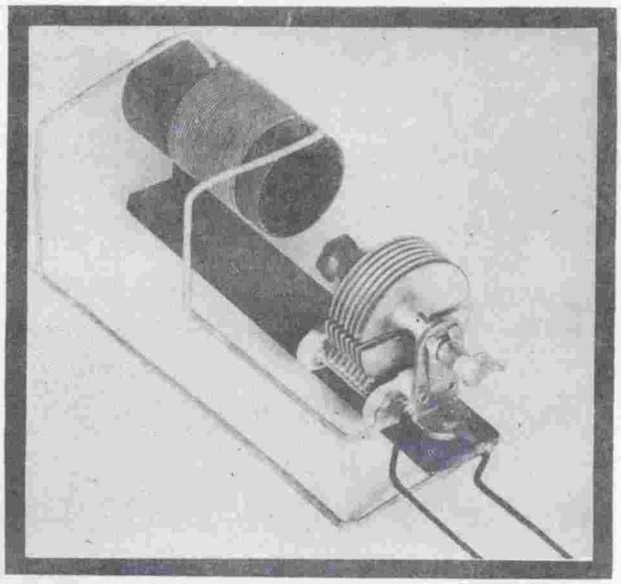

LESSON 9 R

TUNED CIRCUITS IN RADIO

RADIO-TELEVISION TRAINING SCHOOL, INC.

5100 SOUTH VERMONT AVENUE • LOS ANGELES 37, CALIFORNIA, U. S. A.

COPYRIGHT 1949 PRINTED IN U.S.A.

TUNED CIRCUITS IN RADIO

Radio waves which travel through space and carry radio signals consist of two parts. One part is an electric or electrostatic field; the other is a magnetic field. Both fields reverse their directions at the frequency of the radio wave. When a loop antenna, such as the one pictured in Fig. 1, is in the path of a radio wave, the magnetic field lines of the wave cut the conductors of the loop. Then there are induced in the loop conductors alternating emf's at the frequency of the radio wave. This is simply a case of electromagnetic induction.

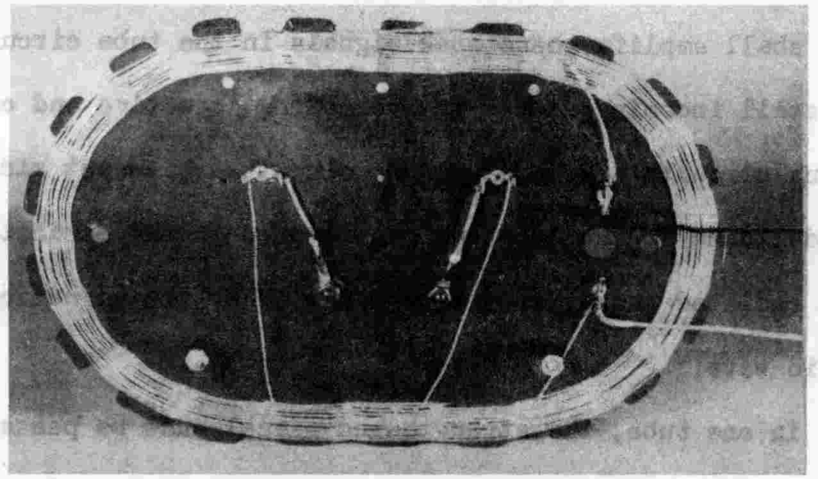

FIG. 1.
A loop antenna such as built into receivers.

Instead of the loop, we may use for our antenna any wire or conductor supported by insulators at some distance above the earth, as in Fig. 2, may connect this elevated conductor to one end of the input circuit of a

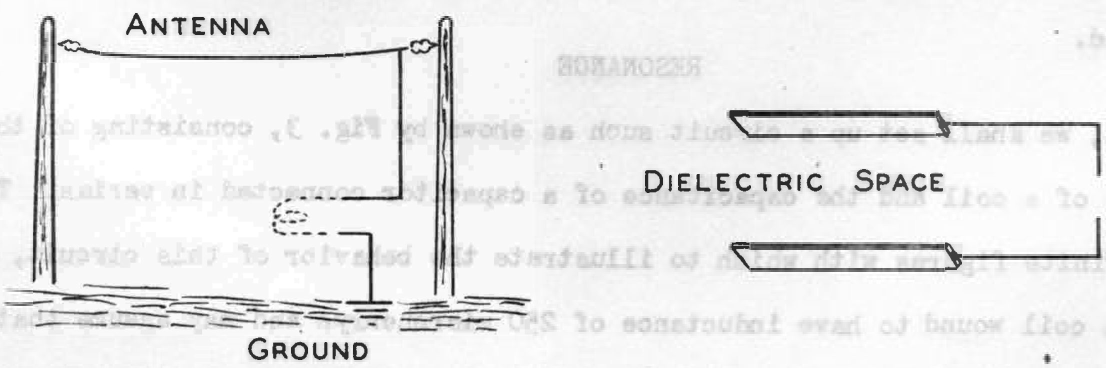

FIG.2.
The principle of one style of capacitance antenna.

receiver, and connect the other end of the input circuit to a second conductor providing a continuous conductive path into the earth. The earth is called the ground.

Now the earth forms one conductive plate and the elevated antenna conductor forms the other plate of a capacitor, which has for its dielectric the air space between the two conductors. Here we have a capacitance antenna. The electric fields of the radio wave act in the dielectric space and induce on the "plates" electric charges which alternate in polarity at the frequency of the radio wave.

The emf's induced in a loop antenna, and the potential differences between charges on a capacitance antenna, are so weak that they are measured in millionths of a volt, in microvolts. Even though we shall amplify these weak signals in the tube circuits, we cannot afford to waste the small incoming energy in overcoming inductive and capacitive reactances in the antenna circuits. We must design circuits which get rid of reactance, yet we must have inductance in the loop and capacitance in the capacitive antenna if these collectors of radiated energy are to be affected by the magnetic and electric fields of the radio wave.

After we amplify the signal in one tube, the strengthened signal must be passed along to a following tube. To do this while keeping the direct potentials and currents of the tube circuits separated, we must allow energy transfer by couplings, in which are inductances, capacitances, or both. In these coupling circuits we must not waste energy in overcoming reactances where reactances can be reduced or eliminated, and so again we have the problem of getting rid of the effects of reactance in circuits containing inductances and capacitances. Let's see how this problem may be solved.

RESONANCE

First, we shall set up a circuit such as shown by Fig.3, consisting of the inductance of a coil and the capacitance of a capacitor connected in series. To have some definite figures with which to illustrate the behavior of this circuit, we may assume a coil wound to have inductance of 250 microhenrys and may assume that the capacitor is adjusted to a capacitance of 110 micro-microfarads. Now supposing that we apply to this series circuit the frequencies in the standard broadcast range, from 500 kilocycles to 1,500 kilocycles. What will be the reactances of the inductance and capacitance at these frequencies?

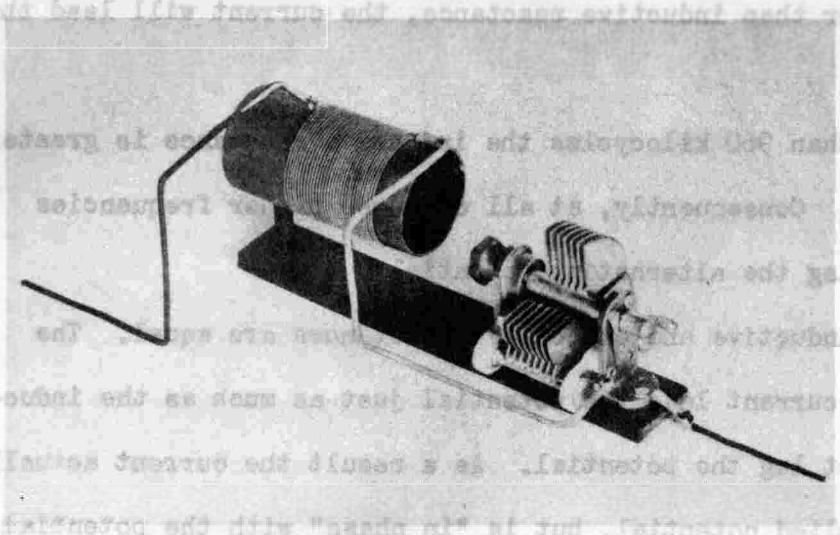

FIG. 3
The inductance and capacitance connected in series.

The reactances at various frequencies may be computed with the help of the reactance formulas in an earlier lesson. When we plot the inductive and capacitive reactances as curves on a graph, they appear as in Fig. 4. Previously we have seen curves like these on separate graphs, but now the two curves are drawn together. The capacitive reactance decreases from about 2,894 ohms at 500 kilocycles to about 964 ohms at 1,500 kilocycles, while the inductive reactance increases from about 785 ohms at 500 kilocycles to about 2,356 ohms at 1,500 kilocycles.

