ALTERNATING CURRENT

Q # 1. What do you know about alternating current?

Ans. The current that is produced by a voltage source whose polarity keeps on reversing with time is called alternating current.

Q # 2. Define following for an alternating quantity:

- i. **Instantaneous value**
- ii. **Peak Value**
- iii. **Peak to Peak Value**
- iv. **Phase of AC**

Ans. Instantaneous Value

The value of the voltage or current that exist in a circuit at any instant of time t measured from some reference point is known as its instantaneous value. Mathematically, it is given by:

$$V = V_0 \sin\theta = V_0 \sin(\omega t)$$

$$V = V_0 \sin\left(\frac{2\pi}{T}\times t\right) = V_0 \sin(2\pi ft)$$

Peak Value

It is the highest value reached by the voltage or current in one cycle. It is denoted by the symbol V_0.

Peak to Peak Value

It is the sum of the positive and negative peak values usually written as p-p value.

Phase of AC

The instantaneous value of the alternating voltage is given by:

$$V = V_0 \sin\theta$$

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

The angle $\theta = \omega t$ specifies the instantaneous value of the instantaneous value voltage or current known as its phase.

Q # 3. What do you mean by Root Mean Square (rms) Value of an alternating quantity? Describe its significance. Also derive an expression to calculate the rms value of an alternating quantity.

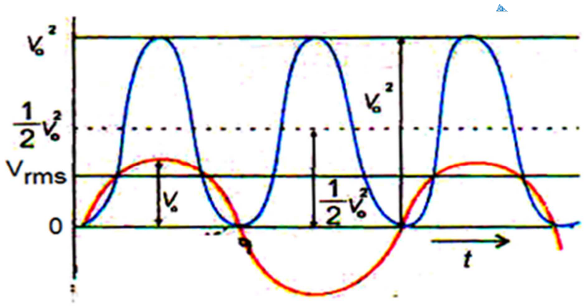
Ans. The alternating current (or voltage) measure by square root of its mean square value is known as root mean square (rms) value.

Significance of RMS Value

The average value of current and voltage over a cycle is zero but the power delivered during a cycle is not zero because power is I^2R and the values of I^2 are positive even for negative values of I. Thus the average value of I^2 is not zero and is called mean square current. The alternating current or voltage is actually measured by square root of its mean square value known as root mean square (rms) value.

RMS Value of Alternating Signal

As the graph of V^2 is symmetrical about the line $\frac{1}{2}V_0^2$, so from this figure, the mean or average value of V^2 is $\frac{1}{2}V_0^2$. The root mean square value of V is obtained by taking the square root of $\frac{1}{2}V_0^2$ (mean square value). Therefore,



$$V_{rms} = \sqrt{\frac{1}{2}V_0^2} = \frac{V_0}{\sqrt{2}} = 0.7\ V_0$$

Similarly, $I_{rms} = \sqrt{\frac{1}{2}I_0^2} = \frac{I_0}{\sqrt{2}} = 0.7\ I_0$

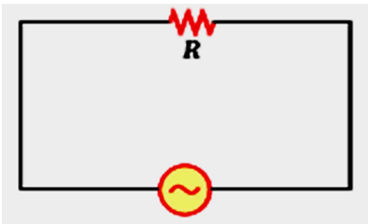
Q # 4. What do you know about AC Circuits?

Ans. The basic element of a direct current circuit is resistor R which controls the current or voltage and the relation between them is given by the Ohm's law:

V=IR

In AC circuits, in addition to resistors R, two new circuit elements such as inductor L and capacitor C are used. The current and voltage in AC circuits is controlled by the three elements R, L and C.

Q # 5. Describe the relationship between instantaneous voltage and current when AC passes through resistor.



A resistor of resistance R is connected with the alternating voltage source is shown in the figure. The potential difference V across the terminals of the resistor is given by the expression:

$$V = V_0 \sin(\omega t) \quad ------- \quad (1)$$

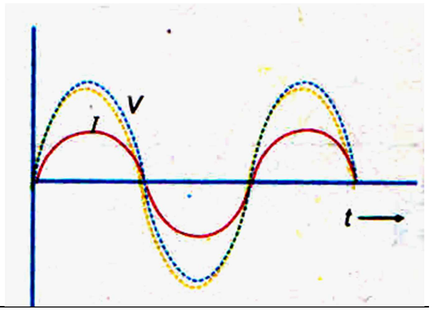
Where V is the instantaneous value of alternating voltage and V_0 is the peak value of the alternating voltage.

