Electronics Radio Television Radar

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COILS AND CAPACITORS IN COMBINATION - RESONANCE

ASSIGNMENT 21

COILS AND CAPACITORS IN COMBINATION—RESONANCE

In this assignment, we are going to study one of the most interesting phenomenon in electronics. This is the **tuning process.** Through this process it is possible to "tune in" a desired radio or television station and reject all of the unwanted stations. Remember that there are thousands of television and radio stations (Broadcast, two-way communications, microwave relay, dispatching services, maritime service, etc.) on the air at all times. Without this tuning process, it would be impossible to listen to the one desired station and reject all of the others.

In industrial electronics equipment this same tuning process makes it possible to design equipment which is frequency-sensitive. That is, the response of the equipment is determined by the frequency of the control signal. Before considering this tuning process, let us discuss another term which has been mentioned in previous assignments but has not been taken up in detail. This term is **impedance.**

Impedance

We have learned that resistors, coils and capacitors produce a certain amount of opposition to the flow of the current in a circuit. The opposition produced by a resistor is called **resistance,** and the opposition produced by a coil or a capacitor to the flow of current is called **reactance. Impedance** is the term used to indicate the opposition produced by a combination of resistance and capacity, resistance and inductance, or resistance, capacitance and inductance.

To illustrate the term **impedance** let us examine Figure 1. In Figure 1(A) we see a 100 ohm resistor, and a capacitor with 100 ohms reactance at the operating frequency, connected in series across a generator. Let us assume that the current flowing in this circuit is 1 ampere. We may apply Ohm's Law formula to find the voltage across the resistance.

$$E = IR$$

$$E = 1 \times 100 = 100 \text{ Volts}$$

We may also find the voltage drop across the capacitor by applying the formula:

$$E = I \times X_C$$

$$E = I \times 100 = 100 \text{ Volts}$$

We have already learned that we cannot add these two voltages directly to find the supply voltage, but rather must add them **vectorially.** Vectors for the circuit shown in Figure 1(A) are given in (B) of this figure. The current vector I is used as the reference vector. The voltage vector E_R is drawn in phase with this current and is drawn 100 units long.

Since the voltage across a capacitor lags the current by 90 degrees, the capacitor voltage vector E_C is drawn lagging the current vector I by 90 degrees. This vector is also 100 units long. We have found that to find the total voltage across this circuit these two voltages must be added vectorially. We do this by completing the parallelogram as explained previously. This is also shown in Figure 1(B). The resultant which we have labelled **E of Source** will be found to be 141 volts.

This vector diagram tells us that if the applied voltage is 141 volts, the current of one ampere will be forced through the circuit shown in Figure 1(A). In this diagram we found E_R by multiplying I x R, and we found E_C by multiplying I x X_C. Now, since the **current is the same in each of these Voltage drops** if the parts are in series (because the same current flows through each part of a series circuit), we may ignore it and draw our vector diagram to represent the resistance and the reactance only.

Figure 2 illustrates the manner in which this is done. First we draw the resistance vector R horizontal, making its length proportional to its value in ohms. Then we draw the capacitive reactance vector X_C straight down, also making its length proportional on the same scale to the ohmic value of the capacitive reactance. If the circuit consists of a coil and a resistor instead of a capacitor and a resistor, we draw the inductive reactance vector, X_L, straight up, again making the vector length proportional to the ohmic value of the reactance. Figure 2(A) shows the vector for a circuit with resistance and capacitance, and Figure 2(B) shows the vector for a circuit with resistance and inductance. In each diagram we have completed the parallelogram and drawn the diagonal vector. We have labelled this vector Z. Let us see just what this vector Z represents. In Figure 1(B) we see that a similar vector which we have labelled E of Source, represents the source voltage—the vector sum of all the voltage drops in the circuit. In the resistance-reactance diagram in Figure 2, the diagonal vector similarly represents the vectorial sum of the reactance and the resistance in the circuit. This is the **impedance** of the circuit—represented by the symbol Z and measured in ohms. The impedance of a circuit is a measure of the **total opposition** to the flow of an a-c current. This term includes the **resistance** and the **reactance** of the circuit.

After the impedance of the series circuit such as Figure 1(A) has been found, the product of the ohmic value of the impedance multiplied by the circuit current in amperes will equal the source voltage. To illustrate this point, let us look at Figure 2(A). R represents the 100 ohms resistance in the circuit in Figure 1, while X_C represents 100 ohms capacitive reactance of the capacitor of the circuit in Figure 1. If these two values are drawn to scale as shown in Figure 2(A), and Z is measured, it will be found to be 1.41 times as long as either R or X_C, or, in this case, the impedance will be 141 ohms. When this 141 ohms impedance is multiplied by the current of one ampere, the source voltage is found to be 141 volts. This is the same answer as obtained by the vector diagram shown in Figure 1(B). Let us write this in the form of a mathematical equation.

$$E = IZ.$$

By rearranging this formula algebraically, we can also find the following two equations:

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

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

These three equations are oft' times called the **Ohm's Law equations for a-c.** It will be noticed that they are exactly like the Ohm's Laws for d-c, except that impedance is substituted for resistance. The use of the first of these formulas has already been demonstrated. Let us demonstrate how to use the other two formulas. Suppose we know the impedance of a certain circuit to be 300 ohms and the voltage of the supply to be 600 volts. Let us find the current flowing in the circuit. We will apply the formula:

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

$$= \frac{600}{300}$$

$$= 2 \text{ amperes.}$$

To demonstrate the use of the other Ohm's Law a-c formula, let us assume that we know that the a-c generator voltage in a certain application is 1000 volts and that the current is 10 milliamperes. Let us find the impedance. We will put our known values in the formula:

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

$$= \frac{1000}{.01}$$

$$= 100{,}000 \text{ ohms.}$$

Another Way to Find Impedance

In the vectors of Figure 2, we have illustrated one method of determining the impedance of a series circuit when the resistance and the reactance are known. This vectorial method is very convenient and will often be used in calculations. However, there is one other method which is accurate and will also find wide application in solving a-c circuits. Later in the training program we will find why the following statement is true, but for the present we will merely accept it as being true. When the value of R and the value of either X_C or X_L is known, the value of Z may be found by the following equation:

$$Z = \sqrt{R^2 + X^2}$$

The term X was used in this equation rather than X_L or X_C. Either of these quantities could be used in this equation in place of the X. To illustrate the use of this equation, let us apply it to the circuit shown in Figure 1(A). In this circuit R is equal to 100, and X_C is equal to 100. Let us put these values in the equation and find the impedance of the circuit.

$$Z = \sqrt{100^2 + 100^2}$$
$$= \sqrt{10{,}000 + 10{,}000}$$
$$= \sqrt{20{,}000}$$
$$= \sqrt{2 \times 10^4}$$
$$= 10^2 \times \sqrt{2} \qquad \text{(the square root of } 10^4 \text{ is } 10^2\text{)}$$

If the square root of 2 is taken either by the long hand method as outlined in Assignment 7, or by using the square root table given in that assignment, it will be found to be 1.41. To complete the solving of our equation then,

$$Z = 10^2 \times 1.41 = 100 \times 1.41 = 141 \text{ ohms.}$$

Thus we see that the application of these equations has given us the third means of finding the circuit impedance. The first method is illustrated in Figure 1(B), the second method in Figure 2, and this is the third.

A few exercises in finding the impedance of circuits should "cement" this information in your mind. Figure 3 is for this purpose. You should, therefore, study it carefully. The vector method of finding Z is illustrated in (B) of this figure, and the mathematical solution is shown in (C) of this figure. Study this carefully until you are completely satisfied with the solutions given. Remember that the value of impedance (Z) is the total opposition produced by the circuit, to the flow of an alternating current.

Figure 4 shows a circuit similar to that of Figure 3, except the capacitor has been replaced by a coil whose reactance is 200 ohms. The vector solution to find the impedance of this series circuit is shown in (B) of this figure, and the mathematical solution is shown in (C).

From these examples, we see that it is not a difficult process to find the impedance of series circuits consisting of resistance and capacitance or resistance and inductance.

Now let us find the current which would flow in the circuit in Figure 3 and in Figure 4. We will apply the Ohm's Law formula for a-c which was given previously. In each case we would apply the formula as follows:

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

$$= \frac{448}{224}$$

$$= 2 \text{ amperes.}$$

Thus we see that 2 amperes of current would flow in the circuit of Figure 3 and also 2 amperes would flow in the circuit of Figure 4. As we have seen previously, the phase angle of the current in respect to the generator voltage would not be the same in the two cases. Since we know the current flowing through each component in these circuits and the ohmic resistance and reactance of each component, let us find the voltage drop across each component. In Figure 3, the voltage drop across the resistance will be found by the formula, $E = IR = 2 \times 100 = 200$ volts. The voltage drop across the capacitor will be found by the formula, $E = IX_C = 2 \times 200 = 400$ volts. Using a similar method, we would find the voltage across the resistor in Figure 4 to be 200 volts, and the voltage across the coil to be 400 volts. Of course these two voltages, in this case 200 volts and 400 volts, could be added vectorially as explained previously to obtain the generator voltage of 448 volts. From the theory we have learned previously, we know that the X_C (capacitive reactance) of 200 ohms of the capacitor in Figure 3 is the **opposition** the capacitor produces to the flow of a-c current in the circuit. Likewise, the 200 ohms of inductive reactance of the coil in Figure 4 is the **opposition** of that coil to the flow of a-c current.

