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It is technical manuals that you can download and buy online. Some of the material make reference to Navey specs so I figure it must be very good information.

The following is presented with emphasis added in yellow highlight.

Tutorial of Series and Parallel LC Resonant Circuits

Basic Introduction and Theory

Effect of Frequency on Inductive Reactance

Effect of Frequency on Inductive Reactance

In an a.c. circuit, an inductor produces inductive reactance which causes the current to lag the voltage by 90 degrees. Because the inductor "reacts" to a changing current, it is known as a reactive component. The opposition that an inductor presents to a.c. is called inductive reactance (X_L). This opposition is caused by the inductor "reacting" to the changing current of the a.c. source. Both the inductance and the frequency determine the magnitude of this reactance. This relationship is stated by the formula:

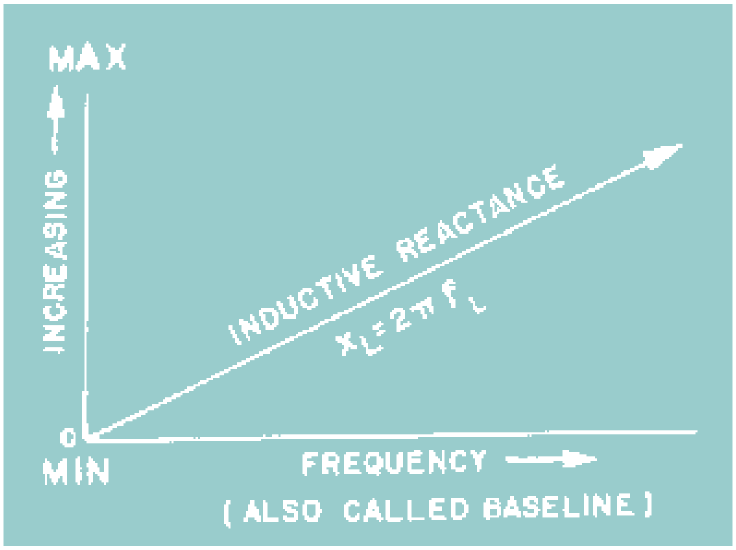
$$X_L = 2\pi f L$$

Where:

X_L = the inductive reactance in ohms
f = the frequency in hertz
L = the inductance in henries
π = 3.1416

As shown in the equation, any increase in frequency, or "f," will cause a corresponding increase of inductive reactance, or "X_L." Therefore, the INDUCTIVE REACTANCE VARIES DIRECTLY WITH THE FREQUENCY. As you can see, the higher the frequency, the greater the inductive reactance; the lower the frequency, the less the inductive reactance for a given inductor. This relationship is illustrated in figure 1-2. Increasing values of X_L are plotted in terms of increasing frequency. Starting at the lower left corner with zero frequency, the inductive reactance is zero. As the frequency is increased (reading to the right), the inductive reactance is shown to increase in direct proportion.

Figure 1-2. - Effect of frequency on inductive reactance.



Effect of Frequency on Capacitive Reactance

In an a.c. circuit, a capacitor produces a reactance which causes the current to lead the voltage by 90 degrees. Because the capacitor "reacts" to a changing voltage, it is known as a reactive component. The opposition a capacitor presents to a.c. is called capacitive reactance (X_C). The opposition is caused by the capacitor "reacting" to the changing voltage of the a.c. source. The formula for capacitive reactance is:

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

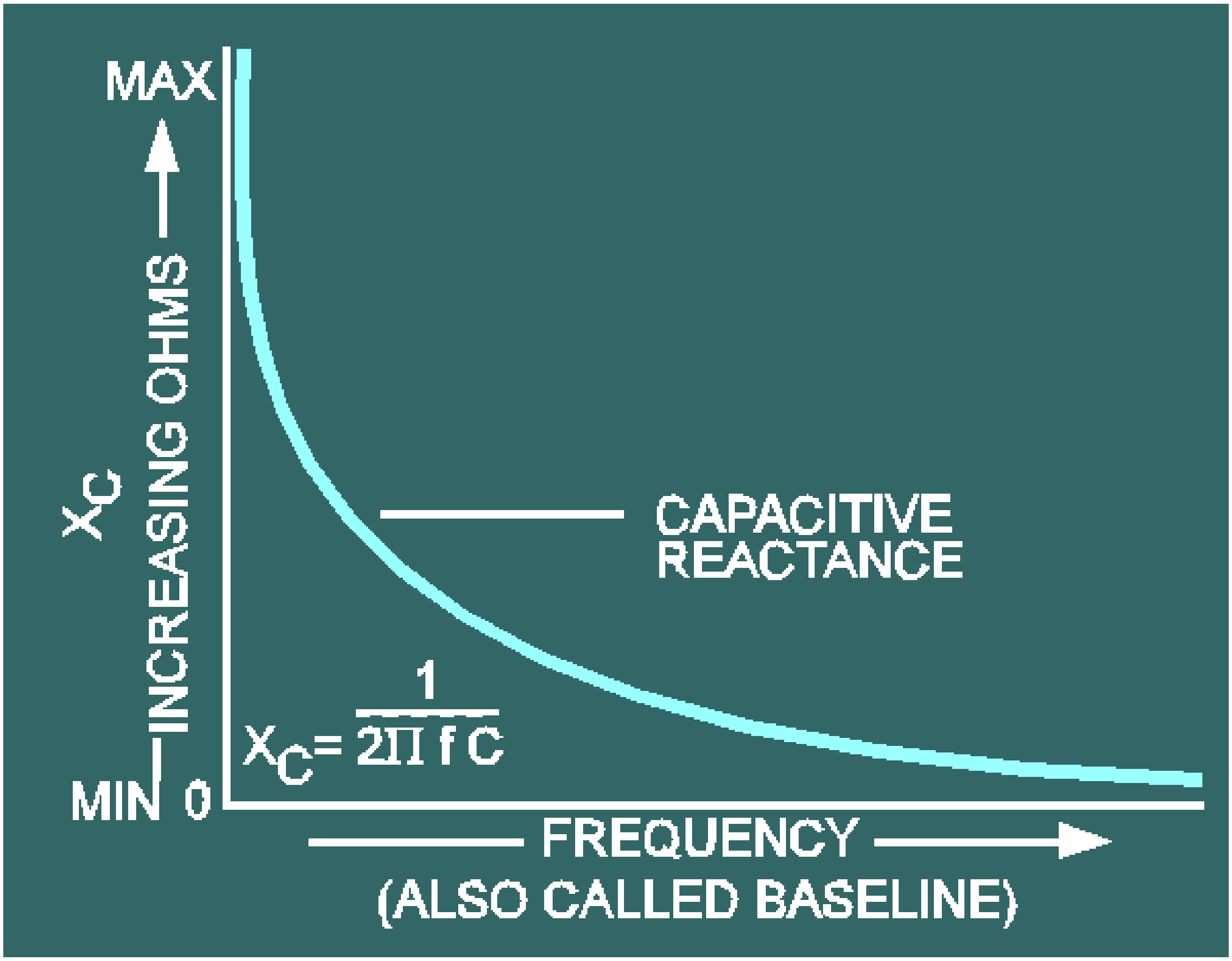
Where:

X_C = the capacitive reactance in ohms
f = the frequency in hertz
C = the capacitance in farads
π = 3.1416

In contrast to the inductive reactance, this equation indicates that the CAPACITIVE REACTANCE VARIES INVERSELY WITH THE FREQUENCY. When f = 0, X_C is infinite and decreases as frequency increases. That is, the lower the frequency, the greater the capacitive reactance; the higher the frequency, the less the reactance for a given capacitor.

As shown in figure 1-3, the effect of capacitance is opposite to that of inductance. Remember, capacitance causes the current to lead the voltage by 90 degrees, while inductance causes the current to lag the voltage by 90 degrees.

Figure 1-3. - Effect of frequency on capacitive reactance.



Effect of Frequency on Resistance

In the expression for inductive reactance, $X_L = 2\pi fL$, and in the expression for capacitive reactance,

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

both contain "f" (frequency). Any change of frequency changes the reactance of the circuit components as already explained. So far, nothing has been said about the effect of frequency on resistance. In an Ohm's law relationship, such as R = E/I no "f" is involved. Thus, for all practical purposes, a change of frequency does not affect the resistance of the circuit. If a 60-hertz a.c. voltage causes 20 milliamperes of current in a resistive circuit, then the same voltage at 2000 hertz, for example, would still cause 20 milliamperes to flow.

NOTE: Remember that the total opposition to a.c. is called impedance (Z). Impedance is the combination of inductive reactance (X_L), capacitive reactance (X_C), and resistance (R). When dealing with a.c. circuits, the impedance is the factor with which you will ultimately be concerned. But, as you have just been shown, the resistance (R) is not affected by frequency. Therefore, the remainder of the discussion of a.c. circuits will only be concerned with the reactance of inductors and capacitors and will ignore resistance.

A.c. Circuits Containing Both Inductive and Capacitive Reactances

A.c. circuits that contain both an inductor and a capacitor have interesting characteristics because of the opposing effects of L and C. X_L and X_C may be treated as reactors which are 180 degrees out of phase. As shown in figure 1-2, the vector for X_L should be plotted above the baseline; vector for X_C, figure 1-3, should be plotted below the baseline. In a series circuit, the effective reactance, or what is termed the RESULTANT REACTANCE, is the difference between the individual reactances. As an equation, the resultant reactance is:

$$X = X_L - X_C$$

Suppose an a.c. circuit contains an X_L of 300 ohms and an X_C of 250 ohms. The resultant reactance is:

$$X = X_L - X_C = 300 - 250 = 50 \text{ ohms (inductive)}$$

In some cases, the X_C may be larger than the X_L. If X_L = 1200 ohms and X_C = 4000 ohms, the difference is: $X = X_L - X_C = 1200 - 4000 = -2800$ ohms (capacitive). The total carries the sign (+ or -) of the greater number (factor).

Q.1 What is the relationship between frequency and the values of (a) X_L, (b) X_C, and (c) R?

Answer

Q.2 In an a.c. circuit that contains both an inductor and a capacitor, what term is used for the difference between the individual reactances? Answer

Resonance

RESONANCE

For every combination of L and C, there is only ONE frequency (in both series and parallel circuits) that causes X_L to exactly equal X_C; this frequency is known as the RESONANT FREQUENCY. When the resonant frequency is fed to a series or parallel circuit, X_L becomes equal to X_C, and the circuit is said to be RESONANT to that frequency. The circuit is now called a RESONANT CIRCUIT; resonant circuits are tuned circuits. The circuit condition wherein X_L becomes equal to X_C is known as RESONANCE.

