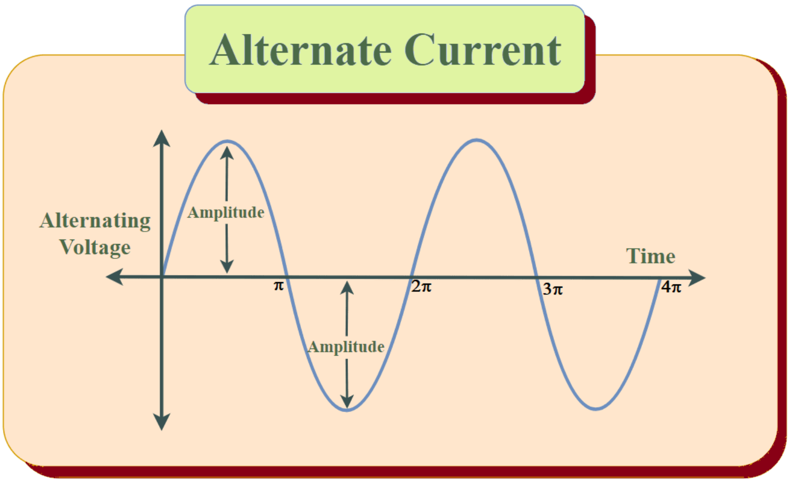
ALTERNATING CURRENT (AC)

Alternating Current (AC) is a type of electrical current in which the direction of the flow of electrons switches back and forth at regular intervals or cycles. This graph visually demonstrates the cyclic variation of the current, depicting a pattern where, during one half of the cycle, the current is positive, while during the other half, it is negative. Consequently, the current alternates its direction in the wires it traverses, flowing first in one direction and then in the opposite direction.



Alternating current (AC) varies in a sinusoidal pattern and follows the shape of a sine wave. This pattern is characterized by a smooth, periodic oscillation that changes direction between positive and negative. While any current that alternates direction could be considered AC, the term typically refers to currents that exhibit this regular, sinusoidal pattern. This sinusoidal nature is fundamental to how AC is generated and utilized in power systems.

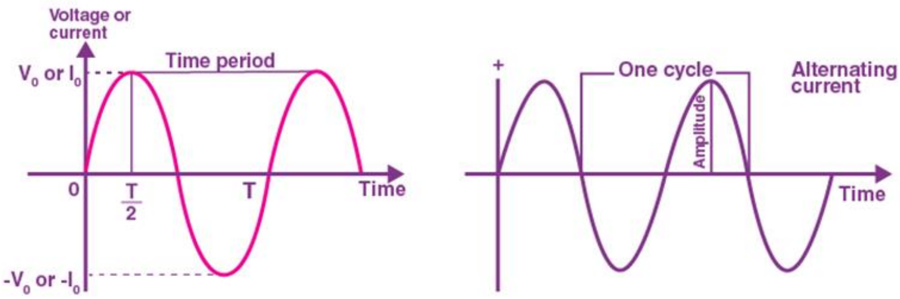
ALTERNATING CURRENT (AC) TEMINOLOGIES

Time Period (T):

The period of an alternating current (AC) or voltage wave is the duration it takes to complete one full cycle. It is typically denoted by the symbol T. The relationship between time period and frequency (f) is given by the equation:

$$time\ period = \frac{1}{frequency}$$

$$T = \frac{1}{f}$$



FREQUENCY (F):

The frequency of alternating current (AC) or voltage wave is the number of complete cycles of the current waveform that occur in one second. It is a measure of how many times the direction of the current reverses per second. Frequency is typically expressed in hertz (Hz), The relationship between frequency and period is expressed as

$$f = \frac{1}{T}$$

INSTANTANEOUS PEAK VALUE:

The instantaneous peak value refers to the maximum amplitude of the alternating current or voltage at any specific point in time. For a sine wave, this is the highest positive or negative value reached during a cycle. It is usually denoted as I_{peak} for current or V_{peak} for voltage.

ROOT MEAN SQUARE (RMS) VALUE:

The average value of voltage or current is not used in electric power calculations. The reason
being that the AC cycle consists of positive and negative half cycles, so the average value is zero. However, there exists a mathematical relation between the peak value V_0 of alternating voltage and a direct current (d.c) voltage that yields an equivalent average electrical power.

- ► Root-mean-square (r.m.s) values of current, or voltage, are a useful way of comparing a.c current, or voltage, to its equivalent direct current, or voltage.
- ► The r.m.s values represent the d.c current, or voltage, values that will produce the same heating effect, or power dissipation, as the alternating current, or voltage
- ► The r.m.s value of an alternating current I_{rms} is defined as:

  The value of a constant current that produces the same power in a resistor as the alternating current

  The r.m.s current I_{rms} is defined by the equation:

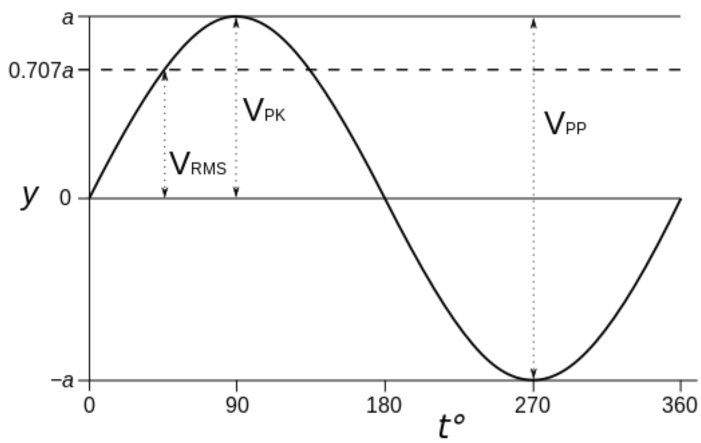
$$I_{rms} = \frac{I_0}{\sqrt{2}}$$

$$I_{rms} = 0.707\, I_0$$

- ► The r.m.s value of an alternating voltage is defined as:
  The value of a constant voltage that produces the same power in a resistor as the alternating voltage
  The r.m.s voltage V_{rms} is defined by the equation:

$$V_{rms} = \frac{I_0}{\sqrt{2}}$$

$$V_{rms} = 0.707\, I_0$$



ALTERNATING VOLTAGE EQUATION:

An alternating voltage is one whose magnitude changes with time and direction reverses periodically.

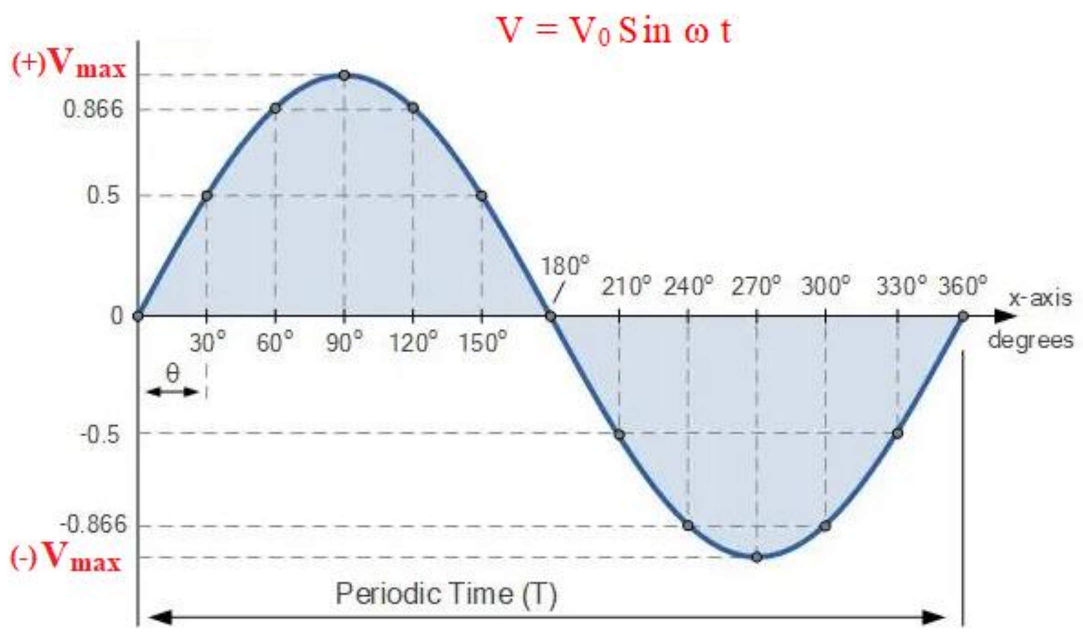
The fundamental equation describing AC voltage in a sinusoidal waveform is:

$$V = V_0 \sin \omega t \dots\dots (i)$$

V, represents the instantaneous value of the voltage

V_0, is the amplitude of the waveform, which represents the maximum value of alternating voltage.

ω is the angular frequency, given by $\omega = 2\pi f$



ALTERNATING CURRENT EQUATION:

An alternating current is one whose magnitude changes with time and direction reverses periodically.

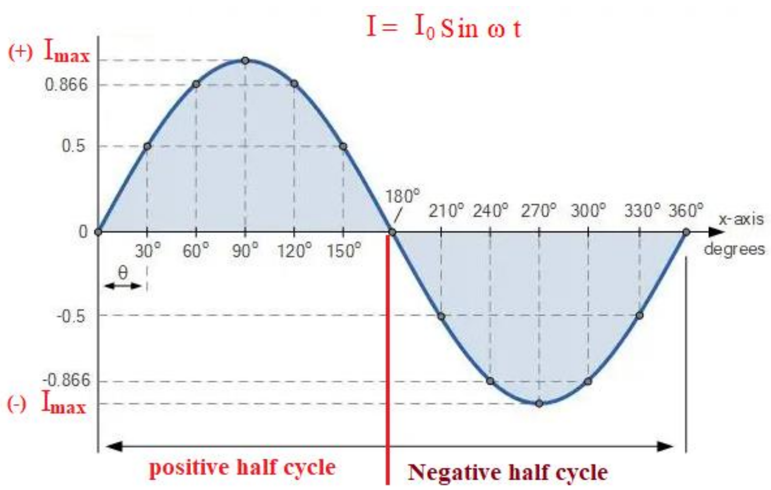
The fundamental equation describing AC current in a sinusoidal waveform is:

$$I = I_0 \sin \omega t \dots\dots (ii)$$

I, represents the instantaneous value of the voltage

I_0, is the amplitude of the waveform, which represents the maximum value of alternating voltage.