Series Resonance

In Figure 5, we have connected a series circuit consisting of the same a-c generator as in Figure 3 and 4, the same value of resistance (100 ohms), a capacity with a reactance of 200 ohms and an inductance with a reactance of 200 ohms. Since we have added more components opposing the flow of current it would seem that less current would flow. To illustrate: In Figure 4, we had only 2 components, a resistance and an inductance. In Figure 3, we had 2 components opposing the flow of current, a resistor and a capacitance. Now in Figure 5, we have three components, a resistance, a capacitance, and an inductance. All of these produce a certain amount of opposition to the flow of current. Consequently, it would seem logical to assume that less current would flow in this circuit than in the previous circuits of Figure 3 or Figure 4. But such is **not** the case. We will find that instead of decreasing, the current will actually increase! If we were to measure the current flowing in the circuit in Figure 5, we would find there that the current was 4.48 amperes. Let us repeat what has happened; we have connected a resistance, a coil, and a capacitor all in series, yet the current flow increased instead of decreased. If we were to measure the voltage drop across the three components in the circuit, we would find voltages as indicated in Figure 5. The voltage drop across the resistance would be 448 volts. The voltage drop across the capacitor would be 896 volts, and the voltage drop across the inductance would be 896 volts.

The circuit shown in Figure 5 is a series circuit, therefore the same current flows through each of the components. (Actually current does not flow **through** the capacitor, but since it has the effect of flowing through the capacitor, it is common practice to say that a-c current flows through a capacitor.) The capacitor voltage **lags** behind the circuit current by 90 degrees, and the coil voltage **leads** the circuit current by 90 degrees. Therefore, the two voltages are 180 degrees out of phase with each other, which means that their effects are exactly opposite. Since these voltages are equal in size and opposite in effect, they cancel each other completely so far as the circuit is concerned. If a voltmeter were connected from point D to point E in Figure 5, it would read zero voltage. Since these two voltages are completely cancelling each other, the effects of the coil and capacitor are completely balancing each other. For this reason, the only circuit component in Figure 5 which is opposing the current flow is the 100 ohm resistor.

Figure 5(B) shows the vector diagram for this circuit. Notice that the inductive reactance vector, X_L, is shown leading the resistance by 90 degrees, and the capacitive reactance vector, X_C, is lagging the resistive vector by 90 degrees. X_L and X_C are equal vectors and 180 degrees out of phase. We have found in a previous assignment that to add vectors which are 180 degrees out of phase, we merely subtract the shorter one from the longer one. In this case, since they are equal, subtracting one from the other gives us zero. The net effect of X_L and X_C in this case is zero. The impedance (Z) is equal to the resistance. In this case, the impedance vector Z is equal to the resistance vector R. When a condition such as that shown in Figure 5 occurs; that is, **when the inductive reactance and the capacitive reactance are equal, the circuit is said to be resonant.**

This cancelling or balancing effect of the capacitor and the coil is always present to some extent in the series circuit containing a coil and a capacitor, whether or not resonance exists. That is, even when the coil and the capacitor reactances are not equal, **some** cancellation occurs. If the capacitor reactance is smaller than the coil reactance, its voltage drop will be smaller than the coil's voltage drop. The small voltage drop across the capacitor will balance out, or cancel, that amount of voltage of the voltage drop across the coil, and so cause a slight increase in circuit current over that which would flow if the coil were used alone. This same condition will hold true if the coil reactance is smaller than the capacitor reactance. This effect becomes extremely noticeable only when the inductive reactance and the capacitive reactance are equal for the **particular frequency** fed into the circuit; that is, when the circuit is at resonance. At resonance we get the large increase in circuit current as shown in Figure 5, where the only limitation to the current flow is the resistance of the circuit. To simplify the circuit shown in Figure 5, the value of inductive

reactance and the value of capacitive **reactance** were given. Also the frequency of the generator was indicated to be 1000 hertz. To obtain capacitive reactance of 200 ohms at 1000 hertz, the size of the capacitor would be .79 microfarads. To obtain an inductive reactance of 200 ohms at 1000 hertz, the value of the inductance would be 31.9 millihenries.

Figure 6 shows a circuit with the same generator, the same inductive reactance, and capacitive reactance as in Figure 5, but the resistance value has been **lowered.** In this figure, the X_C is equal to the X_L and we again have a resonant condition. The only component in the circuit which is opposing current flow is the 50 ohm resistor. We can apply our Ohm's Law formula to find the current flowing in this circuit.

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

$$= \frac{448}{50}$$

$$= 8.96 \text{ amperes.}$$

We may find the voltage drop across each component by applying the formula $E = IX$. The voltage across the capacitor will be 1792 volts, that across the coil will be 1792 volts, and the voltage drop across the resistor will be 448 volts. Notice what has happened in this circuit. The resistance value was lowered and the current increased. Also the voltage across the coil and capacitor increased greatly! This indicates that the value of the resistance in a series-resonant circuit is very important in determining the amount of current flowing in the circuit.

It would seem therefore, that we could produce an almost infinite amount of current flowing in these circuits, and an almost infinite voltage across either the capacitor or the coil by reducing the resistance value of the circuit to zero. This is not possible however, for one reason. The circuit components will have a certain amount of resistance in them. For example, the coil is wound from wire and consequently will have a certain amount of resistance. Also the connecting wires in the circuit will contain a certain amount of resistance, as will the leads of the capacitor. The source of our a-c current, in this case the generator, will have internal resistance which will be effectively in series with the circuit. In most cases, the resistance R in Figures 5 and 6 is not an actual resistor. The resistance shown in these diagrams is merely the lumped resistance of all of the resistances in the circuit, including the resistance of the leads, the resistance of the wire in the coil, and the internal resistance of the generator. By using a well designed coil, one with low resistance windings, it is possible to obtain a very high current in the series circuit such as Figure 6. With this high current, it is possible to obtain voltages across the coil and across the capacitor which are many times the voltage of the source. **Notice in Figure 6 that the generator voltage is 448 volts, yet the voltage drop across the coil is 1792 volts.** This is one of the most useful effects of a series-resonant circuit. The fact that much higher voltage will exist across the coil or the capacitor than exists across the source is called the **resonant rise of voltage**. In utilizing this resonant rise of voltage, the load, such as a vacuum tube or some other component, is connected across either the coil or the capacitor (not both of them). The effect of the resonant circuit has been to increase the voltage.

In Figure 6, the generator voltage is 448 volts, yet the voltage across the capacitor is four times this large. If an external circuit such as a vacuum tube is connected across this capacitor only, the effect of the circuit is to amplify the voltage from the generator, causing a larger voltage to appear across the capacitor and consequently to be applied to the input of the vacuum tube.

To further illustrate the resonant rise of voltage, let us assume the resistance R of Figure 6 was reduced to 10 ohms, by using a coil wound with large wire, large connecting leads, and a generator with low internal resistance. Since the generator frequency is still the same (1000 hertz), the X_C of the capacitor and the X_L of the coil will remain 200 ohms each, and their effects will cancel. The impedance (Z) will be equal to R, or 10 ohms in this case. The current will be:

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

$$= \frac{448}{10}$$

(Resonant rise in voltage)

$$= 44.8 \text{ amperes.}$$

The voltage across the capacitor will be: $E = IX_C = 44.8 \times 200 = 8960$ volts. The voltage across the coil will be 8960 volts also ($E = IX_L = 44.8 \times 200 = 8960$ volts). In actual practice, the source voltage will usually range from a small fraction of a volt to just a few volts. Under these conditions, the resonant rise of voltage produces an amplified voltage which will be many times larger than this. In certain cases this "amplified" voltage may be 100 or more times greater than the source voltage.

There is one point which should be emphasized. This is — these conditions occur only at resonance, for at this time the inductive reactance is equal to the capacitive reactance. In Figure 6, it was pointed out that the inductive reactance of 200 ohms and the capacitive reactance of 200 ohms were equal, and the applied frequency was 1000 hertz. If the applied frequency of this generator were to be changed to any other value, the circuit would no longer be resonant. From the theory which we have learned, we know that if **the frequency is increased, the reactance of a capacitor will decrease, and the reactance of a coil will increase.** Consequently, if in Figure 6 the frequency is changed from 1000 hertz to a higher frequency, X_C will decrease and X_L will increase. Under these conditions, the two are not completely cancelling each other out and the net result is that a certain amount of reactance will still be opposing the flow of current; consequently less current would flow in the circuit.