Each LCR circuit responds to resonant frequency differently than it does to any other frequency. Because of this, an LCR circuit has the ability to separate frequencies. For example, suppose the TV or radio station you want to see or hear is broadcasting at the resonant frequency. The LC "tuner" in your set can divide the frequencies, picking out the resonant frequency and rejecting the other frequencies. Thus, the tuner selects the station you want and rejects all other stations. If you decide to select another station, you can change the frequency by tuning the resonant circuit to the desired frequency.

RESONANT FREQUENCY

As stated before, the frequency at which X_L equals X_C (in a given circuit) is known as the resonant frequency of that circuit. Based on this, the following formula has been derived to find the exact resonant frequency when the values of circuit components are known:

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

There are two important points to remember about this formula. First, the resonant frequency found when using the formula will cause the reactances (X_L and X_C) of the L and C components to be equal. Second, any change in the value of either L or C will cause a change in the resonant frequency.

An increase in the value of either L or C, or both L and C, will lower the resonant frequency of a given circuit. A decrease in the value of L or C, or both L and C, will raise the resonant frequency of a given circuit.

The symbol for resonant frequency used in this text is f_r. Different texts and References may use other symbols for resonant frequency, such as f_o, F_r, and fR. The symbols for many circuit parameters have been standardized while others have been left to the discretion of the writer. When you study, apply the rules given by the writer of the text or reference; by doing so, you should have no trouble with nonstandard symbols and designations.

The resonant frequency formula in this text is:

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

Where:

f_r = the resonant frequency in hertz

L = the inductance in henries

C = the capacitance in farads

π = 3.1416

By substituting the constant .159 for the quantity

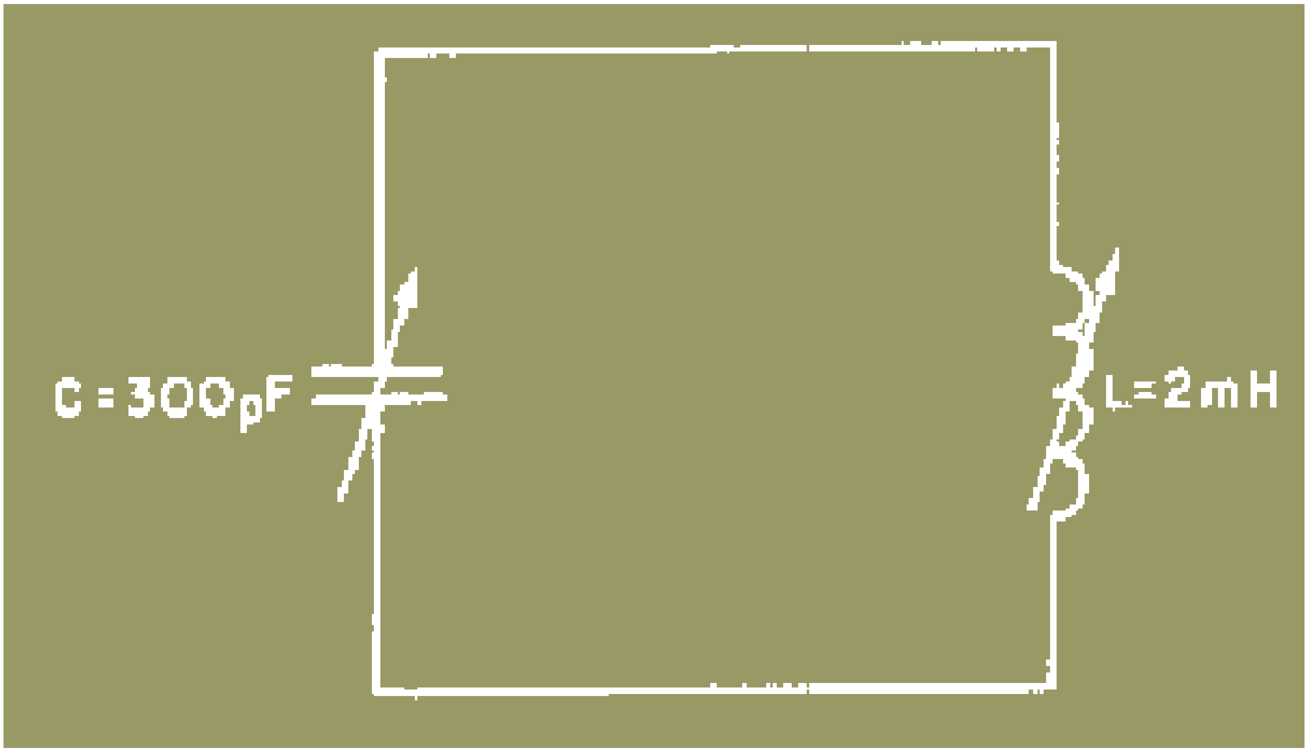
$$\frac{1}{2\pi}$$

the formula can be simplified to the following:

$$f_r = \frac{.159}{\sqrt{LC}}$$

Let's use this formula to figure the resonant frequency (f_r). The circuit is shown in the practice tank circuit of figure 1-4.

Figure 1-4. - Practice tank circuit.



Given:

$L = 2mH\ (2 \times 10^{-3}\ H)$

$C = 300pF\ (300 \times 10^{-12}\ F)$

Solution:

$$f_r = \frac{.159}{\sqrt{LC}}$$

$$f_r = \frac{.159}{\sqrt{(2 \times 10^{-3} H) \times (300 \times 10^{-12} F)}}$$

$$f_r = \frac{.159}{\sqrt{600 \times 10^{-15}}}$$

(F and H are shown in this step to show units)

$$f_r = \frac{.159}{60 \times 10^{-14}}$$

(Solving for square root $60 = 7.75 \quad 10^{-14} = 10^{-7}$)

$$f_r = \frac{.159}{7.75 \times 10^{-7}}$$

$$f_r = \frac{.159 \times 10^{7}}{7.75}$$

$$f_r = \frac{.159 \times 10^{4}}{7.75}$$

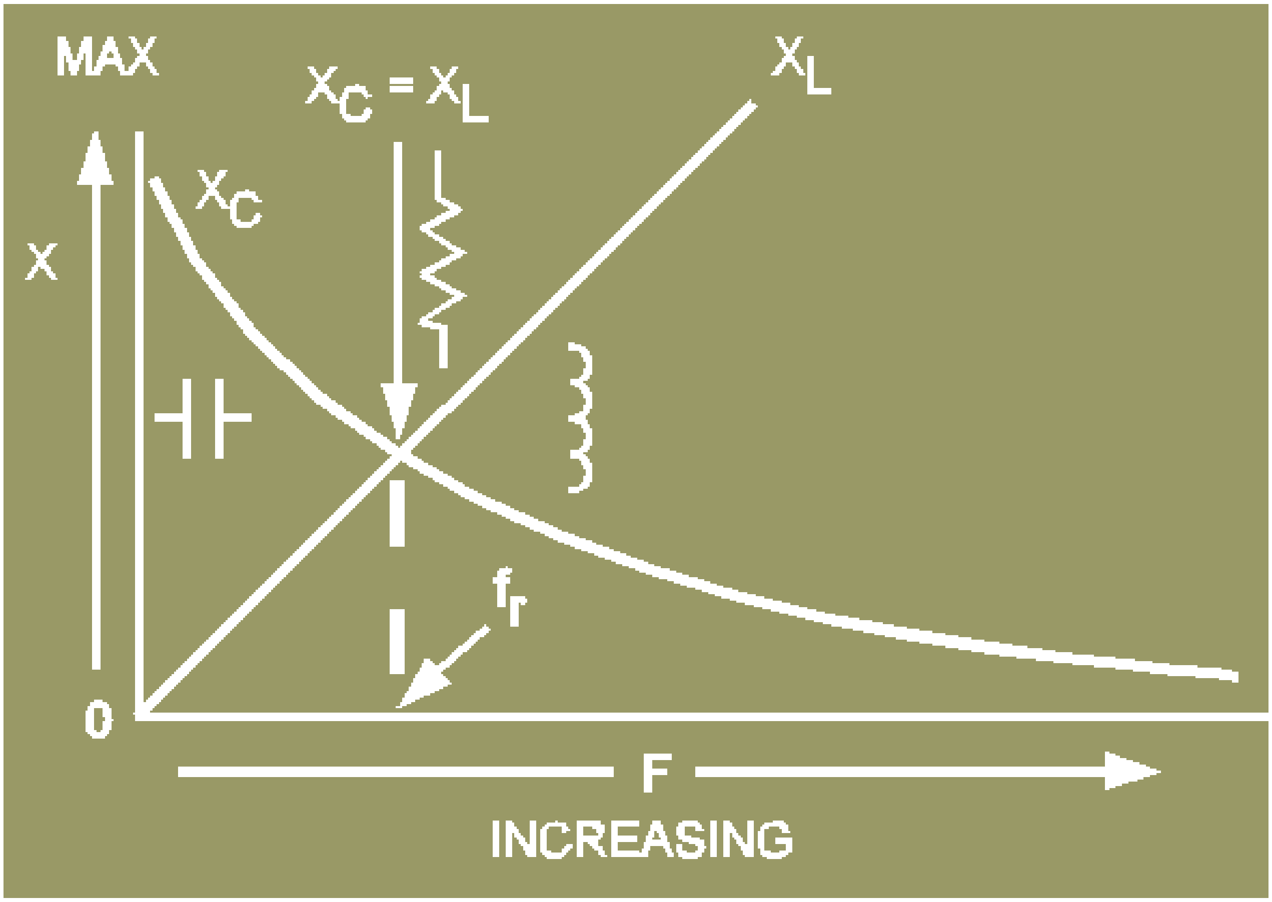
$$f_r = 20.5 \times 10^{4} \text{ (rounded off)}$$

$$f_r = 205{,}000 \text{ Hz or } 205 \text{ kHz}$$

The important point here is not the formula nor the mathematics. In fact, you may never have to compute a resonant frequency. The important point is for you to see that any given combination of L and C can be resonant at only one frequency; in this case, 205 kHz.

The universal reactance curves of figures 1-2 and 1-3 are joined in figure 1-5 to show the relative values of X_L and X_L at resonance, below resonance, and above resonance.

Figure 1-5. - Relationship between X_L and X_C as frequency increases.



