function of the coil is to generate these voltages, the more efficient the coil is the greater will be the response obtained from the receiving circuit. The voltage that a coil can generate depends upon its inductance, and that coil is most efficient which has the greatest inductance for the amount of wire used. It would seem from this that the larger the coil the better results would be obtained. But if too large a coil is used, the wave length range that can be covered by it would be too narrow; and if too small a coil is used, less voltage would be generated in it and the circuit response diminished. Experience has shown that very efficient and satisfactory results are obtained with a coil having an inductance of 290 microhenries and tuned by a condenser having a capacity of .00035 microfarads. This combination will cover the popular broadcast range of 200 to 600 meters.

RESISTANCE LOSSES IN COILS

Resistance decreases the efficiency of a coil by cutting down the effective voltage generated in it. It also broadens the tuning qualities of the circuit into which the coil is connected. This resistance really consists of two components, the ohmic or direct current resistance and the high frequency resistance.

The ohmic resistance, as in any electric circuit, depends upon the size and length of wire used and upon the resistance of the contact points and connections. It would seem that the larger the wire the less would be the resistance of the coil windings; but as we shall see in the next paragraph, the use of larger wire introduces the undesirable effects of increased coil capacity. For all general purposes No. 22 or 24 wire seems to be best, and where compact and small coil construction is needed, No. 26 or 28 can be used. Double cotton covered (D.C.C.) insulation is very good except that it has a tendency to absorb moisture. Double silk covered (D.S.C.) insulation is a little better in this respect. It also has a better appearance, but is somewhat more costly.

High frequency resistance, sometimes known as the skin effect, is due to the tendency of a high frequency alternating current to travel only through the outer layers or on the surface of a conductor instead of throughout the entire wire as a direct current does. This high frequency resistance also increases as larger wire is used. Its effects are greatly reduced, however, by the use of stranded wire in which each strand is insulated continuously from the rest. Such wire is known as Litzendraht wire. The objection to its use, however, is that these component wires are very fine and easily broken and when this occurs, all advantages gained by its use are gone.

The high frequency resistance of a coil is also increased by the presence of any insulating material in the field of the coil. For this reason the amount of insulation on the wire and in the coil supports should be reduced to a minimum. Both of these effects can be reduced by spacing the turns or groups of turns from each other and by using skeleton framework for the coil supports. The coil resistance is also increased if metallic objects are placed within the magnetic field of the coil, for energy is then absorbed in the form of eddy currents set up in the metal.

DISTRIBUTED CAPACITY IN COILS

Although the function of a coil is to provide a definite amount of inductance, it is impossible to wind a coil without also introducing some capacity. This capacity effect exists between the adjacent turns. The successive turns of wire lying next to each other with but a small space between them act as though a small condenser were connected across each turn; and since this capacity is spread throughout the entire length of the coil, it is known as distributed capacity. The total effect of this distributed capacity is similar to having a condenser of equal capacity connected across the coil. The inductance of the coil combined with its distributed capacity form an oscillation circuit, and the frequency of this circuit is known as the natural frequency of the coil. If this natural frequency falls within the wave length range for which the receiving circuit is designed, considerable tuning trouble will be experienced.

At the higher wave lengths this distributed capacity is not so noticeable, but at the shorter wave lengths (higher frequencies) the effect becomes very prominent. In other words, the distributed capacity varies with the frequency. The distributed capacity in a coil can be reduced by spacing the turns, but this also decreases the inductance somewhat. By using a minimum amount of insulating material the distributed capacity is also greatly reduced.

WHAT SIZE COIL TO USE

The process of figuring the number of turns to use in winding coils of different diameters and that are to be used with tuning condensers of different capacities is a rather lengthy one. However, for those who desire this information so that they can make practical use of it, the following table of values has been worked out. The required number of turns have been calculated for eight sizes of tubing and for five different condenser capacities.

