LCR circuits consist of resistors, inductors, and capacitors. Low-pass and high-pass filters are major applications of LCR circuits.

A low-pass filter circuit is one that passes low frequencies and attenuates the high frequencies. A high-pass filter is one that passes high frequencies and attenuates the low frequencies.

This lesson teaches the operating principles of LCR circuits when used as low-pass or high-lass filter circuits. Troubleshooting these circuits is also an important part of the lesson.

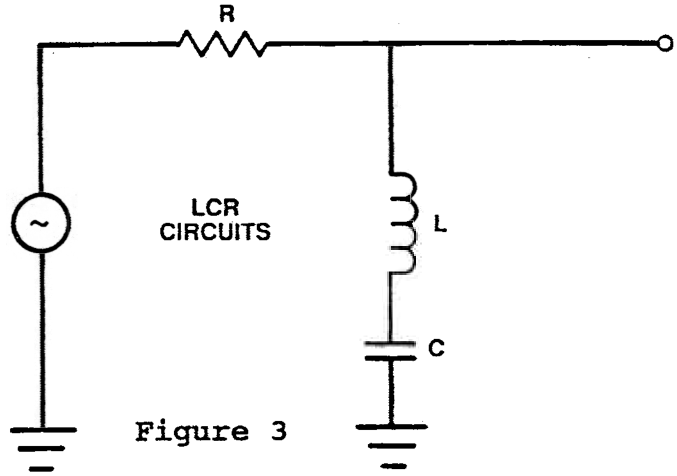


Figure 3

When an alternating voltage is applied to a series AC circuit containing resistance only, the current and voltage in the circuit are in phase. One method of showing the in-phase relationship is by sine waves. The current in the circuit is sinusoidal and will be maximum at the same time as the voltage is maximum, as shown in figure 4.

Another method of showing the same relationship is by a vector diagram. In the vector diagram in figure 4, the current and voltage vectors coincide, showing that they are in phase, and differ only in amplitude.

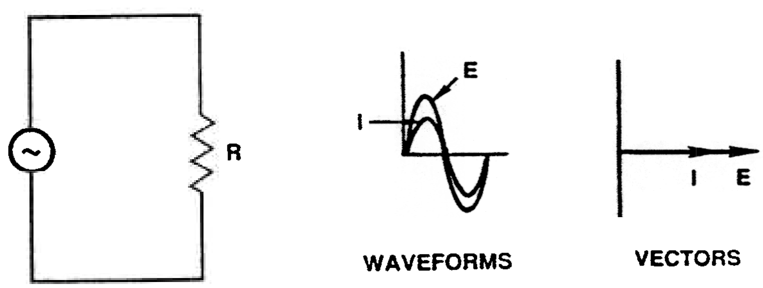


Figure 4

The only opposition of voltage and current in a pure resistive circuit is resistance $R = \frac{E}{I}$. Since voltage and current are in phase in a resistive circuit, only amplitude of current and voltage is affected by the amount of resistance in the circuit.

When an alternating voltage is first applied to a series AC circuit containing capacitance only, there is no opposition and maximum current flows at the first instant. There is no charge on the capacitor, so there is no voltage across it. As a charge builds up on the capacitor, the voltage across the capacitor rises. This voltage opposes the applied voltage and current decreases. When the charge on the capacitor is maximum, current is zero. At this point the applied voltage is reversing polarity. As shown by the sine wave in this view, the current leads the voltage across the capacitor by 90°.

When current leads the voltage of the capacitor by 90°, it can also be said that voltage lags current by 90°.