First, note that f_r, (the resonant frequency) is that frequency (or point) where the two curves cross. At this point, and ONLY this point, X_L equals X_C. Therefore, the frequency indicated by f_r is the one and only frequency of resonance. Note the resistance symbol which indicates that at resonance all reactance is cancelled and the circuit impedance is effectively purely resistive. Remember, a.c. circuits that are resistive have no phase shift between voltage and current. Therefore, at resonance, phase shift is cancelled. The phase angle is effectively zero.

Second, look at the area of the curves to the left of f_r. This area shows the relative reactances of the circuit at frequencies BELOW resonance. To these LOWER frequencies, X_C will always be greater than X_L. There will always be some capacitive reactance left in the circuit after all inductive reactance has been cancelled. Because the impedance has a reactive component, there will be a phase shift. We can also state that below f_r the circuit will appear capacitive.

Lastly, look at the area of the curves to the right of f_r. This area shows the relative reactances of the circuit at frequencies ABOVE resonance. To these HIGHER frequencies, X_L will always be greater than X_C. There will always be some inductive reactance left in the circuit after all capacitive reactance has been cancelled. The inductor symbol shows that to these higher frequencies, the circuit will always appear to have some inductance. Because of this, there will be a phase shift.

RESONANT CIRCUITS

Resonant circuits may be designed as series resonant or parallel resonant. Each has the ability to discriminate between its resonant frequency and all other frequencies. How this is accomplished by both series- and parallel-LC circuits is the subject of the next section.

NOTE: Practical circuits are often more complex and difficult to understand than simplified versions. Simplified versions contain all of the basic features of a practical circuit, but leave out the nonessential features. For this reason, we will first look at the IDEAL SERIES-RESONANT CIRCUIT - a circuit that really doesn't exist except for our purposes here.

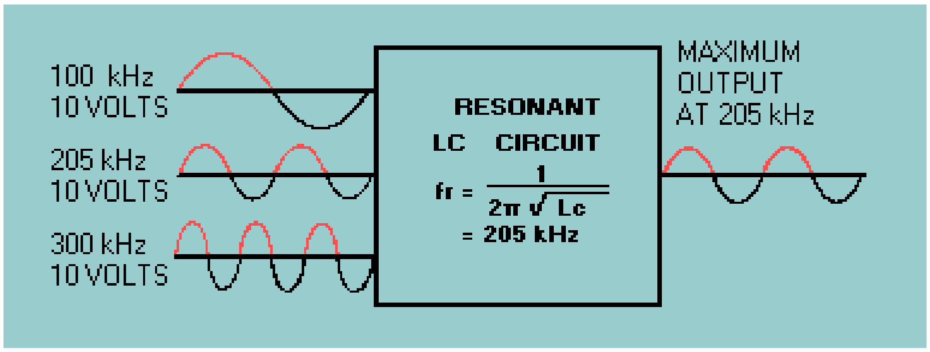
The ideal series-resonant circuit

THE IDEAL SERIES-RESONANT CIRCUIT

The ideal series-resonant circuit contains no resistance; it consists of only inductance and capacitance in series with each other and with the source voltage. In this respect, it has the same characteristics of the series circuits you have studied previously. Remember that current is the same in all parts of a series circuit because there is only one path for current.

Each LC circuit responds differently to different input frequencies. In the following paragraphs, we will analyze what happens internally in a series-LC circuit when frequencies at resonance, below resonance, and above resonance are applied. The L and C values in the circuit are those used in the problem just studied under resonant-frequency. The frequencies applied are the three inputs from figure 1-6. Note that the resonant frequency of each of these components is 205 kHz, as figured in the problem.

Figure 1-6. - Output of the resonant circuit.



How the Ideal Series-LC Circuit Responds to the Resonant Frequency (205 kHz)

Given:

$L = 2\ mH\ (2 \times 10^{-3}\ H)$

$C = 300\ pF\ (300 \times 10^{-12}\ F)$

$f_r = 205\ kHz$ (rounded off)

$$f_r = \frac{.159}{\sqrt{LC}}$$

$X_L = 2580$ ohms $(2\pi fL)$

$X_c = 2580$ ohms $\left(\frac{1}{2\pi FC}\right)$

$E_S = 10$ volts at a frequency 205 kHz

Note: You are given the values of X_L, X_C, and f_r but you can apply the formulas to figure them. The values given are rounded off to make it easier to analyze the circuit.

First, note that X_L and X_C are equal. This shows that the circuit is resonant to the applied frequency of 205 kHz. X_L and X_C are opposite in effect; therefore, they subtract to zero. (2580 ohms - 2580 ohms = zero.) At resonance, then, X = zero. In our theoretically perfect circuit with zero resistance and zero reactance, the total opposition to current (Z) must also be zero.

Now, apply Ohm's law for a.c. circuits:

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

$$I = \frac{10\ \text{volts}}{0\ \text{ohms}}$$

$I =$ INFINITELY HIGH

Don't be confused by this high value of current. Our perfect, but impossible, circuit has no opposition to current. Therefore, current flow will be extremely high. The important points here are that AT RESONANCE, impedance is VERY LOW, and the resulting current will be comparatively HIGH.

If we apply Ohm's law to the individual reactances, we can figure relative values of voltage across each reactance.

$$E_L = I \times X_L$$

$$E_C = I \times X_C$$

These are reactive voltages that you have studied previously. The voltage across each reactance will be comparatively high. A comparatively high current times 2580 ohms yields a high voltage. At any given instant, this voltage will be of opposite polarity because the reactances are opposite in effect. $E_L + E_C$ = zero volts

THE INDIVIDUAL VOLTAGES MAY REACH QUITE HIGH VALUES. ALTHOUGH LITTLE POWER IS PRESENT, THE VOLTAGE IS REAL AND CARE SHOULD BE TAKEN IN WORKING WITH IT.

Let's summarize our findings so far. In a series-LC circuit with a resonant-frequency voltage applied, the following conditions exist:

- X_L and X_C are equal and subtract to zero.
- Resultant reactance is zero ohms.
- Impedance (Z) is reduced to a MINIMUM value.
- With minimum Z, current is MAXIMUM for a given voltage.
- Maximum current causes maximum voltage drops across the individual reactances.

All of the above follow in sequence from the fact that $X_L = X_C$ at the resonant frequency.

How the Ideal Series-LC Circuit Respond to a Frequency Below Resonance (100 kHz)

Given:

$L = 2\ mH\ (2 \times 10^{-3} H)$

$C = 300\ pF\ (300 \times 10^{-12} F)$

$f_r = 205\ kHz$ (at resonant frequency)

$$f_r = \frac{.159}{\sqrt{LC}}$$

$X_L = 1260$ ohms (rounded off) (at 100 kHz)

$X_c = 5300$ ohms (rounded off) (at 100 kHz)

$E_S = 10$ volts (at 100 kHz)
(As in the previous analysys, you are given values that are possible for you to compute. If you do the computations, remember that most values are rounded off.)

First, note that X_L and X_C are no longer equal. X_C is larger than it was at resonance; X_L is smaller. By applying the formulas you have learned, you know that a lower frequency produces a higher capacitive reactance and a lower inductive reactance. The reactances subtract but do not cancel ($X_L - X_C = 1260 - 5300 = 4040$ ohms (capacitive)). At an input frequency of 100 kHz, the circuit (still resonant to 205 kHz) has a net reactance of 4040 ohms. In our theoretically perfect circuit, the total opposition (Z) is equal to X, or 4040 ohms.

As before, let's apply Ohm's law to the new conditions.

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

$$I = \frac{10 \text{ volts}}{4040 \text{ ohms}}$$

$I = .00248$ ampere
(approximately 2.5 mA)

The voltage drops across the reactances are as follows:

$$E_L = I \times X_L$$

$$E_L = .0025\ A \times 1260\ \Omega$$

$$E_L = 3 \text{ volts (approximately)}$$

$$E_C = I \times X_C$$

$$E_C = .0025\ A \times 5300\ \Omega$$

$$E_C = 13 \text{ volts (approximately)}$$

In summary, in a series-LC circuit with a source voltage that is below the resonant frequency (100 kHz in the example), the resultant reactance (X), and therefore impedance, is higher than at resonance. In addition current is lower, and the voltage drops across the reactances are lower. All of the above follow in sequence due to the fact that X_C is greater than X_L at any frequency lower than the resonant frequency.

How the Ideal Series-LC Circuit Responds to a Frequency Above Resonance (300 kHz)

Given:

$$L = 2 \text{ mH } (2 \times 10^{-3} \text{ H})$$

$$C = 300 \text{ pF } (300 \times 10^{-12} \text{ F})$$

$$f_r = 205 \text{ kHz (at resonant frequency)}$$

$$X_L = 3770 \text{ ohms (rounded off) (at 300 kHz)}$$

$$X_c = 1770 \text{ ohms (rounded off) (at 300 kHz)}$$

$$E_s = 10 \text{ volts (at 300 kHz)}$$

Again, X_L and X_C are not equal. This time, X_L is larger than X_C. (If you don't know why, apply the formulas and review the past several pages.) The resultant reactance is 2000 ohms ($X_L - X_C$ = 3770 - 1770 = 2000 ohms.) Therefore, the resultant reactance (X), or the impedance of our perfect circuit at 300 kHz, is 2000 ohms.

By applying Ohm's law as before:

$$I = 5 \text{ milliamperes}$$

$$E_L = 19 \text{ volts (rounded off)}$$

$$E_C = 9 \text{ volts (rounded off)}$$

In summary, in a series-LC circuit with a source voltage that is above the resonant frequency (300 kHz in this example), impedance is higher than at resonance, current is lower, and the voltage drops across the reactances are lower. All of the above follow in sequence from the fact that X_L is greater than X_C at any frequency higher than the resonant frequency.

Summary of the Response of the Ideal Series-LC Circuit to Frequencies Above, Below, and at Resonance

The ideal series-resonant circuit has zero impedance. The impedance increases for frequencies higher and lower than the resonant frequency. The impedance characteristic of the ideal series-resonant circuit results because resultant reactance is zero ohms at resonance and ONLY at resonance. All other frequencies provide a resultant reactance greater than zero.

Zero impedance at resonance allows maximum current. All other frequencies have a reduced current because of the increased impedance. The voltage across the reactance is greatest at resonance because voltage drop is directly proportional to current. All discrimination between frequencies results from the fact that X_L and X_C completely counteract ONLY at the resonant frequency.

How the Typical Series-LC Circuit Differs From the Ideal As you learned much earlier in this series, resistance is always present in practical electrical circuits; it is impossible to eliminate. A typical series-LC circuit, then, has R as well as L and C.