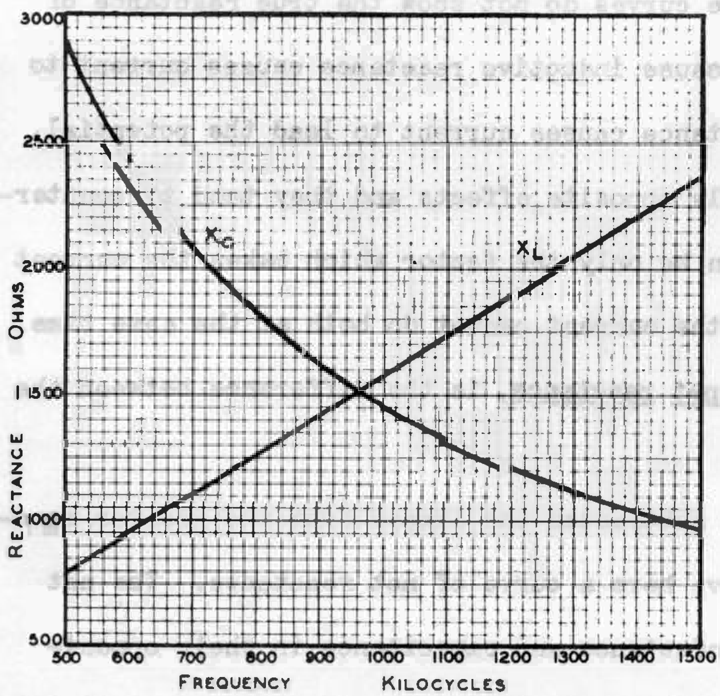

FIG. 4.
With increasing frequency the capacitive reactance drops while the inductive reactance rises.

The two reactance curves cross each other at a frequency of 960 kilocycles. At this frequency each reactance has a value of a little more than 1,507 ohms. At all frequencies lower than 960 kilocycles, the capacitive reactance is greater than the inductive reactance. Capacitive reactance tends to make alternating current lead the alternating potential. Inductive reactance tends to make the current lag the potential. Then at frequencies below 960 kilocycles, where capacitive reactance is greater than inductive reactance, the current will lead the potential.

At all frequencies higher than 960 kilocycles the inductive reactance is greater than the capacitive reactance. Consequently, at all of these higher frequencies the alternating current will lag the alternating potential.

But at 960 kilocycles the inductive and capacitive reactances are equal. The capacitance tends to make the current lead the potential just as much as the inductance tends to make the current lag the potential. As a result the current actually neither leads nor lags the applied potential, but is "in phase" with the potential. We have learned that in a circuit which contains only resistance, with no inductance and no capacitance, the alternating current is in phase with the alternating potential. Then in our experimental circuit we have, at a frequency of 960 kilocycles, the same condition as though the circuit contained neither inductance nor capacitance, but only resistance.

The curves of Fig. 4 show the separate reactances -- each kind as though the other kind were not present. But these curves do not show the true reactance of the circuit considered as a whole. Because inductive reactance causes current to lag the potential, and capacitive reactance causes current to lead the potential, the two kinds of reactance have entirely opposite effects and they tend to counteract each other. The true reactance can be only the factor which makes the current either lead or lag the potential, for the current cannot do both at the same time. Then the true reactance, often called <u>net reactance</u>, is the difference between the inductive and capacitive reactances.

To plot the curve of Fig. 5 we have subtracted the lesser from the greater reactance at all of the frequencies and have here a curve of net reactance. The net reactance is the combined effects of inductance and capacitance in their opposition to current. At frequencies from 500 to 960 kc the net reactance drops rapidly from about 2,109 ohms at 500 kc to zero ohms at 960 kc. Then, with increasing frequency, the net reactances increases from zero up to about 1,392 ohms at 1,500 kc.

In the circuit which is being examined we have succeeded in eliminating the opposition due to reactances at a certain frequency, at 960 kilocycles. Of course, you already have realized that we might eliminate the effects of reactances at any other frequency by choosing suitable values of inductance and capacitance. We shall look into this matter in a few moments.

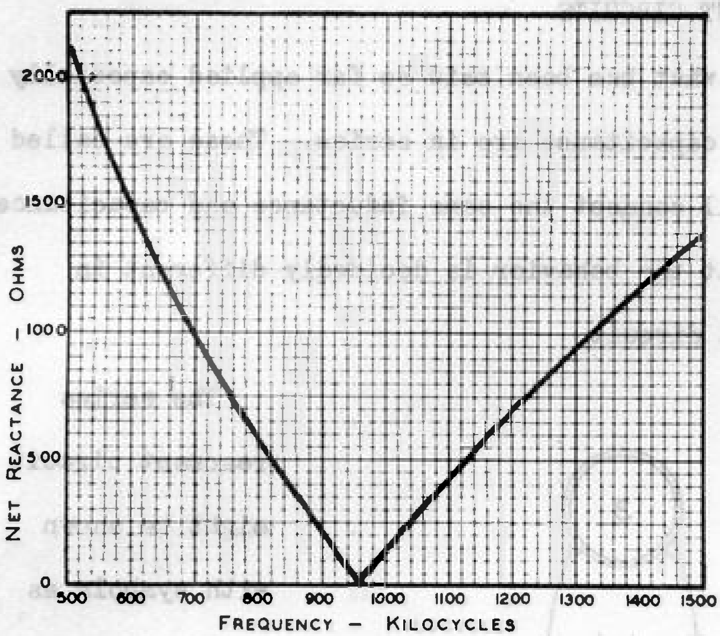

FIG. 5.
Net reactance is equal to the difference between capacitive and inductive reactances.

Although we have eliminated the opposition due to reactances at 960 kc, the circuit still contains some opposition to current, because it still contains resistance. In a well-designed circuit the resistance is very small in comparison with the reactances. The resistance of the conductors in the coil, the capacitor, and the wiring connections of Fig. 3 would be less than one ohm, but this resistance will remain even at 960 kilocycles.

When the relations between inductive reactance, capacitive reactance, and frequency are such that the reactances cancel each other, we have the condition called <u>resonance</u>. A circuit in which this condition exists is said to be <u>resonant</u> at the frequency whereat the reactances cancel. When we adjust either the capacitance, the inductance, or both, to such values that reactances cancel at a certain frequency, we say that the circuit is <u>tuned</u> to that frequency. The process of making the required adjustments is called <u>tuning</u>. A circuit which may be adjusted to produce resonance at various frequencies is called a <u>tuned circuit</u> or a tunable circuit. A capacitor used for adjustments to resonance is called a <u>tuning capacitor</u>. Coils whose inductance is adjustable for the purpose of causing resonance are called tuners as a general rule, because the term "tuning coil" always has been applied to coils of fixed inductance which are used with adjustable tuning capacitors in resonant circuits.

SERIES RESONANT CIRCUITS

It will be well to keep in mind that what has been said so far applied especially to circuits in which the inductance and capacitance are in series. These are called series resonant circuits. Later we shall connect the same inductance and capacitance in parallel with each other and find that the behavior is decidedly different in many respects with the parallel resonant dircuit.

The series resonant circuit might be shown with symbols as in Fig. 6. The same value of current must flow in the inductance L as in the capacitance C, because they are in series.

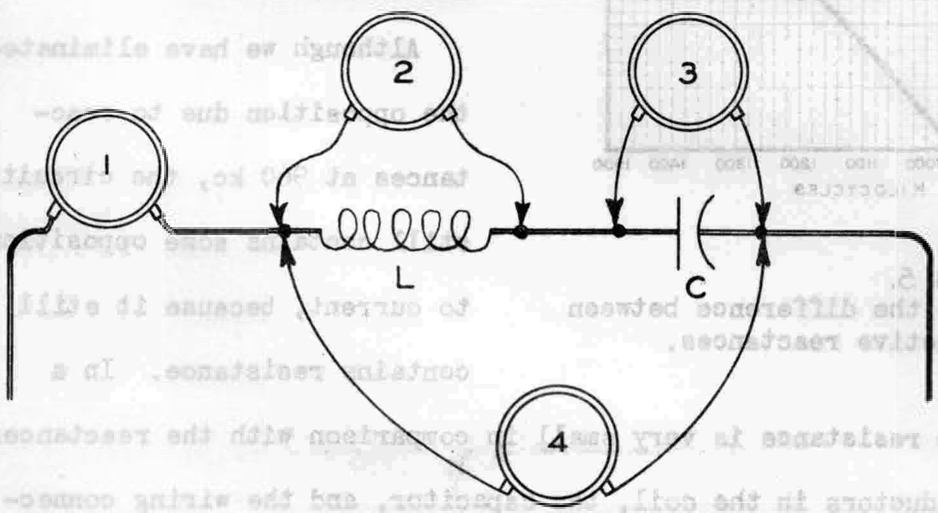

FIG. 6.
Potential difference across the series circuit is not equal to the sum of potentials across the inductance and capacitance.

The current would be shown by a milliammeter at 1. A voltmeter at 2 would show the potential difference across the inductance, a voltmeter at 3 would show the potential difference across the capacitance, and another at 4 would show the difference across the series circuit.