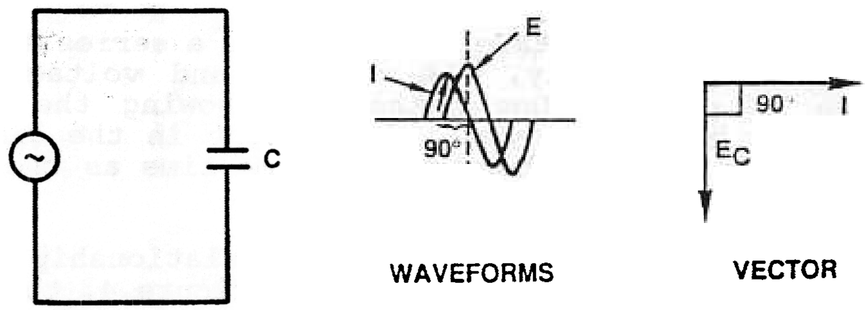


Figure 5

In a series AC circuit containing only inductance, the current and voltage, like those in a capacitive circuit, are not in phase. Because inductance opposes any change in current, the voltage across the inductor leads the current by 90° that is, the voltage reaches its maximum value 90° ahead of the current.

Circuits with inductors and capacitors that oppose changes in current or voltage have reactance. Inductive reactance is the opposition to current change. Capacitive reactance is the opposition to voltage change. X_L represents the opposition of an inductor or inductive reactance. X_C represents the opposition of a capacitor or capacitive reactance.

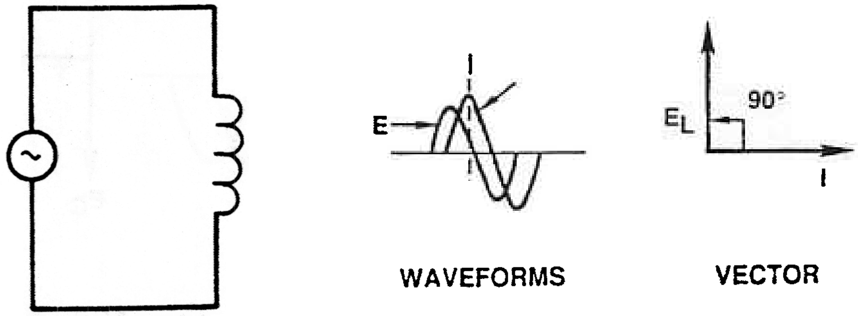


Figure 6

The total opposition in a circuit to alternating current (AC) is called IMPEDANCE (Z). The impedance of the circuit shown in this view includes: Resistance (R), Inductive Reactance (X_L), and Capacitive Reactance (X_C). The unit of measurement for inductive reactance and capacitive reactance, resistance, and impedance is the OHM.

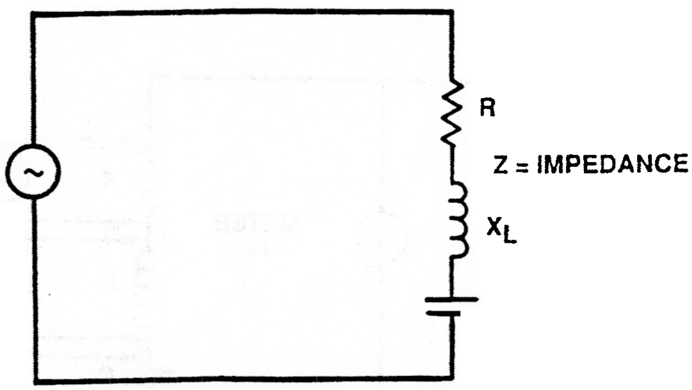


Figure 7

When a capacitor, inductor, and resistor are connected together, a complicated phase relationship exist, as shown in this view. The voltage across the inductor (E_L) leads the voltage across the resistor (E_R), which leads the voltage across the capacitor (E_C) by 90°.

The resistance and each reactance in the circuit make up a series AC voltage divider.