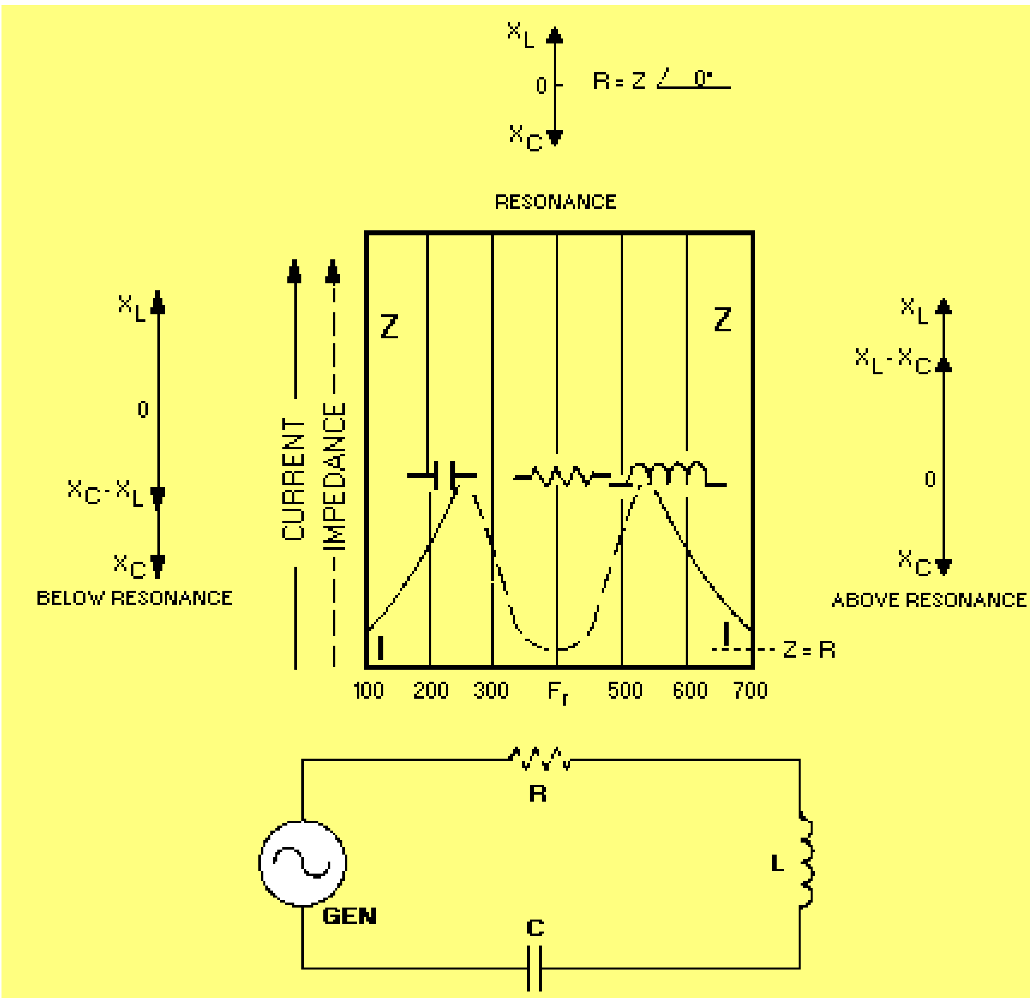
If our perfect (ideal) circuit has zero resistance, and a typical circuit has "some" resistance, then a circuit with a very small resistance is closer to being perfect than one that has a large resistance. Let's list what happens in a series-resonant circuit because resistance is present. This is not new to you - just a review of what you have learned previously.

In a series-resonant circuit that is basically L and C, but that contains "some" R, the following statements are true:

X_L, X_C, and R components are all present and can be shown on a vector diagram, each at right angles with the resistance vector (baseline). At resonance, the resultant reactance is zero ohms. Thus, at resonance, The circuit impedance equals only the resistance (R). The circuit impedance can never be less than R because the original resistance will always be present in the circuit. At resonance, a practical series-RLC circuit ALWAYS has MINIMUM impedance. The actual value of impedance is that of the resistance present in the circuit (Z = R).

Now, if the designers do their very best (and they do) to keep the value of resistance in a practical series-RLC circuit LOW, then we can still get a fairly high current at resonance. The current is NOT "infinitely" high as in our ideal circuit, but is still higher than at any other frequency. The curve and vector relationships for the practical circuit are shown in figure 1-7.

Figure 1-7. - Curves of impedance and current in an RLC series resonant circuit.



Note that the impedance curve does not reach zero at its minimum point. The vectors above and below resonance show that the phase shift of the circuit at these frequencies is less than 90 degrees because of the resistance.

The horizontal width of the curve is a measure of how well the circuit will pick out (discriminate) the one desired frequency. The width is called BANDWIDTH, and the ability to discriminate between frequencies is known as SELECTIVITY. Both of these characteristics are affected by resistance. Lower resistance allows narrower bandwidth, which is the same as saying the circuit has better selectivity. Resistance, then, is an unwanted quantity that cannot be eliminated but can be kept to a minimum by the circuit designers.

More on bandwidth, selectivity, and measuring the effects of resistance in resonant circuits will follow the discussion of parallel resonance.

Q.3 State the formula for resonant frequency. Answer

Q.4 If the inductor and capacitor values are increased, what happens to the resonant frequency? Answer

Q.5 In an "ideal" resonant circuit, what is the relationship between impedance and current? Answer

Q.6 In a series-RLC circuit, what is the condition of the circuit if there is high impedance, low current, and low reactance voltages? Answer

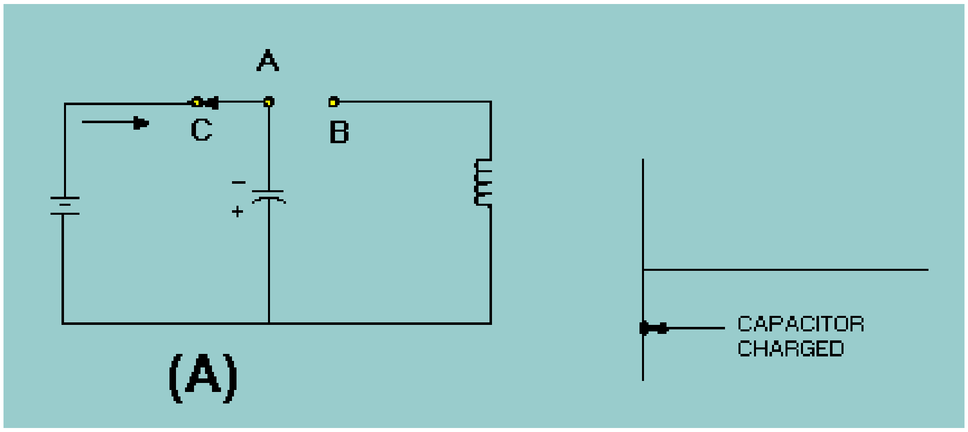
How the Parallel-LC Circuit Stores Energy

How the Parallel-LC Circuit Stores Energy

A parallel-LC circuit is often called a TANK CIRCUIT because it can store energy much as a tank stores liquid. It has the ability to take energy fed to it from a power source, store this energy alternately in the inductor and capacitor, and produce an output which is a continuous a.c. wave. You can understand how this is accomplished by carefully studying the sequence of events shown in figure 1-8. You must thoroughly understand the capacitor and inductor action in this figure before you proceed further in the study of parallel-resonant circuits.

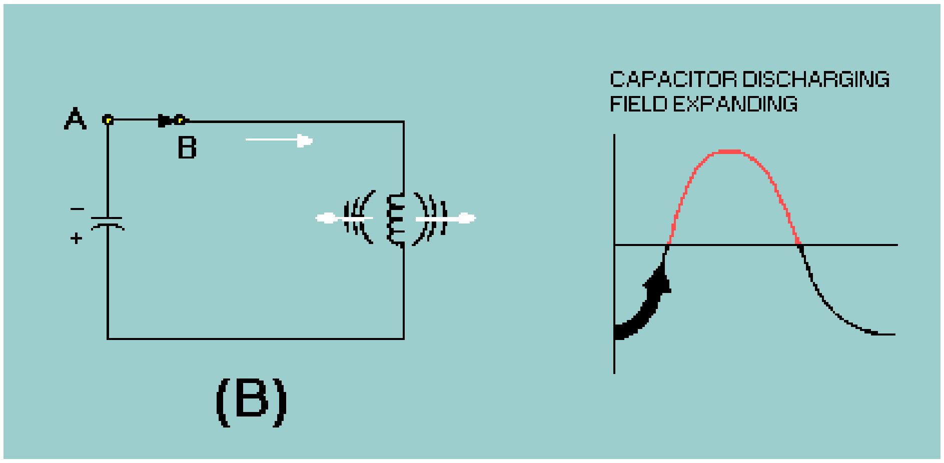
In each view of figure 1-8, the waveform is of the charging and discharging CAPACITOR VOLTAGE. In view (A), the switch has been moved to position C. The d.c. voltage is applied across the capacitor, and the capacitor charges to the potential of the battery.

Figure 1-8A. - Capacitor and inductor action in a tank circuit.



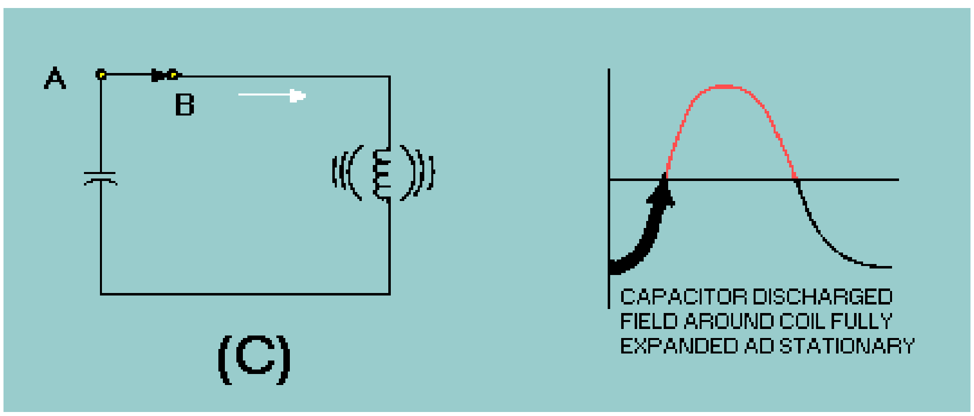
In view (B), moving the switch to the right completes the circuit from the capacitor to the inductor and places the inductor in series with the capacitor. This furnishes a path for the excess electrons on the upper plate of the capacitor to flow to the lower plate, and thus starts neutralizing the capacitor charge. As these electrons flow through the coil, a magnetic field is built up around the coil. The energy which was first stored by the electrostatic field of the capacitor is now stored in the electromagnetic field of the inductor.