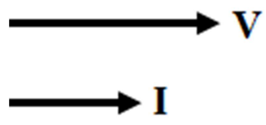
Dividing both sides by R, we get:

$$\frac{V}{R} = \frac{V_0}{R}\sin(\omega t)$$

$$\Rightarrow I = I_0 \sin(\omega t)$$

Where I is the instantaneous current and I0 is the peak value of the current. The graph of I and V verses time describe that





both I and V are proportional to $\sin \omega t$.

Both I and V across the resistor oscillate at the same frequency. Furthermore, both I and V go to zero at the same time, and both reach their peak value at the same time. The current and voltage are in phase.

In phase diagram of resistive circuit, the voltage V and current I are drawn parallel because there is no phase difference between them.

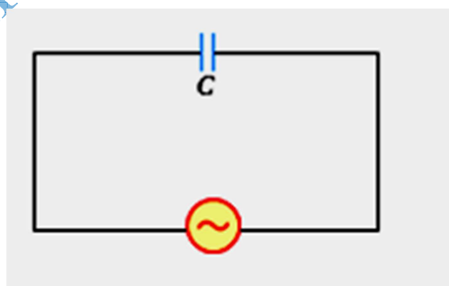
The opposition to the AC which the circuit presents in the resistance is given by:

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

Q # 6. Describe the relationship between instantaneous voltage and current when AC passes through capacitor.

Ans. Direct current flows through a capacitor continuously because of presence of insulating medium between the plates of capacitor.

While the alternating current flow through AC circuit containing capacitor, because the capacitor plates are continuously charged, discharged and charged the other way round by the alternating voltage.



The applied voltage between the plates of the capacitor is given by:

$$V = V_0 \sin \omega t$$

The charge stored on the plates of the capacitor at any instant is given by expression:

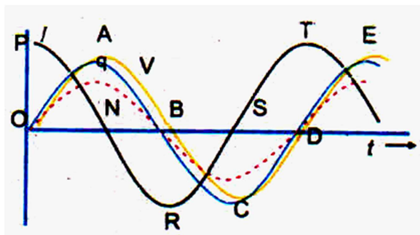
$$q = CV$$

$$\Rightarrow q = CV_0 \sin \omega t$$

Since C and V_0 are constants, it is obvious that q will vary the same way as applied voltage i.e., V and q are in phase. The current I flowing through the connecting wires is equal to the rate of change of q i.e.,

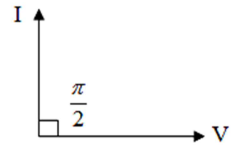
$$I = \frac{\Delta q}{\Delta t}$$

So the value of I at any instant is the corresponding slope of q-t curve or v-t curve. Initially, when q = 0, the slope is maximum, so I is then maximum. From O to A, slop of q-t curve decreases to zero. So I is zero at N. from A to B, the slope to the q-t curve is negative and so I is negative from N to R. In this way, the curve PNRST gives the variation of current with time.



It can be seen from figure, that phase of V and I at O is zero and $\frac{\pi}{2}$, respectively. It means that current leads the voltage by $\frac{\pi}{2}$.

This is vectorically, represented as:



Capacitive Reactance

It is the measure of opposition offered by the capacitor to the flow of alternating current. It is usually represented by X_C. Its value is given by the expression:

$$X_C = \frac{V_{rms}}{I_{rms}}$$

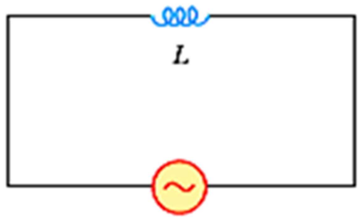
Where V_{rms} is the value of the alternating voltage across the capacitor and I_{rms} is the rms value of the alternating current passing through capacitor. The SI unit of the reactance is Ohm.

The capacitive reactance is inversely proportional to the frequency of the source, i.e.,

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

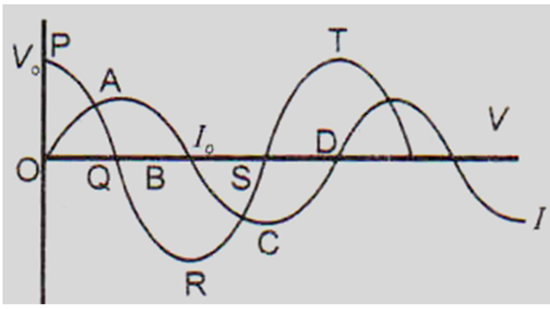
Q # 7. Describe the relationship between instantaneous voltage and current when AC passes through inductor.