Assuming that resistance is everywhere negligible in comparison with reactances, the impedances which oppose the current will be the same as the reactances, which are shown by Figs. 4 and 5. Let's assume a current of 10 milliamperes or 0.010 ampere. Figuring that the potential drops are equal to amperes multiplied by impedance (or reactance in this circuit), we would find for a frequency of 700 kc the following potential drops:

Across inductance 11.00 volts

Across capacitance 20.68 volts

Across both L and C 9.68 volts

At a frequency of 1,300 kc we would find:

Across inductance 20.31 volts

Across capacitance 11.13 volts

Across both L and C 9.18 volts

By checking with the separate reactances and the net reactance at other frequencies, we should find that the potential drops across the inductance and capacitance are not alike except at resonance, and that either of the separate potential drops may be either greater or less than the drop across the whole circuit. These things come about because the separate potential drops are not in phase with each other except at resonance, and they always oppose to leave a difference as the overall potential drop. The insulation of coils and capacitors may be broken

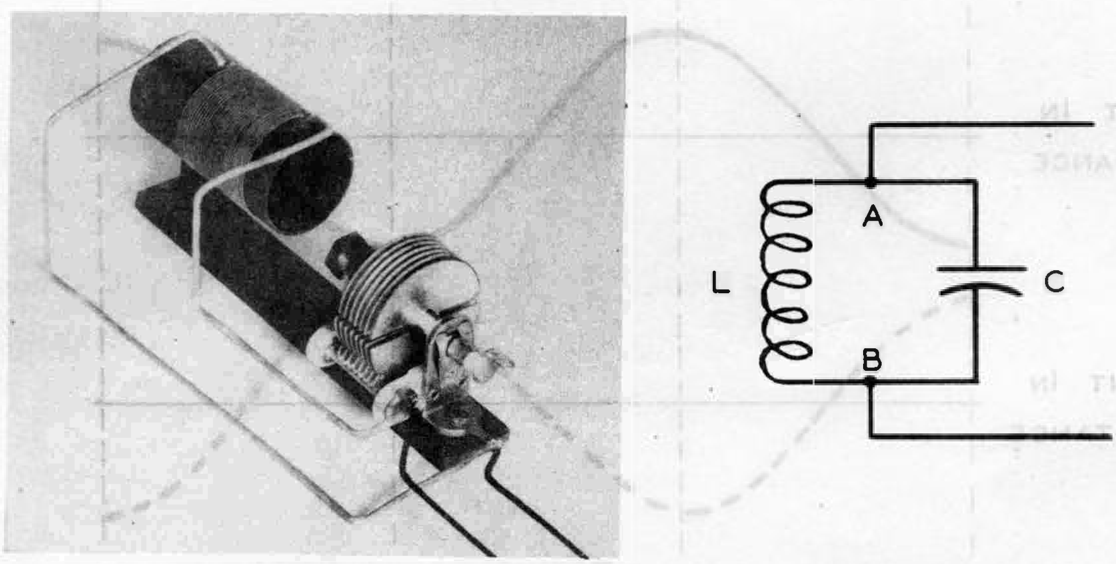

FIG.7.
The inductance and capacitance connected in parallel.

down, especially in transmitter circuits, because the separate potential drops may be many times greater than the potential difference applied to the circuit.

PARALLEL RESONANCE

Now we shall re-connect our coil and capacitor in parallel as at the left in Fig. 7. One end of the coil is connected to one set of capacitor plates, the other end of the coil is connected to the other set of capacitor plates, and a potential difference may be applied to the coil and capacitor in parallel through connections marked A and B in the diagram shown with symbols at the right.

In this parallel circuit, as in every other parallel circuit, there must be the same potential difference across both branches at every instant of time. The potential at the upper ends of both inductance and capacitance at the right in Fig. 7 must be the potential at point A, and at the lower ends of both must be the potential at point B, and whatever may be the difference between potentials at A and B

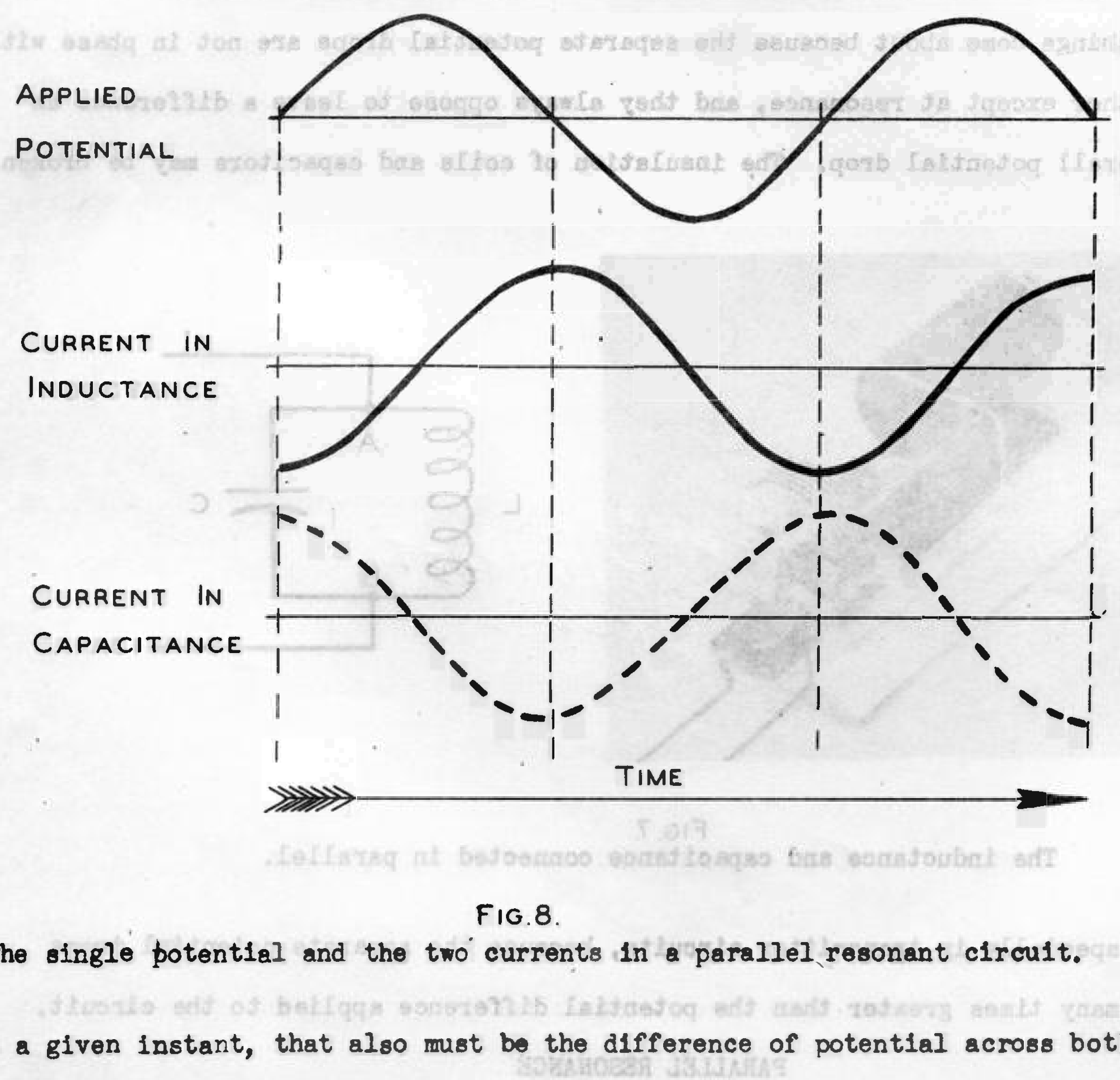

FIG. 8.

The single potential and the two currents in a parallel resonant circuit.

at a given instant, that also must be the difference of potential across both the inductance and the capacitance.

Now we shall go back to the curves, in an earlier lesson, showing the "phase relations" between applied potential and the currents in an inductance and in a capacitance when we assume no resistance to be present. In using these curves with the parallel resonant circuit we can have only one applied potential, because potential difference must be the same across both branches. But we will have one current in the inductance and another current in the capacitance. As shown by Fig. 8, the current in the inductance will lag the potential by 90 degrees, and the current in the capacitance will lead the potential by 90 degrees.

It is apparent that currents in the two parallel branches will flow in opposite directions at the same times. The curves of Fig. 8 make it plain that one of the currents is increasing in a positive direction whenever the other is increasing in a negative direction.

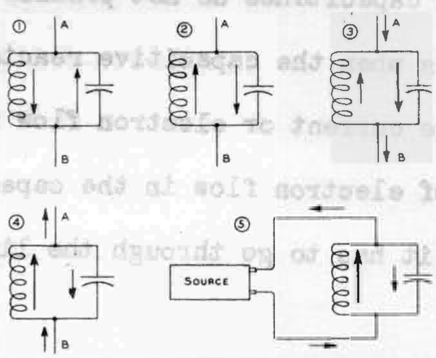

FIG.9.
Directions of currents or electron flows in a parallel resonant circuit.

These relative directions of currents in the inductance and capacitance may be shown as in Fig. 9. During one half-cycle we have current downward in the inductance and upward in the capacitance, as at 1. During the following half-cycle the current directions reverse in both the inductance and the capacitance, as at 2.

Supposing that the inductive reactance is exactly equal to the capacitive reactance, Then, at every instant, the currents will be equal in the inductance and capacitance, because we shall have the same potential difference across the two equal reactances. The electron flows or currents now will simply circulate back and forth between the inductance and the capacitance. Whatever may be the rate of flow in one branch, this rate of flow will simply go around into the other branch. The entire flow will remain within the parallel circuit consisting of the inductance and capacitance, and there will be no current or electron flow in the circuit between A and B through which the potential is being applied.

There will be equal reactances in the two branches only at resonance, only when the applied potential has a frequency at which the inductance and capacitance are resonant. At resonance, with the parallel circuit, we have an applied potential which causes no current or electron flow in the circuit supplying the potential. If an applied potential is able to cause no electron flow, what must be the value of the impedance opposing such flow? Of course, the impedance would have to be infinitely great.