Figure 1-8B. - Capacitor and inductor action in a tank circuit.



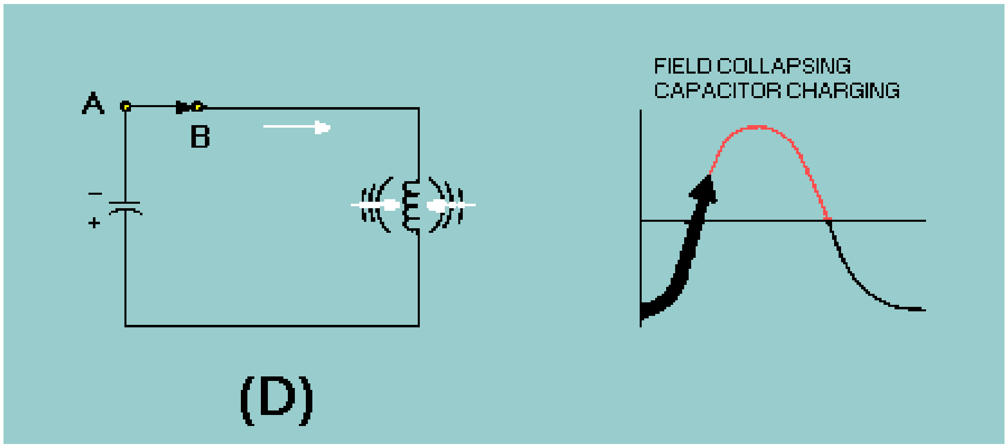
View (C) shows the capacitor discharged and a maximum magnetic field around the coil. The energy originally stored in the capacitor is now stored entirely in the magnetic field of the coil.

Figure 1-8C. - Capacitor and inductor action in a tank circuit.



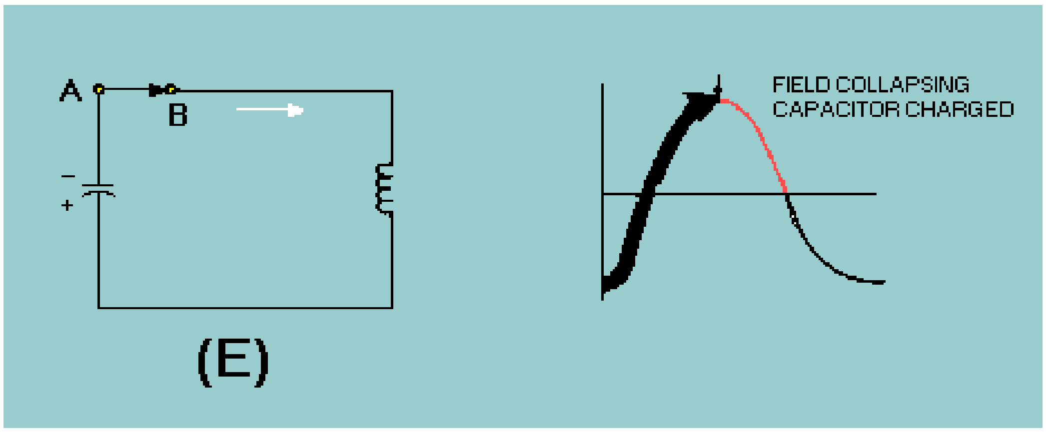
Since the capacitor is now completely discharged, the magnetic field surrounding the coil starts to collapse. This induces a voltage in the coil which causes the current to continue flowing in the same direction and charges the capacitor again. This time the capacitor charges to the opposite polarity, view (D).

Figure 1-8D. - Capacitor and inductor action in a tank circuit.



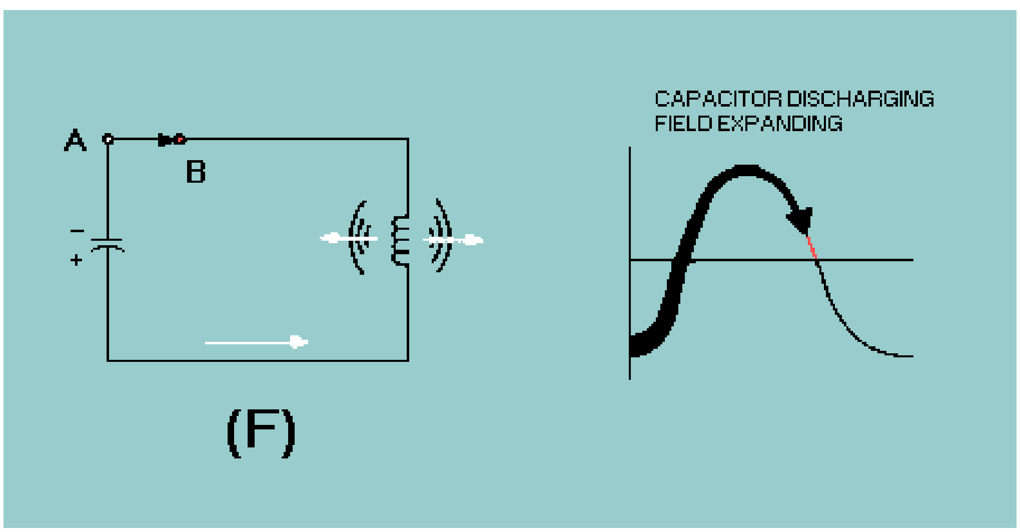
In view (E), the magnetic field has completely collapsed, and the capacitor has become charged with the opposite polarity. All of the energy is again stored in the capacitor.

Figure 1-8E. - Capacitor and inductor action in a tank circuit.



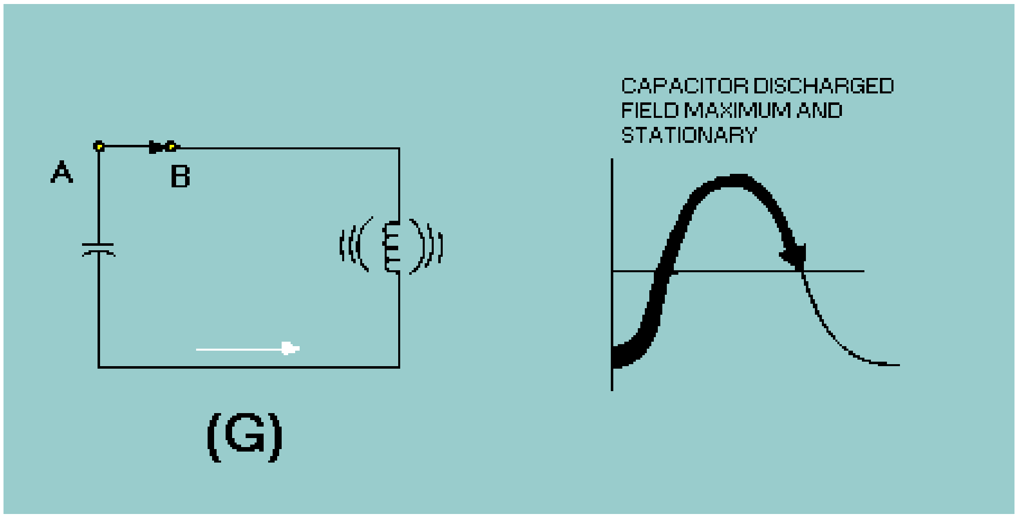
In view (F), the capacitor now discharges back through the coil. This discharge current causes the magnetic field to build up again around the coil.

Figure 1-8F. - Capacitor and inductor action in a tank circuit.



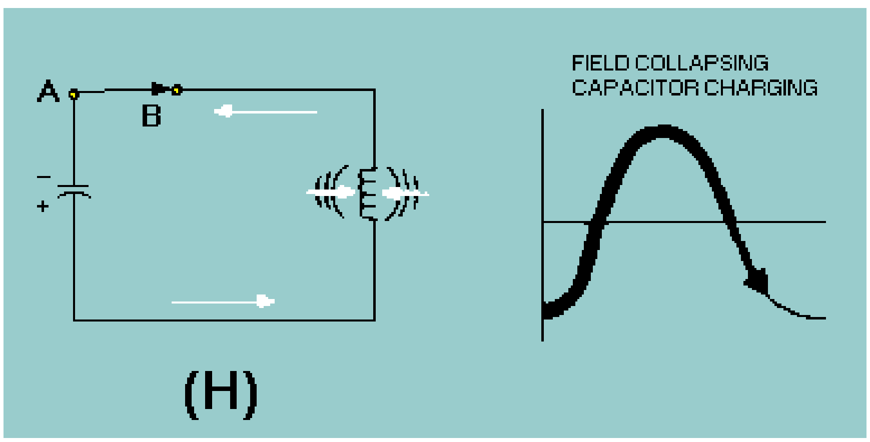
In view (G), the capacitor is completely discharged. The magnetic field is again at maximum.

Figure 1-8G. - Capacitor and inductor action in a tank circuit.



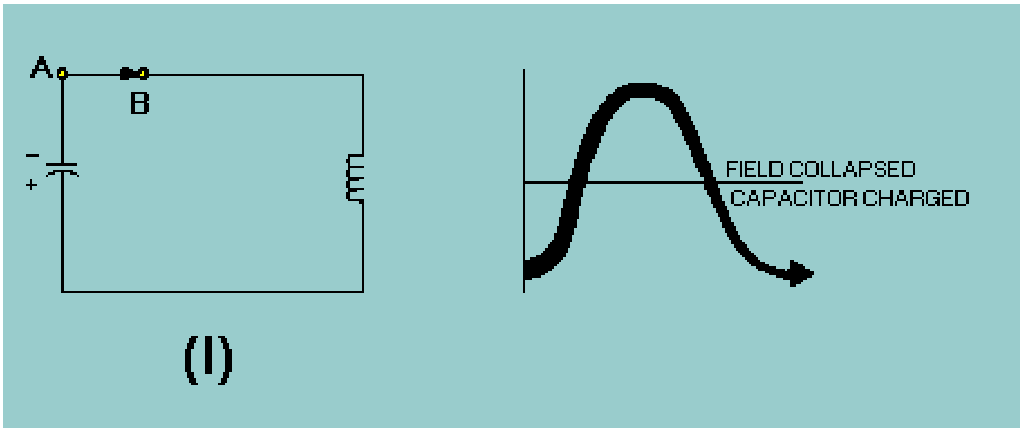
In view (H), with the capacitor completely discharged, the magnetic field again starts collapsing. The induced voltage from the coil maintains current flowing toward the upper plate of the capacitor.