Figure 7 shows a graph of the current which would flow through the circuit shown in Figure 6, if the generator voltage were to be maintained constant at 448 volts, but the generator frequency changed over a range from 0 hertz (pure d-c) to 2000 hertz. Let us look at the curve A in Figure 7. This is the curve for the amount of current flowing in the circuit shown in Figure 6. Notice that at zero hertz (pure d-c), no current would flow in the circuit due to the fact that the capacitor will not pass d-c. As the frequency is gradually increased from zero cycles toward 1000 hertz, we notice that the current flow in the circuit increases also. As the frequency approaches 1000 hertz, notice that the current flow in the circuit increases sharply. At 1000 hertz, the current flow in the circuit is maximum and is 8.96 amperes as indicated on the graph. As the frequency is increased from 1000 hertz toward 2000 hertz, notice that the current flow in the circuit again decreases. This is due to the fact that the reactance of the coil to these higher frequencies becomes greater than the reactance of the capacitor. Therefore, the two reactances are not completely cancelling each other out.

Curve B of Figure 7 is a graph of the current which would flow in Figure 5, as the generator voltage is maintained constant at 448 volts, and the generator frequency was changed from zero hertz to 2000 hertz. Refer again to Figure 5 and notice that the X_C and X_L values are the same as those in Figure 6. The only difference between Figure 5 and Figure 6 is the value of the resistance R. In Figure 5, there is more resistance. Therefore at resonance less current will flow, since the resistance is the only limiting factor at resonance. This is shown in curve B of Figure 7. Notice that this curve is much flatter than curve A. Resonance occurs at the same point, but the current which flows at resonance is much smaller.

The Tuning Process

Figure 8 illustrates a method of using a series-resonant circuit in a radio receiver for the purpose of **tuning in** the desired station. Incoming signals cutting the conductor of the antenna will generate voltages in the antenna circuit between the antenna and ground. This will cause radio-frequency currents to flow through the circuit consisting of the coil and the capacitor in Figure 8. A vacuum-tube amplifier circuit is shown connected across the capacitor. That is—the grid is connected to one side of the capacitor, and the cathode of the vacuum-tube is connected to the other side of the capacitor. Remember that the grid voltage controls the plate current in a vacuum-tube. For explanation of the tuning process, let us assume that three signals of the same amplitude are generated in the antenna circuit. These three signals are shown at the left of Figure 8. One of these signals is at 1000 kilohertz, one at 1500 kilohertz and the third at 500 kilohertz. The amplitude of these three signals is the same.

Let us assume that the tuned series circuit is resonant at a frequency of 1000 kilohertz. At the right of Figure 8, we see the plate current which would flow in each case. Since the circuit is resonant to a frequency of 1000 kilohertz, a resonant rise of voltage will occur at this frequency. Therefore, the 1000 kilohertz signal will cause a large voltage to be developed across the capacitor, and this large voltage, being applied to the grid circuit of the vacuum-tube, will cause large changes in the plate current of that vacuum-tube. This is illustrated in Figure 8. When the 1500 kilohertz signal is applied to the antenna circuit, it is **off resonance**. No resonant rise of voltage occurs. For this reason only a small voltage will be developed across the capacitor at this frequency, and therefore plate current changes produced at this frequency are very small. This is also shown in Figure 8 at the right. The same conditions hold true for the 500 kilohertz signal which is applied to the antenna, and the plate current which would flow due to this signal is also shown in Figure 8. Notice this important point. The three signals which were generated in the antenna were all of the same amplitude. However, the plate current changes produced by the three signals were not the same. The plate current changes were large for the signal which was of the resonant frequency of the tuned circuit, and the plate current changes were small for the two signals which were off the resonant frequency of the tuned circuit. This illustrates how a tuned circuit is able to select the one desired signal and reject all others.

It will be noticed that the two unwanted signals, 500 kilohertz and 1500 kilohertz in this case, are not entirely rejected, as a certain amount of plate current change is produced by these two signals. For this reason, one tuned circuit is seldom used by itself in a radio receiver. As we shall see in our study of receivers in later assignments, it is common practice to use several tuned circuits. For example, a tuned circuit would be used in a manner similar to that shown in Figure 8. The plate circuit of the vacuum tube of Figure 8 would be coupled to another tuned circuit which would add its tuning effect to that of the antenna circuit. In this manner, the circuits are able to select the desired frequency and reject **all** others.

Refer again to Figure 8. The question probably arises, what would we do if we wanted the 1500 kilohertz signal, and did not desire the 1000 kilohertz signal and the 500 kilohertz signal? This is the condition which we have in a normal radio receiver. Many stations are on the air simultaneously, and we are able to tune in the desired one and reject the others. At will, we are able to **change from one station to another**. We do this by changing either the inductance or the capacity. In the circuit shown in Figure 8, a variable capacitor is shown in the series circuit. In our study of capacitors, we learned that such capacitors are so constructed that their capacity may be varied by rotating the shaft on the capacitor. To tune in the 1500 kilohertz signal in Figure 8, the tuning capacitor would be adjusted so that its capacity would be **smaller**. At one particular point, the capacitive reactance of a smaller capacitor would equal the inductive reactance of the coil at 1500 kilohertz and resonance would then occur at this frequency. This will be demonstrated by the following mathematical formula.

It has been stated a number of times that at resonance X_L is equal to X_C.

$$X_L = X_C, \quad X_L = 2\pi fL, \quad X_C = \frac{1}{2\pi fC}$$

$$2\pi fL = \frac{1}{2\pi fC}$$

$$\frac{\cancel{2\pi fL}}{\cancel{2\pi fL}} = \frac{1}{2\pi fC\,(2\pi fL)}$$

$$1 = \frac{1}{4\pi^2 f^2 LC}$$

$$M:\ f^2 \qquad f^2 = \frac{\cancel{f^2}}{4\pi^2\cancel{f^2}LC}$$

$$f^2 = \frac{1}{4\pi^2 LC}$$

$$\sqrt{f^2} = \sqrt{\frac{1}{4\pi^2 LC}}$$

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

Finding the Resonant Frequency

This new formula is the one which may be used for finding the resonant frequency when the inductance and the capacitance are known Let us solve a typical circuit to find the resonant frequency by this formula. For example, let us suppose that the value of the inductance in Figure 8 is 500 microhenries, and the value of the capacitor at one setting is 50 picofarads.

$$L = 500\ \mu\text{henries} = 500 \times 10^{-6}$$

$$C = 50\ \text{picofarads} = 50 \times 10^{-12}$$

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

$$f = \frac{1}{2\pi\sqrt{500 \times 10^{-6} \times 50 \times 10^{-12}}}$$

$$f = \frac{1}{2\pi\sqrt{25{,}000 \times 10^{-18}}}$$

(Note: $\frac{1}{2\pi}$ is equal to .159; the square root of 10^{-16} is equal to 10^{-8})

$$f = \frac{1}{2\pi\sqrt{250 \times 10^{-16}}}$$

(Note: The square root of 250 is approximately 15.8)

$$f = \frac{.159}{10^{-8}\sqrt{250}}$$

$$f = \frac{.159 \times 10^{8}}{15.8}$$

$$f = \frac{15.9 \times 10^{6}}{15.8}$$

$f = 1 \times 10^{6} = 1000$ kilohertz.

This shows that the resonant frequency of the tuned circuit is 1000 kilohertz. Now let us suppose that the capacity of the variable capacitor is adjusted until it is now 22.5 picofarads. Let us now find the resonant frequency of the tuned circuit.

$L = 500$ microhenries $= 500 \times 10^{-6}$
$C = 22.5$ picofarads $= 22.5 \times 10^{-12}$

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

$$f = \frac{1}{2\pi\sqrt{22.5 \times 10^{-12} \times 500 \times 10^{-6}}}$$

$$f = \frac{1}{2\pi\sqrt{11{,}250 \times 10^{-18}}}$$

$$f = \frac{1}{2\pi\sqrt{112.5 \times 10^{-16}}}$$

(Note: The square root of 10^{-16} is 10^{-8} and the square root of 112.5 is approximately 10.6)

$$f = \frac{.159}{10.6 \times 10^{-8}}$$

$$f = \frac{.159 \times 10^{8}}{10.6}$$

$$f = \frac{15.9 \times 10^{6}}{10.6}$$

$f = 1.5 \times 10^{6} = 1500$ kilohertz.