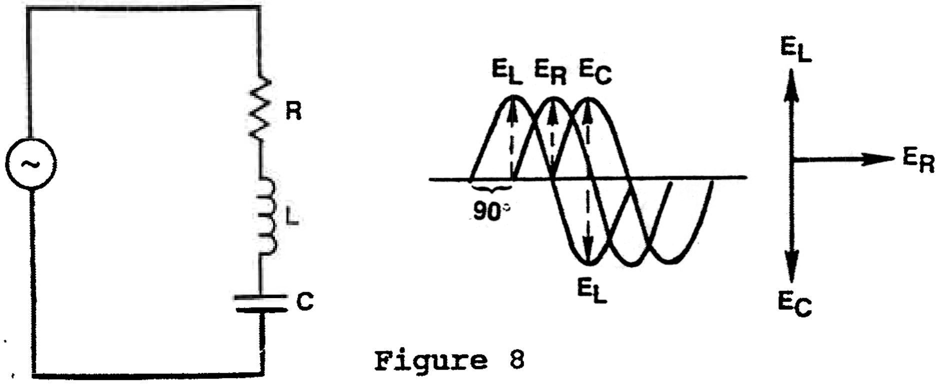


Figure 8

When an AC signal is applied to a series LCR circuit, as shown in figure 9, a voltage drop is developed across the components in the circuit. Due to the voltage and current phase shift, the voltage measured across the resistor (R), inductor (L), and capacitor (C) by the voltmeters when added together, <u>will</u> <u>not</u> total the applied voltage that is measured by Meter #4.

The voltage and current across the inductor and capacitor are out of phase. Therefore, the total applied voltage must be determined by solving a voltage vector equation.

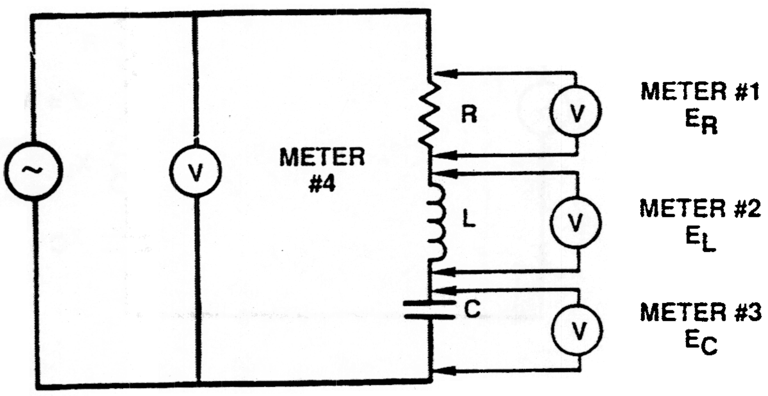
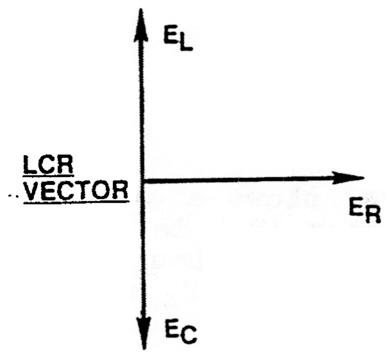


Figure 9

The voltage vector represents amplitude and phase of signal voltage in an LCR circuit. The length of the arrow represents signal amplitude and the direction of the arrow represents phase.

The total LCR circuit applied voltage is calculated using the formula in this view. The total voltage is calculated by taking the square root of the voltage across the resistor (E_R) squared, plus the voltage across the inductor (E_L), minus the voltage across the capacitor (E_C) squared.

This equation can be used on any series AC circuit. Kirchoff's voltage law still applies for series AC circuit, but the voltages must be added vectorially.



$$E_A = \sqrt{E_R2 + (E_L - E_C)2}$$

EQUATION

Figure 10

The first step in solving the vector diagram is to solve for reactance, E_L and E_C. The effective reactance in a series circuit containing both inductive and capacitive reactance is their difference ($X_L - X_C$).

The voltage across the two reactance components, the coil X_L, and capacitor X_C, are 180° out of phase. Therefore, they would cancel each other if X_L and X_C were the same value.

The circuit however will act capacitively or inductively if there is a difference in their values, depending upon which is the larger of the two.