Figure 1-8H. - Capacitor and inductor action in a tank circuit.



In view (I), by the time the magnetic field has completely collapsed, the capacitor is again charged with the same polarity as it had in view (A). The energy is again stored in the capacitor, and the cycle is ready to start again.

Figure 1-8I. - Capacitor and inductor action in a tank circuit.

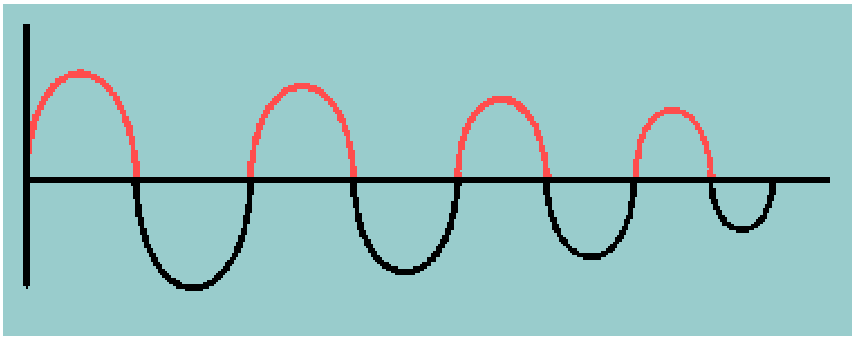


The number of times per second that these events in figure 1-8 take place is called NATURAL FREQUENCY or RESONANT FREQUENCY of the circuit. Such a circuit is said to oscillate at its resonant frequency.

It might seem that these oscillations could go on forever. You know better, however, if you apply what you have already learned about electric circuits.

This circuit, as all others, has some resistance. Even the relatively small resistance of the coil and the connecting wires cause energy to be dissipated in the form of heat (I^2R loss). The heat loss in the circuit resistance causes the charge on the capacitor to be less for each subsequent cycle. The result is a DAMPED WAVE, as shown in figure 1-9. The charging and discharging action will continue until all of the energy has been radiated or dissipated as heat.

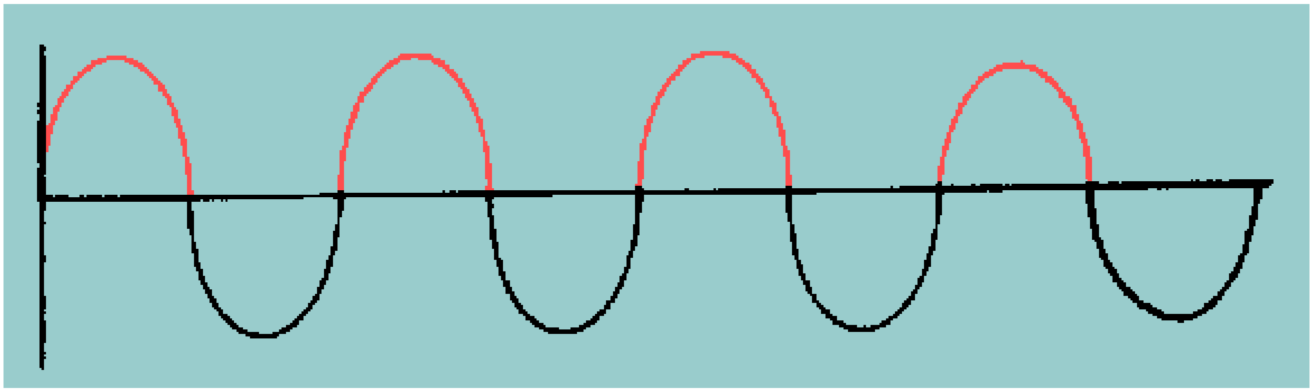
Figure 1-9. - Damped wave.



If it were possible to have a circuit with absolutely no resistance, there would be no heat loss, and the oscillations would tend to continue indefinitely. You have already learned that tuned circuits are designed to have very little resistance. Reducing I^2R losses is still another reason for having low resistance.

A "perfect" tuned circuit would produce the continuous sine wave shown in figure 1-10. Its frequency would be that of the circuit.

Figure 1-10. - Sine wave-resonant frequency.



Because we don't have perfection, another way of causing a circuit to oscillate indefinitely would be to apply a continuous a.c. or pulsing source to the circuit. If the source is at the resonant frequency of the circuit, the circuit will oscillate as long as the source is applied.

The reasons why the circuit in figure 1-8 oscillates at the resonant frequency have to do with the characteristics of resonant circuits. The discussion of parallel resonance will not be as detailed as that for series resonance because the idea of resonance is the same for both circuits. Certain characteristics differ as a result of L and C being in parallel rather than in series. These differences will be emphasized.

Q.7 When the capacitor is completely discharged, where is the energy of the tank circuit stored? Answer

Q.8 When the magnetic field of the inductor is completely collapsed, where is the energy of the tank circuit stored? Answer

Parallel resonance

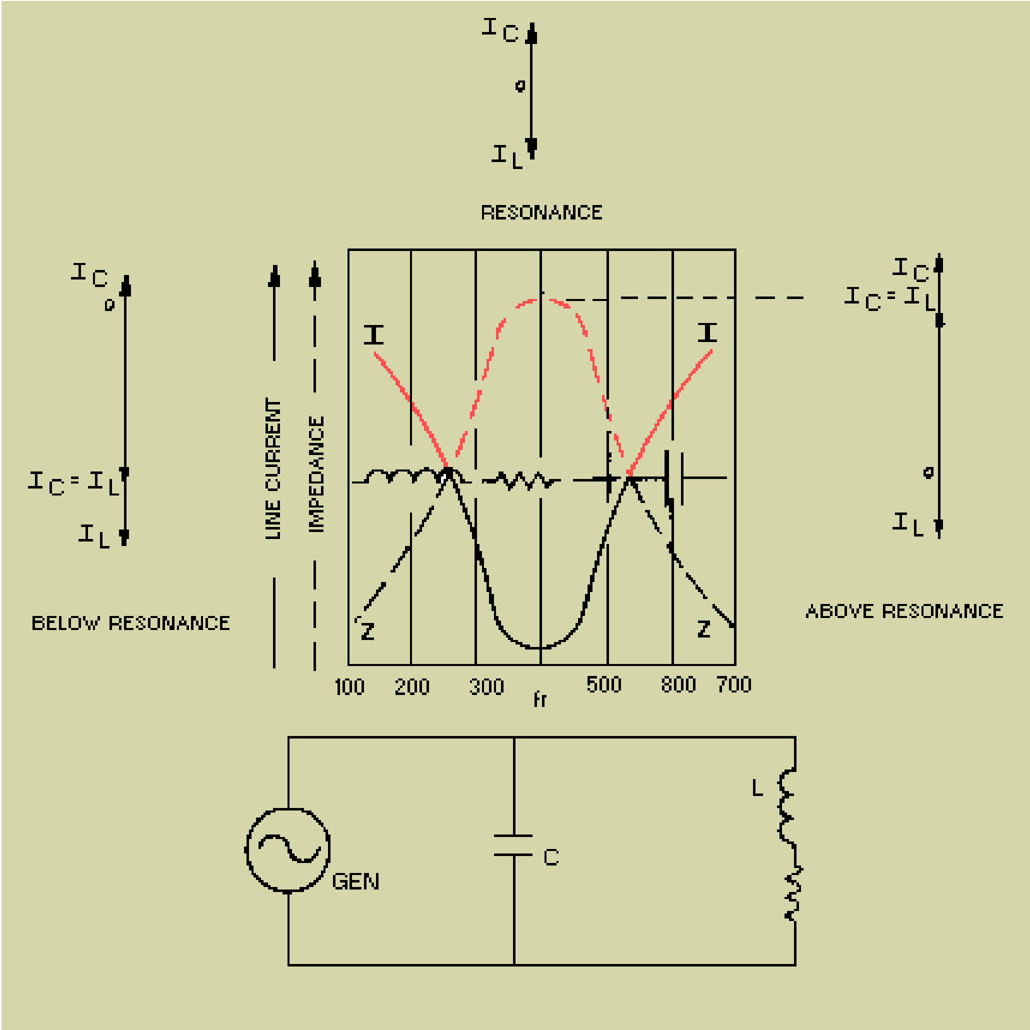
PARALLEL RESONANCE

Much of what you have learned about resonance and series-LC circuits can be applied directly to parallel-LC circuits. The purpose of the two circuits is the same - to select a specific frequency and reject all others. X_L still equals X_C at resonance. Because the inductor and capacitor are in parallel, however, the circuit has the basic characteristics of an a.c. parallel circuit. The parallel hookup causes frequency selection to be accomplished in a different manner. It gives the circuit different characteristics. The first of these characteristics is the ability to store energy.

The Characteristics of a Typical Parallel-Resonant Circuit

Look at figure 1-11. In this circuit, as in other parallel circuits, the voltage is the same across the inductor and capacitor. The currents through the components vary inversely with their reactances in accordance with Ohm's law. The total current drawn by the circuit is the vector sum of the two individual component currents. Finally, these two currents, I_L and I_C, are 180 degrees out of phase because the effects of L and C are opposite. There is not a single fact new to you in the above. It is all based on what you have learned previously about parallel a.c. circuits that contain L and C.

Figure 1-11. - Curves of impedance and current in an RLC parallel-resonant circuit.



Now, at resonance, X_L is still equal to X_C. Therefore, I_L must equal I_C. Remember, the voltage is the same; the reactances are equal; therefore, according to Ohm's law, the currents must be equal. But, don't forget, even though the currents are equal, they are still opposites. That is, if the current is flowing "up" in the capacitor, it is flowing "down" in the coil, and vice versa. In effect, while the one component draws current, the other returns it to the source. The net effect of this "give and take action" is that zero current is drawn from the source at resonance. The two currents yield a total current of zero amperes because they are exactly equal and opposite at resonance.

A circuit that is completed and has a voltage applied, but has zero current, must have an INFINITE IMPEDANCE (apply Ohm's law - any voltage divided by zero yields infinity).

By now you know that we have just ignored our old friend resistance from previous discussions. In an actual circuit, at resonance, the currents will not quite counteract each other because each component will have different resistance. This resistance is kept extremely low, but it is still there. The result is that a relatively small current flows from the source at resonance instead of zero current. Therefore, a basic characteristic of a practical parallel-LC circuit is that, at resonance, the circuit has MAXIMUM impedance which results in

MINIMUM current from the source. This current is often called line current. This is shown by the peak of the waveform for impedance and the valley for the line current, both occurring at f_r the frequency of resonance in figure 1-11.

