CHAPTER 16
ALTERNATING CURRENT

MULTIPLE CHOICE

1. **The velocity of electromagnetic waves in ms^{-1} is**
   A. 3×10^8 B. 3×10^{10} C. 3×10^5 D. 3×10^9
2. **Mathematical treatment for electromagnetic waves was given by**
   A. Faraday B. Maxwell.
   C. Hertz D. Coulomb
3. **The current which keeps on reversing direction with time is called:**
   A. Direct current B. Alternating current
   C. Induced current D. None
4. **The most common source of A.C. is:**
   A. Battery B. A.C. generator
   C. Transformer D. Dynamos
5. **If V_0 is the peak value of A.C. voltage its root mean square value is:**
   A. $V_{rms} = V_0\sqrt{2}$ B. $\frac{V_0}{\sqrt{2}}$ C. $\frac{V_0}{2}$ D. $\sqrt{\frac{V_0}{2}}$
6. **The resonant frequency of series and parallel resonance circuit is given by**
   A. $\frac{1}{\sqrt{2\pi LC}}$ B. $\frac{1}{2\pi\sqrt{LC}}$ C. $\sqrt{2\pi LC}$ D. $\frac{2\pi}{\sqrt{LC}}$
7. **The reactance of an inductor is**
   A. $2\pi f L$ B. $2\pi / f L$
   C. $f L / 2\pi$ D. $1/2\pi f L$
8. **At resonance frequency the current in RLC series circuit is**
   A. Maximum B. Minimum C. Infinite D. Zero
9. **Current flowing from battery or cell is example of:**
   A. Electronic current B. Direct current
   C. Alternating current D. Induced current
10. **The basic element in D.C. circuit which controls the current or voltage is:**
    A. Inductor B. Resistor C. Capacitor D. All
11. **The device which allows only the continuous flow of A.C. through the circuit is:**
    A. Capacitor B. Inductor C. Battery. D. All
12. **The opposition offered by capacitor to the flow of A.C. is called capacitive reactance X_C denoted by:**
    A. $X_c = 2\pi fC$ B. $X_c = \frac{1}{2\pi fC}$ C. $X_c = \frac{1}{2\pi}\sqrt{fC}$ D. None
13. **SI unit of reactance is:**
    A. Farad B. Volt C. Ampere D. Ohm

14. **A 25 μF capacitor is connected to an alternating voltage of 120 V and frequency 50 Hz. The reactance of the capacitor is**
A. 127 Ω B. 137 Ω C. 1.27 Ω D. 12.7 Ω

15. **The frequency of alternating current is**
A. f = [illegible] B. f = t [illegible] C. f = [illegible] D. f = [illegible]

16. **The rms value of emf in a circuit is given by a factor**
A. 1.11 B. 0.707 C. 0 D. 0.637

17. **The sum of positive and negative peak values is taken as**
A. P-P value B. P-P values
C. rms value D. cycle value

18. **In case of capacitor the unit of reactance is**
A. farad B. ohm C. mho D. Henry

19. **The peak value of an A.C. current I_0 is given as**
A. $\frac{I_{rms}}{2}$ B. [illegible] C. $2 I_{rms}$ D. $\sqrt{2} I_{rms}$

20. **An A.C. continuously flows through the plates of a capacitor because of**
A. Charging of plates
B. Discharging of plates
C. dielectric present
D. Charging and discharging both

21. **A basic circuit element in a D.C. circuit is**
A. An inductor B. A resistor
C. A Capacitor D. A battery

22. **At low frequency the value of reactance of a capacitor of A.C. circuit is:**
A. Large B. Small C. Zero D. Infinite

23. **In an inductance of A.C. circuit the current:**
A. Leads the voltage by 90° B. Lags the voltage by 90°
C. Leads the voltage by 180° D. Laps the voltage by 180°

24. **When 100 V are applied in A.C. circuit, the current flowing in it is 100 mA, its impedance is:**
A. 100 Ω B. 1000 Ω C. 10 Ω D. 50 Ω

25. **The resonance frequency of R-L-C series circuit is given by:**
A. $\frac{1}{2\pi\sqrt{LC}}$ B. $\sqrt{\frac{LC}{2\pi}}$ C. $\frac{2\pi}{\sqrt{LC}}$ D. None

26. **The impedance of R-L-C series circuit at resonance frequency is:**
A. Less than R B. Greater than R
C. Equal to R D. None

27. **The impedance of the series resonance circuit at resonance**
A. Maximum B. Minimum C. Zero D. One

28. **High frequency radio wave is called**
A. Fluctuative wave B. carrier wave
C. matter wave D. energetic wave

29. **The total load in A.C. supply can be divided in:**

A. 2-parts B. 3-parts
C. 4-parts D. Many parts

30. The waves which do not require any material medium for their propagation are called:
A. Mechanical wave B. Stationary waves
C. Complex waves D. Electromagnetic wave

31. Electromagnetic waves consist of:
A. Electric field
B. Magnetic field
C. Gravitational field
D. Magnetic field and electric field

32. Which of the following has the smallest wavelength?
A. X-rays B. Radio-waves
C. γ-rays D. Ultra violet waves

33. The phase angle between the voltage and A.C. current through a resistor is
A. 0° B. 45° C. 180° D. 270°

Answers:

1. A	2. B	3. B	4. B	5. B	6. B	7. A
8. A	9. B	10. B	11. A	12. A	13. D	14. A
15. C	16. B	17. B	18. B	19. D	20. D	21. B
22. B	23. B	24. B	25. A	26. C	27. B	28. B
29. B	30. D	31. D	32. C	33. A		

SHORT & LONG QUESTIONS

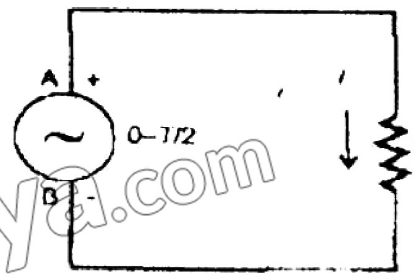
Q1: Give the main reason for the use of A.C.?

Ans: The main reason for the world wide use of A.C. is that it can be transmitted to long distances easily and at a very low cost.

Q2: Define alternating current. Discuss waveform of alternating voltage?

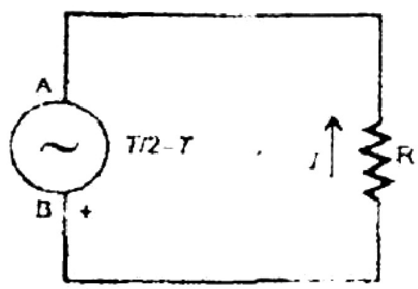
Ans: Alternating current:

The current which reverses its direction many times during one second is known as alternating current. Alternating current (A.C.) is that which is produced by a voltage source whose polarity keeps on reversing with time.



Case 1:

In Fig., the terminal A of the source is positive with respect to terminal B and it remains so during a time interval 0 to T/2. At t = T/2, the terminals change their polarity.



Case 2:

Now A becomes negative with respect to B. This state continues during the time interval T/2 to T,

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B. 3-parts
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B. 45°
C. 180°
D. 270°

Answers:

1. A	**2. B**	**3. B**	**4. B**	**5. B**	**6. B**	**7. A**
8. A	**9. B**	**10. B**	**11. A**	**12. A**	**13. D**	**14. A**
15. C	**16. B**	**17. B**	**18. B**	**19. D**	**20. D**	**21. B**
22. B	**23. B**	**24. B**	**25. A**	**26. C**	**27. B**	**28. B**
29. B	**30. D**	**31. D**	**32. C**	**33. A**		

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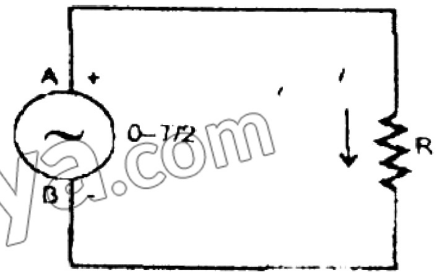

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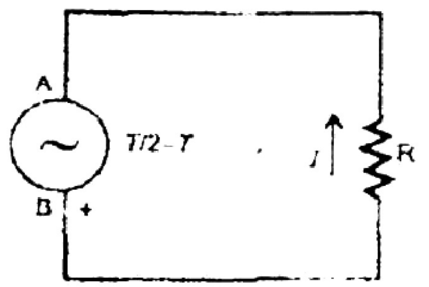


Case 2:

Now A becomes negative with respect to B. This state continues during the time interval T/2 to T, after which terminal A again becomes positive with respect to B and the next cycle starts. As a result of this change of polarity, the direction of the current flow in the circuit also changes.