DIAMETER OF TUBING

Condenser	1½ In.	2 In.	2¼ In.	2½ In.	2¾ In.	3 In.	3¼ In.	3½ In.
.00025	135	125	115	102	80	65	60	55
.0003	139	113	98	85	73	61	55	50
.00035	125	109	95	82	70	60	53	48
.00037	121	105	92	78	66	56	50	45
.0005	110	95	80	62	55	44	40	35

The given data is for use with No. 24 double cotton covered wire. If double silk insulated wire is used, the number of turns will be practically the same in every case. Should it happen that for some reason the stations are rather crowded together and require only three-fourths or less of the dial readings to cover the total wave length range, it is an indication that either the condensers or the coils are too large. The best remedy in that case is to reduce the number of turns in the coils until the greater portion of the tuning range of the dials is used. If the lower wave lengths cannot be reached in some cases, it is an indication that the coils and condensers are too large.

The thing to do is to remove turns of wire (one at a time) until the desired low wave lengths can be reached. If the lower wave length can be reached but not the upper, either the condenser or the coils are not large enough. The easiest way to remedy this difficulty is to add a few turns of wire to the coils until the higher wave length stations can be easily reached. For best results the coils and condensers should be so apportioned that the 200-meter stations will come in between 0 and 5 on the tuning dials and 550-meter stations between 95 and 100 on the dials.

The number of turns given in the table is for coils that are to be used with a variable condenser to form a closed oscillation circuit. The coils may be used individually or as the secondary of a radio frequency transformer. In the latter case the number of turns to use in the primary will depend upon the degree of coupling that is desired. For 2-inch or larger coils a primary of from 7 to 12 turns is recommended. For sharper tuning 7 to 8 turns are the number to use; while if greater energy transference is wanted and sharp tuning is not so essential, 10 to 12 turns serve best.

REACTANCE AND IMPEDANCE

It has just been proven how a circuit containing capacity or inductance offers a certain amount of opposition to the passage of an alternating current, and that the amount of opposition experienced by the current depends upon its frequency. Inductance and capacity manifest themselves only when the current changes or varies. But every circuit always has a definite amount of resistance depending upon the dimensions and materials of the circuit. This resistance is always present, irrespective of whether the current is direct or alternating. Therefore, a complex circuit may contain all three factors, resistance, inductive reactance and capacity reactance. The total combined effect of the resistance and the inductive and capacity reactance is known as the impedance of a circuit. Impedance thus represents the total opposition experienced by an alternating current and is also measured in ohms. Impedance is represented by the capital letter "Z".

Inductance in an alternating current circuit causes the current to lag behind the voltage, that is, the current reaches its maximum and zero values after the voltage has done so. Capacity, on the other hand, causes the current to lead the voltage, that is, the current reaches its maximum and zero values before the voltage does so. In other words, inductance and capacity cause directly opposite effects. When both of these are present in a circuit, one will neutralize part of the other, and the resulting reactance "X" is equal to the difference of the two. That is:

$$X = XL - Xc$$

Since both the inductive reactance and the capacity reactance throw the alternating current and voltage out of phase (cause the current to lead or lag behind the voltage), the impedance is equal to the square root of the sum of the square of the resistance and the square of the reactance. Expressed in formula form, this would be:

$$Z = \sqrt{R^2 + X^2} = \sqrt{R^2 + (XL - Xc)^2}$$

Illustrative Example: Let us assume that we have a circuit in which the inductive reactance is 10 ohms, the capacity reactance is 7 ohms, and the resistance is 4 ohms. What is the impedance of the circuit?

The combined reactance would be 10 - 7 or 3 ohms (XL - Xc). The square of 3 is 9, and the square of 4 is 16, and the sum of the two squares is 25. Lately, the square foot of 25 is 5, and the impedance of the entire circuit is 5 ohms. It must be remembered that the inductive and capacity reactance partly neutralize each other, the combined effect of the two being equal to only 3 ohms.

RESONANCE

If the inductive and capacity reactance of a circuit are exactly equal, they will completely neutralize each other, and the only opposition the current will then experience is the resistance of the circuit. In other words, the total impedance of the circuit is equal to the resistance. When such a condition exists, the circuit is said to be in resonance.

The process of tuning a radio receiving or transmitting circuit consists essentially of so balancing the inductance and capacity that they will mutually neutralize each other. Under these conditions the only opposition the current experiences is the electrical resistance, and therefore, the current will reach its maximum value and the signals will come through loudest. The circuit is then said to be tuned to that particular frequency. If signals of another frequency are desired, the capacity and inductance must be readjusted to take care of the variations in reactance on account of the changes in frequency?

EXAMINATION QUESTIONS ON FOLLOWING PAGE