Ans. Consider an a.c. circuit consisting of an inductor connected across the terminals of an a.c. source. Assume that the resistance of the coil is negligible. Suppose the current flowing at any instant in the circuit is:



$$I = I_0 \sin(\omega t) = I_0 \sin(2\pi ft)$$

If L is the inductance of the coil, the changing current set up a back emf in the coil and its magnitude is given as:



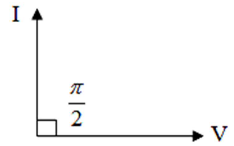
$$\varepsilon_L = L\frac{\Delta I}{\Delta t}$$

Since there is no resistance in the circuit, the applied voltage V must be equal to the back emf:

$$V = L\frac{\Delta I}{\Delta t}$$

As L is the constant of the circuit, therefore, voltage at any instant will be proportional to the rate of change of current.

The value of $\frac{\Delta I}{\Delta t}$ is given by the slop of I-t curve. At O, the value of the slop is maximum, so the maximum value of V (equal to V_0) . From O to A, the slop of I-t graph decreases to zero so the voltage decreases from V_0 to zero at Q. From A to B, the slop of I-t graph is negative, so the voltage goes from Q to R. In this way the voltage is represented by the curve PQRST corresponding to current curve OABCD is obtained.



Inductive Reactance

It is the measure of opposition offered by the inductance coil to the flow of AC. It is represented by the symbol X_L. By definition

$$X_L = \frac{V_{rms}}{I_{rms}}$$

Where is the rms value of the alternating voltage across the capacitor and I_{rms} is the rms value of the alternating current passing through inductor. The SI unit of the reactance is Ohm. The reactance of the inductor is usually represented by the expression:

$$X_C = 2\pi fL = \omega L$$

Q # 8. Define the term impedance.

Ans. A measure of the opposition to the flow of charges in an AC circuit is called impedance.

An AC circuit may be composed of a resistance, inductance and capacitance or a combination of these elements. The combined effect of resistance and reactances in such circuit is known as impedance and is denoted by Z. The SI unit of impedance is ohm.

It measured by the ratio of the rms value of the applied voltage to the rms value of resulting current.

$$Z = \frac{V_{rms}}{I_{rms}}$$

Q # 9. What do you mean by RC Series Circuit? Calculate the impedance of the circuit by drawing their impedance diagram.

Ans. Such a circuit in which resistor R and capacitor C are connected in series is called RC series circuit.

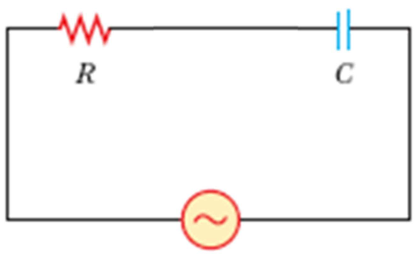


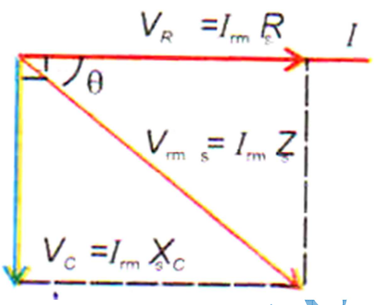
Figure shows an RC series circuit excited by an AC source. The potential difference across resistor 'IR' would be in phase with current I.

Taking the current as the reference, the potential difference across the resistor is represented by the line along the current line because the potential difference is in phase with current.

The potential difference across the capacitor $V_C = \frac{I_{RMS}}{\omega C}$. As the current leads the voltage by 90°, so the line representing vector $\frac{1}{\omega C}$ is drawn at right angle to the current line.

Calculation of Impedance

The value of applied voltage V is obtained by the resultant of vectors $I_{RMS}R$ and $\frac{I_{RMS}}{\omega C}$.



$$V_{RMS} = \sqrt{(I_{RMS}R)^2 + \left(\frac{I_{RMS}}{\omega C}\right)^2}$$

$$\Rightarrow V_{RMS} = I_{RMS}\sqrt{R^2 + \left(\frac{1}{\omega C}\right)^2}$$

$$\Rightarrow \frac{V_{RMS}}{I_{RMS}} = \sqrt{R^2 + \left(\frac{1}{\omega C}\right)^2}$$

We know that $Z = \frac{V_{RMS}}{I_{RMS}}$, therefore

$$Z = \sqrt{R^2 + \left(\frac{1}{\omega C}\right)^2}$$

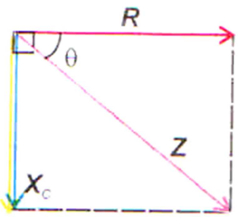


Figure shows that the current and the applied voltage are not in phase. The phase θ by which the current leads the voltage is given by the expression:

$$\theta = \tan^{-1}\left(\frac{1}{\omega CR}\right)$$

Q # 10. What do you mean by RL Series Circuit? Calculate the impedance of the circuit by drawing their impedance diagram.