The example in figure 11, E_L and E_C are not the same value. The inductive reactance is larger. E_C would cancel only part of the E_L, leaving an inductive circuit.

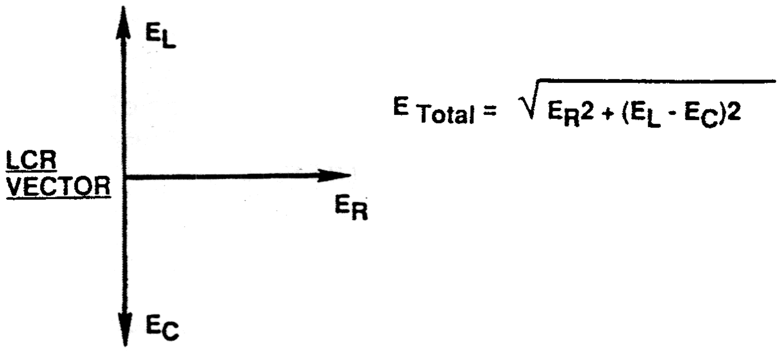


Figure 11

In figure 12, vector diagram "A" shows a circuit condition where the voltage across the inductor (E_L) is larger in value than the voltage across capacitor (E_C). When calculating the total voltage (E_T), E_C is subtracted from E_L as shown in the formula.

The formula for calculating total voltage is the square root of the voltage drop across the resistance squared, added to the difference between the voltage across the inductor E_L and capacitor E_C squared. The total voltage (E_T is represented by the "E total" line in vector diagram "B".

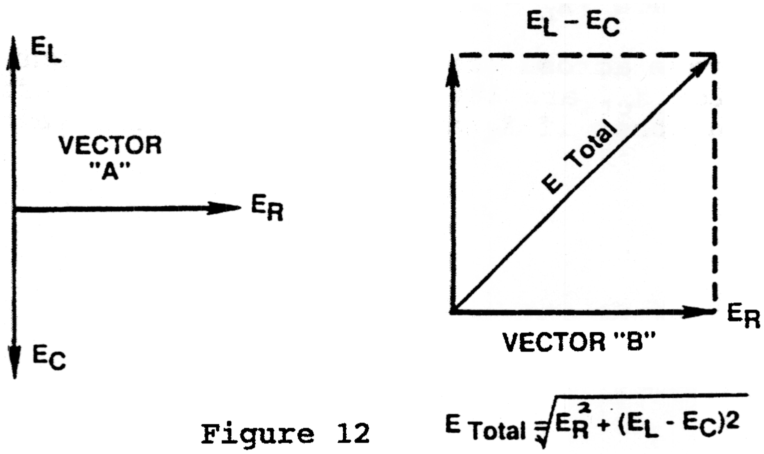


Figure 12

The voltage drop across the coil depends upon the coil's inductive reactance (X_L). The value of voltage across the capacitor depends upon the capacitive reactance (X_C). The resistor (R) also provides a voltage drop depending on its resistance.

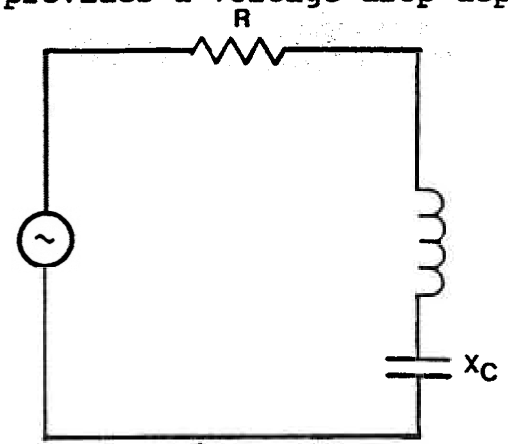


Figure 13

The inductive reactance of a coil depends upon the applied frequency and the inductance of the coil. Inductive reactance is equal to 2 times Pi (6.28), times the frequency in hertz, times the inductance in henries.