There is little difference between the circuit pulsed by the battery in figure 1-8 that oscillated at its resonant (or natural) frequency, and the circuit we have just discussed. The equal and opposite currents in the two components are the same as the currents that charged and discharged the capacitor through the coil.

For a given source voltage, the current oscillating between the reactive parts will be stronger at the resonant frequency of the circuit than at any other frequency. At frequencies below resonance, capacitive current will decrease; above the resonant frequency, inductive current will decrease. Therefore, the oscillating current (or circulating current, as it is sometimes called), being the lesser of the two reactive currents, will be maximum at resonance.

If you remember, the basic resonant circuit produced a "damped" wave. A steady amplitude wave was produced by giving the circuit energy that would keep it going. To do this, the energy had to be at the same frequency as the resonant frequency of the circuit.

So, if the resonant frequency is "timed" right, then all other frequencies are "out of time" and produce waves that tend to buck each other. Such frequencies cannot produce strong oscillating currents.

In our typical parallel-resonant (LC) circuit, the line current is minimum (because the impedance is maximum). At the same time, the internal oscillating current in the tank is maximum. Oscillating current may be several hundred times as great as line current at resonance.

In any case, this circuit reacts differently to the resonant frequency than it does to all other frequencies. This makes it an effective frequency selector.

Summary of Resonance

Both series- and parallel-LC circuits discriminate between the resonant frequency and all other frequencies by balancing an inductive reactance against an equal capacitive reactance.

In series, these reactances create a very low impedance. In parallel, they create a very high impedance. These characteristics govern how and where designers use resonant circuits. A low-impedance requirement would require a series-resonant circuit. A high-impedance requirement would require the designer to use a parallel-resonant circuit.

Tuning a Band of Frequencies

Our resonant circuits so far have been tuned to a single frequency - the resonant frequency. This is fine if only one frequency is required. However, there are hundreds of stations on many different frequencies.

Therefore, if we go back to our original application, that of tuning to different radio stations, our resonant circuits are not practical. The reason is because a tuner for each frequency would be required and this is not practical.

What is a practical solution to this problem? The answer is simple. Make either the capacitor or the inductor variable. Remember, changing either L or C changes the resonant frequency.

Now you know what has been happening all of these years when you "pushed" the button or "turned" the dial. You have been changing the L or C in the tuned circuits by the amount necessary to adjust the tuner to resonate at the desired frequency. No matter how complex a unit, if it has LC tuners, the tuners obey these basic laws.

Q.9 What is the term for the number of times per second that tank circuit energy is either stored in the inductor or capacitor? Answer
Q.10 In a parallel-resonant circuit, what is the relationship between impedance and current? Answer

Q.11 When is line current minimum in a parallel-LC circuit? Answer

RESONANT CIRCUITS AS FILTER CIRCUITS

The principle of series- or parallel-resonant circuits have many applications in radio, television, communications, and the various other electronic fields throughout the Navy. As you have seen, by making the capacitance or inductance variable, the frequency at which a circuit will resonate can be controlled.

In addition to station selecting or tuning, resonant circuits can separate currents of certain frequencies from those of other frequencies.

Circuits in which resonant circuits are used to do this are called FILTER

CIRCUITS.

If we can select the proper values of resistors, inductors, or capacitors, a FILTER NETWORK, or "frequency selector," can be produced which offers little opposition to one frequency, while BLOCKING or ATTENUATING other frequencies. A filter network can also be designed that will "pass" a band of frequencies and "reject" all other frequencies.

Most electronic circuits require the use of filters in one form or another. You have already studied several in modules 6, 7, and 8 of the NEETS.

One example of a filter being applied is in a rectifier circuit. As you know, an alternating voltage is changed by the rectifier to a direct current. However, the d.c. voltage is not pure; it is still pulsating and fluctuating. In other words, the signal still has an a.c. component in addition to the d.c. voltage. By feeding the signal through simple filter networks, the a.c. component is reduced. The remaining d.c. is as pure as the designers require.

Bypass capacitors, which you have already studied, are part of filter networks that, in effect, bypass, or shunt, unwanted a.c. components to ground.

THE IDEA OF "Q"

Several times in this chapter, we have discussed "ideal" or theoretically perfect circuits. In each case, you found that resistance kept our circuits from being perfect. You also found that low resistance in tuners was better than high resistance. Now you will learn about a factor that, in effect, measures just how close to perfect a tuner or tuner component can be. This same factor affects BANDWIDTH and SELECTIVITY. It can be used in figuring voltage across a coil or capacitor in a series-resonant circuit and the amount of circulating (tank) current in a parallel-resonant circuit. This factor is very important and useful to designers. Technicians should have some knowledge of the factor because it affects so many things. The factor is known as Q. Some say it stands for quality (or merit). The higher the Q, the better the circuit; the lower the losses (I^2R), the closer the circuit is to being perfect.

Having studied the first part of this chapter, you should not be surprised to learn that resistance (R) has a great effect on this figure of merit or quality.

Q Is a Ratio

Q is really very simple to understand if you think back to the tuned-circuit principles just covered. Inductance and capacitance are in all tuners. Resistance is an impurity that causes losses. Therefore, components that provide the reactance with a minimum of resistance are "purer" (more perfect) than those with higher resistance. The actual measure of this purity, merit, or quality must include the two basic quantities, X and R.

The ratio

$$\frac{X}{R}$$

does the job for us. Let's take a look at it and see just why it measures quality.

First, if a perfect circuit has zero resistance, then our ratio should give a very high value of Q to reflect the high quality of the circuit. Does it?

Assume any value for X and a zero value for R.

Then:

$$Q = \frac{X}{R} = \frac{\text{Some Value}}{0} = \text{Infinity}$$

Remember, any value divided by zero equals infinity. Thus, our ratio is infinitely high for a theoretically perfect circuit.

With components of higher resistance, the Q is reduced. Dividing by a larger number always yields a smaller quantity. Thus, lower quality components produce a lower Q. Q, then, is a direct and accurate measure of the quality of an LC circuit.

Q is just a ratio. It is always just a number - no units. The higher the number, the "better" the circuit. Later as you get into more practical circuits, you may find that low Q may be desirable to provide certain characteristics. For now, consider that higher is better.

Because capacitors have much, much less resistance in them than inductors, the Q of a circuit is very often expressed as the Q of the coil or:

$$Q = \frac{X_L}{R}$$

The answer you get from using this formula is very near correct for most purposes. Basically, the Q of a capacitor is so high that it does not limit the Q of the circuit in any practical way. For that reason, the technician may ignore it.

The Q of a Coil

Q is a feature that is designed into a coil. When the coil is used within the frequency range for which it is designed, Q is relatively constant. In this sense, it is a physical characteristic.

Inductance is a result of the physical makeup of a coil - number of turns, core, type of winding, etc. Inductance governs reactance at a given frequency. Resistance is inherent in the length, size, and material of the wire. Therefore, the Q of a coil is mostly dependent on physical characteristics.

Values of Q that are in the hundreds are very practical and often found in typical equipment.

Application of Q

For the most part, Q is the concern of designers, not technicians. Therefore, the chances of you having to figure the Q of a coil are remote. However, it is important for you to know some circuit relationships that are affected by Q.

Q Relationships in Series Circuits

Q can be used to determine the "gain" of series-resonant circuits. Gain refers to the fact that at resonance, the voltage drop across the reactances are greater than the applied voltage. Remember, when we applied Ohm's law in a series-resonant circuit, it gave us the following characteristics:

Low impedance, high current. High current; high voltage across the comparatively high reactances.

This high voltage is usable where little power is required, such as in driving the grid of a vacuum tube or the gate of a field effect transistor (F.E.T.). The gain of a properly designed series-resonant circuit may be as great or greater than the amplification within the amplifier itself. The gain is a function of Q, as shown in the following example:

E = the input voltage to the tuned circuit

E_L = the voltage drop across the coil at resonance Q.

Q = the Q of the coil

Then:

$$E_L = EQ$$

If the Q of the coil were 100, then the gain would be 100; that is, the voltage of the coil would be 100 times that of the input voltage to the series circuit.

Resistance affects the resonance curve of a series circuit in two ways - the lower the resistance, the higher the current; also, the lower the resistance, the sharper the curve. Because low resistance causes high Q, these two facts are usually expressed as functions of Q. That is, the higher the Q, the higher and sharper the curve and the more selective the circuit.

The lower the Q (because of higher resistance), the lower the current curve; therefore, the broader the curve, the less selective the circuit. A summary of the major characteristics of series RLC-circuits at resonance is given in table 1-1.

Table 1-1. - Major Characteristics of Series RLC Circuits at Resonance

QUANTITY	SERIES CIRCUIT
At resonance: Reactance $(X_L - X_C)$	Zero, because $X_L = X_C$
Resonant frequency	$f_r = \frac{1}{2\pi\sqrt{LC}}$
Impedance	Minimum: $Z = R$
I_{LINE}	Maximum value
I_L	I_{LINE}
I_C	I_{LINE}
E_L	$Q \cdot E_{LINE}$
E_C	$Q \cdot E_{LINE}$
Phase angle between E_{LINE} and I_{LINE}	0°
Angle between E_L & E_C	180°
Angle between I_L & I_C	0°
Desired value of Q	10 or more
Desired value of R	Low
Highest selectivity	High Q, low R, high $\frac{L}{C}$
When f is greater than f_r Reactance	Inductive
Phase angle between I_{LINE} and E_{LINE}	Lagging current
When f is less than f_r Reactance	Capacitive
Phase angle between I_{LINE} and E_{LINE}	Leading current

Q Relationships in a Parallel-Resonant Circuit

There is no voltage gain in a parallel-resonant circuit because voltage is the same across all parts of a parallel circuit. However, Q helps give us a measure of the current that circulates in the tank.

Given:

I_{LINE} = current drawn from the source

I_L = current through the coil (or circulating current)

Q = the Q of the coil

Then:

$$I_L = I_{LINE} \, Q$$

Again, if the Q were 100, the circulating current would be 100 times the value of the line current. This may help explain why some of the wire sizes are very large in high-power amplifying circuits.

The impedance curve of a parallel-resonant circuit is also affected by the Q of the circuit in a manner similar to the current curve of a series circuit. The Q of the circuit determines how much the impedance is increased across the parallel-LC circuit. ($Z = Q \times X_L$)

The higher the Q, the greater the impedance at resonance and the sharper the curve. The lower the Q, the lower impedance at resonance; therefore, the broader the curve, the less selective the circuit. The major characteristics of parallel-RLC circuits at resonance are given in table 1-2.