ω is the angular frequency, given by $\omega = 2\pi f$



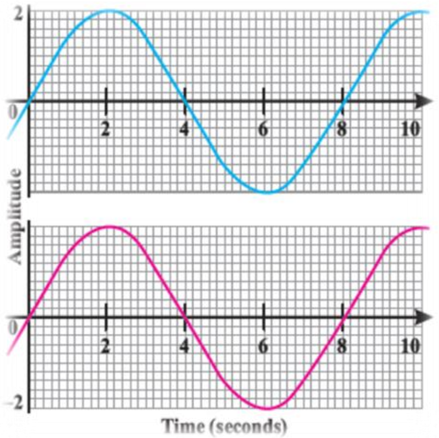
Phase of AC

Phase Difference describes the difference in degrees or radians when two or more alternating quantities reach their maximum or zero values.

The phase difference between two waves carries more important than their magnitudes. The phase describes the relative positions of these waveforms. Hence, in alternating current (A.C.) circuits, the concept of phase refers to the relationship between different waveforms as time passes.

In phase

When two waveforms have the same frequency and reach their peak values or zero values at the same time, they are said to be in phase, as shown in figure.

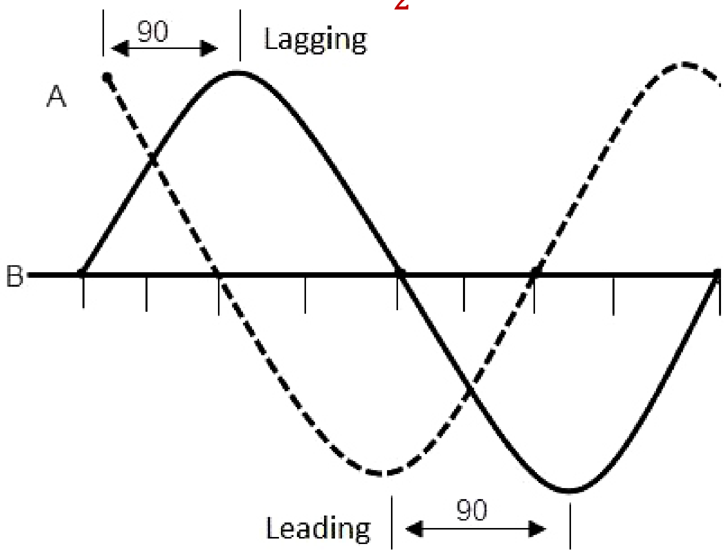


Phase Lag

If one waveform reaches its peak or zero value after the other, there is a phase difference, and the second waveform is said to lag the first. It is shown in the figure, where a wave shown by a dotted line lags the wave shown by the solid line. It can be said that the dotted waveform lags the solid line waveform by 90° or $\frac{\pi}{2}$ radians.

Phase Lead

If one waveform reaches its peak or zero value before the other, the second waveform is said to lead the first. It is shown by the figure where a wave, shown by a solid line leads the wave shown by a dotted line by a phase difference of 90° or $\frac{\pi}{2}$ radians.



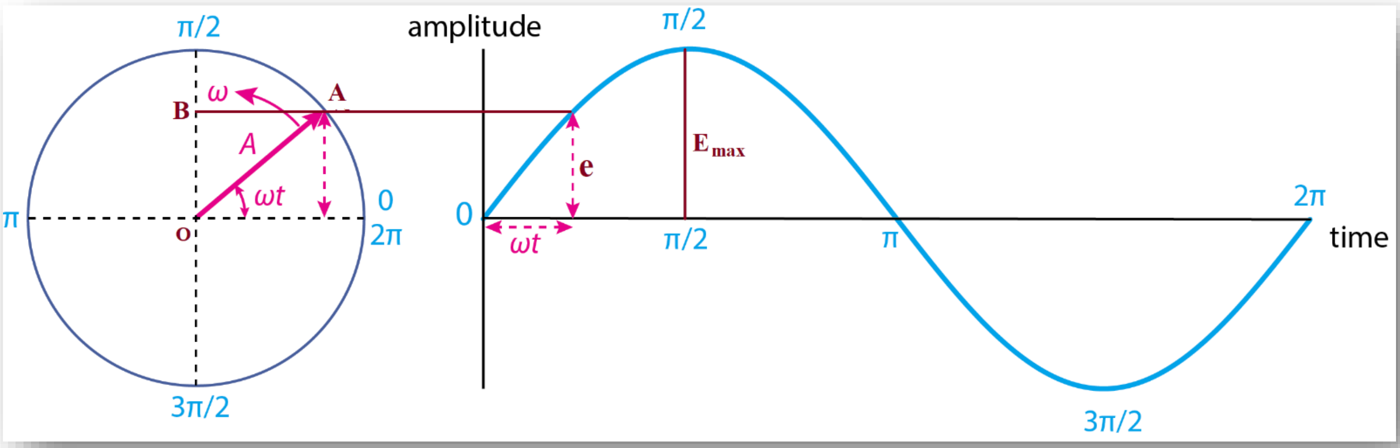
UNIT 20 AC CIRCUITS

VECTORS

Definition: A vector is a physical quantity that has both magnitude and direction. It can represent various quantities, such as force, torque, or acceleration, and is not limited to sinusoidal functions.
Representation: Vectors are usually represented in Cartesian coordinates (e.g., A = (Ax, Ay)) or in polar form (magnitude and angle). They can exist in any number of dimensions.
Usage: Vectors are used in a wide range of fields, including physics, engineering, and AI tools, to describe quantities that have both magnitude and direction.
Independence from Frequency: Vectors are not inherently tied to a specific frequency and can represent static or dynamic quantities.
Conclusion:
Both phasors and vectors describe quantities with magnitude and direction. Phasors are specifically tailored for sinusoidal signals in AC analysis, whereas vectors have a broader application across different fields and contexts. For AC circuits, voltage and current are best described as phasors.

VECTOR REPRESENTATION OF ALTERNATING QUANTITY

Alternating quantities, like AC voltage and current, are represented by rotating vectors called phasors, where the length of the vector represents magnitude and the angle represents phase. .
Let's consider a line denoted as OA, referred to as a phasor, which accurately represents, to scale, the maximum value of an alternating quantity, such as electromotive force (emf). In this representation, OA equals the maximum emf value and rotates counterclockwise at an angular velocity of m radians per second around the point 0, as illustrated in Figure

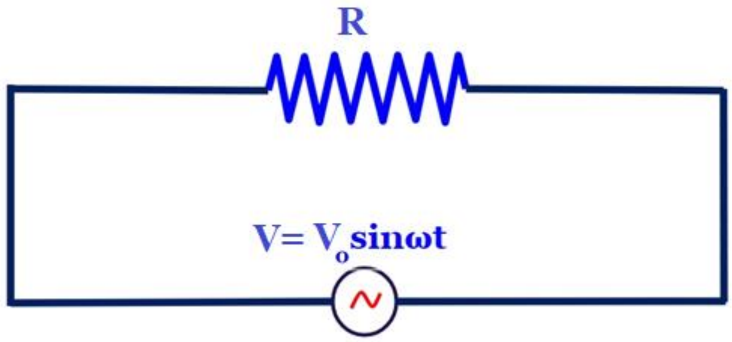


An arrowhead is placed at the outer end of the phasor, serving both to indicate the assumed the direction of movement and to specify the precise length of the phasor, especially when multiple phasors coincide.

In the above figure, OA represents the phasor after it has rotated through an angle θ, equivalent to ωt, from its initial position when the emf was at its zero value. The projection of OA on the Y-axis, denoted as OB, equals OA, multiplied by $\sin\theta$, which is equivalent to $E_{max} \sin \omega t$, representing the instantaneous value of the emf, denoted as 'e,' at that particular moment. Therefore, the projection of OA on the vertical axis accurately portrays, to scale, the instantaneous value of the emf.

A.C. circuit contains resistance only

Let us consider an alternating circuit containing resistance R only. This resistor R is connected to an alternating voltage source, as shown in the figure.



The alternating voltage induces oscillatory motion of free electrons within the resistor, constituting the alternating current. At any given time 't,' the potential difference across the resistor's terminals is expressed as

$$V = V_0 \sin \omega t \dots\dots (i)$$

Where V_0 signifies the peak value of alternating voltage. According to **Ohm's Law**, the current I in the circuit is given by:

$$I = \frac{V}{R}$$

Substituting the alternating voltage $V = V_0 \sin \omega t$, the current becomes:

$$I = \frac{V_0 \sin \omega t}{R}$$

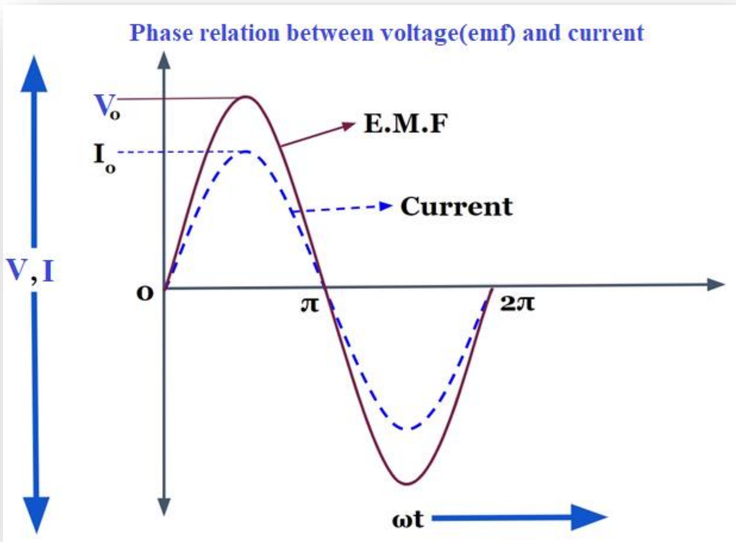
$$I = \left(\frac{V_0}{R}\right) \sin \omega t \qquad \left\{ I_0 = \frac{V_0}{R} \right\}$$

$$I = I_0 \sin \omega t \dots\dots (ii)$$

Where I_0 is the peak value or amplitude of the current, which has

$$I_0 = \frac{V_0}{R}$$

Now, compare equation (i) and equation (ii), which shows that if a circuit contains a resistor only, then the current is always in phase with the applied voltage. The phase diagram between voltage and the current of the resistor is shown below



PHASOR DIAGRAM OF RESISTIVE CIRCUIT

The current I_R flowing through a resistor R is in phase with the voltage V_R across the resistor. This alignment can be visually represented on a phasor diagram by depicting a vector (h) that coincides with the voltage (V_R).