Study these two examples very carefully to make sure that you understand exactly what has taken place. The small coil used in each of these problems, a 500 microhenry coil. With the capacitor set at one point, the resonant frequency of the circuit was 1000 kilohertz. When the capacity of the capacitor was decreased, the resonant frequency increased. Notice that the capacitor was changed from 50 picofarads to 22.5 picofarads. The resonant frequency increased from 1000 kilohertz to 1500 kilohertz. This should show clearly the operation of the tuning process in a radio receiver. With the capacitor set as in the first example, the 1000 kilohertz signal would be **tuned in** and with the capacitor set as in the second example, a 1500 kilohertz signal would be **tuned in.**

It is also possible to make a tuned circuit adjustable by using a variable inductance and a fixed capacitor. This is being done in some of the modern receivers. For example, if the circuit consisted of a fixed capacitor of 50 picofarads and of a variable inductance, and if the variable inductance were adjusted to 500 microhenries as in our first problem, the resonant frequency would be 1000 kilohertz. Then if the variable inductance were changed so that its inductance was now 225 microhenries, the resonant frequency would be 1500 kilohertz. If you wish, you may place these two values in the frequency formula given and check the resonant frequency of 1500 kilohertz for your own benefit. In passing, it might be well to point out the very great benefit from using powers of ten in the solution to this type of problem. It can be seen in the two examples given that if powers of ten were not used, these problems would be very long and tedious. It would also be very difficult to properly locate the decimal point in the answer. Through powers of ten, most of the work can be done in your head and very little paper work is required.

One other thing which should be emphasized concerning the frequency of the tuned circuit is the LC value. In the formula, it will be noted that $f = \frac{1}{2\pi \sqrt{LC}}$ For a given frequency, this value of L times C is a fixed value. Any combination of capacity and inductance which will give the fixed value of LC will produce the same resonant frequency. To illustrate this point, in the first example given, the resonant frequency was 1000 kilohertz, L was 500 microhenries and C was 50 picofarads. Multiplying these two together gives us $25{,}000 \times 10^{-18}$. Any other values of L and C which, when multiplied together, will give $25{,}000 \times 10^{-18}$ will also produce the same resonant frequency. For example, if the inductance was 250 microhenries, and the capacitance was 100 picofarads, the resonant frequency would be the same: 1000 kilohertz. Or if the inductance was 1000 microhenries, a capacitance of 25 picofarads would produce resonance at 1000 kHz.

Before proceeding with parallel resonance, let us consider one more factor concerning series-tuned circuits. In a series circuit, at resonance the X_L is equal to the X_C. But we may wonder how the circuit operates when the circuit is tuned to one frequency and another is applied. We have seen in Figure 8, that the resonant rise of voltage or "amplification" is not obtained, but one other factor should be pointed out. This is the fact that at frequencies off of the resonant frequency, a tuned circuit no longer acts like a resistance. It was pointed out that at resonance the series tuned circuit looked like a resistance, since the inductive reactance and the capacitive reactance cancelled each other out. At some frequency other than the resonant frequency, the reactance becomes predominant. For example, refer to Figure 7. The circuit is tuned to 1000 hertz. Let us assume that the generator frequency is 500 hertz. In this case, the capacitive reactance will be much greater than the inductive reactance. You may also compute this from the formula given to prove it to your own satisfaction. Since the capacitive reactance at this frequency is much higher than the inductive reactance at this frequency, the capacitive reactance is the component which is producing the main opposition to the flow of current in the circuit. Therefore, this circuit will act **as a capacity.**

To generalize, we might say: When a frequency other than the resonant frequency is applied to a **series tuned circuit**, the circuit will act the same as **that reactance which is the larger, or is predominant.** In the case of applying 500 hertz to the tuned circuit which is resonant to 1000 hertz, the capacitive reactance is larger than the inductive reactance, consequently the circuit will act like a capacitor. In other words, the current drawn from the source will be leading the supply voltage. On the other side of resonance, for example, if 1500 hertz were applied to the resonant circuit whose graph is shown in Figure 7, the inductive reactance is predominant and therefore the circuit will act as an inductance.

RES. RISE = SOURCE Voltage X Q

Summary of Series Circuit

Let us summarize what we have learned about the series circuit. (1) at resonance, the only opposition to the flow of current is the resistance in the circuit. We could state this in the form of an equation. This equation would be, $Z = R$; that is, the impedance of the circuit is equal to the resistance. (2) At resonance, the voltage drop across the inductance is equal to the voltage drop across the capacitor and 180 degrees out of phase with this voltage. (3) Since the resistance of a tuned circuit is usually low, in the order of a few ohms, the impedance of a series-tuned circuit is very low at resonance and a high value of current will flow. (4) The resonant frequency of a series-tuned circuit may be changed by changing either the value of L or C in the circuit. Decreasing either of these will increase the resonant frequency, and increasing either of these will decrease the resonant frequency.

Parallel-Resonant Circuits

In the series-tuned circuit which we have been considering, the generator voltage has been applied in series with the coil and the capacitor. Let us now consider a circuit such as the one shown in Figure 9, wherein the generator voltage is applied to the coil and capacitor in parallel. Look at this figure closely to make sure that you understand the difference between this parallel circuit and the series circuit, which we have been considering. In this circuit, we have used the same coil and capacitor as in Figures 5 and 6. The capacitive reactance is 200 ohms, and the inductive reactance is 200 ohms. Notice that we have connected three meters in this circuit. Meter M_1 reads the current drawn from the generator, meter M_2 reads the current flowing through the capacitor, and meter M_3 reads the current flowing through the inductance. Since we are using the same values of inductance and capacitance as were used in Figures 5 and 6, it would seem that a similar condition would happen; that is, it would seem that the current drawn from the generator would be maximum. However, such is not the case! We would find that meter M_1, which indicates the current drawn from the generator will indicate only a **very low** value of current flowing. Also meters M_2 and M_3 would indicate a **very high** value of current flowing. At first glance, this would seem to be an impossibility, but here again he have neglected the phase angle. It will be recalled that in a parallel circuit each component will have the same applied voltage. In this case, the generator voltage is applied to both the coil and the capacitor. The capacitor draws a current which leads this applied voltage by 90 degrees, and the coil draws a current which lags this applied voltage by 90 degrees. This is shown in the vector diagram in Figure 9(B). The current flowing in the coil and the capacitor are 180 degrees out of phase, since one is leading the applied voltage by 90 degrees, and the other is lagging the applied voltage by 90 degrees. The current drawn from the generator as indicated by meter M_1 is the difference between these two values of current, and if the coil and capacitor had zero resistance, there would be no current flowing at all through meter M_1. If we will consider what we have learned about coils and capacitors, we will see why such a thing is possible.

We have learned that a capacitor stores energy in the form of electrostatic lines of force, and that a coil stores energy in the form of magnetic lines of force. What actually happens in the parallel-resonant circuit is that once the operation has been started, the coil stores energy in the form of magnetic lines of force. Then as these lines of force collapse, they generate a voltage which charges the capacitor and energy is then stored in the capacitor in the form of electrostatic lines of force. After the coil's magnetic lines of force have collapsed, there is no longer a voltage across the coil and the capacitor will now discharge through the coil, again setting up magnetic lines of force. To simplify this explanation, we might say that the energy is stored in first the coil, then the capacitor, then the coil, etc. This back and forth process will continue, and the only energy which is drawn from the generator will be that which will be required to overcome the losses in the tuned circuit due to the resistance of the coil, capacitor, and interconnecting leads. In most applications, the major portion of this resistance will be located in the windings of the coil.

The formula for finding the resonant frequency of a parallel-resonant circuit is the same as that of the series-resonant circuit. Therefore, the values of capacitance and inductance which are shown in Figure 9 will make this circuit resonant at 1000 hertz, just as these same values of coil and capacity made the circuits in Figures 5 and 6 resonant at 1000 hertz. This is about the only thing which is similar between a parallel-resonant circuit and the series-resonant circuit. It was shown that in the series-resonant circuit, that the current flowing from the generator was maximum at resonance, yet we see in the parallel-resonant circuit, that the current from the generator is minimum at resonance. Also it was pointed out, that the impedance of the series-resonant circuit was very low at resonance. The formula, of course, being $Z = R$. If the resistance of the coil, capacitor and interconnecting leads were made low, the current from the generator in the series circuit was very high. In the parallel-resonant circuit, just the opposite occurs. If the resistance of the coil, capacitor, and interconnecting leads is made very low, the line current is also very low. We have stated previously that $Z = \frac{E}{I}$. Since the applied voltage is the generator voltage, and the line current is very low, it can be seen that the impedance of this circuit will be very high.

One other point in which the parallel circuit is entirely different from the series circuit, is the fact that in the series circuit we obtain a **resonant rise of voltage.** In the parallel-resonant circuit we obtain a resonant rise of current. The current flowing in the resonant circuit is indicated by meters M_2 and M_3 is very high. This current will be many times the value of the line current as indicated by meter M_1.

It is the fact that the impedance of a parallel circuit is high at the resonant frequency that makes this circuit application so frequent. The curves in Figure 10 show the impedance of the typical parallel-resonant circuit. Curve A in this figure shows the impedance curve for the parallel circuit when the resistance of the circuit is low. (By resistance, we mean the resistance of the coil, capacitor and interconnecting leads.) In this case, it will noticed that the impedance of the circuit at resonance is very high. Resonance in the circuit occurs at 1000 kilohertz. The impedance, as indicated by curve A at 1000 kilohertz, is approximately 115,000 ohms. The curve shown in Figure B is for a parallel-resonant circuit which is resonant at the same point (1000 kilohertz), but which has higher resistance in the windings, etc. The resonant impedance of this circuit is about 70,000 ohms. Notice that at frequencies off resonance, the impedance of the parallel-resonant circuit falls off very sharply. For example in curve A of Figure 10, at just 5 kilohertz off of the resonant frequency, the impedance has dropped from approximately 115,000 ohms to approximately 70,000 ohms. At a point just 40 kilohertz off resonance, the impedance has dropped to approximately 10,000 ohms. To thoroughly explain why a high impedance is of value in a vacuum tube circuit would require more vacuum tube theory than has been covered in the training program previously. But it can be said that the high impedance which can be obtained from a parallel-resonant circuit enables a vacuum tube amplifier to amplify much more. The parallel-tuned circuit is **often** connected in the plate circuit of a tube.