Table 1-2. - Major Characteristics of Parallel RLC Circuits at Resonance

QUANTITY	PARALLEL CIRCUIT
At resonance : Reactance $(X_L - X_C)$	Zero; because nonenergy currents are equal
Resonant frequency	$f_r = \frac{1}{2\pi\sqrt{LC}}$
Impedance	Maximum: $Z = \frac{L}{CR}$
I_{LINE}	Minimum value
I_L	$Q \cdot I_{LINE}$
I_C	$Q \cdot I_{LINE}$
E_L	E_{LINE}
E_C	E_{LINE}
Phase angle between E_{LINE} and I_{LINE}	0°
Angle between E_L & E_C	0°
Angle between I_L & I_C	180°
Desired value of **Q**	**10** or more
Desired value of **R**	Low
Highest selectivity	High **Q**, low **R**, $\frac{L}{C}$
When **f** is greater than f_r Reactance	Capacitive
Phase angle between I_{LINE} and E_{LINE}	Leading current
When **f** is less than f_r Reactance	Inductive
Phase angle between I_{LINE} and E_{LINE}	Lagging current

Summary of Q

The ratio that is called Q is a measure of the quality of resonant circuits and circuit components. Basically, the value of Q is an inverse function of electrical power dissipated through circuit resistance. Q is the ratio of the power stored in the reactive components to the power dissipated in the resistance. That is, high power loss is low Q; low power loss is high Q.

Circuit designers provide the proper Q. As a technician, you should know what can change Q and what quantities in a circuit are affected by such a change.

Pulsed oscillators

PULSED OSCILLATORS

A sinusoidal (sine-wave) oscillator is one that will produce output pulses at a predetermined frequency for an indefinite period of time; that is, it operates continuously. Many electronic circuits in equipment such as radar require that an oscillator be turned on for a specific period of time and that it remain in an off condition until required at a later time. These circuits are referred to as PULSED OSCILLATORS or RINGING OSCILLATORS. They are nothing more than sine-wave oscillators that are turned on and off at specific times.

Figure 2-25, view (A), shows a pulsed oscillator with the resonant tank in the emitter circuit. A positive input makes Q1 conduct heavily and current flow through L1; therefore no oscillations can take place. A negative-going input pulse (referred to as a gate) cuts off Q1, and the tank oscillates until the gate ends or until the ringing stops, whichever comes first.

Figure 2-25A. - Pulsed oscillator.

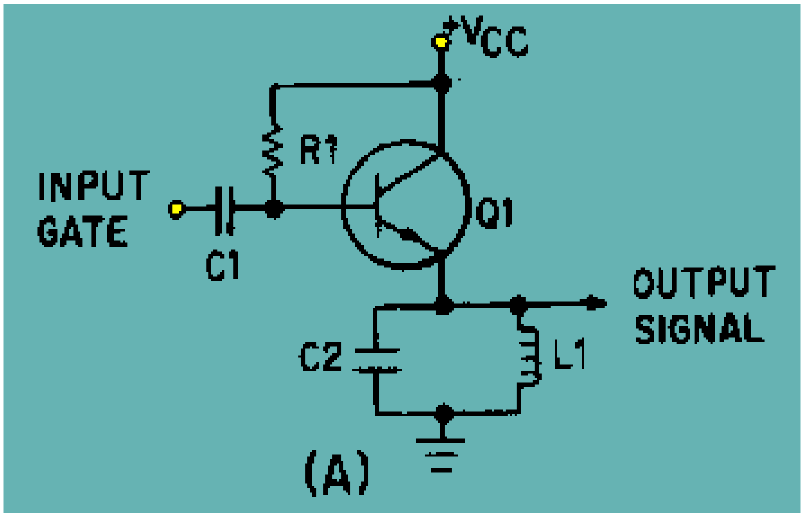
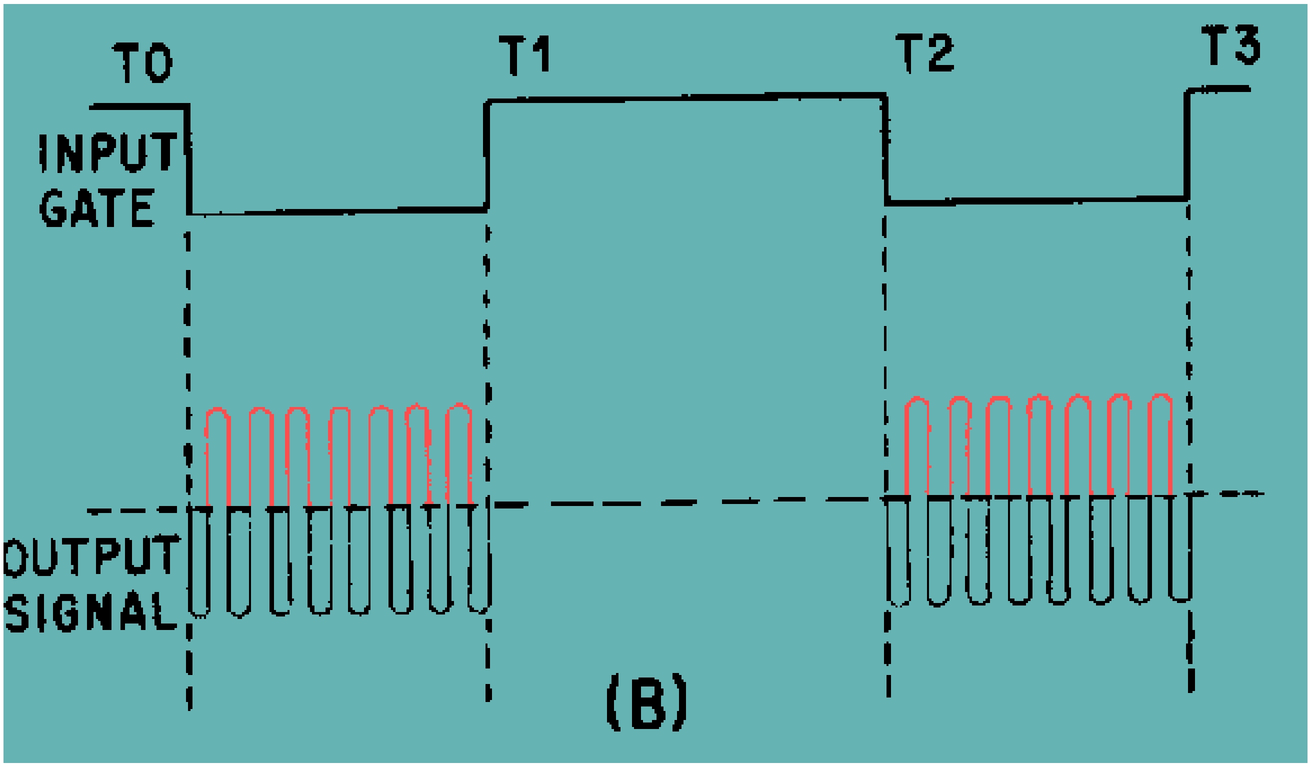


Figure 2-25B. - Pulsed oscillator.



The waveforms in view (B) show the relationship of the input gate and the output signal from the pulsed oscillator. To see how this circuit operates, assume that the Q of the LC tank circuit is high enough to prevent damping. An output from the circuit is obtained when the input gate goes negative (T0 to T1 and T2 to T3). The remainder of the time (T1 to T2) the transistor conducts heavily and there is no output from the circuit. The width of the input gate controls the time for the output signal. Making the gate wider causes the output to be present (or ring) for a longer time.

Frequency of a Pulsed Oscillator

The frequency of a pulsed oscillator is determined by both the input gating signal and the resonant frequency of the tank circuit. When a sinusoidal oscillator is resonant at 1 megahertz, the output is 1 million cycles per second. In the case of a pulsed oscillator, the number of cycles present in the output is determined by the gating pulse width.

If a 1-megahertz oscillator is cut off for 1/2 second, or 50 percent of the time, then the output is 500,000 cycles at the 1 -megahertz rate. In other words, the frequency of the tank circuit is still 1 megahertz, but the oscillator is only allowed to produce 500,000 cycles each second.

The output frequency can be determined by controlling how long the tank circuit will oscillate. For example, suppose a negative input gate of 500 microseconds and a positive input gate of 999,500 microseconds (total of 1 second) are applied. The transistor will be cut off for 500 microseconds and the tank circuit will oscillate for that 500 microseconds, producing an output signal. The transistor will then conduct for 999,500 microseconds and the tank circuit will not oscillate during that time period. The 500 microseconds that the tank circuit is allowed to oscillate will allow only 500 cycles of the 1-megahertz tank frequency.

You can easily check this frequency by using the following formula:

$$t = \frac{1}{f}(\text{one cycle of resonant frequency})$$

$$t = \text{time}$$

$$f = \text{resonant frequency of tank circuit}$$

One cycle of the 1-megahertz resonant frequency is equal to 1 microsecond.

$$\frac{1}{1{,}000{,}000} = .000001 \text{ or } 1 \times 10^{-6} \text{ seconds}$$

Then, by dividing the time for 1 cycle (1 microsecond) into gate length (500 microseconds), you will get the number of cycles (500).

There are several different varieties of pulsed oscillators for different applications. The schematic diagram shown in figure 2-25, view (A), is an emitter-loaded pulsed oscillator. The tank circuit can be placed in the collector circuit, in which case it is referred to as a collector-loaded pulsed oscillator. The difference between the emitter-loaded and the collector-loaded oscillator is in the output signal. The first alternation of an emitter-loaded npn pulsed oscillator is negative. The first alternation of the collector-loaded pulsed oscillator is positive. If a pnp is used, the oscillator will reverse the first alternation of both the emitter-loaded and the collector-loaded oscillator.

You probably have noticed by now that feedback has not been mentioned in this discussion. Remember that regenerative feedback was a requirement for sustained oscillations. In the case of the pulsed oscillator, oscillations are only required for a very short period of time. You should understand, however, that as the width of the input gate (which cuts off the transistor) is increased, the amplitude of the sine wave begins to decrease (dampen) near the end of the gate period because of the lack of feedback. If a long period of oscillation is required for a particular application, a pulsed oscillator with regenerative feedback is used. The principle of operation remains the same except that the feedback network sustains the oscillation period for the desired amount of time.

Q.20 Oscillators that are turned on and off at a specific time are known as what type of oscillators? Answer

Q.21 What is the polarity of the first alternation of the tank circuit in an emitter-loaded npn pulsed oscillator? Answer