The capacitive reactance is equal to one divided by the product of 2 times Pi (6.28), the frequency in hertz, and the capacitance in farads.

The coil's inductive reactance increases as the frequency or inductance increases. Inductive reactance decreases with a decrease in frequency or inductance. The capacitive reactance operates just the opposite to the inductive reactance.

INDUCTIVE AND CAPACITIVE REACTANCE

$$X_L = 2\pi FL$$

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

Figure 14

Although capacitive reactance operates opposite to inductive reactance, the capacitive reactance of a capacitor depends upon the frequency applied and the value of capacitance.

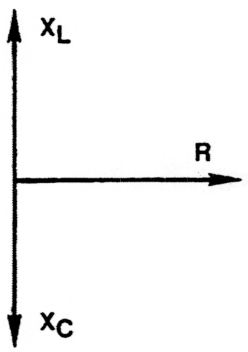
This relationship is shown in the equation in this view. When the applied frequency or the capacitance is increased, the capacitive reactance decreases. When frequency or capacitance is decreased, the capacitive reactance increases.

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

Figure 15

The total opposition to AC current and voltage is the impedance "Z". The total impedance is the square root of the resistance squared plus the difference of the reactances (X_L - X_C) squared.

Notice in the vector diagram in figure 16, that the inductive reactance (X_L) and the capacitive reactance (X_C) are equal and opposite in phase. Since they are equal in value, and 180° out of phase, the reactances will cancel each other and the total opposition to current flow is the resistance (R) only.



$X_L = X_C$

$Z = \sqrt{R2 + \cancel{(X_L - X_C)2}}$

$Z = R$

Figure 16

LCR circuits are used as frequency filters. When a coil and a capacitor are connected in series as shown in this view, it is referred to as a LOW-PASS FILTER. The low-pass filter will pass low frequencies with maximum output and attenuate the high frequencies.

The operation of the LOW-PASS FILTER can be best understood, when a function or signal generator is connected to the input of the filter and the input frequency is varied from a low to a high frequency, while measuring the output.

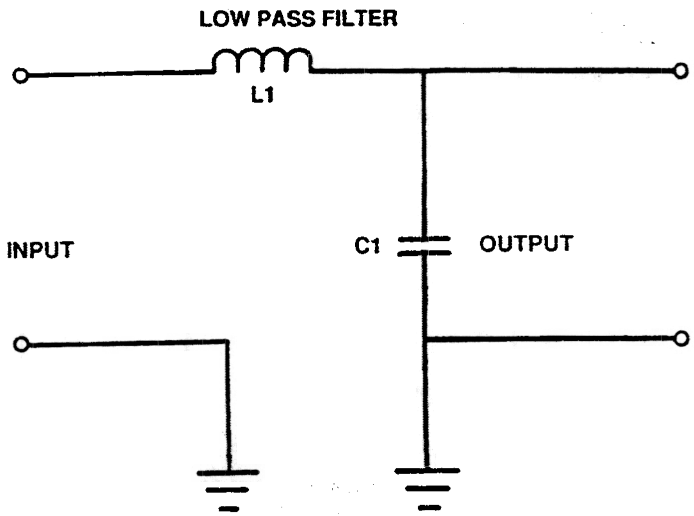


Figure 17

When the frequency from the function generator is reduced to a low frequency (a few hundred hertz), the capacitive reactance X_C of capacitor C1 is high. Remember $X_C = \frac{1}{FC}$ and therefore the capacitor C1 acts as a large opposition to AC.

Since C acts as a large opposition at low frequencies, there will be a large voltage drop across C1. Therefore, the low frequency input is developed across the capacitor.