Supposing now that the inductive and capacitive reactances are not equal, meaning that the values of inductance and capacitance do not produce resonance. Diagram 3 of Fig. 9 represents conditions when the capacitive reactance is less than the inductive reactance, allowing more current or electron flow in the capacitance than in the inductance. The excess of electron flow in the capacitance cannot go around through the inductance, so it has to go through the line connected to A and B.

If inductive reactance is less than capacitive reactance, we shall have more electron flow in the inductance than in the capacitance, as at 4, and the excess of flow in the inductance will have to go through the connected circuit instead of through the capacitance. The connected circuit is shown as a source of potential in diagram 5. Here the greater electron flow shown in the inductance of the parallel circuit has to go through the source. Were there greater flow in the capacitance, the excess would similarly have to go through the source.

If the two reactances are not equal, the circuit is not resonant at the applied frequency. When the circuit is not resonant, there is electron flow or current, not only around and back again in the inductance and capacitance, but also through the source. Now the potential difference being applied to the parallel circuit does cause electron flow or current in the connected line circuit. When a potential difference does cause electron flow, the impedance is something less than infinitely great and may be measured as some certain number of ohms.

With an inductance and a capacitance connected in parallel across an applied potential difference, assuming no resistance anywhere in the parallel circuit, this parallel circuit has infinitely great impedance at the frequency of resonance. At all other frequencies the impedance is less than at resonance.

It is not difficult to figure out how the impedance changes with frequency. We take the inductive and capacitive reactances as shown by Fig. 4, assume any potential difference, such as 100 volts, and compute currents at the various frequencies on the basis of impedance being equal to reactance when no resistance is present. When we know corresponding values of current and potential difference at the various frequencies, we may compute the impedance by using the formula: $Z = E/I$. For the inductance of 250 microhenrys and capacitance of 110 micro-microfarads in parallel the impedance would be as shown by Fig. 10.

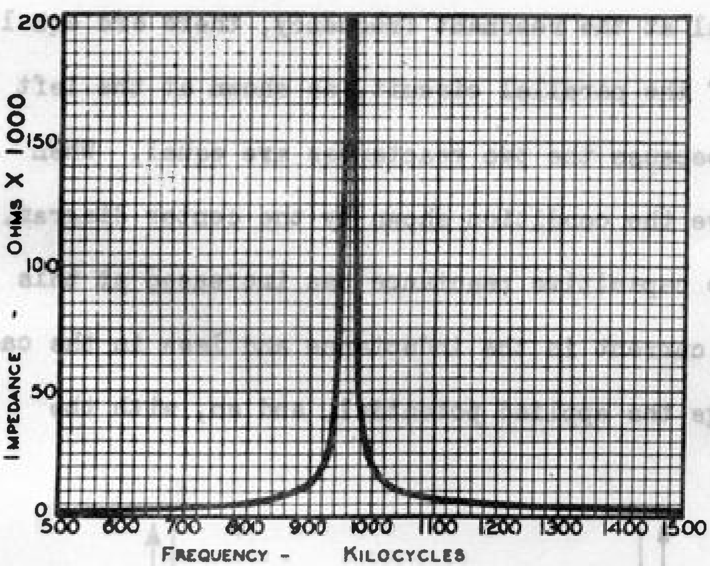

FIG.10.
The impedance of a parallel resonant circuit containing no resistance.

We know that our combination of inductance and capacitance is resonant at a frequency of 960 kc, also that at resonance the impedance becomes infinitely high for currents trying to flow in the line connected to A and B in Fig. 9. Consequently, the impedance curve of Fig. 10 would go to an infinite height at 960 kilocycles. This accounts for the break across the tops of the two sides where the graph ends at 200,000 ohms. The impedance falls off very rapidly at frequencies only a little below and above resonance, being down to around 25 ohms at 15 kcs. either below or above resonance. At frequencies still farther from resonance the impedance falls to only a very few ohms.

With the inductance and capacitance in parallel we have very high impedance to current at the resonant frequency when that current attempts to pass through the parallel circuit. As the frequency departs from resonance in either direction, the impedance becomes less. With the inductance and capacitance in series we have very low impedance at the resonant frequency, and have greater impedance at frequencies either below or above resonance.

When examining the series resonant circuit, we found that capacitive reactance is greater than inductive reactance at all frequencies below resonance, and that the inductive reactance is greater at all frequencies above resonance. So far as its effect in causing current to lag or lead the applied potential, the series circuit acted like a capacitance (with leading current) at frequencies below resonance, and like an inductance (with lagging current) at frequencies above resonance. Now let's inquire as to how the parallel resonant circuit acts in causing lag or lead on either side of resonance.

When we apply an alternating potential at the resonant frequency, there are equal alternating currents in both branches of the parallel circuit, as shown at the left in Fig. 11. There are equal currents, because the two reactances are equal. When the frequency is below resonance, we have the condition shown by the center diagram. Inductive reactance has decreased, while capacitive reactance has increased at this lower frequency. Then there is greater current in the inductance and less in the capacitance. Current in an inductance lags the applied potential, and so, with the

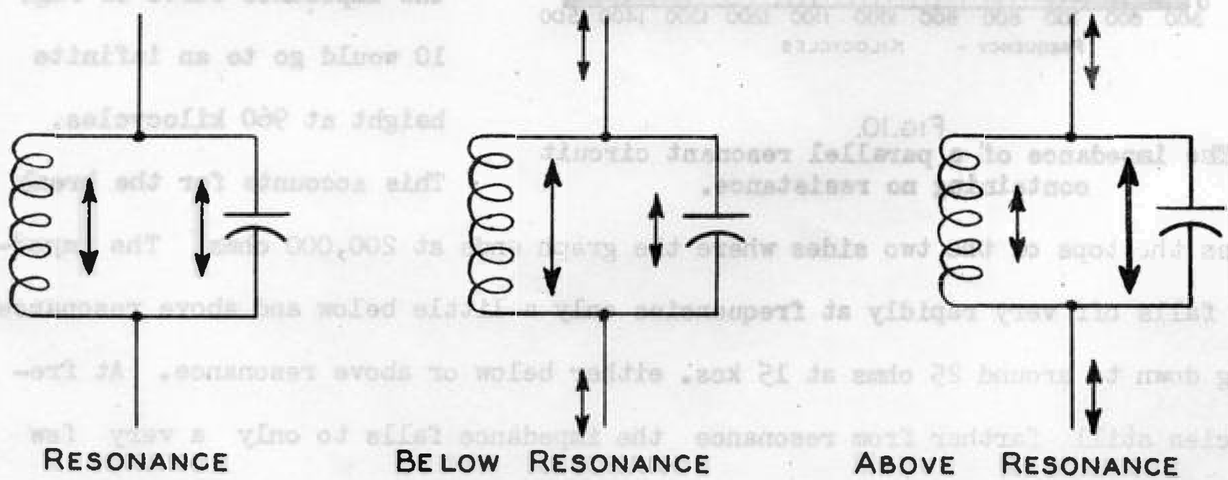

FIG. 11.
Currents in a parallel resonant circuit.

frequency below resonance, we have more lagging current than leading current, there is a net lagging current and the circuit is acting like an inductance so far as its effect on lag and lead is concerned.

With a frequency above resonance we have the conditions of the right-hand diagram of Fig. 11. Capacitive reactance is less than inductive reactance. Therefore, the current is greater in the capacitance than in the inductance. Current in a capacitance leads the applied voltage, and so we have more leading current than lagging current and the circuit is acting like a capacitance so far as lag and lead of current is concerned. We find that the effects of a parallel circuit on lag and lead are the opposite of the effects of a series circuit.

It will be a good idea to tabulate some of the things that we have learned about series and parallel resonant circuits, like this:

	Parallel Resonant Circuit	Series Resonant Circuit
Impedance at resonance	Maximum	Minimum
Line current at resonance	Minimum	Maximum
At frequencies below resonance	Acts like an inductance	Acts like a capacitance
At frequencies above resonance	Acts like a capacitance	Acts like an inductance
Frequency for given inductance and capacitance	Same as series circuit	Same as parallel circuit

FREQUENCY OF RESONANCE

At the bottom of the preceding table it is stated that the resonant frequency for any given combination of values of inductance and capacitance is the same whether the circuit is parallel resonant or series resonant. In our examples we have been using an inductance of 250 microhenrys and a capacitance of 110 mmfds. These values cause resonance at a frequency of 960 kc. The resonant frequency is 960 kc whether the inductance and capacitance are connected in parallel or in series with each other.

All possible values of inductance and capacitance are resonant at some frequency.

The frequency of resonance depends solely and only on the values of inductance and capacitance. Whether or not resistance is present, and where it exists and to what amount it extends, have no effect whatever on the frequency of resonance.

The frequency of resonance may be calculated with the help of formulas. The basic formula is:

$$\text{Resonant frequency in cycles} = \frac{1}{6.2832 \times \sqrt{\text{inductance, henrys} \times \text{capacitance, farads}}}$$

Formulas derived from the basic one are of more practical usefulness. There may be many derived formulas, because frequencies may be measured in cycles, kilocycles or megacycles, inductances may be in henrys, millihenrys or microhenrys, and capacitances may be in microfarads or in micro-microfarads. Following are several useful formulas for frequency of resonance.

$$\text{Cycles} = \frac{159{,}155}{\sqrt{\text{mfd} \times \text{henrys}}} \qquad \text{Kilocycles} = \frac{159{,}155}{\sqrt{\text{mfd} \times \text{microhenrys}}}$$

$$\text{Kilocycles} = \frac{159155}{\sqrt{\text{mmfd} \times \text{microhenrys}}}$$

When you want to determine the frequency in megacycles, use a formula for kilocycles and divide the resulting number of kilocycles by 1,000 to change it to megacycles. If you originally have inductance in millihenrys, multiply the number of millihenrys by 1,000 to change it to microhenrys and then use a formula for microhenrys.