Flow of current during the time 0 – T/2 and T:

During the time 0 - T/2, it flows in one direction and during the interval T/2 – T in opposite direction.

Period T of the alternating current or voltage:

This time interval T during which the voltage source changes its polarity once is known as period T of the alternating current or voltage. Thus an alternating quantity is associated with a frequency f given by

$$f = \frac{1}{T} \quad .... \quad (1)$$

Output voltage of A.C. generator:

The most common source of alternating voltage is an A.C. generator. The output V of this A.C. generator at any instant is given by

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

Where T is period of the rotation of the coil and is equal to the period of A.C. and $\frac{2\pi}{T} = 2\pi f = \omega$ is angular frequency of rotation of the coil. Thus $\frac{2\pi}{T} \times t = \omega t$ is the angle θ through which the coil rotates in time t.

Eq.2 shows that the value of alternating voltage V is not constant. It changes with time t.

i. **When t = 0**, $\theta = \frac{2\pi}{T} \times t$ is 0 and V is zero.

ii. **When t = T/4**, $\theta = \frac{2\pi}{T} \times \frac{T}{4} = \frac{\pi}{2}$ and V attains its maximum value V_0 at this instant.

iii. **At t = T/2**, $\theta = \pi$ and V is zero. At this instant V changes its polarity and becomes negative henceforth.

iv. **When** $t = \frac{3T}{4}$, $\theta = \frac{3\pi}{2}$ and $V = -V_0$

v. Finally at the end of the cycle when t = T, $\theta = 2\pi$ and V = 0.

Variation of V with time t and θ:

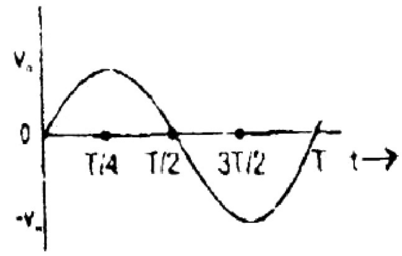
The variation of V with time t and θ is shown in Fig.

Waveform of alternating voltage (sine curve):

The graph between voltage and time is known as waveform of alternating voltage. It can be seen that it is a sine curve. Thus the output voltage of an A.C. generator varies sinusoidal with time.

Q3: Discuss instantaneous value, peak value and peak to peak value?

Ans: Instantaneous value:



The value of voltage or current that exists in a circuit at any instant of time t measured from some reference point is known as its instantaneous value. It can have any value between plus maximum value $+V_0$ and negative maximum value $-V_0$ and is denoted by V. The entire waveform shown in Fig. is actually a set of all the instantaneous values that exist during a period T. Mathematically, it is given by

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

$$V = V_0 \sin\frac{2\pi}{T} \times t = V_0 \sin 2\pi f t \quad \ldots\ldots (1)$$

2. Peak value:

It is the highest value reached by the voltage or current in one cycle. For example, voltage shown in Fig. has a peak value of V_0.

3. Peak to peak value (p-p):

It is the sum of the positive and negative peak values usually written as p-p value. The p-p value of the voltage waveform shown in Fig. is $2V_0$.

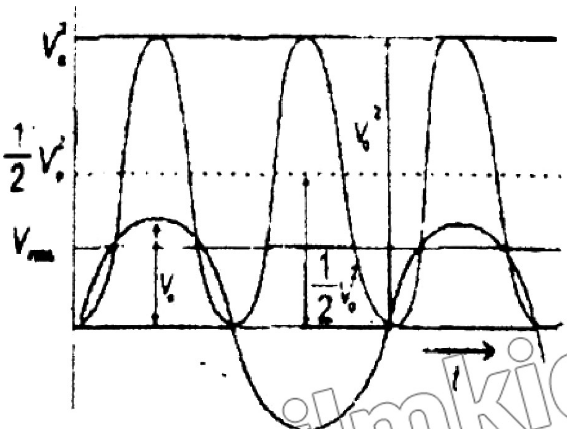
Q4: Describe root mean squares (rms) value of voltage and current?

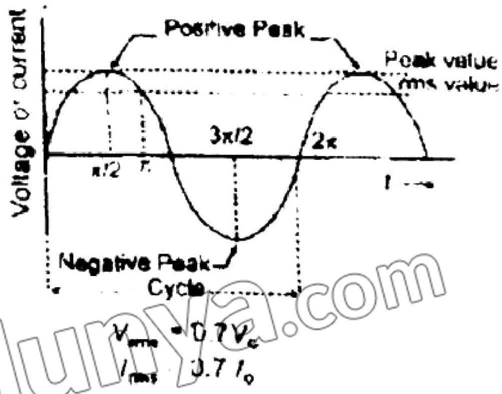
Ans: Root mean squares (rms) value:

The root mean square value is the square root of average value of V^2 or I^2 during one complete cycle. It is the effective value of alternating voltage or current

Explanation:

i. It can be seen in Fig. that 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 the mean square current.





A.C. Waveform

ii. The alternating current or voltage is actually measured by square root of its mean square value known as root mean square (rms) value.

iii. Calculation of the average value of V^2 over a cycle:

Let us compute the average value of V^2 over a cycle. Fig. shows an alternating voltage and the way its V^2 values vary. Note that the values of V^2 are positive on the negative half cycle also. As the graph of V is symmetrical about the line $\frac{1}{2}$ V_0^2, so for this figure the mean or the average value of V^2 is $\frac{1}{2}$ V_0^2.

iv. The root mean square value of V is obtained by taking the square root of $V_0^2/2$. Therefore,

$$V_{rms} = \sqrt{\frac{V_0^2}{2}} = \frac{V_0}{\sqrt{2}} = 0.7\ V_0 \quad \ldots\ldots (2)$$

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

Note:

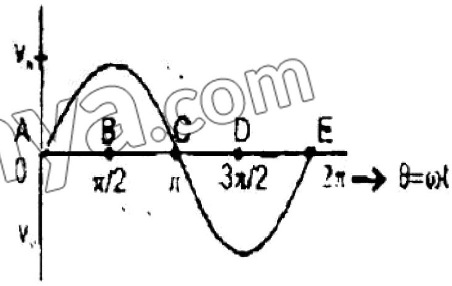
Most of the alternating current and voltage meters are calibrated to read rms values.

Q5: What is meant by phase of A.C.?

Ans: Phase of A.C.:

The angle θ which specifies the instantaneous value of the alternating voltage or current is known as its phase.

Explanation:



i. In Fig., we can say that the phase at the points A, B, C, D and E is 0, $\pi/2, \pi$, $3\pi/2$ and 2π respectively because these angles are the values of θ at these points. Thus each point on the A.C. waveform corresponds to a certain phase.

ii. The phase at the positive peak is $\pi/2$ = 90° and it is $3\pi/2$ = 270° at the negative peak.

iii. The points where the waveform crosses the time axis correspond to phase 0 and π.

Q6: What do you meant by phase lag and phase lead?

Ans: Phase lag and phase lead:

The angle θ which specifies the instantaneous value of the alternating voltage and current gives phase lag and phase lead of one quantity over the other.

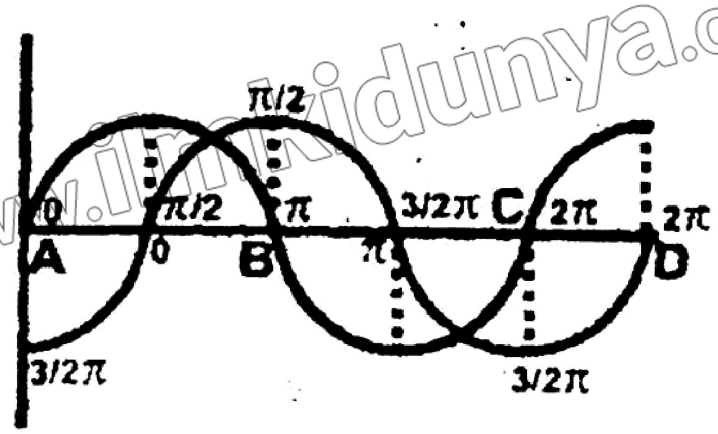
Phase lag:

A lagging alternating quantity is one which reaches its maximum or zero value later than the other quantity.

Phase lead:

A leading alternating quantity is one which reaches its maximum or zero value earlier than the other quantity.