POWER DISSIPATION

The power loss in a resistor in an AC circuit results from the conversion of electrical energy into heat due to the resistance of the resistor. The instantaneous power in the resistance can be expressed using the formula

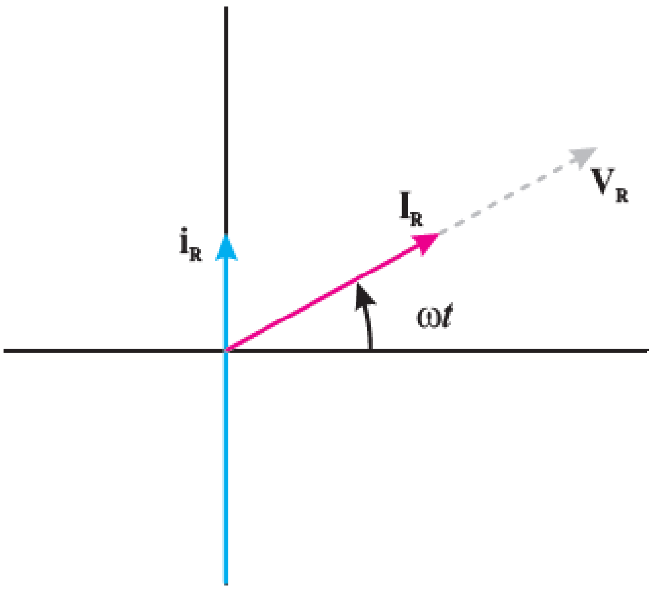
$$P = V\,I$$
$$P = (V_0 \sin\omega\, t)\,(I_0 \sin\omega\, t)$$
$$P = V_0\, I_0\, \sin^2(\omega\, t)$$

The average power P_{av} over one cycle is:

$$P_{av} = \frac{V_0\, I_0}{2} \quad \left(\because\ I_0 = \frac{V_0}{R}\right)$$
$$P_{av} = \frac{V_0}{2}\left(\frac{V_0}{R}\right)$$
$$P_{av} = \frac{V_0^2}{2R}$$
$$P_{av} = \frac{V_0^2}{2R} \times \frac{R}{R}$$
$$P_{av} = \frac{V_0^2}{R^2} \times \left(\frac{R}{2}\right) = I_0^2\left(\frac{R}{2}\right)$$

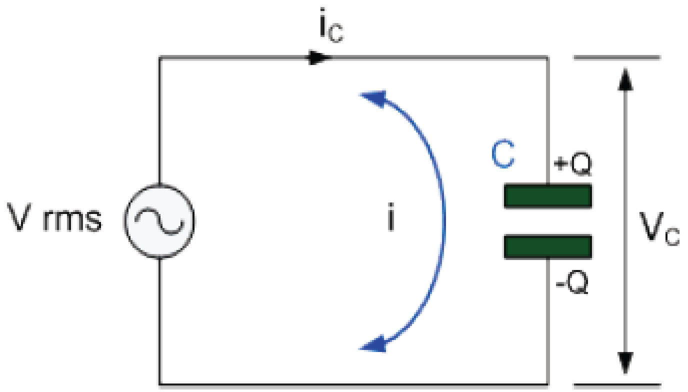
In terms of RMS value (root Mean square), the average power is:

$$P_{av} = \frac{V_0\, I_0}{2}$$
$$P_{av} = \frac{V_0}{\sqrt{2}} \times \frac{I_0}{\sqrt{2}}$$
$$P_{avg} = V_{rms}\, I_{rms}$$



A.C. THROUGH CAPACITOR

Consider a capacitor connected to the AC source, as shown in the figure. During the positive half cycle of alternating voltage, the electrons flow from the upper capacitor plate to the source, leaving it as positively charged +Q and the source supplies an equal number of electrons to the lower plate, making it a negatively charged -Q as shown in the figure. During the negative half cycle of alternating voltage, the direction of motion of electrons is also reverted, resulting in the capacitor plates becoming charged in the opposite manner and current flowing in opposite direction, hence capacitor charges and discharges. In this way, the alternating current flows through the capacitor.



If alternating source voltage $V = V_0 \sin\omega t$ is applied to the capacitor, the charge on any plate of the capacitor is given by

$$Q = CV$$

$$Q = C V_0 \sin\omega t \ldots\ldots (i)$$

The above equation clearly shows that q and V are in phase. Due to the applied current flows through the capacitor is given by

$$I_C = \frac{Q}{t} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (ii)$$

Substituting the expression for charge Q in equation (ii), we get

$$I_C = \frac{C V_0 \sin\omega t}{t} \quad \boldsymbol{or} \quad I_C = C V_0 \omega \cos\omega t \ldots. (iii)$$

Multiply and divide right hand side of equation (iii) *by* $\boldsymbol{\omega C}$

$$I_C = C V_0 \omega \cos\omega t \times \frac{\omega C}{\omega C}$$

$$I_C = \frac{V_0 \sin\left(\omega t + \frac{\pi}{2}\right)}{\frac{1}{\omega C}} \qquad \left\{\cos\omega t = \sin\left(\omega t + \frac{\pi}{2}\right)\right\}$$

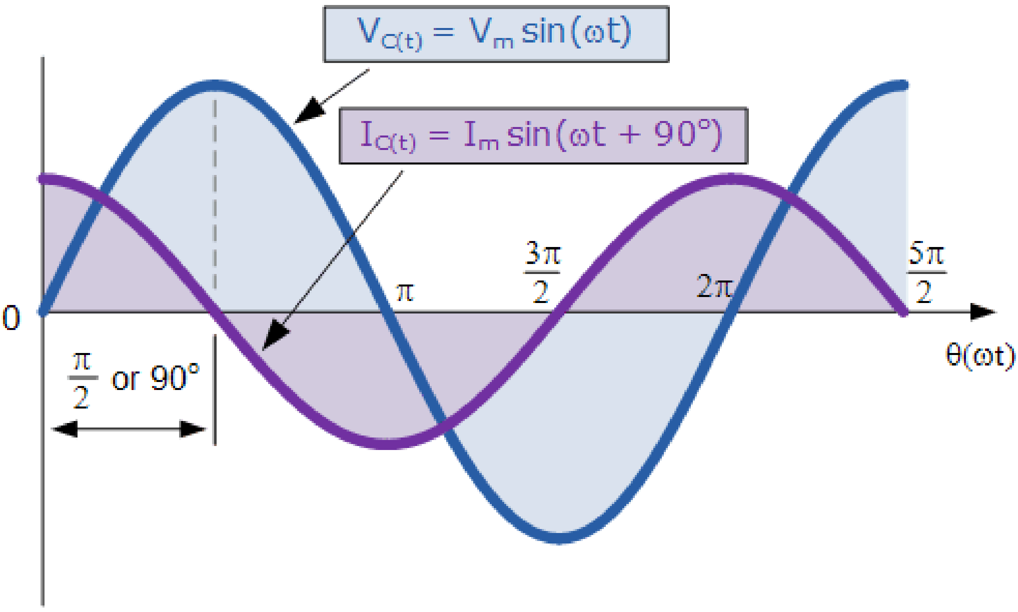
The instantaneous value of the current

$$I_C = I_0 \sin\left(\omega t + \frac{\pi}{2}\right) \ldots\ldots. (iv)$$

Where $\frac{V_0}{\frac{1}{\omega C}} = I_0$, which is the alternating current's peak value.

Equation (iv) shows that in the pure capacitive circuit the current exhibits sinusoidal variation and it leads the voltage by 90 degrees or $\frac{\pi}{2}$ radians or the voltage lags the current by 90 degrees o r $\frac{\pi}{2}$ radians as shown in the figure.

The reason is that when a voltage is introduced to an initially uncharged capacitor, the capacitor exhibits low impedance, resulting in the maximum current draw. As the capacitor becomes charged, the current diminishes, causing the voltage across the capacitor to increase. Once the capacitor is fully charged, there is no further current flow, and the voltage attains its maximum level, hence voltage lags the current by 90°.



REACTANCE OF CAPACITOR

Capacitive Reactance in a purely capacitive circuit is the opposition to current flow in AC circuits only. Like resistance, reactance is also measured in Ohm's but is given the symbol X to distinguish it from a purely resistive value.

We know that

$$\frac{V_0}{\frac{1}{\omega\ C}} = I_0$$

$$\frac{V_0}{I_0} = \frac{1}{\omega\ C} \qquad \left\{R = \frac{V_0}{I_0}\right\}$$

$$R = \frac{1}{\omega\ C}$$

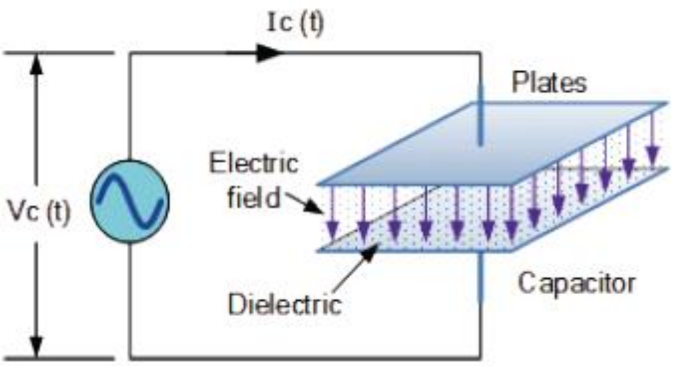
Similar to Ohm's law the term R, in this case, is called reactance of capacitance

$$R = X_C$$

The above equation can be written as

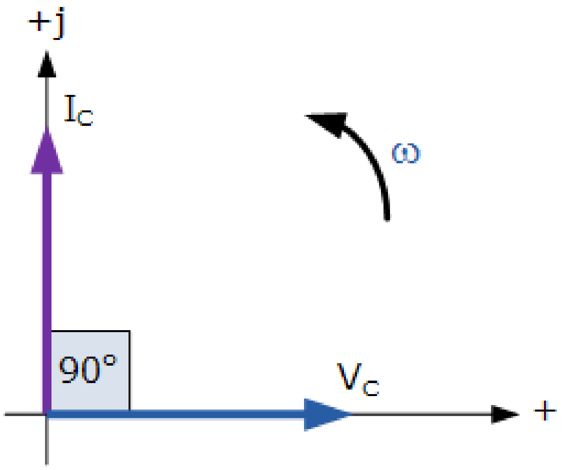
$$X_C = \frac{1}{\omega\ C} \qquad \{\omega = 2\pi\ f\}$$

$$X_C = \frac{1}{2\pi\ f\ \ C}$$



The capacitive reactance shows an inverse relationship with the frequency of the applied alternating voltage. Consequently, for lower frequencies, the reactance of the capacitor increases, while at high frequencies, the reactance decreases.