Suppose the parallel-tuned circuit, whose curve is shown at A in Figure 10, were to be connected into a vacuum tube amplifier circuit similar to the one shown in Figure 11. As mentioned, to fully explain the operation of this circuit would require more vacuum tube theory than we have had at present. But we have learned that amplification in a vacuum tube takes place due to the changing plate current producing a voltage drop across the load impedance of the plate circuit of the vacuum tube. In this circuit, the parallel-resonant circuit forms the load impedance of the vacuum tube. When this load impedance is high, the vacuum tube will amplify greatly, and when this load impedance is low, the amplifier will not amplify greatly. Suppose now that three signals were applied to the input of this circuit. Referring to Figure 10, let us assume that each signal has the same amplitude but that one signal is on the resonant frequency of the tuned circuit (1000 kilohertz), another signal is on the frequency of 960 kilohertz, and the third signal is at the frequency of 1040 kilohertz. Remember, that under normal conditions, the amount of amplification which the vacuum tube circuit will produce is directly proportional to the value of load impedance. Since the three signals which were applied to the grid circuit have the same amplitude, the one at 1000 kilohertz will be amplified by this amplifier much more than the other two, due to the fact that the impedance of the parallel-resonant circuit is very high at this particular frequency. The other two signals will find a low impedance in the parallel-resonant circuit. Therefore, the vacuum tube amplifier will produce only a weak output signal from the two frequencies, 960 and 1040 kilohertz. Thus, we see that the parallel-resonant circuit can also be used for tuning in the desired signal and rejecting the unwanted signals. For example, the 1000 kilohertz signal to which we were tuned is the desired signal, and the 960 kilohertz and 1040 kilohertz signals are two unwanted signals. Since the vacuum tube amplified the desired signal a great deal more (approximately twelve times as much), it will make the desired signal of sufficient strength to be heard in the output from our radio, whereas the undesired signals will be practically eliminated. To add to this action, as has been mentioned previously, several such stages will be used and their actions will combine to eliminate, for all practical purposes, the unwanted signals and produce only the wanted signals.

Refer again to Figure 9 to determine what happens to the line current as the generator frequency is changed. We have seen that the line current would be very low when the generator frequency was 1000 hertz, which is the resonant frequency of the coil and capacitor combination in this diagram. If the generator frequency is changed to either side of this resonant point, that is, if it is increased or decreased, it will be found that the line current will increase. To illustrate: If the generator frequency were changed to 1500 hertz, it would be found that the line current has increased greatly. Let us examine Figure 9 to see why this is true. As the frequency increases, the reactance of the capacitor will decrease. Also the reactance of the coil will increase. Consequently, since the same voltage is applied to each, the capacitor will draw an increased current, while the inductance will draw a decreased current. Or to state this differently, the capacitor current will be much greater than the coil current. The line current as read by meter M_1 will be the difference between these two, and since the capacitive current is much greater than the inductive current, the line current will be much greater than previously. Since in this case, the line current is produced by the large value of capacitive current and the small value of inductive current, the tuned circuit acts as a capacitor when the generator frequency is higher than the resonant frequency. In this case, the generator frequency is higher than the resonant frequency of the tuned circuit and the current which flows from the generator will act as though a capacitor was being used as the load. That is: The current will lead the generator voltage by approximately 90 degrees. Notice that here again the parallel-resonant circuit is exactly opposite the series circuit. In the series circuit, if a frequency higher than the resonant frequency were applied, the entire circuit would appear as an inductance, but in the parallel-resonant circuit when a higher than resonant frequency is applied, the entire circuit appears to be a capacitor. Of course, just the opposite effects occur if a frequency lower than resonant frequency is applied to the tuned circuit.

Effect of Q on Resonance

In our study of coils and capacitors, we learned that losses in capacitors were very low. That is, for capacitors such as are normally used in a tuned circuit (air dielectric capacitors or mica capacitors) the losses are very low. However, coil losses are high compared to capacitor losses since coils are wound of wire and therefore have resistance. We also learned a term which took the coil losses into consideration. This term was the Q of the coil. This Q, which is oft' times called the "factor of merit" of the coil, can be found by the formula $Q = \frac{X_L}{R}$. As practically all the loss in a resonant circuit occurs in the coil, we usually assume that the coil Q is also the Q of the resonant circuit using that coil. This factor (Q) applies to both series and parallel-resonant circuits.

To illustrate the effect of Q on a tuned circuit, consider Figure 7. It will be recalled that these are the current curves for a series circuit. In curve A, we find that the resistance is 50 ohms while in curve B, the resistance is 100 ohms. It was given in the figures that the inductive reactance X_L was 200 ohms, therefore we could easily compute the Q of two curves shown in Figure 7. The Q's are shown in this figure. In Figure 7(A), the Q is 4 and the curve in 7(B) is 2. If the Q of the series-resonant circuit is known, the value of voltage drop which can be obtained across the coil or capacitor can be found by multiplying the generator voltage by the Q. For example, notice Figure 6. In this case, the Q of the circuit is 4. Multiplying the generator voltage of 448 by 4 will give us 1792 volts, which is the voltage across the capacitor; whereas in Figure 5, the Q was only 2 and the voltage across the capacitor was only twice that of the generator voltage. Thus, we see that the resonant rise of voltage obtained from a series-resonant circuit is directly dependent upon the Q of the coil. For this reason, it is advantageous to use a coil which has as high a Q as possible.

The effect of Q upon a parallel circuit is also very important. For example, the curves in Figure 10 are for the same resonant condition, except the Q of the coil is 125 in the curve shown at (A) and is 75 in the curve shown at (B). The impedance of the curve at (A) is much greater than the impedance of the curve shown in (B) of Figure 10. A practical formula for finding the impedance of a parallel-resonant circuit at resonance is:

$$Z = 2\pi fL \times Q.$$

in parallel

This formula shows that the impedance is directly proportional to the Q of the coil. For this reason, it can be seen that a high-Q coil should always be used in a parallel-resonant circuit also. The circuit, such as the one illustrated in curve A of Figure 10, will do a much more thorough job of **tuning in** the desired signal than would the curve as shown in (B). To illustrate this, if two signals were appearing on the input of a vacuum tube circuit with a parallel circuit whose Q was 125, as illustrated in (A) of Figure 10, and the frequency of one of these signals was 1000 kilohertz and the other was 1005 kilohertz, the ratio of the amplification of the stage of these two frequencies would be 115 over 70, or almost twice as much amplification for the desired signal as for the unwanted signal. If these same two signals were applied to the circuit with a Q of 75 as illustrated in (B) of Figure 10, the relative amplification of the 1000 kilohertz signal and the 1005 kilohertz signal would be approximately 70 to 55. Thus we see that the high-Q circuit will do a much better job of selecting the desired signal and rejecting the unwanted signal. Such a process is called the selectivity of the tuned circuit, and a high-Q circuit will be found to have a much better selectivity than a low-Q circuit. For this reason, it is highly desirable to use high-Q circuits as tuned circuits in a radio receiver.

The step by step comparison of the series-resonant circuits and the parallel-resonant circuits is given on page 22 of this assignment. Examine this comparison carefully, and see if you understand the meaning of each statement and the reason for each statement. If this page is well understood, the subject of resonance is well fixed in your mind.

The question often arises, "How can I tell whether a circuit is the series-resonant type or the parallel-resonant type when I see it in the electronics diagram"? Generally speaking, it is very easy to determine whether a circuit is acting as a series-resonant or a parallel-resonant circuit. **The determining factor is the manner in which the generator is connected to the coil and capacitor in question.**

If the generator, or source voltage (source might be receiving antennas, plate circuits of vacuum-tubes, transformer primaries, etc.), for the resonant circuit is **in series** with the coil and the capacitor, the circuit will act as a series-resonant circuit. If the source for the resonant circuit is connected in parallel with **both the coil and the capacitor,** the circuit will act as a parallel-resonant circuit.