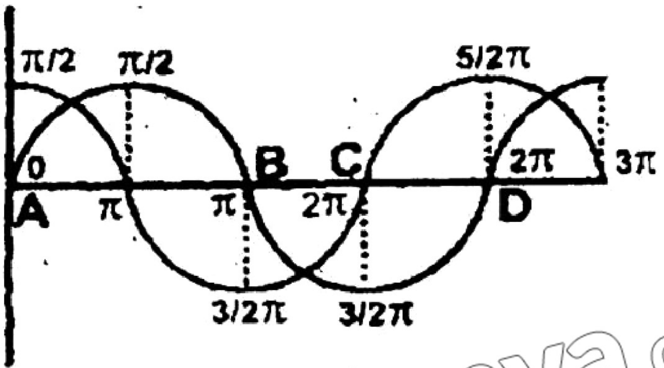
Explanation:



i. Fig. shows two waveforms 1 and 2. The phase angles of the waveform 1 at the points A, B, C, D and E have been shown above the axis and those of waveform 2 below the axis.

ii. At the point B, the phase of 1 is $\pi/2$ and that of 2 is 0.

iii. Similarly it can be seen that at each point the phase of waveform 2 is less than the phase of waveform 1 by an angle of $\pi/2$. We say that A.C. 2 is lagging behind A.C. 1 by an angle of $\pi/2$. It means that at each instant, the phase of A.C. 2 is less than the phase of A.C. 1 by $\pi/2$.



iv. Similarly it can be seen in Fig., that the phase at each point of the waveform of A.C. 2 is greater than that of waveform 1 by an angle $\pi/2$. In this case, it is said that A.C. 2 is leading the A.C. 1 by $\pi/2$. It means that at each instant of time, the phase of A.C. 2 is greater than that of 1 by $\pi/2$.

Q7: Describe the vector representation of an alternating quantity?

Ans: Vector representation of an alternating quantity:

Phase lead and lag between two alternating quantities is conveniently shown by representing the two A.C quantities as vectors.

A sinusoidal alternating voltage or current can be graphically represented by a counter clockwise rotating vector provided it satisfies the following conditions.

Conditions:

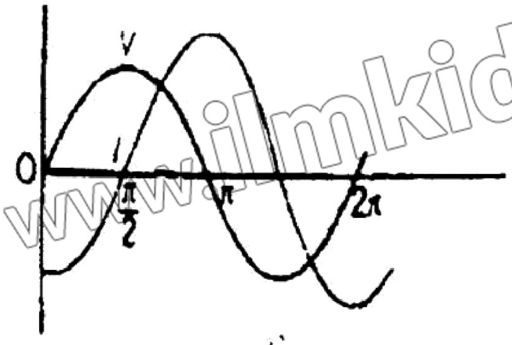
1. Its length on a certain scale represents the peak or rms value of the alternating quantity.
2. It is in the horizontal position at the instant when the alternating quantity is zero and is increasing positively.
3. The angular frequency of the rotating vector is the same as the angular frequency ω of the alternating quantity.

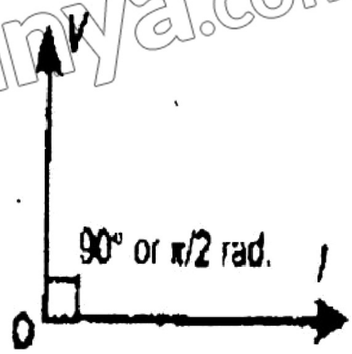
Explanation:

i. Fig. shows a sinusoidal voltage waveform leading an alternating current waveform by $\pi/2$. The same fact has been shown vectorially in Fig.

ii. Here vector OI represents the peak or rms value of the current which is taken as the reference quantity.

iii. Similarly OV represents the rms or peak value of the alternating voltage which is leading the current by 90°.





iv. Both vectors are supposed to be rotating in the counter clockwise direction at the angular frequency ω of the two alternating quantities. Fig. shows the position of voltage and current vector at t = 0.

Q8: How current and voltage in A.C. circuits controlled?

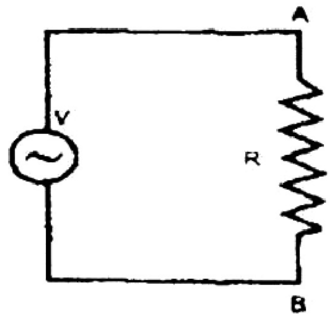
Ans: A.C. circuits:

i. The basic circuit element in a D.C. circuit is a resistor (R) which controls the current or voltage and the relationship between them is given by Ohm's law that is V= IR.

ii. In A.C. circuits, in addition to resistor R, two new circuit elements namely INDUCTOR (L), and CAPACITOR (C) become relevant. The current and voltages in A.C. circuits are controlled by three elements R, L and C.

Q9: Discuss the flow of current through resistor in A.C. circuit?

Ans: A.C. through a resistor:



i. Fig. shows a resistor of resistance R connected with an alternating voltage source.

ii. At any time t the potential difference across the terminals of the resistor is given by

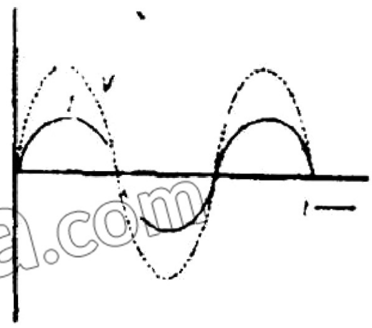
$$V = V_0 \sin\omega t \quad .... \quad (1)$$

Where V_0 is the peak value of the alternating voltage. The current I flowing through the circuit is given by Ohm's law

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

Or

$$I = I_0 \sin\omega t \quad .... \quad (2)$$

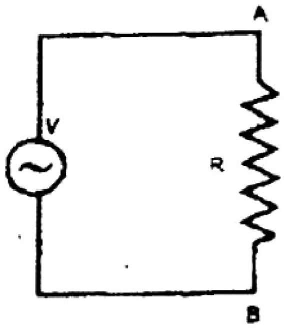


Where I is the instantaneous current and $I_0 = \frac{V_0}{R}$ is the peak value of the current.

iii. It follows from Eqs.1 and 2 that the instantaneous values of both voltage and current are sine functions which vary with time.

iv. This figure shows that when voltage rises, the current also rises. If the voltage fails, the current also does so - both pass their maximum and minimum values at the same instant. Thus in a purely resistive A.C. circuit, instantaneous values of voltage and current are in phase. This behaviour is shown graphically in Fig. and vectorially in Fig.

v. Fig. shows V and I vectors for resistance. They are drawn parallel because there is no phase difference between them. The opposition to A.C. which the circuit presents is the resistance



$$R = \frac{V}{I} \quad \ldots\ldots\ldots \quad (3)$$

vi. The instantaneous power in the resistance is given by

$$P = I^2R = VI = V^2/R \quad \ldots\ldots\ldots \quad (4)$$

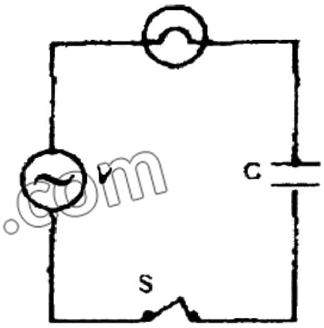
P is in watts, V is in volts, I is in amperes and R is in ohms.

Note:

It is very important to note that the Eq. 4 holds only when the current and voltage are in phase.

Q10: Discuss the flow of current through capacitor in A.C. circuit? Discuss phase between current and voltage? Derive a relation for reactance of a capacitor?

Ans: A.C. through a capacitor:



i. Alternating current can flow through a resistor, but it is not obvious that how it can flow through a capacitor. This can be demonstrated by the circuit shown in Fig.

ii. A low power bulb is connected in series with a 1 μF capacitor to supply mains through a switch.

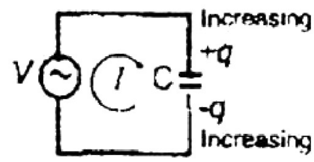
iii. When the switch is closed, the bulb lights up showing that the current is flowing through the capacitor.

iv. Direct current cannot flow through a capacitor continuously because of the presence of an insulating medium between the plates of the capacitor.

Flow of A.C. through a capacitor:

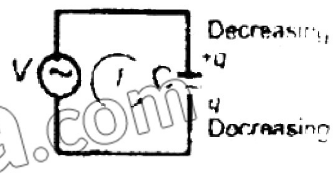
The current flows because the capacitor plates are continuously charged, discharged and charged the other way round by the alternating voltage.

Relation between the charge and applied alternating voltage:



The basic relation between the charge q on a capacitor and the voltage V across its plates i.e. q = CV holds at every instant. If $V = V_0 \sin \omega t$ is the applied alternating voltage, the charge on the capacitor at any instant will be given by

$$q = CV = CV_0 \sin\omega t \quad \ldots\ldots\ldots \quad (1)$$



Since C, 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.