Ans. A circuit in which resistor R and inductor L are connected in series is called RL series circuit.

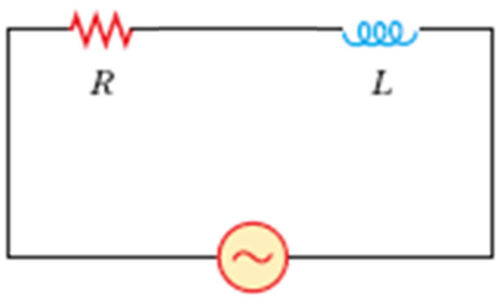


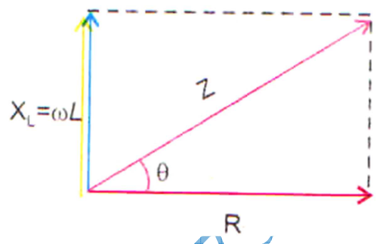
Figure shows an RL series circuit excited by an AC source. The potential difference across resistor 'IR' would be in phase with current I.

Taking the current as the reference, the potential difference across the resistor is represented by the line along the current line because the potential difference is in phase with current.

The potential difference across the inductor $V_L = I_{RMS}(\omega L)$. As the current lags the voltage by 90°, so the line representing vector ωL is drawn at right angle to the current line.

Calculation of Impedance

The value of applied voltage V is obtained by the resultant of vectors $I_{RMS}R$ and $I_{RMS}\omega L$.



$$V_{RMS} = \sqrt{(I_{RMS}R)^2 + (I_{RMS}\omega L)^2}$$

$$\Rightarrow V_{RMS} = I_{RMS}\sqrt{R^2 + (\omega L)^2}$$

$$\Rightarrow \frac{V_{RMS}}{I_{RMS}} = \sqrt{R^2 + (\omega L)^2}$$

We know that $Z = \frac{V_{RMS}}{I_{RMS}}$, therefore

$$Z = \sqrt{R^2 + (\omega L)^2}$$

Figure shows that the current and the applied voltage are not in phase. The phase θ by which the current leads the voltage is given by the expression:

$$\theta = \tan^{-1}\left(\frac{\omega L}{R}\right)$$

Q # 11. Describe the power dissipation in AC circuits.

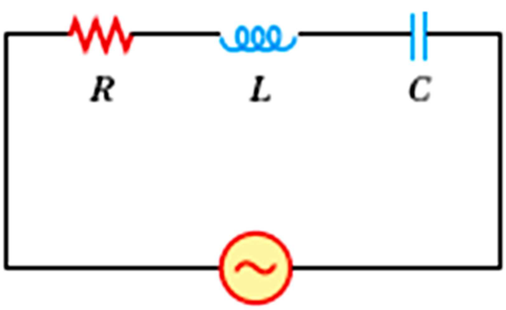
Ans. The expression for power is $P = V_{RMS}I_{RMS}$. This exprfession is true in case of AC circuits, only when V and I are in phase as in case of purely resistive circuits.

In AC circuits, the potential difference between the applied voltage and the current is θ. The component of V along current I_{RMS} is $V_{RMS}\cos\theta$. Actually, it is this component of the voltage vector which is in phase with current. So power dissipated in AC circuit is:

$$P = I_{RMS}(V_{RMS}\cos\theta)$$

The factor $\cos\theta$ is known as power factor.

Q # 12. Find out expression for resonance frequency for the case of series resonance circuit. Also describe its properties.



Ans. Consider RLC series circuit which is excited by an alternating voltage source whose frequency can be varied. It can be seen from the impedance diagram, that the inductive reactance $X_L = \omega L$ and capacitive reactance $X_C = \frac{1}{\omega C}$ are directed opposite to each other.

- When the frequency of the source is very small, $X_C = \dfrac{1}{\omega C}$ is much greater than $X_L = \omega L$. So the capacitance dominates at low frequencies and circuit behaves like an RC circuit.