Figure 12 shows some typical resonant circuits and explains whether they are acting as a series or a parallel-resonant circuit. Figure 12(A) shows a series-resonant circuit in which there can be little doubt about the way the circuit is connected. Likewise, Figure 12(B) shows a parallel-resonant circuit which is clearly understandable. Figure 12(C) shows another parallel-resonant circuit which was explained in Figure 11. These circuits are used very much. Look at Figure 12(D) carefully. Notice that the parallel-resonant circuit, such as was shown in Figure 12(C), is included in the plate of the vacuum-tube. The coil in this resonant circuit forms the primary of a radio-frequency transformer (an air-core transformer). Notice that the diagram in Figure 12(D) states that the secondary circuit of this transformer forms a series-resonant circuit. At first glance, this would seem to be a parallel-resonant circuit, since it looks like the coil and the capacitor are in parallel with the source voltage which is the induced voltage from the primary. This is a popular misconception. The decision as to whether this is a series or parallel circuit lies in the manner in which the voltage is applied to this circuit. It will be recalled that in a transformer the magnetic lines of force from the primary cut the turns of the secondary and induce a voltage **into** the secondary winding. Notice that the **voltage is induced in series with the secondary windings,** and we have a condition which is much the same as that illustrated in Figure 12(E). In this case, the coil which is the secondary of the transformer shown in Figure 12(D) has been opened in the middle and the generator has been inserted in series with this coil. Now if the circuit is carefully analyzed, it will be seen that the coil, the capacitor, and the generator are all in series. Therefore this circuit will act as a series-resonant circuit. Since the secondary voltage is induced in series with the windings, the secondary circuit of the transformer in Figure 12(D) will act as a series-resonant circuit. Let us emphasize this point. The tuned secondary of a transformer will act as a series-resonant circuit. The resonant rise of voltage will produce a large voltage drop across the capacitor which is applied directly to the grid circuit of the vacuum tube.

At this point, it will be found interesting and informative to refer to your tube manual. Locate a circuit showing a complete schematic diagram for a superheterodyne receiver using vacuum tubes. Notice the large number of tuned circuits used in this receiver. Some of these include the tuned circuits in the grid and plate circuits of the converter and IF amplifier tubes.

Notice that the **primary** of the transformer between the converter and IF amplifier is a parallel-resonant circuit. The circuit consisting of the secondary winding of this transformer forms a series-resonant circuit in the grid circuit of the IF amplifier. Notice how closely this circuit compares with Figure 12(D). These circuits are called I-F transformers (Intermediate-Frequency transformers) and are tuned to 455 kHz in most broadcast receivers.

The tuned circuits in the receiver are all working together to perform one job. That job is to **tune in** the desired station and **tune out** all of the thousands of unwanted stations.

When we study radio-frequency amplifiers and oscillators in receivers, transmitters, and electronics equipment in detail, we will find that resonant circuits are used very widely in these applications. We have seen that it is the use of these resonant circuits that make possible the tuning process in a radio receiver. Without this tuning process which is produced by resonant circuits, radio as it is known today would be impossible. There would be no method of tuning in the desired station from the thousands operating at all times; consequently it would not be possible to listen to only one radio station. In industrial electronics, for example in an induction heating unit, without the amplification which can be obtained through the use of tuned circuits, it would be impossible to build up radio-frequency signals to the amount of power required to perform the desired heat treating. For these reasons, the clear understanding of resonant circuits cannot be over emphasized. You are advised to read this assignment several times and study each individual part step by step to make sure that you clearly understand the action of the two fundamental types of resonant circuits. If, in future assignments on radio-frequency amplifiers, etc., a question arises in your mind concerning the action of the resonant circuit, refer to this assignment to clear the matter up.

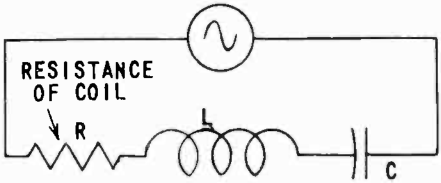
"HOW TO PRONOUNCE . . ."

(Note: the accent falls on the part shown in CAPITAL letters.)

capacitive	ka-PASS-ih-teeve
resonance	REZZ-uh-nance

Step by Step Comparison of Series and Parallel-Resonant Circuits

Series-Resonant Circuit

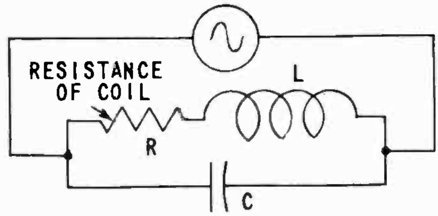


1. The generator, coil, and the capacitor are all in series.
2. At resonance, the line current supplied by the generator is **maximum.**
3. Resonance occurs when $X_L = X_C$.
4. At resonance, $Z = R$.
5. At resonance, the impedance is minimum.
6. At resonance, the current from the generator is maximum.
7. At resonance, the same current flows through each component, and the voltage drops across the coil and capacitor are 180° out of phase.
8. At resonance, a **resonant rise of voltage** is obtained across either the coil or the capacitor.
9. The resonant frequency may be found by the formula:

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

10. Decreasing L or C will increase the resonant frequency.
11. Increasing L or C will decrease the resonant frequency.
12. At resonance the circuit acts as a **low** value of resistance.

Parallel-Resonant Circuit



1. The generator, coil, and the capacitor are all in parallel.
2. At resonance, the line current supplied by the generator is **minimum.**
3. Resonance occurs when $X_L = X_C$.
4. At resonance, $Z = 2\pi fLQ$.
5. At resonance, the impedance is maximum.
6. At resonance, the current from the generator is minimum.
7. At resonance, the same voltage (the generator voltage) is applied to the coil and capacitor, and the two currents are 180° out of phase.
8. At resonance, a **resonant rise of current** is obtained in the coil and the capacitor.
9. The resonant frequency may be found by the formula:

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

10. Decreasing L or C will increase the resonant frequency.
11. Increasing L or C will decrease the resonant frequency.
12. At resonance the circuit acts as a **high** value of resistance.

13. If a frequency higher than the resonant frequency is applied, the circuit will act as an inductance.
14. If a frequency lower than the resonant frequency is applied, the circuit will act as a capacitance.

13. If a frequency higher than the resonant frequency is applied, the circuit will act as a capacitance.
14. If a frequency lower than the resonant frequency is applied, the circuit will act as an inductance.

ASSIGNMENT 21

TEST QUESTIONS

Use a multiple-choice answer sheet for your answers to this assignment.

The questions on this test are of the multiple-choice type. In each case four answers will be given, one of which is the correct answer, except in cases where two answers are required, as indicated. To indicate your choice of the correct answer, **mark out** the letter opposite the question number on the answer sheet which corresponds to the correct answer. For example, if you feel that answer (A) is correct for Question No. 1, indicate your preference on the answer sheet as follows:

1. ~~(A)~~ (B) (C) (D)

Submit your anwers to this assignment immediately after you finish them. This will give you the greatest possible benefit from our personal grading service.

1. At resonance, a parallel-resonant circuit acts like:

   (A) A low resistance.
   (B) A coil.
   (C) A high resistance.
   (D) A capacitor.

2. (CHECK TWO)

   (A) In a series-resonant circuit, the current flow is at a high value.
   (B) In a series-resonant circuit, the current flow is at a low value.
   (C) The impedance of a parallel-resonant circuit is maximum at resonance.
   (D) The impedance of a parallel-resonant circuit is minimum at resonance.

3. In a series-resonant circuit, what is the phase relationship of the voltage drop across the coil and the voltage drop across the capacitor?

   (A) They are in phase.
   (B) They are 180 degrees out of phase.
   (C) The voltage drop across the coil leads the voltage drop across the capacitor by 90 degrees.
   (D) The voltage drop across the coil lags the voltage drop across the capacitor by 90 degrees.

4. The tuned secondary of a transformer acts as a:

   (A) Series-resonant circuit. (C) Capacitor.
   (B) Parallel-resonant circuit. (D) Inductance.

5. (CHECK TWO)

(A) A high degree of selectivity will be produced by a tuned circuit containing a coil with a low Q.
(B) A high degree of selectivity will be produced by a tuned circuit containing a coil with a high Q.
(C) A high degree of selectivity will be produced by a tuned circuit containing a coil with low resistance.
(D) A high degree of selectivity will be produced by a tuned circuit containing a coil with high resistance.

6. If a variable capacitor in a resonant circuit tuned to a frequency of 1200 kilohertz is so adjusted that it has a larger capacity, the resonant frequency will:

(A) Increase.
(B) Decrease.
(C) Remain the same.
(D) Become a multiple of its former frequency.

7. If the Q of a coil in a series-resonant circuit is 10, the applied generator voltage is 110 volts, what will be the value of the voltage across the capacitor?

(A) 110 volts
(B) 11 volts
(C) 1100 volts
(D) 120 volts

8. What will be the resonant frequency of a parallel-resonant circuit which contains a coil with 100 microhenries and a capacitor of 100 picofarads?