Graphical variation of current with time:

The current I is the rate of change of q with time i.e.,

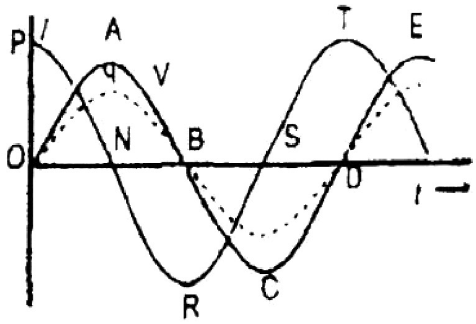
$$I = \frac{\Delta q}{\Delta t}$$

So the value of I at any instant is the corresponding slope of the q-t curve.

i. At O when q = 0, the slope is maximum, so I is then a maximum. From O to A, slope of the q-t curve decreases to zero. So I is zero at N.

ii. From A to B the slope of 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.

iii. Referring to the Fig. it can be seen that the phase at O is zero and the phase at the upper maximum is $\pi/2$. So in Fig. the phase of V at O is zero but the current at this point is maximum so its phase is $\pi/2$. Thus, the current is leading the applied voltage by 90° or $\pi/2$.

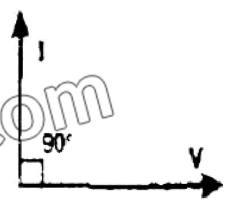


iv. Now consider the points A and N. The phase of alternating voltage at A is $\pi/2$ but the phase of current at N is π. Again the current is leading the voltage by 90° or $\pi/2$.

v. Similarly by comparing the phase at the pair of points (B, R), (C, S) and (D, T) it can be seen that at all these points the current leads the voltage by 90° or $\pi/2$. This is vectorially represented in Fig.

Reactance of a capacitor:

Reactance of a capacitor is a measure of the opposition offered by the capacitor to the flow of A.C. It is usually represented by X_c. Its value is given by



$$X_C = \frac{V_{rms}}{I_{rms}} \quad \ldots\ldots (2)$$

Where V_{rms} is the rms value of the alternating voltage across the capacitor and I_{rms} is the rms value of current passing through the capacitor.

Unit of reactance:

The unit of reactance is ohm.

Relation between reactance (X_c) and frequency:

In case of capacitor

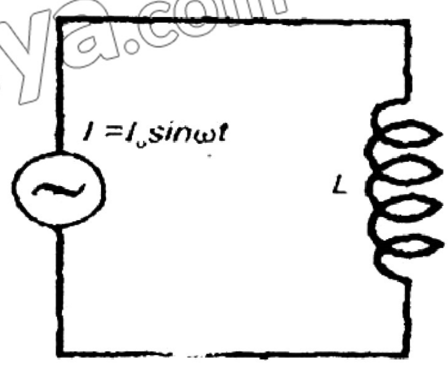
$$X_c = \frac{1}{2\pi fC} = \frac{1}{\omega C} \quad \ldots\ldots\ldots (3)$$

According to Eq.3. a certain capacitor will have a large reactance at low frequency. So the magnitude of the opposition offered by it will be large and the current in the circuit will be small.

On the other hand at high frequency, the reactance will be low and the high frequency current through the same capacitor will be large.

Q11: Discuss the flow of current through an inductor in A.C. circuit? Discuss phase between current and voltage? Derive a relation for inductive reactance of an inductor?

Ans: A.C. through an inductor:



i. An inductor is usually in the form of a coil or a solenoid wound from a thick wire so that it has a large value of self inductance and has a negligible resistance.

ii. Self inductance opposes changes of current. So when an alternating source of voltage is applied across an inductor, it must oppose the flow of AC which is continuously changing

iii. Let us assume that the resistance of the coil is negligible. Suppose the current is $I = I_0 \sin 2\pi t$. If L is the inductance of the coil, the changing current sets up a back emf in the coil of magnitude

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

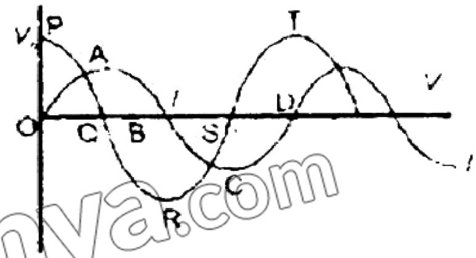
iv. To maintain the current, the applied voltage must be equal to the back emf. The applied voltage across the coil must, therefore, be equal to

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

Since L is a constant, V is proportional to $\frac{\Delta I}{\Delta t}$.

Graphical variation of current (I) with time (t):

i. Fig. shows how the current I varies with time. The value of $\Delta I/\Delta t$ is given by the slope of the I-t curve at the various instants of time

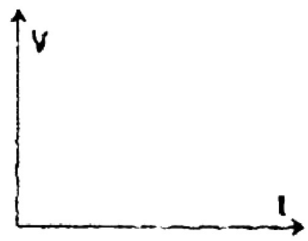


ii. At O, the value of the slope is maximum, so the maximum value of V equal to V_0 occurs at O and is represented by OP.

iii. From O to A the slope of I- t graph decreases to zero so the voltage decreases form V_0 to zero at Q.

iv. From A to B, the slope of the I - t graph is negative, so the voltage curve goes from Q to R. In this way the voltage is represented by the curve PQRST corresponding to current curve OABCD

v. By comparing the phases of the pair of points (O, P), (A, Q), (B, R), (C, S) and (D, T), it can be seen that the phase of the current is always less than the phase of voltage by 90° or $\pi/2$ i.e., current lags behind the applied voltage by 90° or $\pi/2$ or the applied voltage leads the current by 90° or $\pi/2$.



Inductive reactance:

Inductive reactance is a measure of the opposition offered by the inductance coil to the flow of AC. It is usually denoted by X_L.

$$X_L = \frac{V_{rms}}{I_{rm}} \quad \text{... (1)}$$

If V_{rms} is rms value of the alternating voltage across an inductance and I_{rms}

Relation between reactance of a coil and frequency:

The rms value of the current passing through it, the value of X_L is given by

$$X_L = \frac{V_{rms}}{I_{rm}} = 2\pi f L = \omega L \quad (2)$$

The reactance of a coil, therefore, depends upon the frequency of the A C and the inductance L

It is directly proportional to both f and L. L is expressed in henry, f in hertz, and X_L in ohms

Note:

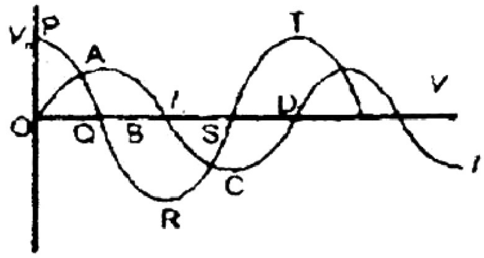
i. It is to be noted that inductance and capacitance behave oppositely as a function of frequency

ii. If f is low X_L is small but X_C is large. For high f, X_L is large but X_c is small

iii. The behaviour of resistance is independent of frequency.

Q12: Explain why there is no net change of energy in a complete cycle of inductor coil (pure inductor)? OR Why no power is dissipated in a pure inductor?

Ans: Referring to Fig., it can be seen that no power is dissipated in a pure inductor.



i. In the first quarter of cycle both V and I are positive so the power is positive, which means energy is supplied to inductor.

ii. In the second quarter, V is positive but I is negative. Now power is negative which implies that energy is returned by the inductor.

iii. Again in third quarter, it receives energy but returns the same amount in the fourth quarter. Thus, there is no net change of energy in a complete cycle.

Choke:

Since an inductor coil does not consume energy, the coil is often employed for controlling A.C. without consumption of energy. Such an inductance coil is known as choke.

Q13: What is meant by impedance of a circuit?

Ans: Impedance:

An A.C. circuit may consist of a resistance R, an inductance L, a capacitance C or a combination of these elements. The combined effect of resistance and reactances in such a circuit is known as impedance and is denoted by Z.

It is measured by the ratio of the rms value of the applied voltage to the rms value of resulting A.C. Thus

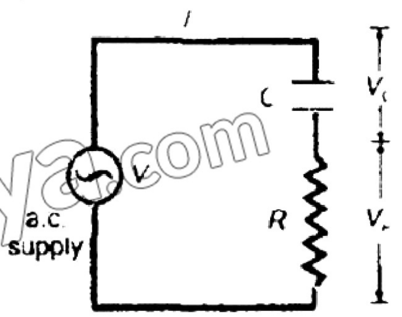
$$Z = \frac{V_{rms}}{I_{rm}}$$

It is expressed in ohms.

Q14: Explain R-C and R-L series circuits in detail?

Ans: R-C series circuits:

A circuit in which resistance R and capacitance C are connected in series with the source of alternating voltage is known as R-C series circuit.