PHASOR DIAGRAM FOR AC CAPACITANCE



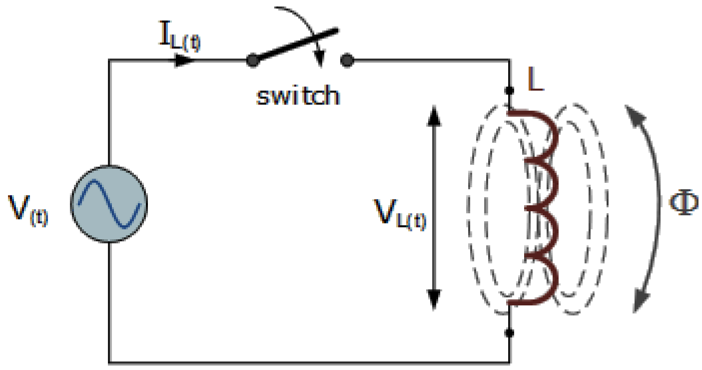
So for a pure capacitor, V_C "lags" I_C by 90°, or we can say that I_C "leads" V_C by 90°.
There are many different ways to remember the phase relationship between the voltage and current flowing in a pure AC capacitance circuit, but one very simple and easy-to-remember way is to use the mnemonic expression called "**ICE**".

ICE stands for current **I** first in an AC capacitance, **C** before Electromotive force. In other words, current before the voltage in a capacitor, I, C, E equals "ICE",

A.C. THROUGH INDUCTOR

An inductor, also known as a coil, choke, or reactor, is a passive electrical component that stores energy in a magnetic field when an electric current flows through it, and it opposes changes in current.

Consider an inductor in the form of a solenoid connected with an A.C source as shown in Figure.



When switch is closed, the current starts to flow. through the inductor, notice that the magnitude and direction of current are changing hence, the associated magnetic field also varies due to which an induced emf is set up in the inductor to oppose the change by the Lenz law. The magnitude of induced emf is given by

$$emf \;=\; -L\,\frac{\Delta I}{\Delta t}$$

Therefore, to sustain the current, the applied voltage must match the back electromotive force (EMF). Thus, the magnitude of voltage supplied to the coil is expressed as

$$V \;=\; L\,\frac{\Delta I}{\Delta t} \quad \ldots\ldots(i)$$

The alternating voltage produces a sinusoidal current given by

$$I = I_0 \sin \omega\, t$$

Hence the equation becomes

$$V \;=\; L\,\frac{I_0\,\Delta \sin \omega t}{\Delta t}$$

$$V \;=\; \omega\, L\, I_0\; \cos \omega t$$

Where

$$V_0 = \omega L I_0$$

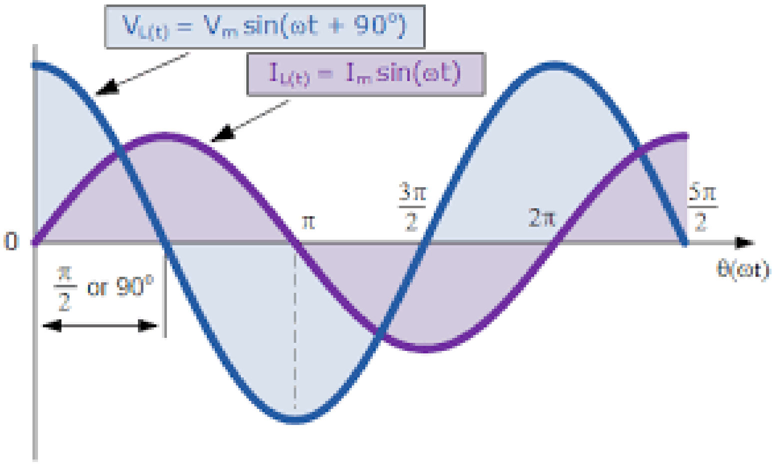
$$V = V_0 \cos\omega t \;\ldots\ldots\ldots (ii)$$

Using that,

$$\cos\omega t = \sin\left(\omega t + \frac{\pi}{2}\right)$$

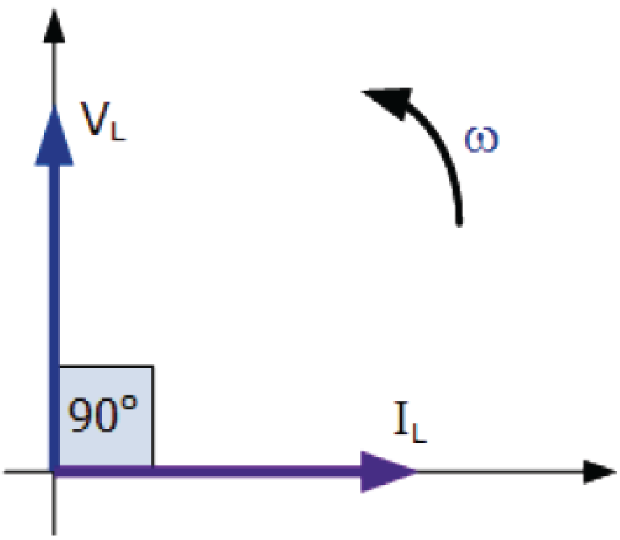
Equation (ii) becomes

$$V = V_0 \sin\left(\omega t + \frac{\pi}{2}\right) \;\ldots\ldots..(iii)$$



From equation (iii) it is clear that in the case of an inductor connected in an A.C circuit the voltage leads the current by $\frac{\pi}{2}$ radians as shown in Figure.

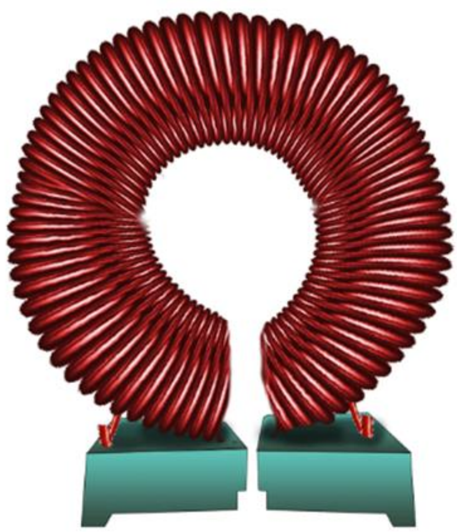
The reason for voltage leading in an inductive circuit is due to the generation of induced electromotive force (EMF), commonly known as back EMF when an alternating voltage is applied to the inductor. This back EMF appears instantaneously and induces a counter-current flow, introducing a time delay, typically in the order of milliseconds. As a result, there is a brief time lag for the circuit current to overcome this opposing current and attain its maximum value. That is why the voltage manifests first followed by the appearance of the current after a short interval. Hence the voltage leads the current or the current lags behind the voltage in an inductive AC circuit, drawing I_L behind V_L by a phase angle of 90 degrees as shown by the phasor diagram in the figure.



CHOCK COIL

A choke coil is an inductance coil of very small resistance used for controlling current in an a.c. circuit.

A choke is **an inductor used to block higher-frequency alternating currents** (AC) while passing direct current (DC) and lower-frequency AC in a circuit.



CONSTRUCTION

A choke coil consists of a large number of turns of insulated copper wire wound over a soft iron core. A laminated core is used to minimize eddy current loss

TYPES OF A CHOKE COIL

Choke coils are divided into two types based on the type of frequency they are supposed to resist and not allow to pass through them. They are:

1 Audio Frequency choke inductor
2 Radiofrequency choke inductor

Application of Choke Coil

There are various applications of choke coils in physics and electronics such as:

- Choke coils are used in car audio systems to prevent the high audio frequency signals from the amplifier.
- It also has a wide range of uses in computer cables, radio receivers, and amplifiers.
- In tuned circuits and filters, the choke coils are used to block the various high-frequency signals from the AC currents.

INDUCTIVE REACTANCE

The term inductive reactance refers to the opposition that an inductor offers to the flow of alternating current. It is denoted by X_L. It is measured in ohms. The inductive reactance can be calculated by following the method. The formula for inductive reactance is given by:

$$X_L = \omega L$$

$$X_L = (2\pi f) L \ldots.(i)$$

where:

X_L is the inductive reactance,
f is the frequency of the AC signal,
L is the inductance of the inductor.

Equation (i) shows that inductive reactance is directly proportional to the frequency of the AC signal. As the frequency increases, the inductive reactance also increases.

RLC CIRCUIT

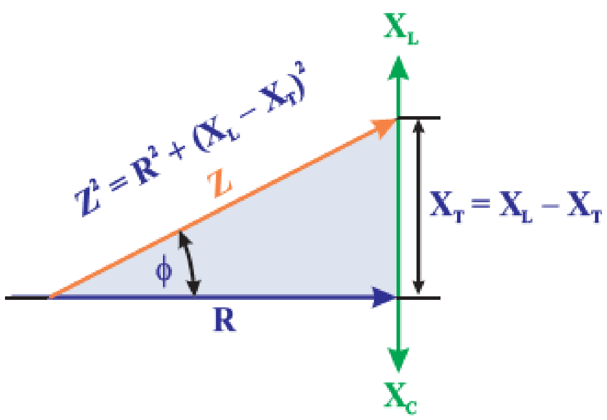
A RLC circuit (Resistor-Inductor-Capacitor Circuit), also known as a tuned or resonant circuit, is an electric circuit composed of resistors (R), inductors (L), and capacitors (C). It's a powerful tool that allows us to describe and predict how circuits will respond to various inputs.

THE COMPONENTS OF AN RLC CIRCUIT

Resistors (R): Resistors limit current flow and drop voltage in a circuit. They exhibit a constant resistance regardless of the frequency of an applied signal. This constant resistance is crucial for the balance of the RLC circuit.