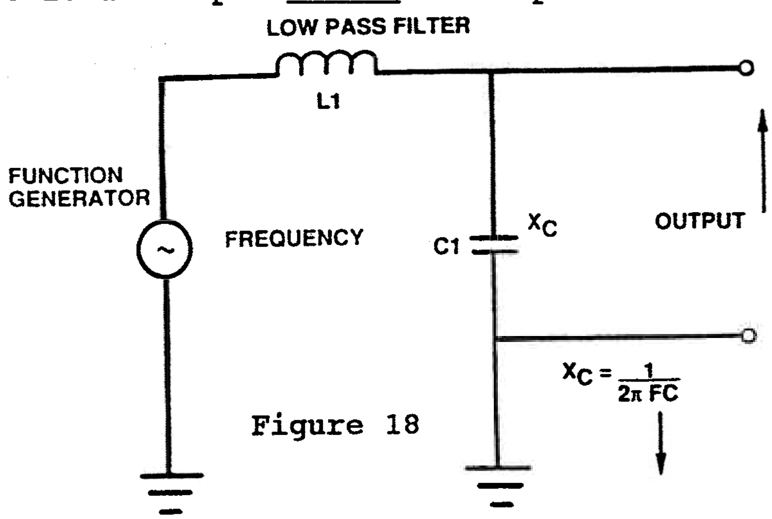


Figure 18

When the input frequency from the generator is <u>increased</u>, the reactance of C1 <u>decreases</u>. This is indicated by the reactance formula $X_C = \frac{1}{2\pi FC}$. If C1 has low reactance at high frequencies the output will also by low in amplitude. In other words, the LOW PASS FILTER will attenuate the HIGH frequencies and pass the LOW frequencies.

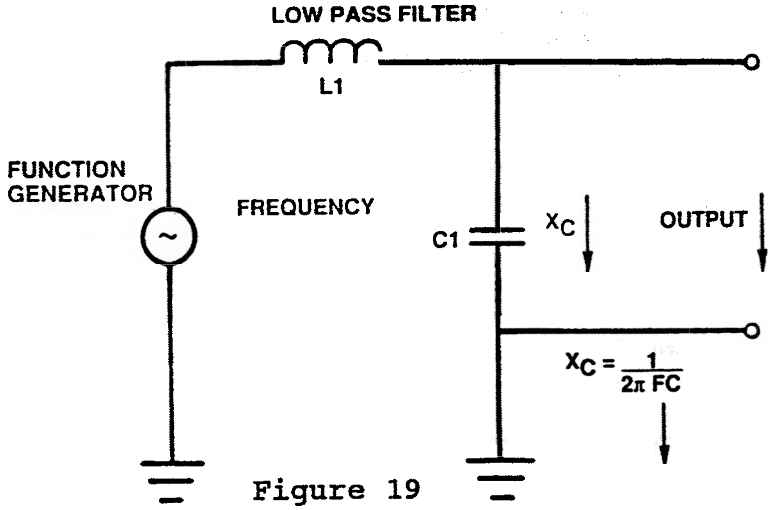


Figure 19

Figure 20 is a schematic diagram of a High Pass Filter. The High Pass Filter will pass high frequencies to the output and attenuate or decrease the low frequencies.

The High Pass Filter output is the coil while the output of a Low Pass Filter is the capacitor.

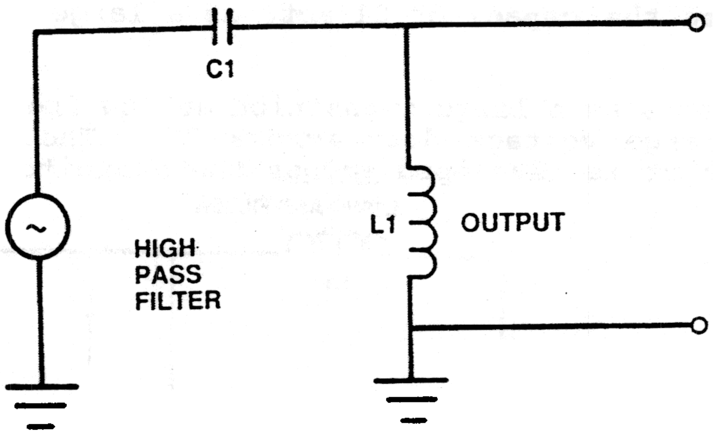


Figure 20

When the frequency from the signal generator is increased the inductive reactance X_L of the coil increases, $X_L = 2\pi FL$. If the coil opposition increases when frequency increases, the output also increases. In other words, the circuit is passing high frequencies.