Explanation:

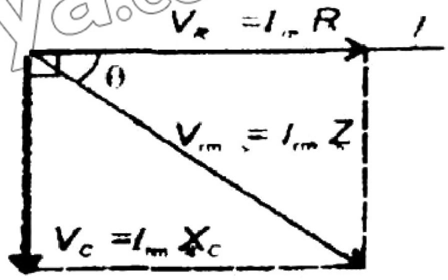
i. Consider a series network of resistance R and a capacitor C excited by an alternating voltage.

ii. As R and C are in series, the same current would flow through each of them.

iii. If I_{rms} is the value of current, the potential difference across the resistance R would be I_{rms} R and it would be in phase with current I_{rms}. The vector diagram of the voltage and current is shown in Fig.

iv. Taking the current as reference, the potential difference I_{rms}, R across the resistance is represented by a line along the current line because potential drop I_{rms}, R is in phase with current.

v. The potential difference across the capacitor will be $I_{rms} X_c = I_{rms}/\omega C$. As this voltage lags the current by 90°, so the line representing the vector $I_{rms}/\omega C$ is drawn at right angles to the current line



vi. The applied voltage V_{rms} that will send the current I in the circuit is obtained by the resultant of the vectors I_{rms} R and $\frac{I_{rms}}{\omega C}$ i.e.,

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

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

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

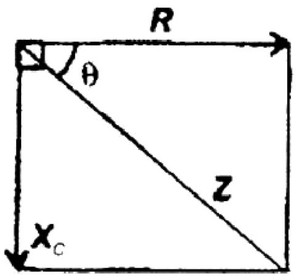
$$\frac{V}{I} = \sqrt{R^2 + \left(\frac{1}{\omega C}\right)^2}$$

$$\textbf{Impedance} = Z = \frac{V_{rms}}{I_{rms}} = \sqrt{R^2 + \left(\frac{1}{\omega C}\right)^2} \quad \text{.........} \quad (1)$$

vii. It can be seen in Fig. that the current and the applied voltage are not in phase. The current leads the applied voltage by an angle θ such that

$$\theta = \tan^{-1}\left(\frac{1}{\omega CR}\right) \quad \text{........} \quad (2)$$

viii. We can find the impedance of a series A.C. circuit by vector addition. The resistance R is represented by a horizontal line in the direction of current which is taken as reference.



ix. The reactance $X_c = \frac{1}{\omega C}$ is shown by a line lagging the R- line by 90°. The impedance Z of the circuit is obtained by the vector summation of resistance and reactance.

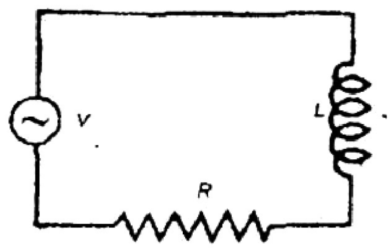
Fig. is known as impedance diagram of the circuit.

x. The angle which the line representing the impedance Z makes with R line gives the phase difference between the voltage and current. In Fig., the current is leading the voltage applied by an angle

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

R-L series circuit:

A circuit in which resistance R and inductance L are connected in series with the source of alternating voltage is known as R-L series circuit



Explanation:

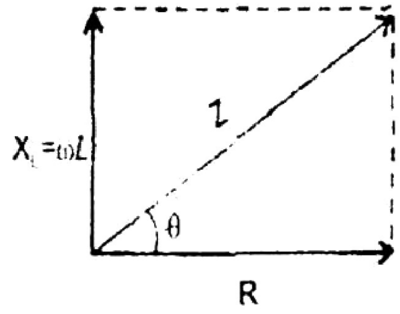
Now we will calculate the impedance of an R-L series circuit by drawing its impedance diagram.

i. Fig. shows an R-L series circuit excited by an A.C. source of frequency ω.

ii. The current is taken as reference, so it is represented by a horizontal line

iii. Resistance R is drawn along this line because the potential drop I_{rms} R is in phase with current.

iv. As the potential across the inductance $V_L = I_{rms}$, $X_L = I_{rms}$ (ωL), leads the current by 90°, so the vector line of reactance $X_L = \omega L$ is drawn at right angle to R line.



v. The impedance Z of the circuit is obtained by the vector sum of R and ωL lines.

Thus

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

vi. The angle $\theta = \tan^{-1}\left(\frac{\omega L}{R}\right)$ which Z makes with R line gives the R phase difference between the applied voltage and current. In this case the voltage leads the current by $\theta°$

Note:

By comparing the impedance diagrams of R-C and L-R circuits, it can be seen that the vector lines of reactances X_c and X_L are directed opposite to each other with R as reference.

Q15: Discuss the power dissipation in A.C. circuits?

Ans: Power in A.C. circuits:

i. The expression for power is $P = V_{rms} I_{rms}$. This expression is true in case of A.C. circuits, only when V and I are in phase as in case of a purely resistive circuit.

ii. The power dissipation (loss) in a pure inductive or in a pure capacitance circuit is zero. In these cases the current lags or leads the applied voltage by 90° and component of applied voltage vector V along the current vector is zero.

iii. In A.C. circuit the phase difference between applied voltage V and the current I_{rms} is θ.

iv. The component of V along current I_{rms}, is $V_{rms} \cos\theta$. Actually it is this component of voltage vector which is in phase with current. So the power dissipated in A.C. circuit

$$P = I_{rms} \times V_{rms} \cos\theta$$

Power factor:

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

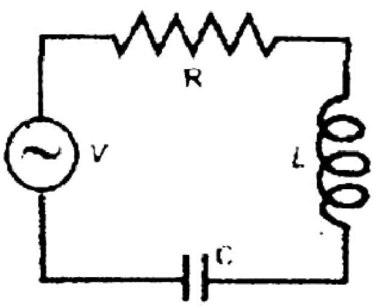
$$\cos\theta = \frac{P}{I_{rms} \times V_{rms}}$$

Q16: Derive a relation for resonance frequency in R-L-C circuit. Also describe the properties of the series resonance circuit?

OR

Explain series resonance circuit?

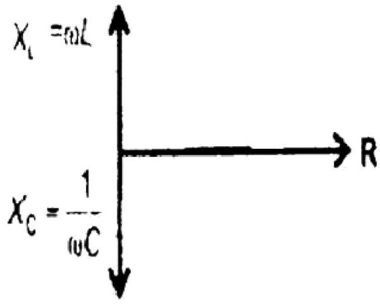
Ans: Series resonance circuit:



i. Consider an R-L-C series circuit which is excited by an alternating voltage source whose frequency could be varied.

ii. The impedance diagram of the circuit is shown in Fig.

iii. The inductive reactance $X_L = \omega L$ and capacitor reactance $X_C = \frac{1}{\omega C}$ are directed opposite to each other.



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

v. At high frequencies $X_L = \omega L$, is much greater than $X_c = \frac{1}{\omega C}$. In this case the inductance dominates and the circuit behaves like R-L circuit.

vi. Resonance:

In between these 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 capacitor reactance, cancel each other and the impedance diagram assumes the form as in Fig.

vii. The value of the resonance frequency can be obtained by putting

$$\omega_r = \frac{1}{\omega_r C}$$

Or $\omega_r^2 = \frac{1}{LC}$ or $\omega_r = \frac{1}{\sqrt{LC}}$

Or $f_r = \frac{1}{2\pi\sqrt{LC}}$ .... **(1)**

Properties of the series resonance circuit:

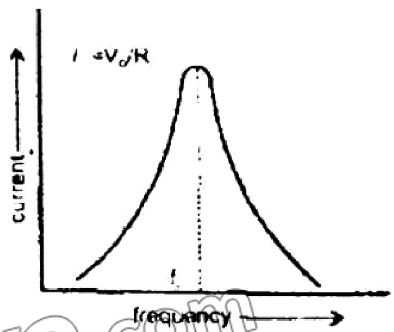
The following are the properties of the series resonance.

(i) The resonance frequency is given by

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

(ii) The impedance of the circuit at resonance is resistive so the current and voltage are in phase. The power factor is 1.

$$\cos\theta = \frac{P}{I_{rms} \times V_{rms}} = 1$$



(iii) The impedance of the circuit is minimum at this frequency and it is equal to R.

(iv) If the amplitude of the source voltage V_0 is constant, the current is a maximum at the resonance frequency and its value is V_0 / R. The variation of current with the frequency is shown in Fig.

(v) At resonance V_L, the voltage drop across inductance and V_c the voltage drop across capacitance may be much larger than the source voltage.

Q17: Derive a relation for resonance frequency in parallel resonance circuit. Also describe the properties of the parallel resonance circuit? OR Explain parallel resonance circuit?