Inductors (L): Inductors store energy in the form of a magnetic field when current passes through them. They oppose changes in current, with the degree of opposition dependent on the frequency. The higher the frequency, the higher the inductive reactance, which is the resistance provided by an inductor to alternating current (AC).

Capacitors (C): Capacitors store energy in an electric field and oppose changes in voltage. Like inductors, capacitors also have a reactance, called capacitive reactance, which decreases with increasing frequency.



WORKING OF AN RLC CIRCUIT

An RLC circuit responds to a wide range of signals, whether steady DC, simple AC, or complex waveforms. This response depends on how the energy flows and oscillates between the inductor and the capacitor, with the resistor acting as a mediator that controls this oscillation by dissipating energy.

IMPEDANCE TRIANGLE

A circuit containing a resistor, inductor, and capacitor offers opposition to the flow of current due to all these circuit elements known as impedance. It is denoted by Z. The impedance triangle is shown in figure

To draw an impedance triangle, represent the resistance (R) as the horizontal side of the triangle.

Represent the inductive reactance (X_L) or capacitive reactance (X_C) as the vertical side of the triangle. The direction (up or down) depends on whether it's inductive or capacitive reactance.

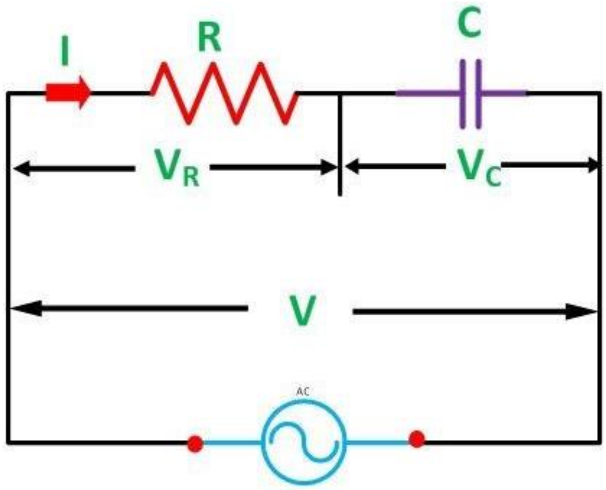
Now the hypotenuse of the triangle represents the impedance (Z). From the right-angle triangle impedance can be calculated by using the following relation

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

Where Z is impedance, R is resistance in a circuit and X_T^2 sum of capacitive and inductive reactance of circuit.

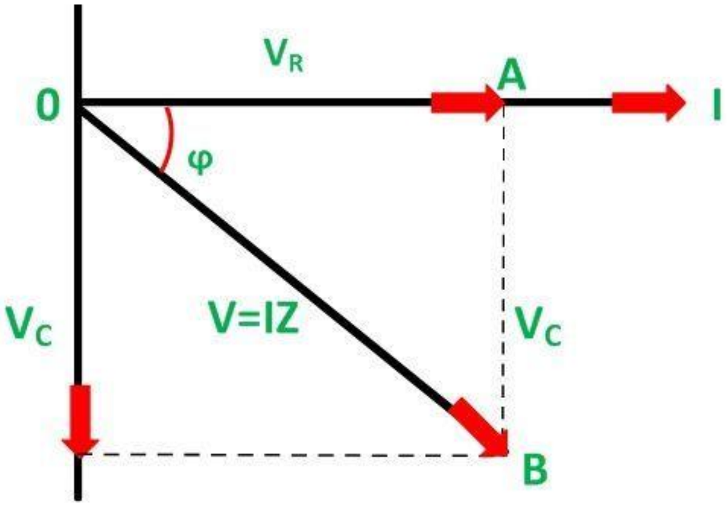
AC THROUGH RC SERIES CIRCUIT

A circuit that contains pure resistance R ohms connected in series with a pure capacitor of capacitance C farads is known as an RC Series Circuit.



Phasor Diagram of RC Series Circuit

The phasor diagram of the RC series circuit is shown below:



Steps to Draw a Phasor Diagram

The following steps are used to draw the phasor diagram of the RC Series circuit

- Take the current I (r.m.s value) as a reference vector
- Voltage drops in resistance $V_R = IR$ is taken in phase with the current vector
- Voltage drops in capacitive reactance $V_C = I\,X_C$ is drawn 90 degrees behind the current vector, as current leads voltage by 90 degrees (in the pure capacitive circuit)
- The vector sum of the two voltage drops is equal to the applied voltage V (r.m.s value).

In the right triangle OAB

$$V = \sqrt{V_R^2 + V_C^2}$$

$$V = \sqrt{(IR)^2 + (I\,X_C)^2}$$

$$V = \sqrt{I^2R^2 + I^2\,X_C^2}$$

$$V = I\sqrt{R^2 + X_C^2}$$

$$\frac{V}{\sqrt{R^2 + X_C^2}} = I$$

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

Where,

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

Z is the total opposition offered to the flow of alternating current by an RC series circuit and is called the **impedance** of the circuit. It is measured in ohms (Ω).

Phase angle

From the phasor diagram shown above, it is clear that the current in the circuit leads the applied voltage by an angle ϕ and this angle is called the phase angle.

$$\tan \Phi = \frac{V_C}{V_R}$$

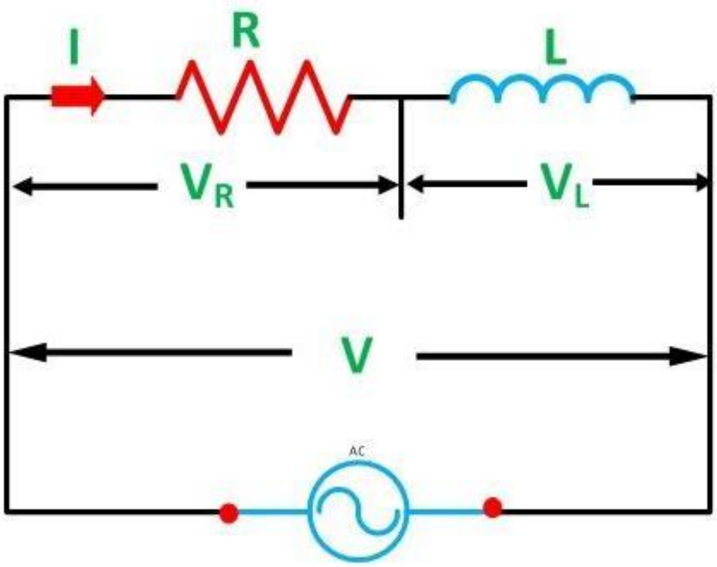
$$\tan \Phi = \frac{I\,X_C}{I\,R}$$

$$\tan \Phi = \frac{X_C}{R}$$

$$\Phi = \tan^{-1}\left(\frac{X_C}{R}\right)$$

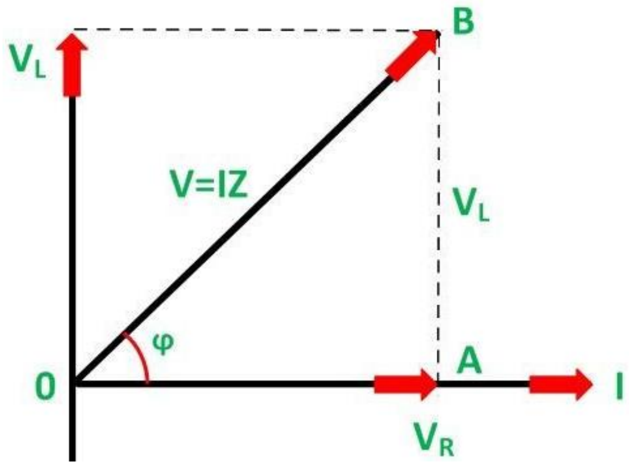
AC through RL series circuits

A circuit that contains a pure resistance R ohms connected in series with a coil having a pure inductance of L (Henry) is known as RL Series Circuit.



Phasor Diagram of the RL Series Circuit

The phasor diagram of the RL Series circuit is shown below:



Steps to draw the Phasor Diagram of RL Series Circuit

The following steps are given below which are followed to draw the phasor diagram step by step:

- Current I is taken as a reference.
- The Voltage drop across the resistance $V_R = IR$ is drawn in phase with the current I.
- The voltage drop across the inductive reactance $V_L = I X_L$ is drawn ahead of the current I. As the current lags voltage by an angle of 90 degrees in the pure Inductive circuit.
- The vector sum of the two voltages drops V_R and V_L is equal to the applied voltage V.

Now,
In right-angle triangle OAB

$$V = \sqrt{V_R^2 + V_L^2}$$

$$V = \sqrt{(IR)^2 + (I X_L)^2}$$

$$V = \sqrt{I^2R^2 + I^2X_L^2}$$

$$V = I\sqrt{R^2 + X_L^2}$$

$$\frac{V}{\sqrt{R^2 + X_L^2}} = I$$

$$\frac{V}{Z} = L = I$$

Where,

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

Z is the total opposition offered to the flow of alternating current by an **RL** Series circuit and is called the impedance of the circuit. It is measured in ohms (Ω).

PHASE ANGLE

In RL Series circuit the current lags the voltage by 90 degrees angle known as phase angle. It is given by the equation:

$$\tan\Phi = \frac{V_L}{V_R}$$

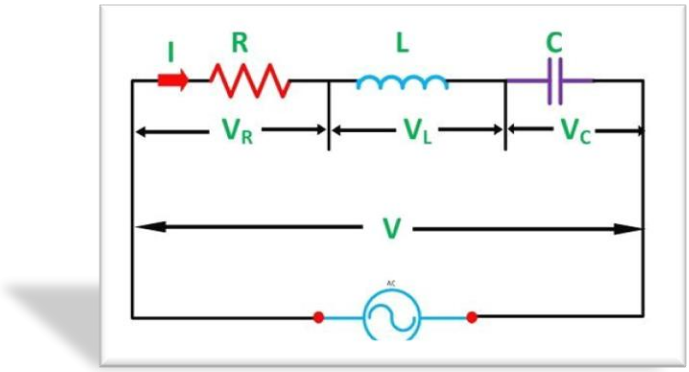
$$\tan\Phi = \frac{I X_L}{I R}$$

$$\tan\Phi = \frac{X_L}{R}$$

$$\Phi = \tan^{-1}\left(\frac{X_L}{R}\right)$$

RLC series AC circuit

When a pure resistance of R ohms, a pure inductance of L Henry and a pure capacitance of C farads are connected together in series combination with each other then **RLC Series Circuit** is formed. As all the three elements are connected in series so, the current flowing through each element of the circuit will be the same as the total current I flowing in the circuit.