- When the frequency of the source is high, $X_L = \omega L$ is much greater than $X_C = \dfrac{1}{\omega C}$. So the inductance dominates at high frequencies and circuit behaves like an RL circuit.
- In between low and high frequencies, there will be a frequency ω_R at which $X_L = X_C$. This condition is called resonance.

Thus at resonance, the inductive reactance being equal and opposite to capacitive reactance, cancel each other. The value of resonance frequency can be find out by putting value in equation $X_L = X_C$:

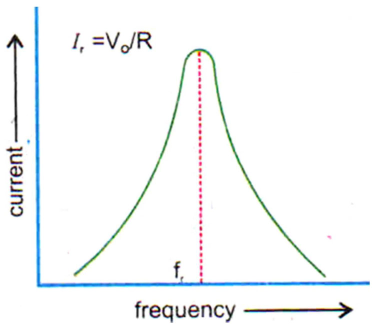
$$\omega_R L = \frac{1}{\omega_R C}$$

$$\Rightarrow (\omega_R)^2 = \frac{1}{LC}$$

$$\Rightarrow \omega_R = \frac{1}{\sqrt{LC}}$$

$$\Rightarrow f_R = \frac{1}{2\pi\sqrt{LC}}$$

Properties of series resonance circuit

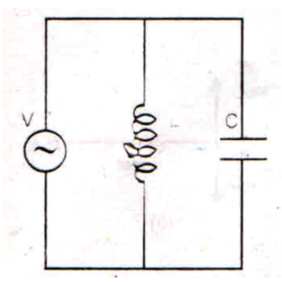


- The resonance frequency is given by the expression:

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

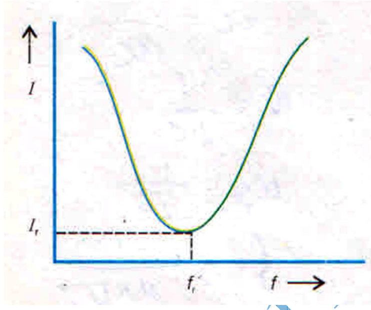
- The impedance of the circuit is minimum at this frequency and is equal to R.
- The impedance of the circuit at resonance is resistive so the current and the voltage are in phase and power factor is 1.
- If the amplitude of the source voltage V_0 is constant, the current is maximum at the resonant frequency and its value is $\frac{V_0}{R}$.

Q # 13. What is parallel resonance circuit? Also describe the properties of this circuit.



Ans. The LC-parallel circuit connected to alternating voltage source is shown in the figure. The inductance coil L has negligibly small resistance. The circuit resonates at frequency ω_r for which capacitive reactance becomes equal to inductive reactance i.e., $X_C = X_L$

Properties of Parallel Resonance Circuit



- The resonance frequency of parallel resonance circuit can be determined by using expression:

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

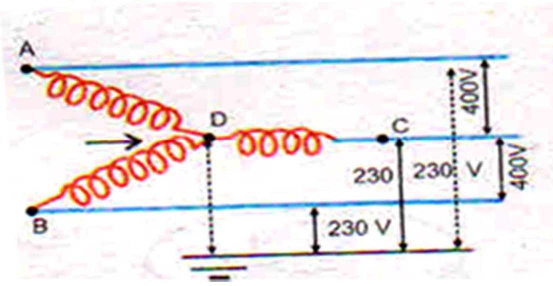
- At resonance frequency, the circuit impedance is maximum.
- At resonance, the circuit current is minimum and is in phase with the applied voltage.

Q # 14. What do you know about choke.

Ans. It is a coil of thick copper wire wound closely over a soft iron laminated cores. It is used in AC circuits to limit current with extremely small wastage of energy as compared to a resistance or a rheostat.

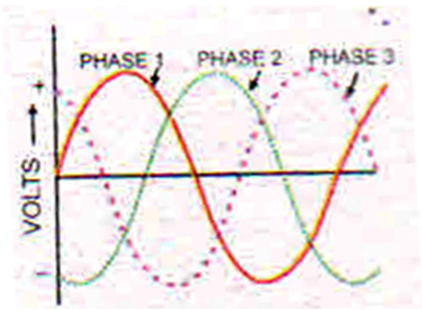
The choke uses the induction phenomenon to limit the current of the circuit. As its resistance is very small, therefore, it consumes extremely small power.

Q # 15. Write a note on three phase AC supply.



Ans. In three phase AC supply (generator), there are three coils inclined at an angle 120° to each other. Each coil is connected to its own part of slip rings. As the coils rotate in the magnetic field, an alternating voltage is generated across all slip rings.