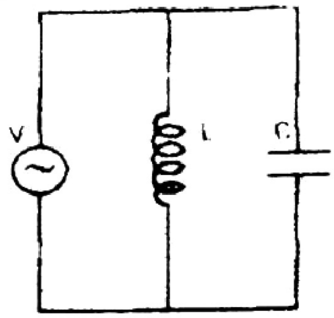
Ans: Parallel resonance circuit:

i. Fig. shows an L-C parallel circuit It is excited by an alternating source of voltage whose frequency could be varied.

ii. The inductance coil L has a resistance r which is negligibly small.

iii. The capacitor draws a leading current. Whereas the coil draws a lagging current.

iv. The circuit resonates at a frequency a $\omega = \omega_r$ which makes $X_L = X_C$, so that the two branch currents are equal but opposite Hence, they cancel out with the result that the current drawn from the supply is zero In actual practice, the current is not zero but has a minimum value due to small resistance r of the coil.



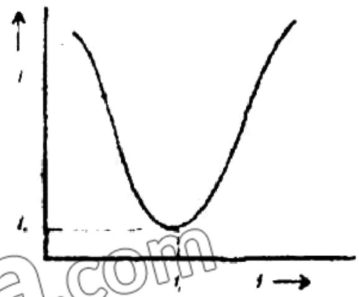
Properties of parallel resonant circuits:

Properties of parallel resonant circuits are

(i) Resonance frequency is $f_r = \frac{1}{2\pi\sqrt{LC}}$

(ii) At the resonance frequency, the circuit impedance is maximum. It is resistive.

(iii) At the resonance the current is minimum and it is in phase with the applied voltage. So the power factor is one. The variation of current with the frequency of the source is shown in Fig.



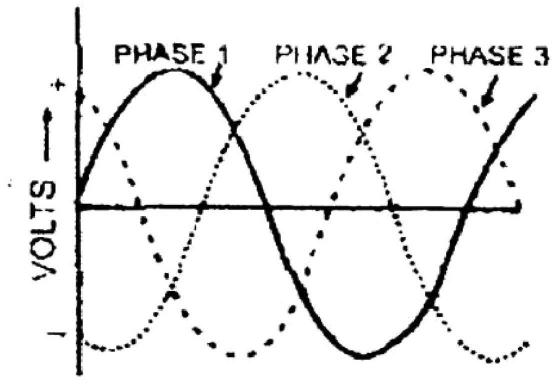
(iv) At resonance, the branch currents I_L and I_C may each be larger than the source current I_r

Q18: What do you know about three phase A.C. supply? Gives its advantages also?

Ans: Three phase A.C. supply:

i. In a three phase A.C. generator, instead of one coil, there are three coils inclined at 120° to each other, each connected to its own pair of slip rings.

ii. When this combination of three coils rotate in the magnetic field, each coil generates an alternating voltage across its own pair of slip rings. Thus, three alternating voltages are generated. The phase difference between these voltages is 120°. Such a voltage is called three phase supply.



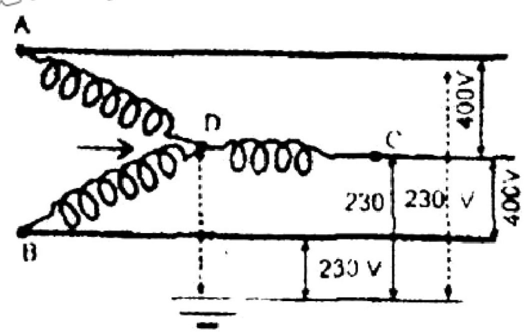
Explanation:

i. Pair of slip rings:

When voltage across the first pair of slip rings is zero, having a phase of 0, the voltage across the second pair of slip rings would not be zero but it will have a phase of 120°. Similarly at this instant the voltage generated across the third pair will have a phase 240°. This is shown in Fig.

ii. Terminals:

The machine, instead of having six terminals, two for each pair of slip rings, has only four terminals because the starting point of all the three coils has a common junction which is often earthed to the shaft of the



generator and the other three ends of the coils are connected to three separate terminals on the machine. These four terminals along with the lines and coils connected to them are shown in Fig.

iii. Voltage:

The voltage across each of lines connected to terminals A, B, C and the neutral line is 230 V. Because of 120° phase shift, the voltage across any two lines is about 400 V.

Advantages of three phase A.C. supply (three phase supply is better than single phase supply):

i. 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 over loaded.

ii. If heavy load consisting of a number of air conditioners and motors etc., is supplied power from a single phase supply, its voltage is likely to drop at full load.

iii. Moreover, the three phase supply also provides 400 V which can be used to operate some special appliances requiring 400 V for their operation.

Q19: Explain principle of metal detectors? OR How a metal detector is used to locate buried metal objects?

Ans: Principle of metal detectors:

Such detectors are extensively used not only for various security checks but also to locate buried metal objects.

Explanation:

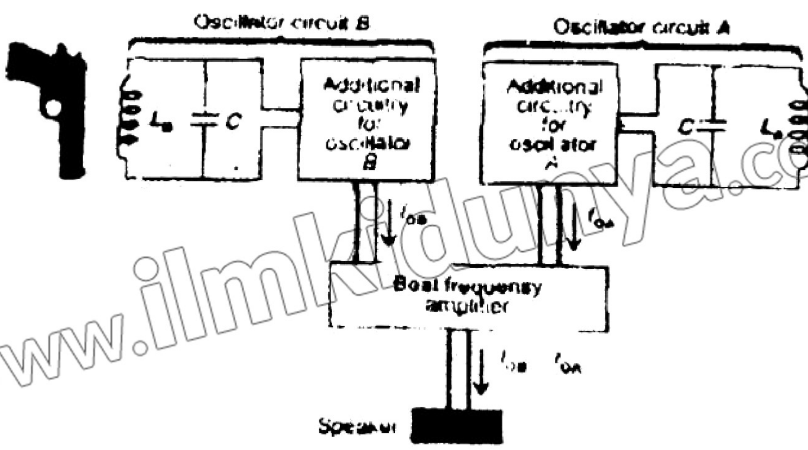
i. A coil and a capacitor are electrical components which together can produce oscillations of current.

ii. Electrical oscillates:

An L-C circuit behaves just like an oscillating mass-spring system. In this case energy oscillates between a capacitor and an inductor. The circuit is called an electrical oscillator. Two such oscillators A and B are used in the operation of a common type of metal detector.

Working of metal detectors:

i. In the absence of any nearby metal object, the inductances L_A and L_B are the same and hence the resonance frequency of the two circuits is also same.



ii. When the inductor B, called the search coil 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.

Use of metal detectors:

Such detectors are extensively used not only for various security checks but also to locate buried metal objects.

Q20: What is choke and describe its functions?

Ans: Choke:

It is a coil which consists of thick copper wire wound closely in a large number of turns over a soft iron laminated cores.

Function of choke:

i. Choke makes the inductance L of the coil quite large whereas its resistance R is very small. Thus it consumes extremely small power.

ii. It is used in A.C. circuits to limit current with extremely small wastage of energy as compared to a resistance or a rheostat.

Q21: Write a short note on the electromagnetic waves?

Ans: Electromagnetic waves:

The wave that consists of an electric field in conjunction with the magnetic field, oscillating with same frequency is known as electromagnetic waves.

Electromagnetic wave requires no medium for transmission and can rapidly propagate through vacuum.

Explanation:

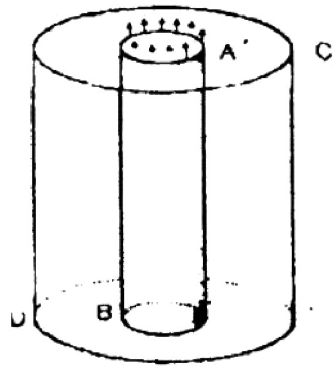
i. In 1864 British physicist James Clark Maxwell formulated a set of equations known as **Maxwell's equations** which explained the various electromagnetic phenomena.

ii. According to these equations, a changing magnetic flux creates an electric field and a changing electric flux creates a magnetic field.

Production of electromagnetic waves:

i. Consider a region of space AB as shown in Fig.

Suppose a change of magnetic flux is taking place through it. This changing magnetic flux will set up a changing electric flux in the surrounding region.



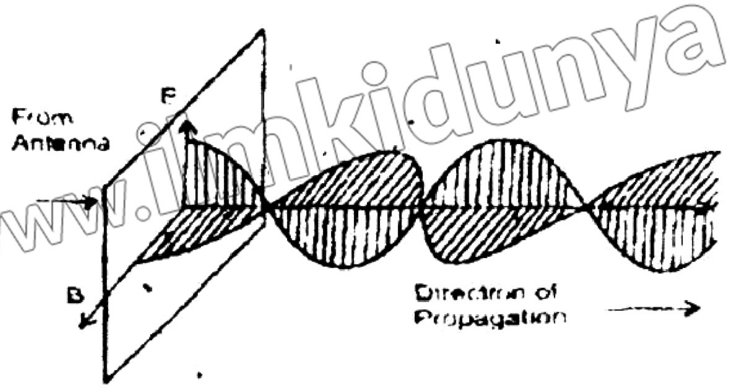
ii. The creation of electric field in the region CD will cause a change of electric flux through it due to which a magnetic field would be set up in the space surrounding CD and so on. Thus each field generates the other and the whole package of electric and magnetic fields will move along propelling itself through space. Such moving electric and magnetic fields are known as electromagnetic waves.