Using our values of 250 microhenrys and 110 mmfds in the last formula would give:

$$\text{Kc} = \frac{159155}{\sqrt{110 \times 250}} = \frac{159155}{\sqrt{27500}} = \frac{159155}{165.75} = 960 \text{ kilocycles}$$

All of the frequency formulas require finding square roots of the products of capacitance and inductance. Those who do much of such work usually use tables or charts of square roots, or use a slide rule. Fortunately, we seldom need to figure out the resonant frequency for a certain combination of capacitance and inductance. More often we have either some certain capacitance or some certain inductance, and wish to determine the other value which will cause resonance at some certain frequency. That is, you may have a capacitor of 100 mmfds and want to determine the inductance to be used with this capacitor for resonance at some particular frequency. This is where we conveniently use numbers called "oscillation constants" or "LC constants", the latter meaning inductance-capacitance (LC) constants.

There is an oscillation constant for every frequency. When you divide that constant by a certain value of inductance, the result is the value of capacitance that will produce resonance at the frequency of the constant. And if you divide the constant by some value of capacitance, the result is the value of inductance which will produce resonance at the frequency of the constant. As an example, the constant for 960 kc is the number 27,500. If you divide this number by 250 (microhenrys), the result is 110, which is the required capacitance in mmfds for resonance at 960 kc with an inductance of 250 microhenrys. If you divide 27,500 by 110 (mmfds), the result is 250, the corresponding inductance in microhenrys for resonance at 960 kc.

The accompanying table of "Oscillation Constants" lists the constants from 1,000 to 100 kilocycles at intervals of 10 kilocycles. This table applies only when frequency is in kilocycles, inductance in microhenrys, and capacitance in micro-microfarads. The table may be extended to cover any frequency as explained in the note at the bottom of the table. Following are two examples of extension.

What is the oscillation constant for a frequency of 2,300 kc? This frequency is equal to 230 kc multiplied by 10. The constant for 230 kc is 479000. Since the frequency is multiplied by 10, we divide the constant by 100 to find that 4790 is the oscillation constant for a frequency of 2,300 kc.

What is the constant for a frequency of 75 kc? This frequency is equal to 750 kc divided by 10. The constant for 750 kc is 45030. Having divided the frequency by 10, we must multiply the constant by 100, which gives for 75 kc a constant of 4503000.

If a frequency is in megacycles, first change it to the equivalent number of kilocycles by multiplying the number of megacycles by 1,000. Then use this number of kilocycles with the table of constants.

OSCILLATION CONSTANTS

Inductance in microhenrys. Capacitance in micro-microfarads. Frequency in kilocycles.

Kc	Constant	Kc	Constant	Kc	Constant	Kc	Constant
1000	25 330	750	45 030	500	101 320	250	405 200
990	25 840	740	46 280	490	105 500	240	439 900
980	26 370	730	47 530	480	110 000	230	479 000
970	26 920	720	48 850	470	114 800	220	523 600
960	27 500	710	50 240	460	119 800	210	574 500
950	28 060	700	51 695	450	125 100	200	633 300
940	28 670	690	53 200	440	130 900	190	702 000
930	29 290	680	54 800	430	137 000	180	782 100
920	29 930	670	56 450	420	143 600	170	876 800
910	30 590	660	58 180	410	150 700	160	990 000
900	31 270	650	59 980	400	158 300	150	1126 000
890	31 980	640	61 860	390	166 500	140	1 293 000
880	32 700	630	63 830	380	175 500	130	1 499 000
870	33 470	620	65 910	370	185 100	120	1 760 000
860	34 280	610	68 060	360	195 500	110	2 094 000
850	35 060	600	70 360	350	208 500	100	2 533 000
840	35 910	590	72 790	340	219 100		
830	36 770	580	75 320	330	232 800		
820	37 670	570	78 000	320	247 500		
810	38 600	560	80 810	310	263 700		
800	39 580	550	83 740	300	281 400		
790	40 590	540	86 870	290	301 300		
780	41 630	530	90 210	280	323 300		
770	42 720	520	93 670	270	347 700		
760	43 880	510	97 400	260	374 800		

Note: To extend the range of this table: Divide the number of kilocycles by 10 and multiply the constant by 100. Multiply the number of kilocycles by 10 and divide the constant by 100. (Moving the decimal point one place in the number of kilocycles requires moving it two places in the opposite direction in the constant)

We have been discussing resonant circuits as though they had no resistance, as though only inductance and capacitance were present, and as though the currents always lag or lead the applied potentials by 90 degrees. Actually there always is more or less resistance present; we have impedances rather than only reactances, and the lag and lead of currents is less than 90 degrees because of the resistance.

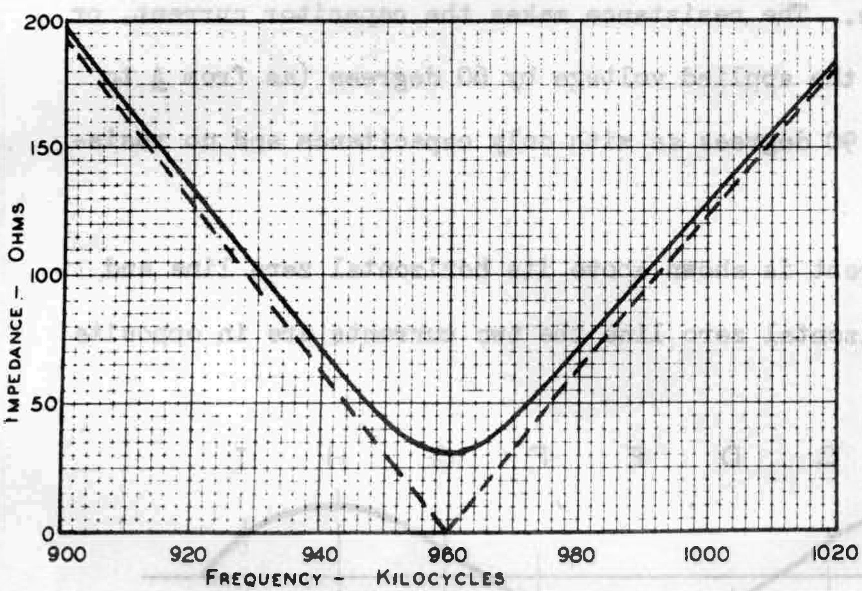

FIG.12.
The (full-line) impedance curve with 30 ohms of resistance compared with the (broken-line) curve when there is no resistance.

In Fig. 5 we looked at a graph showing the net reactance of a series resonant circuit at various frequencies when only inductance and capacitance are considered. If we have in series with the same inductance and capacitance a resistance of 30 ohms, then compute the resulting impedances below and above the resonant frequency, we may plot an impedance curve such as shown in a full-line by Fig. 12. This graph covers frequencies 60 kilocycles each side of resonance at 960 kilocycles. The broken-line curve shows the original impedance (net reactance), without any resistance, in this range of frequencies.

With resistance present the impedance does not drop to zero at resonance, but decreases only to the value of the resistance, which here is 30 ohms. With any other value of series resistance the impedance at resonance would drop to the same value as the resistance only, because the two kinds of reactance cancel each other at resonance.

To understand what happens in a parallel resonant circuit containing resistance we may examine the curves of Fig. 13. At the top is a sine-wave curve for applied potential, which would be the alternating potential applied from a line connected at A and B of Fig. 9. Note that the intervals between lettered instants of time are equal to 60 degrees each.

It is assumed that the amount of resistance in the circuit is such as makes the coil current, or current in the inductance, lag the applied potential by 60 degrees (as from B to C and from F to G) instead of the 90-degree lag which would exist with no resistance and only inductance. The resistance makes the capacitor current, or current in the capacitance, lead the applied voltage by 60 degrees (as from A to B and from G to H) instead of by 90 degrees as with only capacitance and no resistance.