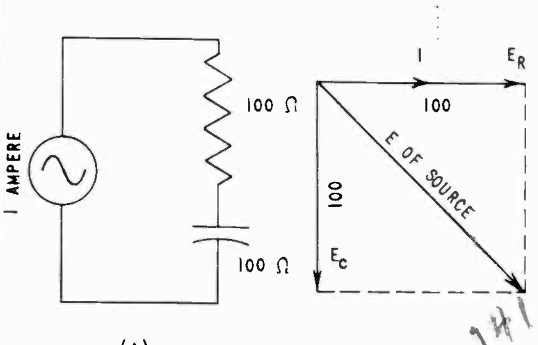
(A) 1590 kilohertz.
(B) 15.90 megahertz.
(C) 15,900 hertz.
(D) 1 megahertz.

9. The term **impedance** means:

(A) The opposition offered by a coil to the flow of an a-c current.
(B) The opposition offered by a capacitor to the flow of an a-c current.
(C) The total opposition offered by a coil, capacitor and resistance to the flow of an a-c current.
(D) The opposition offered by a resistance to the flow of an a-c current.

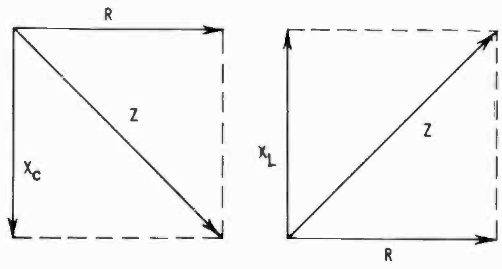
10. What letter is used in formulas to represent impedance?

(A) X
(B) Z
(C) R
(D) I



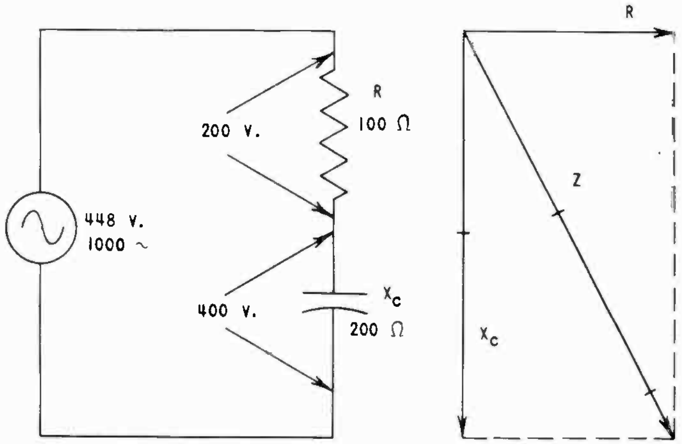
(A) (B)

FIGURE 1



(A) (B)

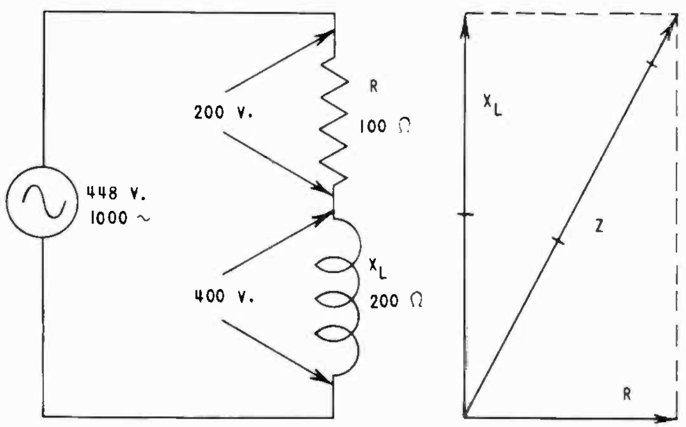
FIGURE 2



$$Z = \sqrt{R^2 + (X)^2}$$
$$Z = \sqrt{100^2 + 200^2}$$
$$Z = \sqrt{10000 + 40000}$$
$$Z = \sqrt{50000}$$
$$Z = \sqrt{5 \times 10^4}$$
$$Z = 10^2\sqrt{5}$$
$$Z = 10^2 \times 2.24$$
$$Z = 224\ \Omega$$

(A) (B) (C)

FIGURE 3



$$Z = \sqrt{R^2 + (X)^2}$$
$$Z = \sqrt{100^2 + 200^2}$$
$$Z = \sqrt{50000}$$
$$Z = 224\ \Omega$$

(A) (B) (C)