Characteristics of electromagnetic waves:

i. The electric field, magnetic field and the direction of their propagation are mutually orthogonal.

ii. It can be seen that the electromagnetic waves are periodic, hence they have a wavelength λ which is given by the relation $c = f\lambda$ where f is the frequency and c is the speed of the wave.

iii. In free space the speed of electromagnetic waves is $3 \times 10^8\ ms^{-1}$



Classification of electromagnetic waves:

i. radio waves, **ii.** microwaves, **iii.** infrared rays, **iv.** visible light

Note:

Electromagnetic waves from the low radio waves to high frequency gamma rays.

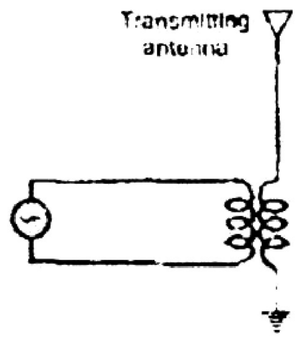
Q22: Describe the principle of generation, transmission and reception of electromagnetic waves?

Ans: Principle of generation of electromagnetic waves:

Electromagnetic waves are generated when electric or magnetic flux is changing through a certain region of space.

Methods for the generation of electromagnetic waves:

i. An electric charge at rest gives rise to a Coulomb's field which does not radiate in space because no change of flux takes place in this type of field. A charge moving with constant velocity is equivalent to a steady current which generates a constant magnetic field in the surrounding space, but such a field also does not radiate out because no changes of magnetic flux are involved. Thus only chance to generate a wave of moving field is when we accelerate the electrical charges.

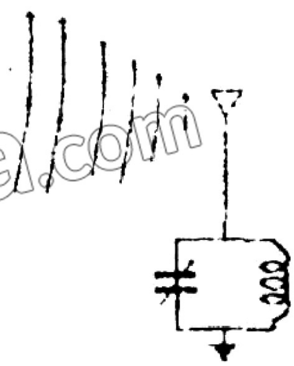


ii. Shake an electrically charged object to and fro then electromagnetic waves will be produced.

Transmission of electromagnetic waves:

Radio transmitting antenna:

A radio transmitting antenna provides a good example of generating electromagnetic waves by acceleration of charges. The piece of wire along which charges are made to accelerate is known as transmitting antenna.



Procedure:

i. It is charged by an alternating source of potential of frequency f and time period T.

ii. As the charging potential alternates, the charge on the antenna also constantly reverses. For example if the top has + q charges at any instant, then after time T/2 the charge on it will be -q. Such regular reversal of charges on the antenna gives rise to an electric flux that constantly changes with frequency f. This changing electric flux sets up an electromagnetic wave which propagates out in space away from the antenna

iii. The frequency with which the fields alternate is always equal to the frequency of the source generating them. These electromagnetic waves which are propagated out in space from antenna of a transmitter are known as **radio waves**. In free space these waves travel with the speed of light.

Reception of electromagnetic waves:

Receiving antenna:

Suppose these waves impinge on a piece of wire. The electrons in the wire move under the action of the oscillating electric field which give rise to an alternating voltage across the wire. The frequency of this voltage is the same as that of the wave intercepting the wire. This wire receiving the wave is known as receiving antenna.

Transmitter:

As the electric field of the wave is very weak at a distance of many kilometers from the transmitter, the voltage that appears across the receiving antenna is very small. Each transmitter propagates radio waves of one particular frequency.

Function of L-C circuit:

If one adjusts the value of the capacitor so that the natural frequency of L-C circuit is the same as that of the transmitting station to be picked up, the circuit will resonate under the driving action of the antenna. Consequently, the L-C circuit will build up a large response to the action of only that radio wave to which it is tuned. In your radio receiver set when you change stations you actually adjust the value of C.

Q23: Describe the method of modulation? Explain the difference between its different types?

Ans: Modulation:

Modulation is the process of combining the low frequency signal with a high frequency radio wave called carrier wave.

Modulated carrier wave:

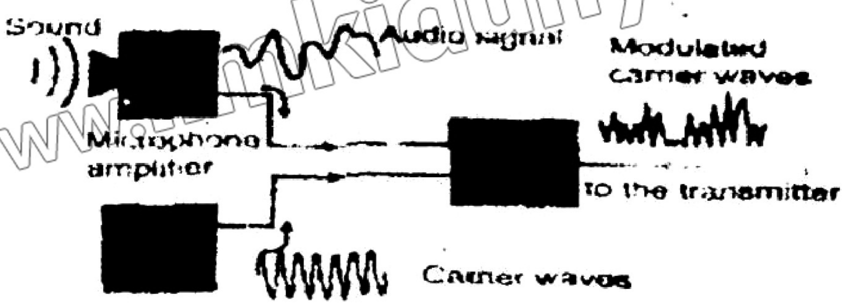
The resultant wave is called modulated carrier wave.

Modulation signal:

The low frequency signal is known as modulation signal.

Principle of modulation:

Modulation is achieved by changing the amplitude or the frequency of the carrier wave in accordance with the modulating signal.



Amplitude modulation

Types of modulation:

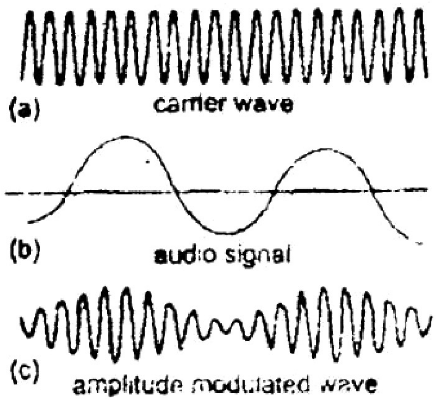
There are two types of modulations which are:

1. Amplitude modulation (A.M) 2. Frequency modulation (F.M)

Amplitude modulation (A.M):

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

Fig (a) represents a high frequency carrier wave of constant amplitude and frequency. Fig (b) represents a low or audio frequency signal of a sine waveform. Fig (c) shows the result obtained by modulating the carrier waves with the modulating wave.



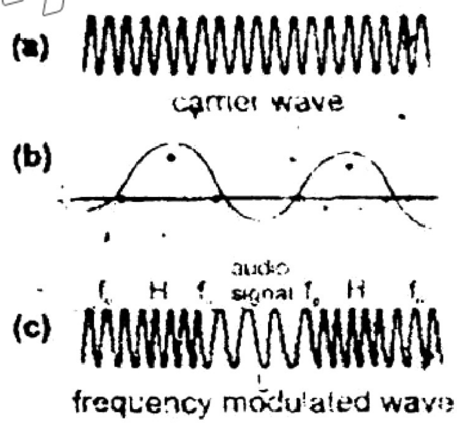
Transmission frequencies range of A.M:

The A.M transmission frequencies range from 540 kHz to 1600 kHz.

Frequency modulation (F.M):

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

Fig shows frequency modulation. The frequency of the modulated carrier wave is highest (point H) when the signal amplitude is at its maximum positive value and is at its lowest frequency (point L) when signal amplitude has maximum negative. When the signal amplitude is zero the carrier frequency is at its normal frequency f_0.



Transmission frequencies range of F.M:

The F.M. transmission frequencies range from 88 MHz to 108 MHz.

Advantages of F.M transmission over A.M transmission:

i. The F.M. transmission frequencies are much higher and ranges between 88 MHz to 108 MHz.

ii. F.M. radio waves are affected less by electrical interference than A.M. radio waves and hence, provide a higher quality transmission of sound.

Disadvantage of F.M transmission over A.M transmission:

F.M has a shorter range than A.M. waves and is less able to travel around obstacles such as hills and large buildings.

SUMMARY

1. Alternating current is that which is produced by a voltage source whose polarity keeps on reversing with time.

2. The time interval during which the voltage source changes its polarity once is known as period T of the alternating current or voltage.
3. The value of voltage or current that exists in a circuit at any instant of time measured from some reference point is known as its instantaneous value.
4. The highest value reached by the voltage or current in one cycle is called the peak value of the voltage or current.
5. The sum of positive and negative peak values is called peak to peak value and is written as p-p value.
6. The root mean square value (rms) is the square root of the average value of V^2 or I^2.
7. The angle θ which specifies the instantaneous value of the alternating voltage or current, gives the phase lag or phase lead of one quantity over the other.
8. An inductor is usually in the form of a coil or a solenoid wound from a-thick wire so that it has a large value of self inductance and has negligible resistance.
9. The combined effect of resistance and reactance in a circuit is known as impedance and is denoted by Z.
10. Choke is a coil which consists of thick copper wire wound closely in a large number of turns over a soft iron laminated core.
11. Electromagnetic waves are those which require no medium for transmission and rapidly propagate through vacuum.
12. Modulation is the process of combining the low frequency signal with a high frequency radio wave. called carrier waves. The resultant wave is called modulated carrier wave.