During times in which one current is shown above its horizontal zero line and the other is shown below its horizontal zero line the two currents are in opposite

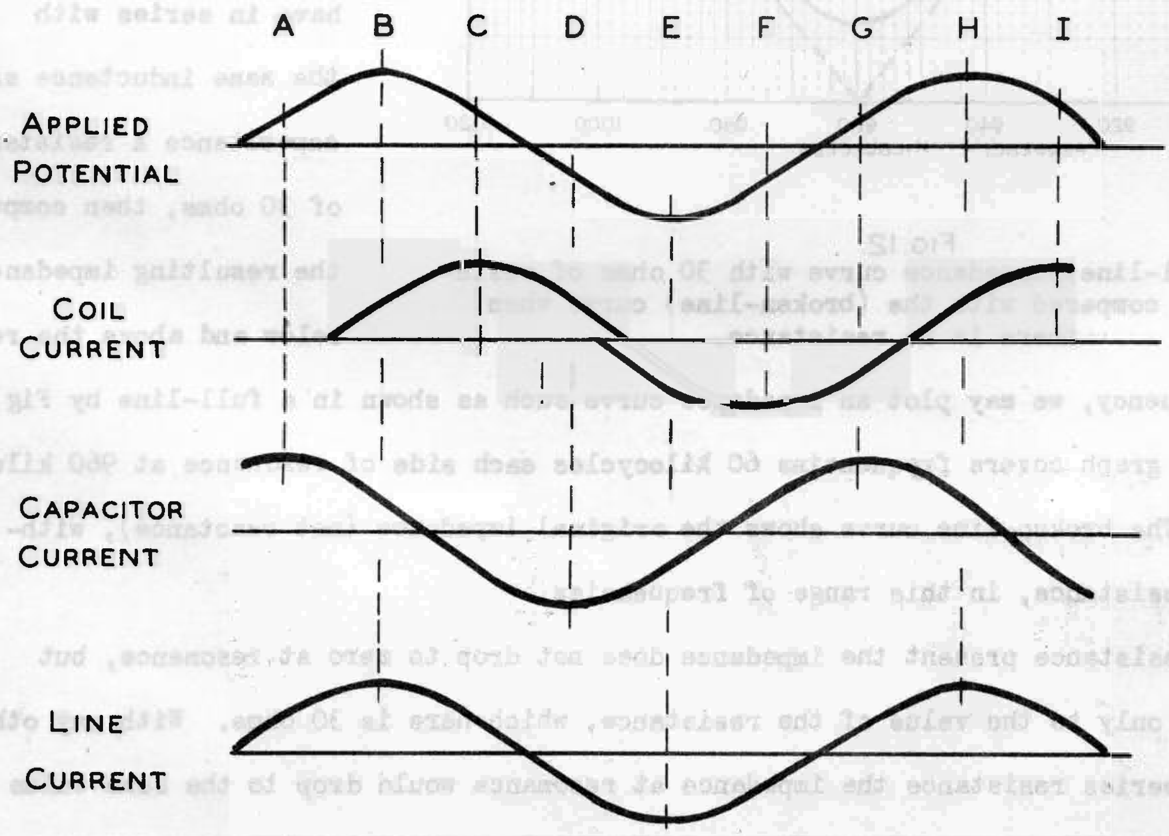

FIG.13.
Resistance brings parallel resonant currents more nearly into phase with the applied potential.

directions. If the two currents also were equal, they would circulate entirely within the parallel circuit and there would be no current in the line. This was explained in connection with Fig. 9, diagrams 1 and 2. If the opposite currents are not equal, the amount of current which is their difference must go through the connected line. During times in which coil and capacitor currents are shown either above or below their horizontal zero lines in Fig. 13, they are moving in the same direction and their sum must go through the connected line.

By taking the differences between opposite currents and the sums of currents in the same directions we arrive at the current shown by the bottom curve of Fig. 13, which is the current that must flow in the connected line rather than circulating in the coil and capacitor.

Because we now have current in the line, the impedance of the parallel resonant circuit cannot be infinitely great, as it was when we had no resistance. That is, even at the resonant frequency we do not have infinite impedance; because if we did have such impedance, there could be no line current.

The more resistance we have in the parallel resonant circuit, the less will be the lag and lead of the currents, the more nearly they will come to being in phase with the applied potential. And the more nearly the coil and capacitor currents come to being in phase with the applied potential, the greater will be the line current. The greater the line current, the less must be the impedance of the parallel circuit, and so we come to the rather astonishing conclusion that the greater is the resistance in a parallel resonant circuit, the less is the impedance of this circuit to current flowing in the line. Conversely, the less the resistance, the greater is the impedance of the parallel resonant circuit at resonance.

Fig. 14 shows how the impedance varies for frequencies between 60 kilocycles below and 60 kilocycles above a resonant frequency of 960 kilocycles when the parallel resonant circuit contains 30 ohms of resistance in addition to the 250 microhenrys of inductance and 110 mmfds of capacitance. Compare this impedance curve with the one of Fig. 10, which shows the impedance with no resistance.

The more resistance we have in a parallel resonant circuit, the lower and broader becomes the curve showing impedance to line current. The less the resistance, the steeper and narrower becomes the curve as we approach the condition of Fig. 10, where we have no resistance at all.

OSCILLATIONS

Series resonant circuits are used in radio chiefly as a means for providing very small impedance for frequencies at and near resonance, and large impedance for all other frequencies. Then currents at and near the resonant frequency flow quite freely through the circuit, while currents at other frequencies are held to low values.

Parallel resonant circuits are used to provide large impedance for line currents at and near the resonant frequency, and small impedance for line currents at other higher and lower frequencies. Currents at and near the resonant frequency then are reduced to low values while currents at other frequencies flow quite freely through the parallel combination of inductance and capacitance.

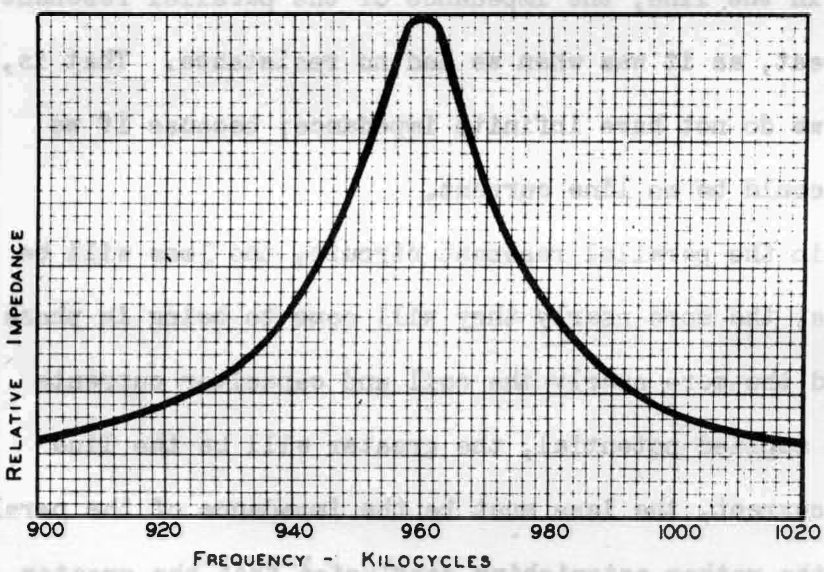

FIG.14.
The effect of adding resistance in a parallel resonant circuit.

But the chief use of parallel resonant circuits is not for providing impedance, rather these circuits are used for providing potential differences. The arrangement most often found in radio is represented by the diagram of Fig. 15. The coil of the parallel resonant circuit is the secondary winding of a transformer whose primary winding is in another circuit which furnishes energy. The two windings are inductively coupled. When there are changes of current in the primary, emf's are induced in the secondary and there are corresponding currents in the secondary. These currents flow back and forth between the coil and the capacitor of the parallel

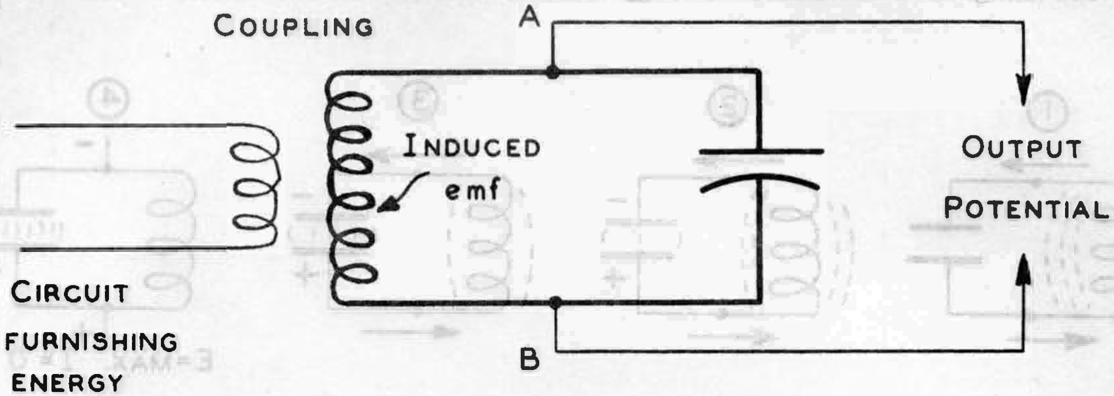

FIG.15.
A parallelresonant circuit used for providing potential differences.

resonant circuit. Potential differences occur between points A and B, and these potential differences may be applied to a following circuit.

The circuit furnishing energy in Fig. 15 may be the plate circuit of an amplifying tube, and the output potential may be applied to the control grid circuit of a following tube. Then energy representing a signal in the plate circuit is transferred to the following control grid circuit.

Fig. 16 shows what happens in the parallel resonant circuit during one complete cycle. The magnetic field around the coil is shown by broken lines representing magnetic lines of force. The electric field between the plates of the capacitor is shown by short lines representing electric lines of force. Electron flow is shown by arrows. Here are the explanations of each diagram.

1. An emf induced in the coil is causing an electron flow. The flow is changing at the maximum possible rate, because the capacitor is not charged and has no voltage which would oppose the very rapid increase in rate of electron flow. Keep in mind that the capacitor plates are directly connected to the ends of the coil; consequently, the potential difference across the coil must always be the same as across the capacitor. This potential difference is between top and bottom of the circuit.