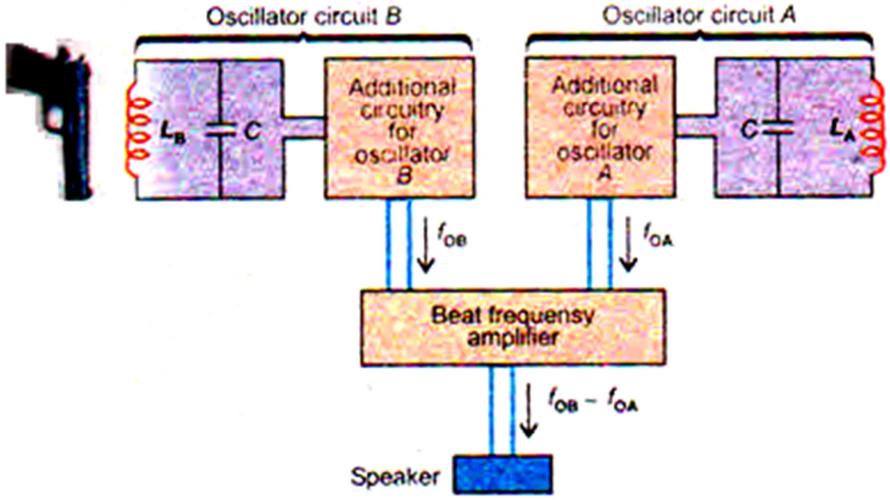
The phase difference between the alternating voltages are 120°. It means that when the voltage between the first pair of slip rings is zero, the voltage across the second pair of slip rings 120°. Similarly, the voltage generated across the third pair will have a phase difference of 240°.



The main advantage of having a three phase supply is that the total load of the house or a factory is divided in three parts, so that none of the line is overloaded.

Q # 16. Describe the basic principle of metal detectors.

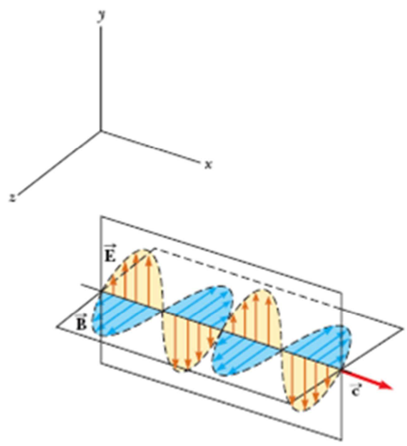
Ans. metal detectors are the electrical instruments that are used for detection and security purposes. A metal detector consist of LC-circuits, which behave just like an oscillating mass-spring system. This circuit is called electrical oscillator. Two such electrical oscillators are used in the operation of a metal detector. The schematic diagram of a metal detector is shown in the figure below:



In the absence of any nearby metal object, the inductances L_A and L_B are the same and hence the resonant frequency of the two circuits is also same. Ehen the inductor B comes near a metal object, its inductance L_B decreases and corresponding oscillator frequency increases and thus a beat note is heard in the attached speaker.

Metal detectors are used for security purposes and to locate buried objects.

Q # 17. Write a note on electromagnetic waves.



Ans. The waves which don't require any material medium for their propagation are called electromagnetic waves. It consists of vibrating electric and magnetic fields which move at the speed of light and are at right angle to each other and to the direction of propagation.

These waves are periodic waves, hence they have wavelength λ, which is given by:

$$\lambda = \frac{c}{f}$$

Where c and f are is the speed and frequency of wave respectively.

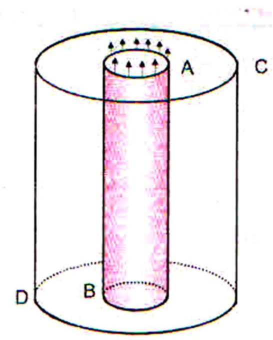
Depending upon the values of wavelength and frequency, the electromagnetic waves are classified into different types such as

- Radio waves
- Microwaves
- Infrared Waves
- Visible light rays etc.