Components of RLC Circuits

RLC circuits incorporating resistors, inductors, and capacitors form the foundation of electric circuit design. Each element exhibits specific physical characteristics that contribute to overall circuit behavior.

Resistors

Resistors are lumped circuit elements that “resist” the flow of currents, causing a voltage drop. They’re characterized by a constant resistance (measured in ohms) that is independent of the frequency of an applied signal.

Inductors

Inductors are typically constructed from coils of wire, storing energy in a magnetic field as current passes through the wire. They oppose variations in current, where the degree of opposition is known as the inductive reactance (measured in ohms). This inductive reactance is dependent on the frequency of an applied signal. It increases as frequency increases, and vice versa.

The inductive reactance was determined as

$$X_L = 2\pi f L$$

Capacitors

Where inductors store energy in a magnetic field, capacitors store energy in an electric field. Capacitors oppose variations in voltage where the degree of opposition is known as the capacitive reactance (also measured in ohms). The capacitive reactance is also frequency dependent: It decreases with increasing frequency, and vice versa.

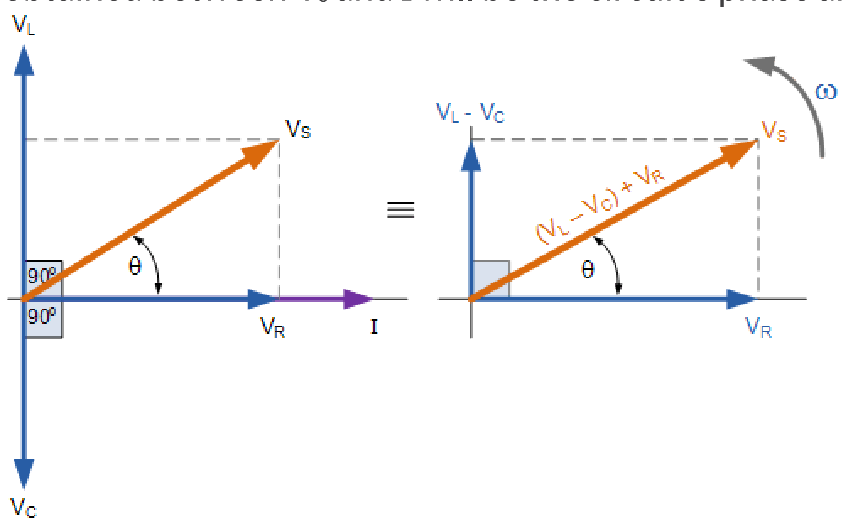
$$X_C = \frac{1}{2\pi f C}$$

When smaller frequency capacitive reactance is much greater than inductive reactance i-e $X_C > X_L$ causing the circuit to exhibit behavior akin to an RC circuit. For larger frequencies inductive reactance dominates over capacitive reactance i-e $X_L > X_C$ and the circuit behaves like an RL circuit. Hence the circuit is said to be more inductive than capacitive.

Phasor Diagram for a Series RLC Circuit

The phasor diagram for a series RLC circuit is produced by combining the three individual phasors above and adding these voltages vectorially.

The resulting vector V_S is obtained by adding together two of the vectors, V_L and V_C, and then adding this sum to the remaining vector V_R. The resulting angle obtained between V_S and I will be the circuit's phase angle as shown below.



POWER IN A.C CIRCUITS

The calculation of power dissipation in a resistor involves the formula $P = VI$. However, this equation is not applicable in circuits where capacitors and inductors are connected to an alternating voltage source. The reason is that in a purely resistive circuit, the current and voltage are in phase. Whereas, circuits containing capacitive or inductive elements exhibit a lead or lag of $\frac{\pi}{2}$ radians between the current and voltage, respectively, disrupting the applicability of this relationship. Therefore, in such a case to determine power dissipation, project V onto the direction of the reference current phasor as shown in RC circuit figure. This approach ensures that the applied voltage is in phase with the current. Hence power dissipation in an AC circuit is expressed as follows

$$P = VI\cos\theta$$

Where cosθ represents the power factor.

RESONANT FREQUENCY

For a certain frequency, the capacitive and inductive reactance becomes equal, $X_C = X_L$. This frequency is called resonant frequency f_r and the circuit is said to be in a resonance state.

The Formula for Resonant Frequency:

the resonant frequency formula is:

$$f_r = \frac{1}{2\pi\sqrt{L\,C}}$$

Where f_r is the resonant frequency denoted as the inductance is L and the capacitance is C.

DERIVATION:

To calculate the resonant frequency, use the fact that

$$X_C = X_L$$

$$\frac{1}{2\pi f_r C} = 2\pi f_r L$$

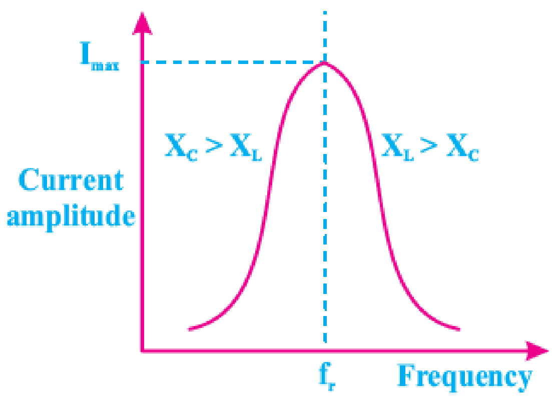
$$\frac{1}{2\pi \times 2\pi L\,C} = f_r \times f_r$$

$$\frac{1}{4\pi^2 L\,C} = f_r^2$$

Taking Square root on both sides

$$\sqrt{f_r^2} = \sqrt{\frac{1}{4\pi^2 L\,C}}$$

$$f_r = \frac{1}{2\,\pi\sqrt{L\,C}}$$

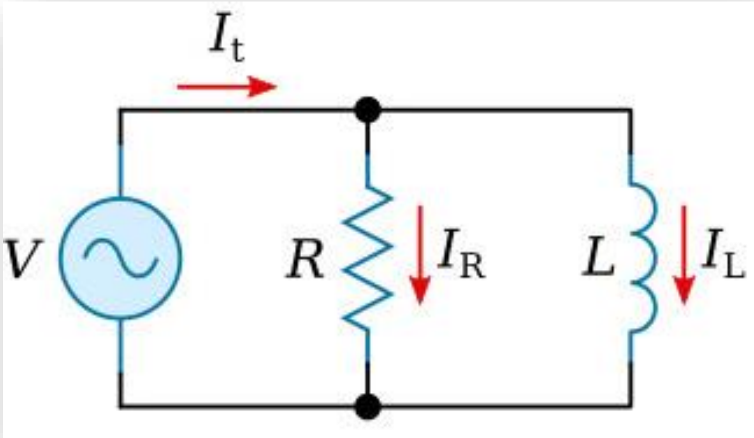


CONCLUSION

From the figure note that X_C and X_L are in opposite directions. Therefore, at resonant frequency, they cancel each effect in the circuit. Now opposition to the current flow is solely offered by a resistor, resulting in maximum current flowing through the circuit, moreover either side of the resonant frequency the current in the circuit decreases, as shown in the figure. RLC series circuit is an important circuit it is used in; Electronic filters, Electromagnetic Interference (EMI) Suppression, Tuned Circuits, etc.

PARALLEL RL CIRCUIT

The combination of a resistor and inductor connected in parallel to an AC source, as illustrated in Figure, is called a parallel RL circuit.

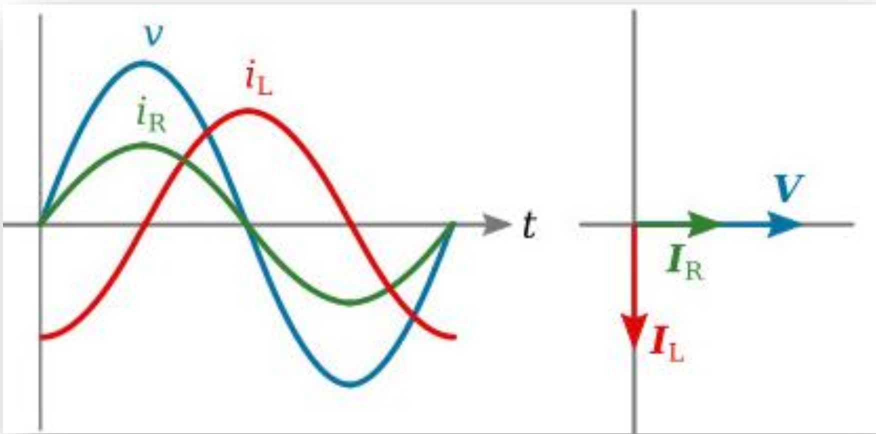


In a parallel DC circuit, the voltage across each parallel branch is equal. This is also true of the AC parallel circuit.
The voltages across each parallel branch are:

- the same value.
- Equal in value to the total applied voltage V.
- All in phase with each other.

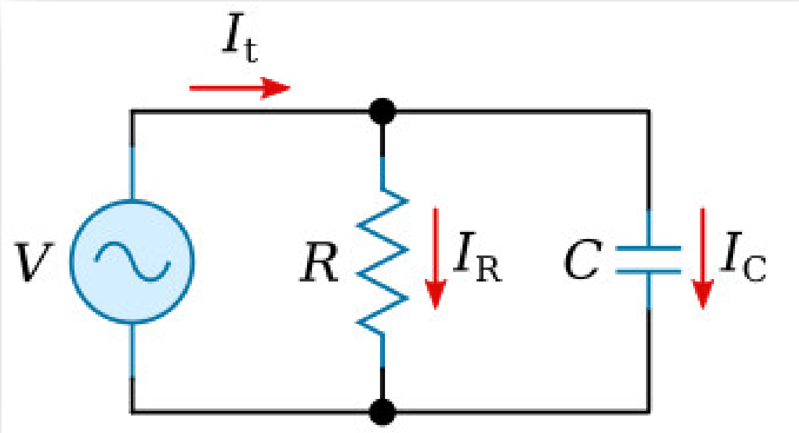
Phasor diagram for a parallel RL circuit.