2. The electron flow is charging the capacitor. We assume the flow to be in such direction as to make the upper plate negative and the lower plate positive. The magnetic field around the coil is shrinking and the electric field of the capacitor is becoming more intense. Energy which has been in the field of the coil is

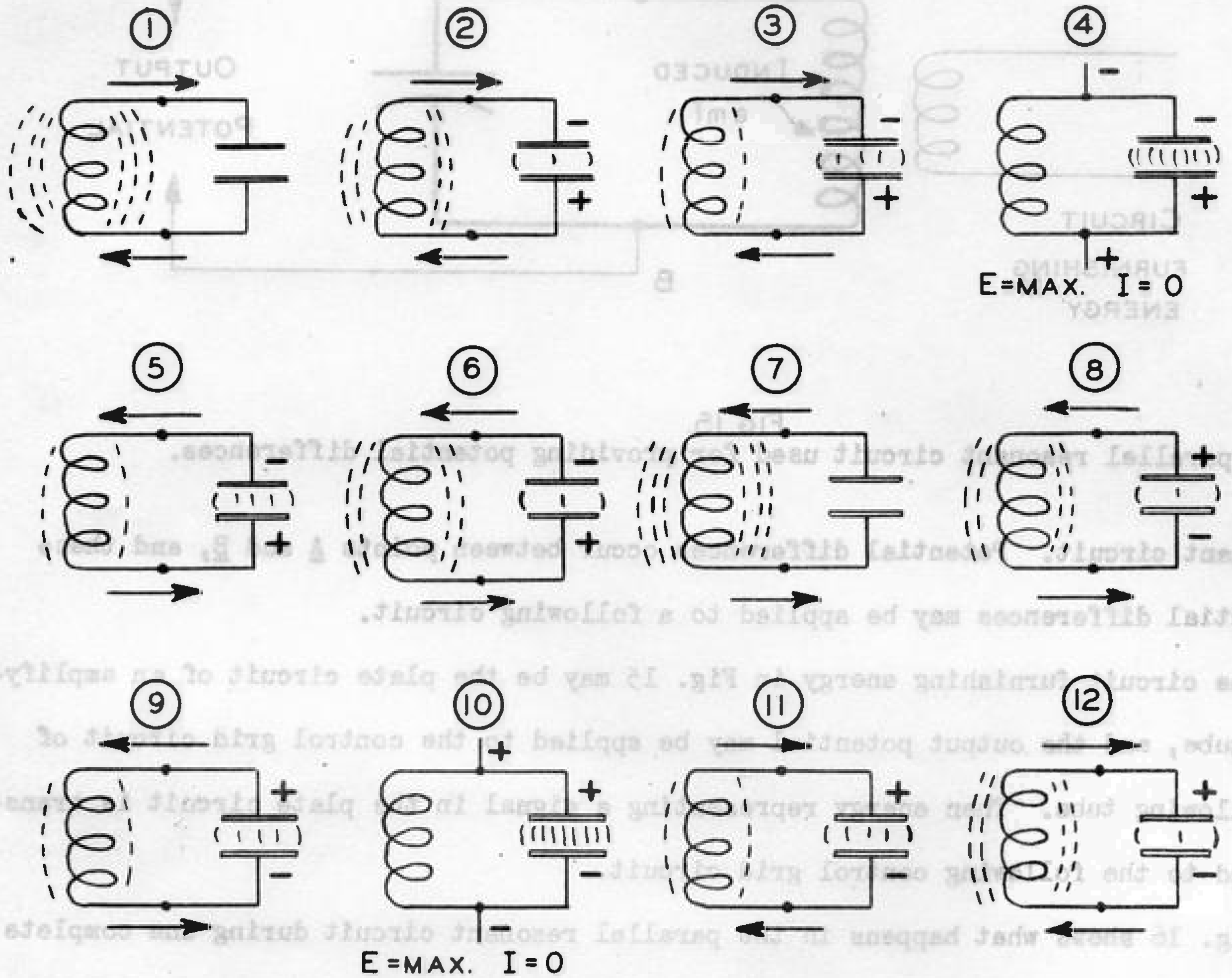

FIG.16.
The actions during one cycle in an oscillatory circuit.

going over into the field of the capacitor.

3. The action continues, with the magnetic field of the coil growing weaker while the electric field of the capacitor grows stronger.

4. The capacitor has reached its maximum charge and maximum field strength. The field of the coil has disappeared. During this instant there is no electron flow, because no more electrons can be forced into and taken out of the capacitor plates. Potential difference across the capacitor is maximum, because of the maximum

charge. This maximum potential difference is negative at the upper end of the circuit and positive at the lower end, these being the ends from which the potential difference is taken and applied to some following circuit.

5. The capacitor has commenced to discharge. Consequently, the direction of electron flow has reversed in the circuit. The upper plate of the capacitor still is negative and the lower plate positive. The increasing rate of electron flow through the coil is building up a magnetic field around the coil while the electric field of the capacitor grows weaker. Energy is passing from the electric field over into the magnetic field.

6. The action continues, with the magnetic field becoming stronger while the electric field grows weaker.

7. All of the energy now is in the magnetic field. The capacitor is discharged, and the potential difference across its plates (and across the connected coil) has dropped to zero. Conditions are the same as at 1, except that the direction of electron flow is reversed.

8. Conditions are the same as at 2, except for the reversed direction of electron flow.

9. Conditions are the same as at 3, except for reversed electron flow.

10. The capacitor again is fully charged, with maximum field strength and maximum voltage or potential difference, just as in diagram 4. But now we have positive potential at the top and negative at the bottom, whereas in the diagram 4 we have negative potential at the top and positive at the bottom.

11. Conditions are the same as at 5, except that direction of electron flow is reversed.

12. Conditions are the same as at 6, except for reversed electron flow.

In the next step we return to diagram 1, with all of the energy in the magnetic field of the coil and none in the capacitor, which is discharged. Thus the action continues during all following cycles.

Energy swings back and forth between the magnetic field of the coil and the electric field of the capacitor. All of the energy is in the magnetic field at instants represented at 1 and 7 of Fig. 16, and all of it is in the electric field at instants represented at 4 and 10. The energy "oscillates" back and forth in the circuit. Consequently, the parallel resonant circuit may be called an oscillatory circuit or an oscillating circuit, and in the circuit we have what are called electrical oscillations.

Because we assume a resonant frequency, the inductive and capacitive reactances balance or cancel each other, and there is nothing except the resistance of the circuit to oppose the electron flows which transfer the energy back and forth. During every cycle there is some energy used for overcoming the resistance. This energy produces heat in the conductors, and is wasted so far as we are concerned. If oscillations are to continue, the loss of energy in resistance must continually be replaced from the circuit which furnishes energy in Fig. 15. That is, the circuit which furnishes the energy must induce just enough additional emf in the coil of the resonant circuit to produce the electron flow and electron energy that is being continually lost in resistance of the resonant circuit.

The great advantage of using an oscillatory circuit is explained thus: The electron flows in the circuit are proportional to the induced emf's and the resistance. That is, the rates of flow in amperes are equal to the emf's in volts divided by the resistance in ohms. The resistance may be made small in well-designed circuits, which means that small emf's will cause large electron flows. But the potential differences which are produced across the circuit are proportional to the reactances of the coil and capacitor, not to the resistance. That is, the potential differences at instants 4 and 10 of Fig. 16, when measured in volts, are equal to the product of the electron flows, in amperes, and the reactances in ohms. The reactances are large in comparison with the resistance, and so we may have large potential differences with very small induced emf's.

The oscillatory circuit has a gain of voltage. Voltages developed across the circuit are greater than those applied in or to the circuit. But while there is a gain of voltage, there is a loss of energy at the same time.

The energy which induces emf's in the oscillatory circuit must be applied at exactly the correct instants, and in the correct direction each time, if we are to have the results shown by Fig. 16. This means that the applied energy must have a frequency exactly the same as the resonant frequency of the oscillatory circuit. The directions of electron flows and the polarities of the potentials in the oscillatory circuit then will match the polarities of the induced emf's, because it is the induced emf's that start and maintain the electron flows.

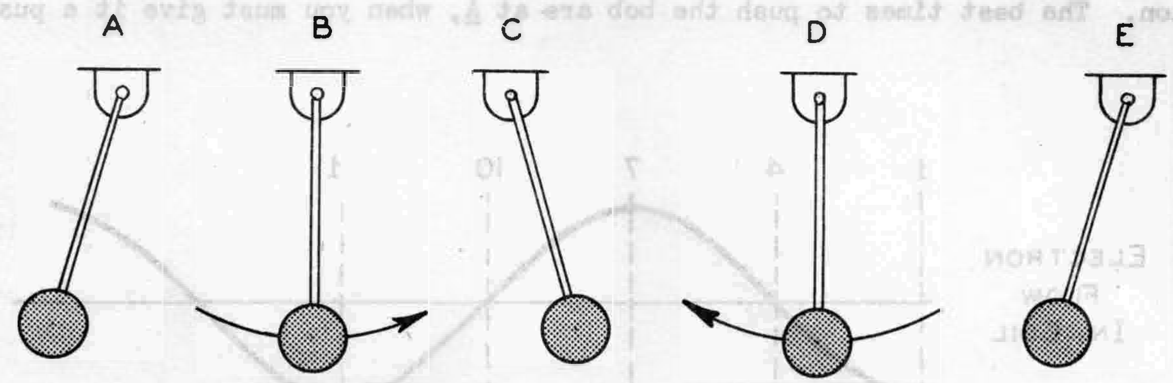

FIG.17
Actions in an oscillatory circuit are comparable to actions of a pendulum.