Principle of Generation of Electromagnetic Waves

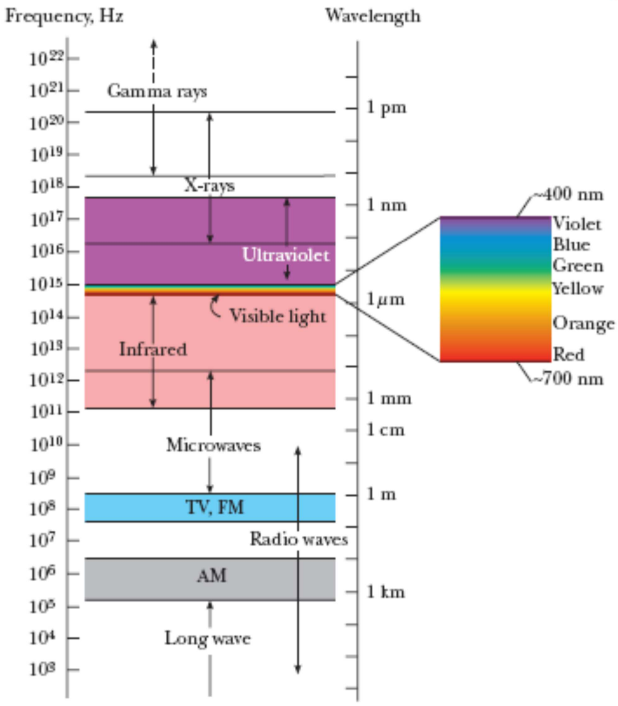
The basic principle of generation of electromagnetic waves is:

"A changing magnetic flux creates an electric field and a changing electric flux creates magnetic field"



For example, if the change of magnetic flux takes place in region of space AB. This change of magnetic flux will set up an electric field in the surrounding region CD. The creation of the electric field in the region CD will cause a change of electric flux through it due to which a magnetic field will be set up in the space surrounding CD and so on.

Thus each field will generate the other and the whole package of electric and magnetic fields will move along propelling itself through space.



Q # 18. Define the term modulation. Describe its different types.

Ans. The process of combining the low frequency signal with a high frequency

Amplitude Modulation

In this type of modulation, the amplitude of the carrier wave is increased or diminished as the amplitude of the superposing modulating signal increases or decreases.

Frequency Modulation

In this type of modulation, the frequency of the carrier wave is increased or diminished as the amplitude of the superposing modulating signal increases or decreases. But the carrier wave amplitude remains constant.

EXERCISE SHORT QUESTIONS

Q # 1. A sinusoidal current has rms value of 10 A. What is the maximum or peak value?

Ans.

$RMS\ value\ of\ current\ = I_{rms} = 10\ A$

$Peak\ Value\ (maximum\ value) = I_0 = ?$

Using formula:

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

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

$$\Rightarrow I_0 = \sqrt{2}(10\ A)$$

$$\Rightarrow I_0 = 14.14\ A$$

Thus, the maximum value of the current is $14.14\ A$.

Q # 2. Name the devices that will

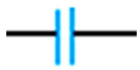
(a) Permit flow of direct current but oppose the flow of alternating current

(b) Permit flow of alternating current but not the direct current.

Ans.

(a) An inductor (choke) is a device which permits flow of direct current but opposes the flow of alternating current. It is represented by the following symbol:

(b) A capacitor is a device which permits flow of alternating current but not the direct current. It is represented by the symbol given below:



Q # 3. How many times per second will an incandescent lamp reaches maximum brilliance when connected to a 50 Hz source?

Ans. The brilliance of the lamp will become maximum twice in one AC cycle because the current also becomes maximum two times in a cycle (i.e., for +ve half cycle and –ve half cycle).

As the frequency “f” of AC cycle is 50 Hz.

$So\ maximum\ brilliance\ shown\ by\ lamp\ per\ second\ = Twice\ the\ frequency\ of\ AC\ source$

$So\ maximum\ brilliance\ shown\ by\ lamp\ per\ second\ = 2f = 2 \times 50 = 100\ times$

Hence, the brilliance will be maximum 100 time in one second.

Q # 4. A circuit contains an iron-cored inductor, a switch and a DC sources arranged in series. The switch is closed and after an interval reopened. Explain why a spark jumps across the switch contacts?

Ans. When a switch of circuit containing iron cored inductor is closed, current increases from zero to maximum value. This changing current produce change of magnetic flux and hence emf is produced.

After an interval, when switch is reopened, the current changes from maximum to zero. Again emf is developed across the coil. This is back emf. This produces spark across the switch contacts.

Q # 5. How does doubling the frequency affect the reactance of (a) an inductor (b) capacitor?

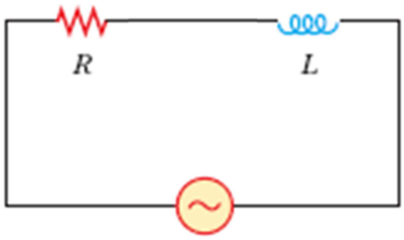
Ans.