The High Pass Filter circuit passes high frequencies but attenuates low frequencies.

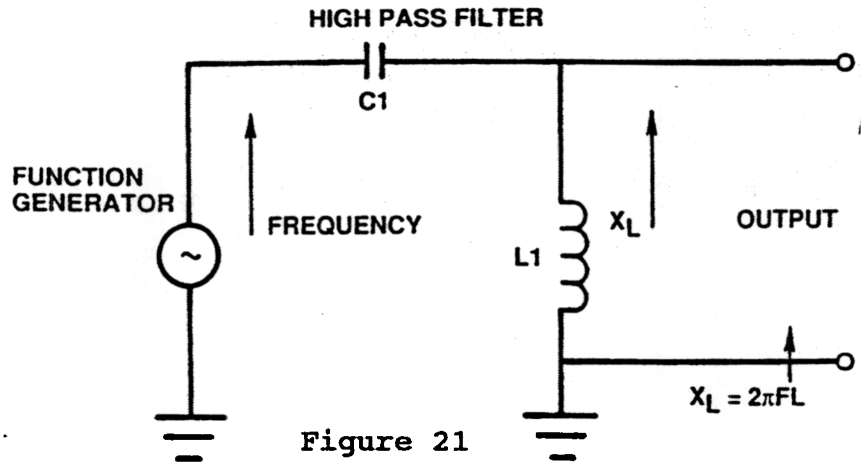


Figure 21

When the frequency from the generator is decreased the reactance of L1 decreases. This is indicated by the formula $X_L = 2\pi FL$. If L1 has low reactance at low frequencies the output will also be low in amplitude. In other words, the HIGH PASS FILTER will attenuate the LOW frequencies and pass the HIGH frequencies.

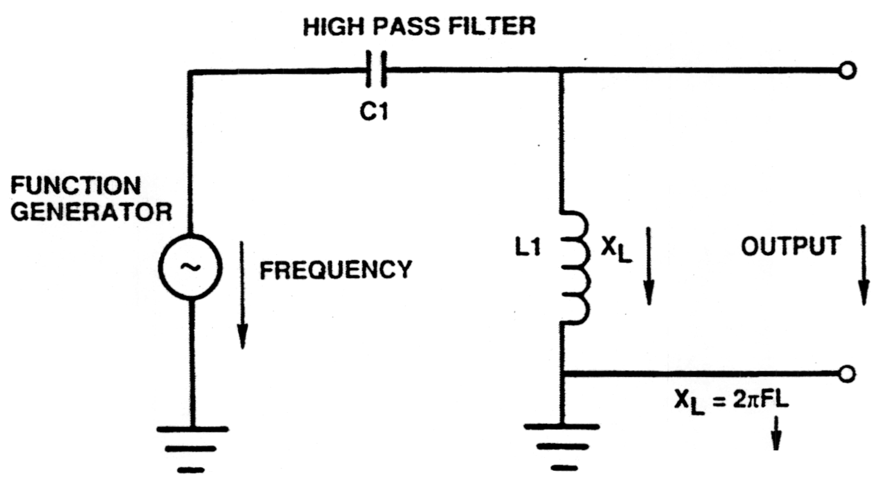


Figure 22

During this lesson you have found how resistance, inductance, and capacitance develop different voltages in LCR circuits.

An LCR circuit is a combination of an inductor, capacitor, and a resistor. The circuits are used specifically as Low Pass and High Pass Filters. LCR circuits use the opposition characteristics of reactive components to pass high frequencies or low frequencies.