We may think of the swings of energy, and the reversing electron flows by which energy is carried hack and forth, as similar to the swings of the pendulum shown by Fig. 17. At A the pendulum bob is poised, stationary, while raised to the left. There is energy in the pendulum, because it will move downward if it is released, but there is no motion. This might correspond to instant 4 of Fig. 16, where there is maximum energy in the capacitor, but no electron motion or flow. At B the pendulum bob is at the bottom of its swing and is moving toward the right. Here we would have instant 7 of Fig. 16. The pendulum has no more energy available, because it can drop no farther down, and the capacitor has no more energy because it is discharged.

At C of Fig. 17 the pendulum bob has reached the end of its travel and is stationary at the right. The bob again has available energy, but has no motion. This is instant 10 of Fig. 16, where there is no electron flow or motion, but where the capacitor has regained energy with the energy in opposite direction or polarity. At D the bob is swinging back toward the left, and we have instant 1 of Fig. 16, where there is maximum motion (electron flow) but no energy (in the capacitor). At E the pendulum bob has returned to its original position, and starts over again from A.

If you let the pendulum swing by itself, it will dissipate its energy in friction and finally will come to a standstill. If you are going to keep the bob swinging, you will have to give it little pushes, just enough to replace the energy lost in friction. The best times to push the bob are at A, when you must give it a push

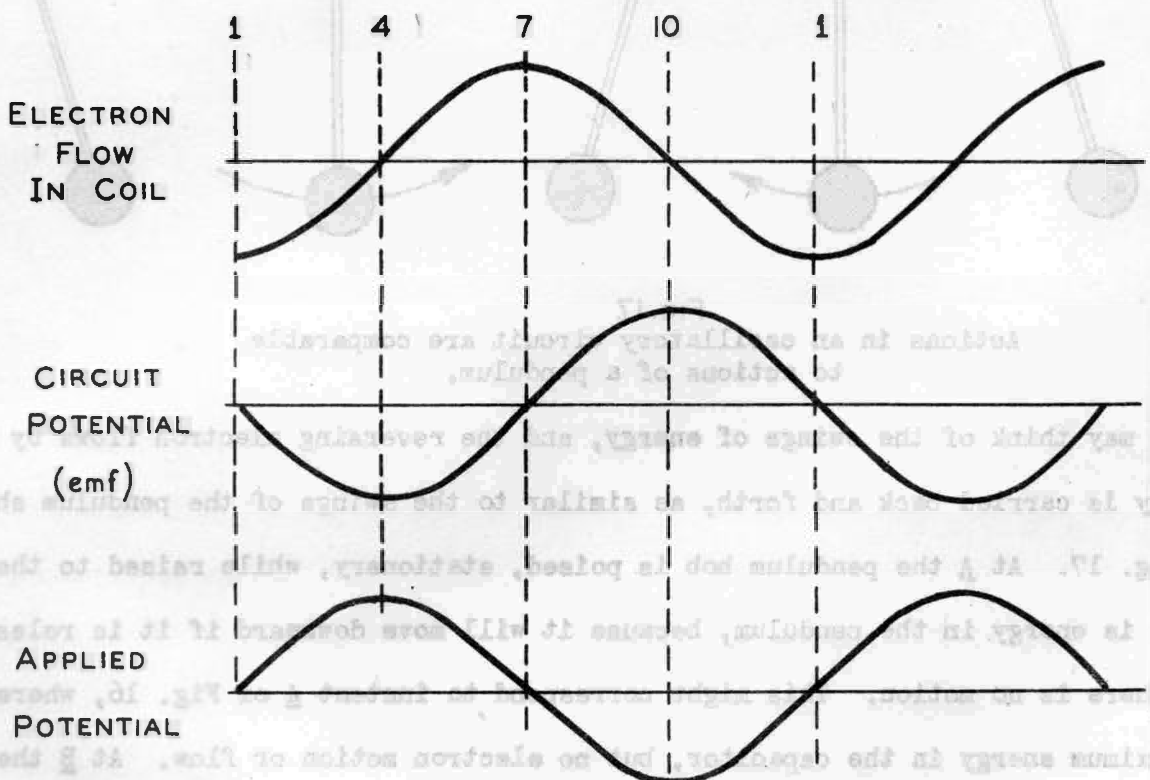

FIG.18.
Electron flow and potentials in an oscillatory circuit.

toward the right, and at C, when you must give it a push toward the left. If you push in opposite directions or at different times, you will oppose the swing of the bob. Similarly, we must add energy at certain times and in certain directions or polarities to the oscillating circuit.

The electrical "pushes" are shown by Fig. 18. The upper curve shows reversing electron flows as they would exist in the coil. The center curve shows the potentials produced at the top and bottom of the circuit. The lower curve shows the applied potential. Note that the circuit potential, corresponding to induced emf is opposite in phase to the applied potential, and that the electron flow in the coil lags the applied potential, because the coil possesses inductance and inductive reactance. Maximum push from the applied potential occurs in one direction (polarity) at 4 and in the opposite direction at 10, which correspond to similarly numbered instants in Fig. 16, and which correspond to A and C in Fig. 17. If the maximum pushes, which are the peaks of applied potential, occur at a frequency different from the resonant frequency of the oscillatory circuit, they sometimes will oppose the electron flows and reduce or stop the oscillations of energy.

In actual radio circuits we cannot match the frequency of the applied potential to some fixed resonant frequency of the oscillatory circuit, because it is the applied potential whose frequency is fixed or determined by the signal frequency or by what is happening in circuits which furnish the energy. Therefore, we must adjust the resonant frequency of the oscillatory circuit so that it matches the applied frequency.

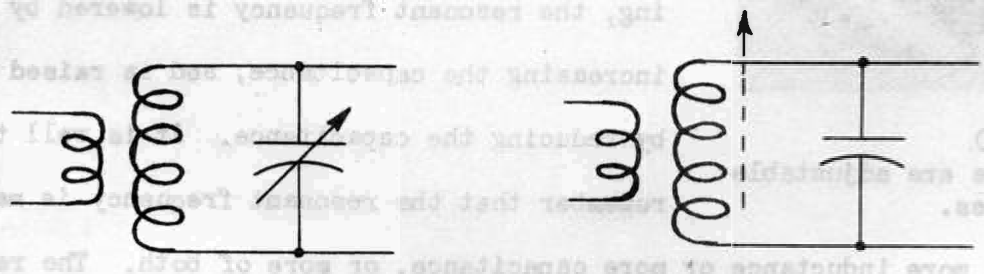

FIG. 19.
Either capacitance or inductance may be adjustable for tuning.

The resonant frequency of the oscillatory circuit is adjusted by tuning this circuit. Tuning may be accomplished by varying the capacitance of the capacitor with a variable capacitor as represented at the left in Fig. 19, or by varying the inductance of the coil as represented at the right. We have looked at many variable capacitors of types used for tuning, and at a few variable inductors.

Fig. 20 is a different view of a variable inductance tuner which has been shown once before. Two coils may be seen on opposite sides of a central shielding barrier. In each coil is a powdered-iron core which may be raised and lowered by the pulley arrangement which is mechanically connected to the tuning dial. A powdered-iron core consists of exceedingly small particles of iron embedded in a mass of insulating and supporting material to form a solid cylinder. With the core farther inside the coil, the inductance is increased and the resonant frequency is lowered. With the core farther out, the inductance is decreased and the resonant frequency is raised.

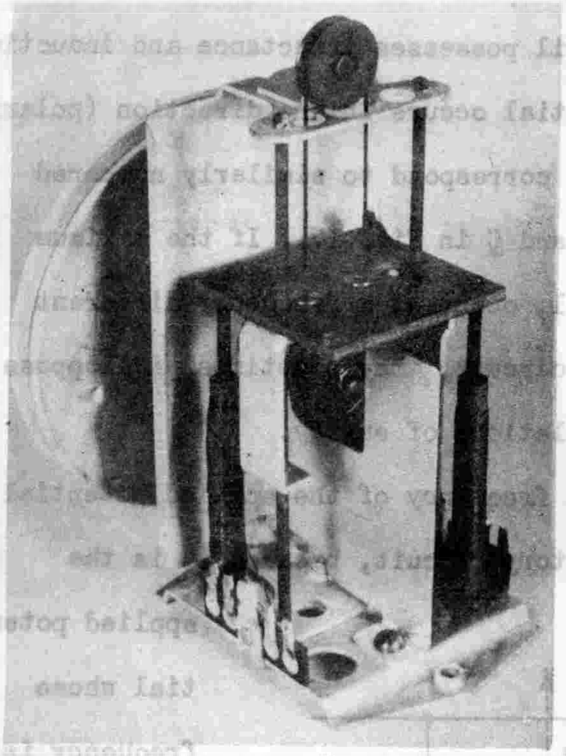

FIG. 20.
A tuner in which there are adjustable inductances.

With a variable capacitor used for tuning, the resonant frequency is lowered by increasing the capacitance, and is raised by reducing the capacitance. It is well to remember that the resonant frequency is made lower by using either more inductance or more capacitance, or more of both. The resonant frequency is made higher by using less inductance, less capacitance, or less of both.

EXAMINATION QUESTIONS ON FOLLOWING PAGE.