For instance, applied voltage V is still the quantity that is common to both components and is therefore plotted in the standard position in the phasor diagram. Also, the magnitude of the individual branch currents is determined by the opposition (reactance) of the individual branches. The figure below shows a composite diagram of waveforms and phasors. Since the phasor diagram shows that the two branch currents are not in phase, it will be necessary to use phasor addition to determine the total current.



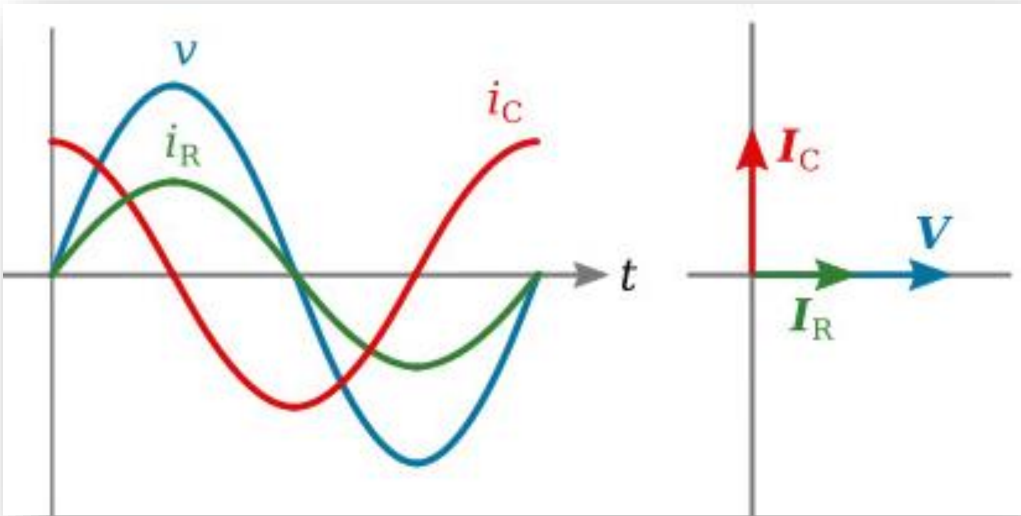
PARALLEL RC CIRCUIT

The combination of a resistor and capacitor connected in parallel to an AC source, as illustrated in Figure, is called a parallel RC circuit.



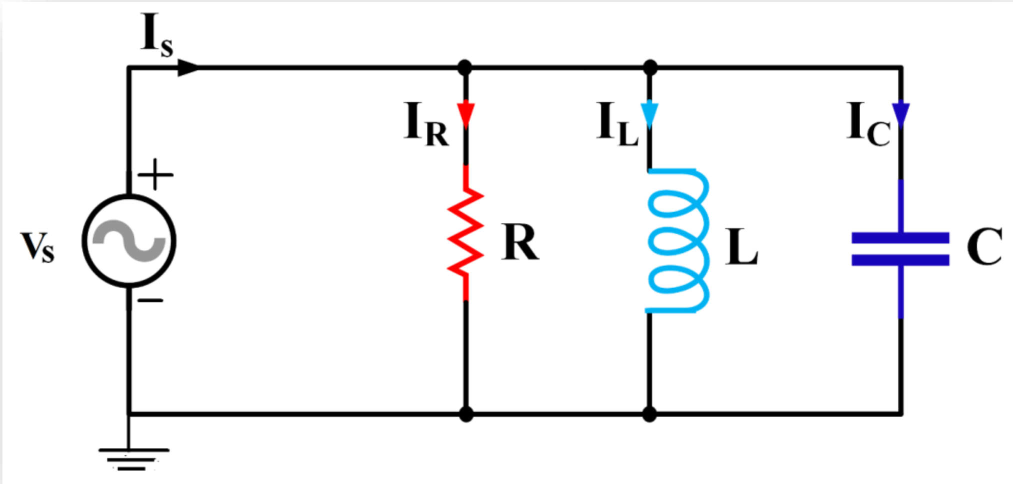
The figure below shows a composite diagram of the circuit conditions. The current phasors I_R and I_C are out of phase, therefore, phasor addition must be used to determine the total current. The solving of an RC circuit follows the method previously applied to LR circuits.

In a pure capacitor, the current leads the voltage by 90 degrees, while in a pure inductor the current lags the voltage by 90 degrees.



PARALLEL RLC AC CIRCUIT

A Parallel RLC AC Circuit is one where the resistor, inductor, and capacitor are connected in parallel to each other and the AC source. In this configuration, the voltage across each component is the same, but the currents through them differ. The parallel arrangement affects the overall impedance and current distribution in the circuit, making it distinct from its series counterpart. In a parallel circuit, the voltage V (RMS) across each of the three elements remains the same. Hence, for convenience, the voltage may be taken as a reference phasor.



In the above parallel RLC circuit, we can see that the supply voltage, V_S is common to all three components whilst the supply current IS consists of three parts. The current flowing through the resistor, I_R, the current flowing through the inductor, I_L and the current through the capacitor, I_C.

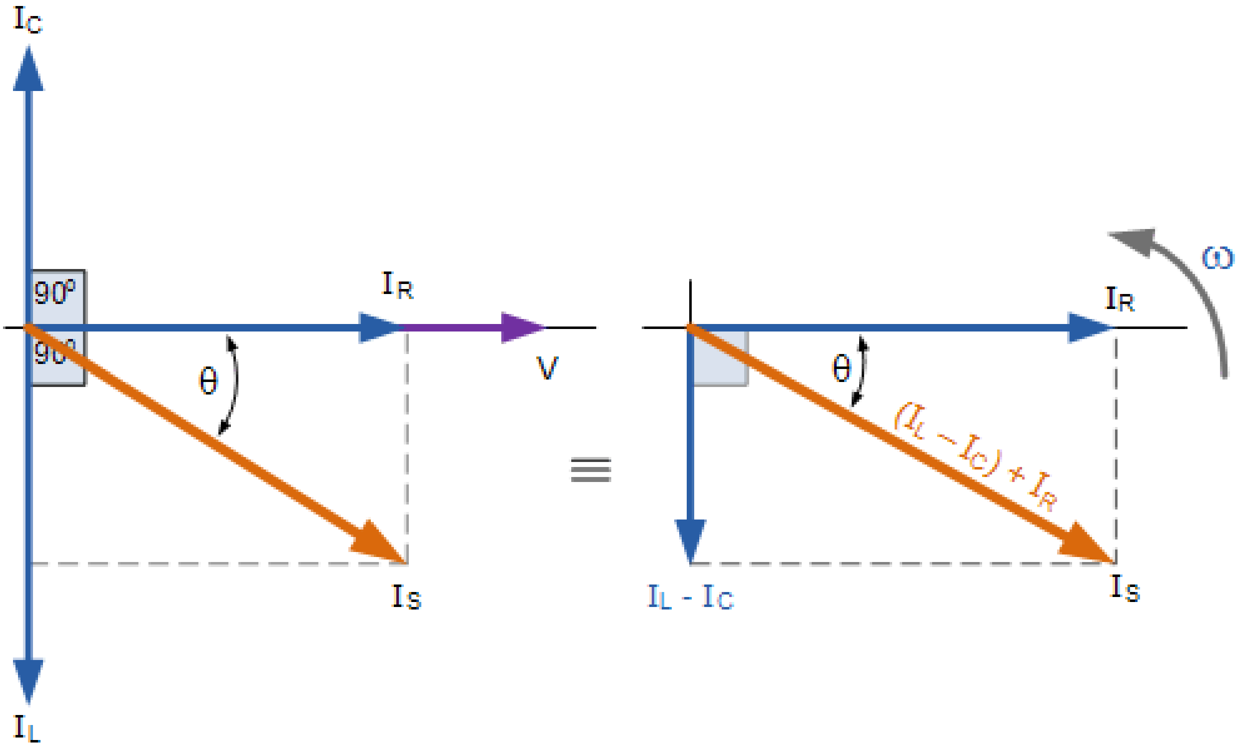
But the current flowing through each branch and therefore each component will be different from each other and also to the supply current, I_S. The total current drawn from the supply will not be the mathematical sum of the three individual branch currents but their vector sum.

Like the series RLC circuit, we can solve this circuit using the phasor or vector method but this time the vector diagram will have the voltage as its reference with the three current vectors plotted with respect to the voltage. The phasor diagram for a parallel RLC circuit is produced by combining together the three individual phasors for each component and adding the currents vectorially.

Since the voltage across the circuit is common to all three circuit elements we can use this as the reference vector with the three current vectors drawn relative to this at their corresponding angles. The resulting vector current I_S is obtained by adding together two of the vectors, I_L and I_C and then adding this sum to the remaining vector I_R. The resulting angle obtained between V_S and I_S will be the circuit's phase angle as shown below.

Phasor Diagram for a Parallel RLC Circuit

From the phasor diagram of the AC RLC parallel circuit given below, we observe that the current vectors form a right triangle, with the hypotenuse represented by I_S, the horizontal axis by I_R and the vertical axis by $(I_L - I_C)$. This configuration forms what is known as a Current Triangle. Consequently, we can apply Pythagoras's theorem to this current triangle to mathematically determine the individual magnitudes of the branch currents along the x-axis and y-axis. This will allow us to calculate the total supply current I_S of these components, as illustrated in the figure. The circuit's phase angle is given.



RESONANCE OF PARALLEL RLC AC CIRCUIT

A parallel circuit containing resistance, R, an inductance, L, and a capacitance, C will produce a parallel resonance (also called anti-resonance) circuit when the resultant current through the parallel combination is in phase with the supply voltage. At resonance, there will be a large circulating current between the inductor and the capacitor due to the energy of the oscillations, then parallel circuits produce current resonance.

Current in a Parallel Resonance Circuit

In the solution of AC parallel resonance circuits we know that the supply voltage is common for all branches, so this can be taken as our reference vector. Each parallel branch must be treated separately as with series circuits so that the total supply current taken by the parallel circuit is the vector addition of the individual branch currents.

$$I_R = \frac{V}{R}$$

$$I_L = \frac{V}{X_L}$$

$$I_L = \frac{V}{2\,\pi\,f\,L}$$

$$I_C = \frac{V}{X_C}$$

$$I_C = \frac{V}{\frac{1}{2\,\pi\,f\,C}}$$

$$I_C = V \times \frac{2\pi f C}{1}$$

$$I_C = V\ (2\pi f C)$$

Therefore,

$$I_T = I_R + I_L + I_C$$

$$I_T = \sqrt{I_R^2 + (I_L + I_C)^2}$$

At resonance, currents I_L and I_C are equal and cancelling giving a net reactive current equal to zero. Then at resonance, the above equation becomes.