	Formula for Reactance	**Doubling frequency**	**Result**
Inductor	$X_L = \omega L$	$X_L' = 2\omega L = 2X_L$	Inductive Reactance will become double
Capacitor	$X_C = \dfrac{1}{\omega C}$	$X_C' = \dfrac{1}{2\omega C} = \dfrac{1}{2}X_C$	Capacitive Reactance will becomes half

Hence by doubling the frequency, the inductive reactance will become double, while capacitive reaction remains half.

Q # 6. In a RL circuit, will the current lag or lead the voltage? Illustrate your answer by a vector diagram.

Figure shows an RL series circuit excited by an AC source. The potential difference across resistor 'IR' would be in phase with current I.

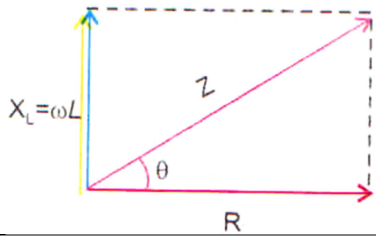


Taking the current as the reference, the potential difference across the resistor is represented by the line along the current line because the potential difference is in phase with current.

The potential difference across the inductor $V_L = I_{RMS}(\omega L)$. As the current lags the voltage by 90°, so the line representing vector ωL is drawn at right angle to the current line.

Figure shows that the current and the applied voltage are not in phase. The phase θ by which the current leads the voltage is given by the expression:

$$\theta = \tan^{-1}\left(\frac{\omega L}{R}\right)$$



Q # 7. A choke coil placed in series with an electric lamp in an AC circuit causes the lamp to become dim. Why is it so? A variable capacitor added in series in this circuit may be adjusted until the lamp glows with normal brilliance. Explain, how this is possible?

Ans. Let an electric lamp connected to a source of alternating voltage V in AC circuit. When there is no inductance or capacitance in the circuit, the impedance is equal to the resistance of the circuit, say R. it means that the current flowing through the lamp is

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

(a) When a choke coil is connected in series with an electric lamp

If, now, a choke coil of inductive reactance X_L is placed in series with the electric lamp, the new impedance of the circuit will be:

$$Z_1 = \sqrt{R^2 + X_L^2}$$

Therefore, the current flowing through the circuit in this case will be:

$$I_1 = \frac{V}{Z_1} = \frac{V}{\sqrt{R^2 + X_L^2}}$$

From the comparison of both currents, we see that I_1 is smaller than I and that is why the electric lamp is dimmed on placing a choke coil in the circuit.

(b) A Variable capacitor added in series with an electric lamp

When a variable capacitor also is in series with the circuit, its capacitive reactance X_C opposes X_L and thus the impedance of the circuit is

$$Z_2 = \sqrt{R^2 + (X_L - X_C)^2}$$

Therefore, the current flowing through the circuit in this case will be:

$$I_2 = \frac{V}{Z_2} = \frac{V}{\sqrt{R^2 + (X_L - X_C)^2}}$$

If the $X_L = X_C$, then $I_2 = \frac{V}{Z_2} = \frac{V}{\sqrt{R^2+(0)^2}} = \frac{V}{R} = I$

Hence, the current I_2 becomes equal to the current I for $X_L = X_C$, as if there is no reactance in the circuit and hence the lamp glow with normal brilliance.

Q # 8. Explain the condition under which electromagnetic waves are produced from a source.

Ans. When alternating voltage is applied across the ends of a metallic antenna, and oscillating electric field comes into existence which accelerates the electrons again and again as the polarities of the antenna changes after half a cycle.

The accelerated electrons radiate energy carried by changing electric field. A changing electric field creates a magnetic field and a changing magnetic field creates electric field. Thus each field will generate the other and the whole package of electric and magnetic fields will move along propelling itself through space.

Q # 9. How the reception of a particular radio station is selected on your radio set?

Ans. A particular radio station can be selected on a radio set by tuning it. When the frequency of the LC-oscillator in the radio set is equal to the frequency of the radio wave from a particular radio station, a resonance is produced. The current of this signal becomes maximum and can detected and amplified. The resonance frequency:

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

Q # 10. What is meant by A.M and F.M?

Ans. Amplitude Modulation

In this type of modulation, the amplitude of the carrier wave is increased or diminished as the amplitude of the superposing modulating signal increases or decreases.

Frequency Modulation

In this type of modulation, the frequency of the carrier wave is increased or diminished as the amplitude of the superposing modulating signal increases or decreases. But the carrier wave amplitude remains constant.

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