FIGURE 4

21

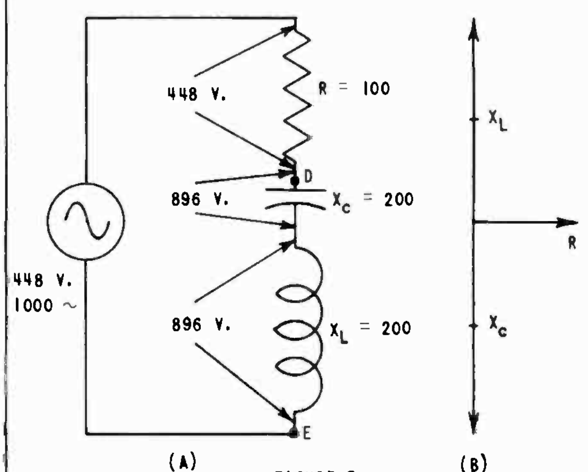


FIGURE 5

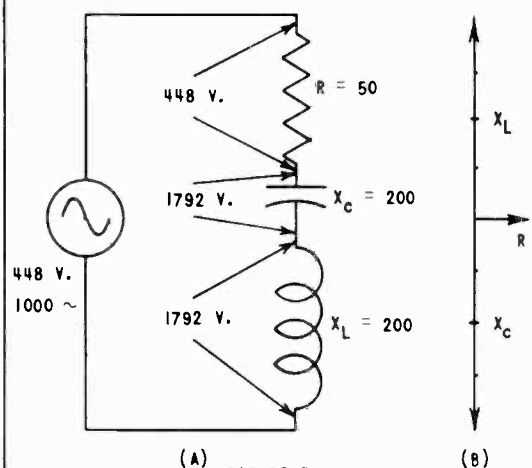


FIGURE 6

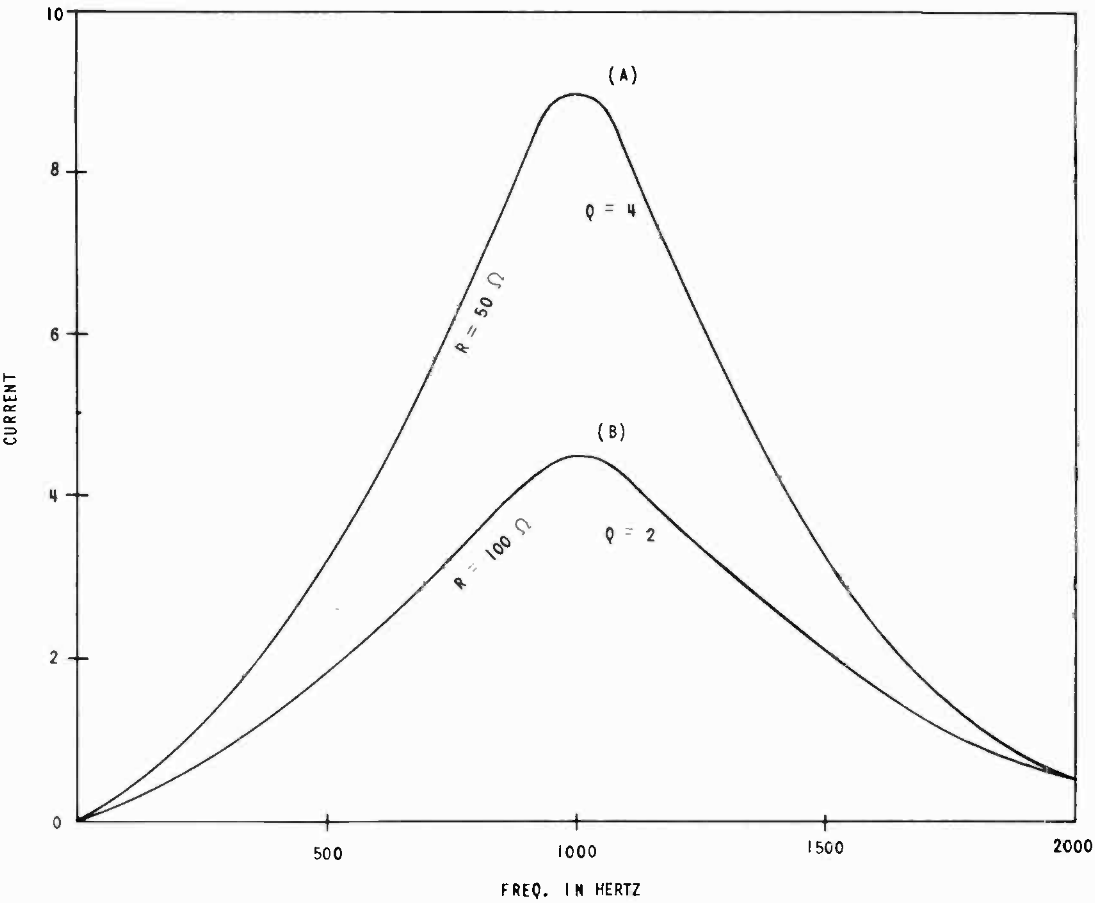


FIGURE 7

21

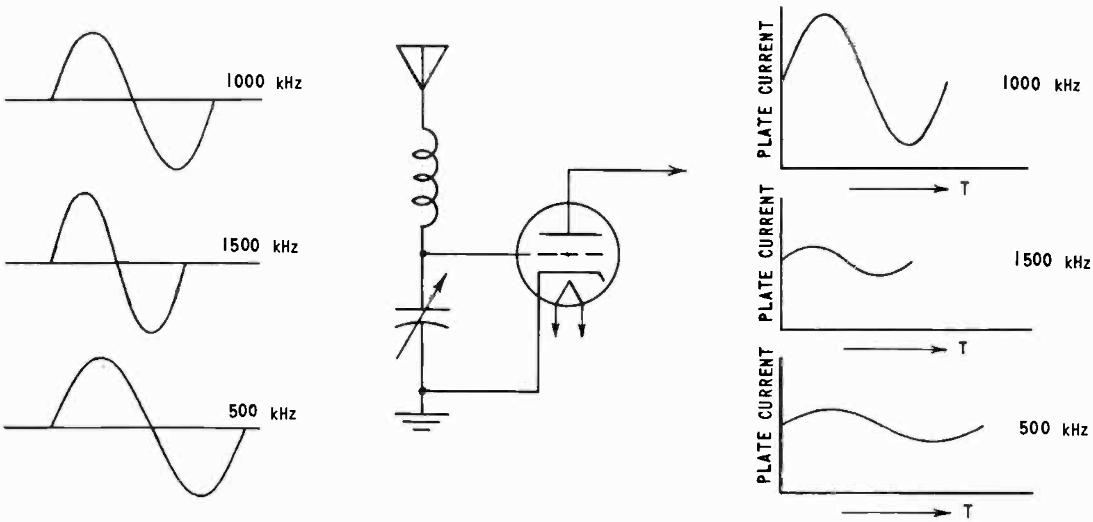


FIGURE 8

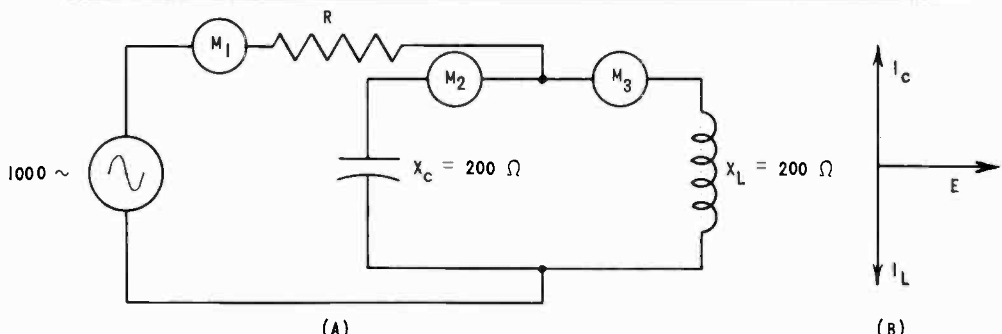


FIGURE 9

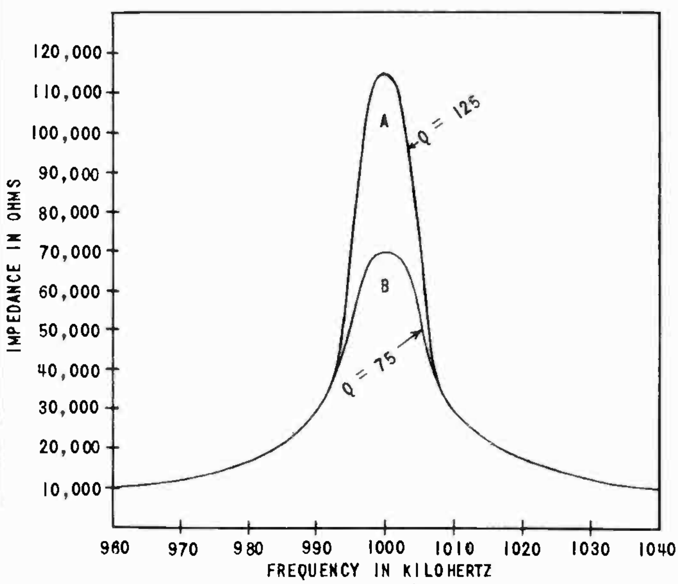


FIGURE 10

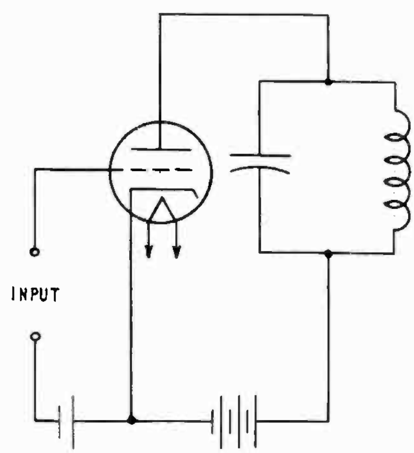


FIGURE 11

21

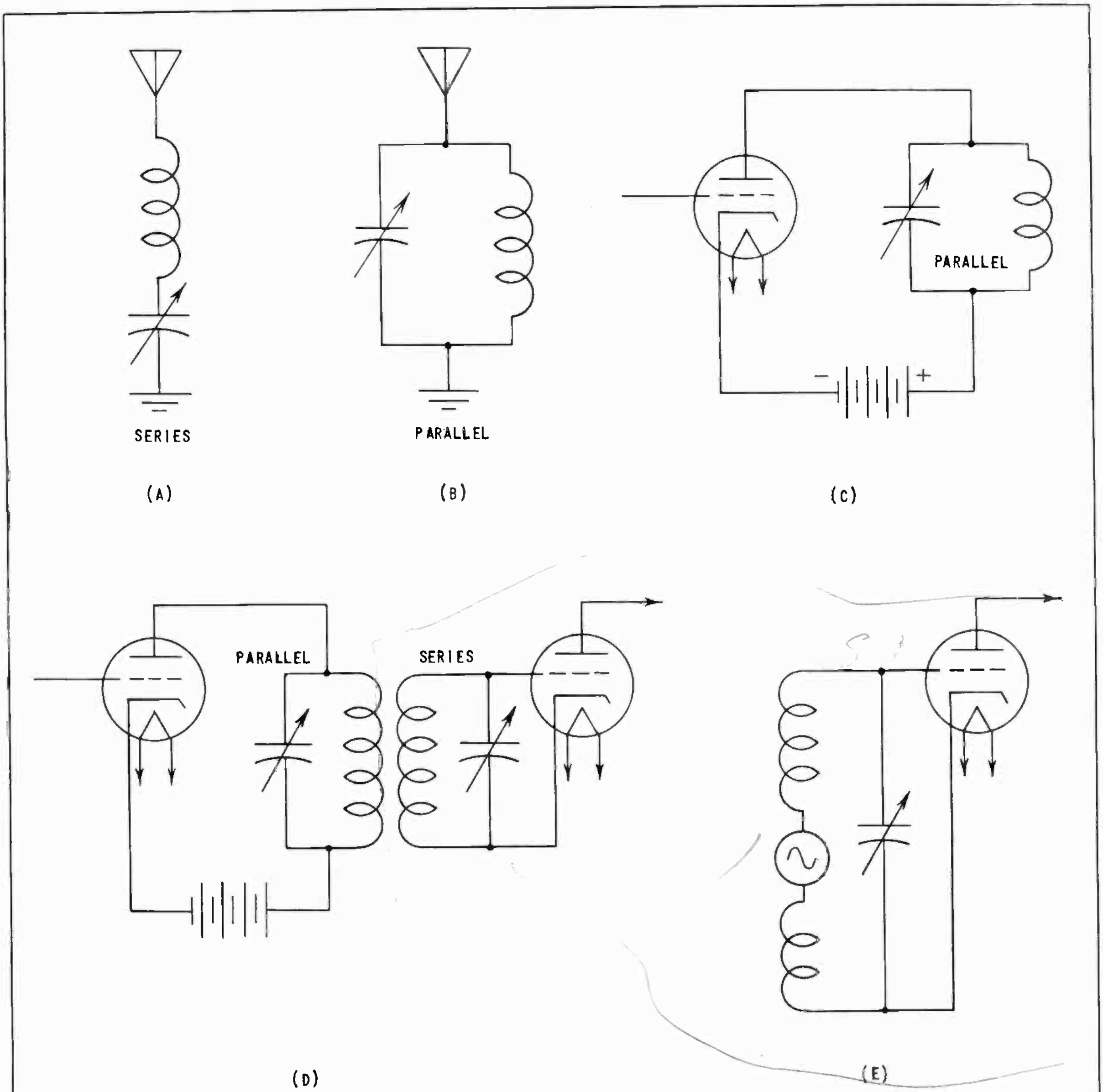


FIGURE 12

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