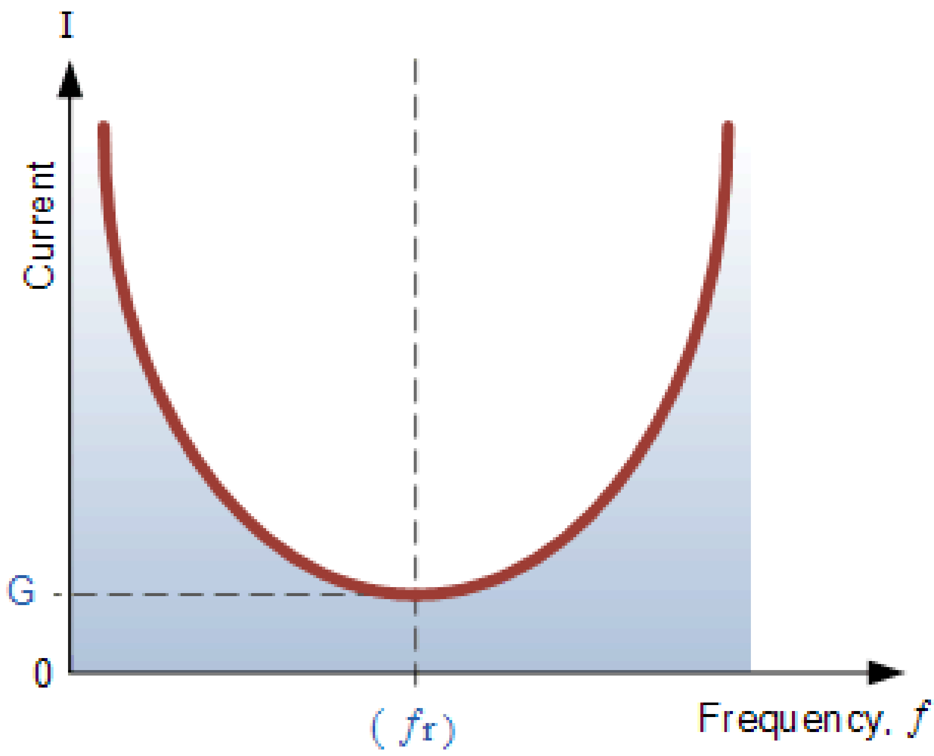
$$I_T = \sqrt{I_R^2 + (0)^2}$$
$$I_T = \sqrt{I_R^2}$$
$$I_T = I_R$$

Parallel Circuit Current at Resonance

The frequency response curve of a parallel resonance circuit shows that the magnitude of the current is a function of frequency and plotting this onto a graph shows us that the response starts at its maximum value, and reaches its minimum value at the resonance frequency when $I_{MIN} = IR$ and then increases again to maximum as f becomes infinite.

The result of this is that the magnitude of the current flowing through the inductor, L, and the capacitor, C tank circuit can become many times larger than the supply current, even at resonance but as they are equal and at opposition (180º out-of-phase) they effectively cancel each other out.

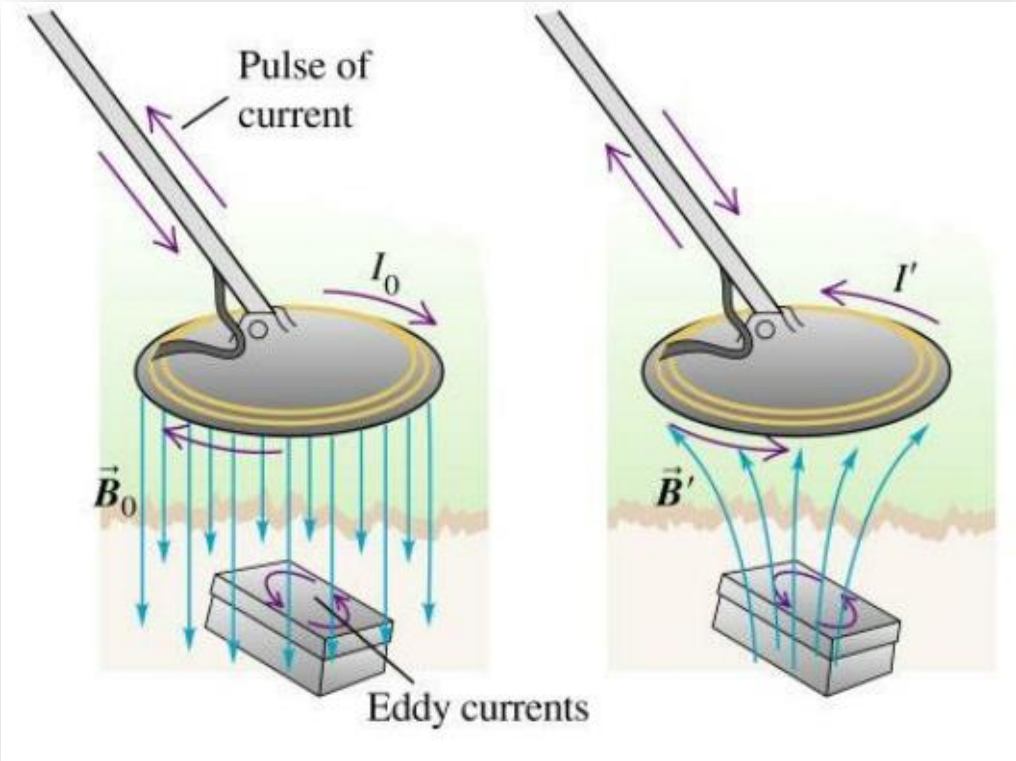
As a parallel resonance circuit only functions on the resonant frequency, this type of circuit is also known as a Rejecter Circuit because, at resonance, the impedance of the circuit is at its maximum thereby suppressing or rejecting the current whose frequency is equal to its resonant frequency. The effect of resonance in a parallel circuit is also called “current resonance”.



Parallel Resonance

Metal detector

The oscillator circuit is used in metal detectors. Metal detectors used for security checks operate on the principle of electromagnetic induction.



A simplified explanation of the working of a metal detector is described below:

1. Generating an Electromagnetic Field:

The metal detector contains a coil of wire through which an electric current flows, creating a magnetic field around the coil. This coil is often housed in a special arrangement, such as a loop or wand.

2. Interaction with Metals:

When a conductive metal object is brought into the vicinity of the electromagnetic field, it disturbs the field. This disturbance induces a secondary magnetic field in the metal object.

3. Eddy Currents:

The changing magnetic field induces circulating electric currents within the metal object, known as eddy currents. These eddy currents, in turn, generate their own magnetic fields.

4. Detection of Changes:

The metal detector has a receiver coil or coils that are close to the transmitter coil. The receiver coil(s) detect changes in the magnetic field caused by the presence of the metal.

5. Alert Mechanism:

When the metal detector senses a significant change in the magnetic field, indicating the presence of a metal object, it triggers an alert. This alert can be in the form of an audible sound, a visual signal, or both, depending on the design of the metal detector.

THE ELECTROCARDIOGRAPH

The electrocardiograph (ECG) is a medical diagnostic tool used to record the electrical activity of the heart over a period of time.

Principle:

An electrocardiogram (ECG or EKG) records the heart's electrical activity by detecting small voltage changes on the skin, which are caused by the heart's electrical impulses during each heartbeat

Working:

The heart is a muscular organ that contracts rhythmically to pump blood throughout the body. This contraction is initiated and coordinated by electrical signals generated within the heart. Electrodes are attached to specific points on the skin of the patient. The standard placement involves attaching electrodes to the limbs and chest. These electrodes are conductive and are used to detect the electrical signals produced by the heart. The electrical signals produced by the heart are picked up by the electrodes. The detected electrical signals are amplified to make them more measurable and are then recorded on a graph or displayed on a monitor. The resulting graph is called an electrocardiogram. The ECG graph represents the electrical activity of the heart over time. It consists of waves and intervals, each of which corresponds to a specific phase of the cardiac cycle. Physicians analyze the ECG to gather information about the heart's rhythm, rate, and various other aspects of its electrical activity. Deviations from the normal ECG pattern can indicate cardiac abnormalities, such as arrhythmias, ischemia, or other heart conditions.

OSCILLATOR CIRCUIT

An oscillator circuit is an electronic circuit that generates a continuous periodic signal at a specific frequency.

Oscillator circuits produce the carrier wave, which serves as the central frequency around which the information-carrying signal is modulated.

Oscillator circuits are designed to be tunable, allowing broadcasters to set the carrier frequency to a specific value. This turnability is essential for assigning unique frequencies to different radio stations, preventing interference between them. Oscillators are designed to be modulated by an information-carrying signal. In amplitude modulation, the amplitude of the carrier wave is varied according to the audio signal, while in frequency modulation; the frequency of the carrier wave is modulated. This modulation process allows the transmission of audio information. The carrier wave itself does not convey information; it serves as a medium to carry the modulated information signal. The oscillator generates a stable carrier wave, ensuring that the modulated signal can be reliably transmitted over long distances. The carrier wave, when modulated with the audio signal, forms the composite radio wave that propagates through space. This transmitted signal can be received by radio receivers tuned to the carrier frequency.

RESONANCE IN TUNING CIRCUIT OF RADIO:

In radio tuning circuits resonance is an important phenomenon that enables the selective reception of a desired radio frequency while rejecting others.

PRINCIPLE:

The principle of resonance is crucial in the tuning circuits of radio to enhance the reception of specific radio frequencies. Resonance occurs when the inductive and capacitive reactance in a circuit cancel each other out, resulting in a condition where the circuit efficiently absorbs energy at a particular frequency. Resonance is integral to the functioning of radio tuning circuits. It ensures that radios can selectively receive signals from desired stations with clarity and efficiency, making it possible to enjoy various broadcasted content without interference from other frequencies.

IMPORTANCE OF BROADCASTING:

Broadcasting remains a powerful medium with far-reaching impacts on society. It informs, educates, entertains, and connects people, playing a crucial role in cultural preservation, economic development, and social cohesion. Its ability to reach a wide audience makes it an indispensable tool for communication in the modern world.