SOLUTION OF EXERCISE

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

Ans: Given that $I_{rms} = 10$ A

As maximum or peak value of current $= I_0 = \sqrt{2}(I_{rms})$

$\Rightarrow \quad I_0 = (1.4142)(10\text{ A}) = 14\text{ A}$

16.2. Name the device that will (a) Permit the 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) will oppose A.C. due its inductive reactance.

(b) Capacitor will oppose the flow of direct current but allows the flow of alternating current.

16.3. How many times per second will an incandescent lamp reach maximum brilliance when connected to a 50 Hz source?

Ans: Since in each cycle, alternating voltage reaches its maximum value two times (once for positive peak value and one for negative peak value). Therefore lamp will show maximum brilliance twice the frequency of A.C.

Brilliance of lamp $= 2 \times f = 2 \times 50 = 100$ times

2. The time interval during which the voltage source changes its polarity once is known as period T of the alternating current or voltage.

3. The value of voltage or current that exists in a circuit at any instant of time measured from some reference point is known as its instantaneous value.

4. The highest value reached by the voltage or current in one cycle is called the peak value of the voltage or current.

5. The sum of positive and negative peak values is called peak to peak value and is written as p-p value.

6. The root mean square value (rms) is the square root of the average value of V^2 or I^2.

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10. Choke is a coil which consists of thick copper wire wound closely in a large number of turns over a soft iron laminated core.

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SOLUTION OF EXERCISE

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$\Rightarrow \quad I_0 = (1.4142)(10\ A) = 14\ A$

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Brilliance of lamp $= 2 \times f = 2 \times 50 = 100$ times

16.4. A circuit contains an iron-cored inductor, a switch and a D.C. source arranged in series. The switch is closed and after an interval reopened. Explain why a spark jumps across the switch terminals?

Ans: When a current flows through the inductor energy is stored in the inductor in the form of magnetic field. When the switch is closed current grows from zero to maximum and when the switch is opened it creases from maximum to zero. Hence at the instant we reopen the switch the current through it is maximum which causes the spark jumps.

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

Ans: **(a)** Inductive reactance = $X_L = 2\pi f L \Rightarrow X_L \propto f$.

If frequency is doubled inductive reactance will also be doubled.

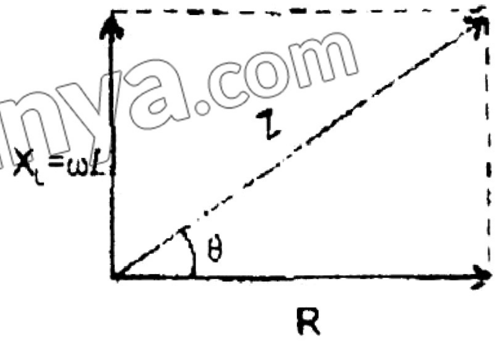
(b) Capacitive reactance = $X_c = \frac{1}{2\pi f C} \Rightarrow X_c \propto \frac{1}{f}$.

If frequency is doubled reactance will be halved.

16.6. In R-L circuit, will the current lead or lag the voltage? Illustrate your answer by a vector diagram.

Ans: **i.** As the potential across the inductance $V_L = I_{rms} X_L = I_{rms} (\omega L)$ leads the current by 90°, so the vector line of reactance $X_L = \omega L$ is drawn at right angle to R line.

ii. The angle $\theta = \tan^{-1}\left(\frac{\omega L}{R}\right)$ which Z makes with R line gives the R phase difference between the applied voltage and current. In this case the voltage leads the current by $\theta°$.



16.7. A choke coil placed in series with an electric lamp in an A.C. 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: **Choke:**

Since an inductor coil does not consume energy, the coil is often employed for controlling A.C. without consumption of energy. Such an inductance coil is known as choke.

Inductor offers high resistance to A.C, decreases current, so bulb becomes dim. By adjusting value of 'C', we achieve resonance condition (inductive and capacitive reactance cancel the effect of each other) so maximum current flows due to the balancing of reactances.

16.8. Explain the conditions under which electromagnetic waves are produced from a source.

Ans: When antenna is connected to a.c. source which accelerates the electrons. The vibrations of electrons create a changing magnetic field which then produces a changing electric filed. In this way the electromagnetic waves are produce from a source.

These waves are produced by the oscillation of electric charges (either by using some electric oscillator (LC circuit) or by waving the conductor in space or by, regularly, reversing the polarity of the voltage attached with the conductor).

16.9. How the reception of a particular radio station is selected on our radio set?

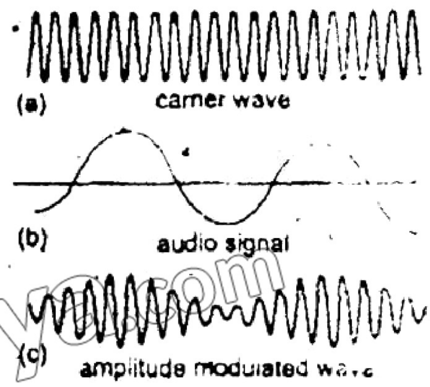
Ans: Since resonance frequency is $f_r = \frac{1}{2\pi\sqrt{LC}}$. We keep changing the value of C of our radio set unless its resonance-frequency becomes equal to the frequency of the particular radio station. At this point, resonance takes place and the station is tuned on our radio set

16.10. What is meant by A.M. and F.M.?

Ans: Amplitude modulation (A.M):

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

Fig. (a) represents a high frequency carrier wave of constant amplitude and frequency. Fig. (b) represents a low or audio frequency signal of a sine waveform. Fig. (c) shows the result obtained by modulating the carrier waves with the modulating wave.



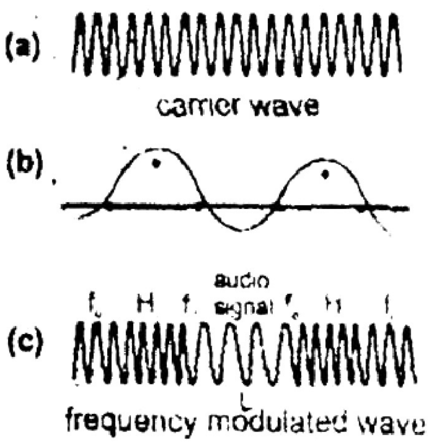
Transmission frequencies range of A.M:

The A.M. transmission frequencies range from 540 kHz to 1600 kHz.

Frequency modulation (F.M):

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

Fig. shows frequency modulation. The frequency of the modulated carrier wave is highest (point H) when the signal amplitude is at its maximum positive value and is at its lowest frequency (point L) when signal amplitude has maximum negative. When the signal amplitude is zero the carrier frequency is at its normal frequency f_c



Transmission frequencies range of F.M:

The F.M. transmission frequencies range from 88 MHz to 108 MHz.

SOLUTION OF EXAMPLES

Example 16.1: **An A.C. voltmeter reads 250 V. What is its peak and instantaneous values if the frequency of alternating voltage is 50 Hz?**

Solution:

rms values of alternating voltage = V_{rms} = 250 V

Frequency of alternating voltage = f = 50 Hz

Peak value of alternating voltage = V_0 = ?

Instantaneous voltage = V = ?

Peak value V_0 of alternating voltage:

$$V_{rms} = \frac{V_0}{\sqrt{2}}$$

$$V_0 = \sqrt{2}\ V_{rms}$$

$$V_0 = \sqrt{2} \times 250 = 1.414 \times 25V \quad (\because \sqrt{2} = 1.414)$$

$$V_0 = 353.5\ V$$

Since Angular frequency = $\omega = 2\pi f$

$$\omega = 2 \times \pi \times 50 = 100\ \pi\ Hz$$

Instantaneous value of alternating voltage:

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

$$V = 353.5 \sin(100\ \pi t)\ V$$

Example 16.2: **A 100 μF capacitor is connected to an alternating voltage of 24 V and frequency 50 Hz. Calculate**

(a) The reactance of the capacitor, and

(b) The current in the circuit

Solution:

Capacitance of capacitor = C = 100 μF

= 100×10^{-6} F ($\because$ 1μF = 10^{-6}F)

Alternating voltage = V = 24 V

Frequency = f = 50 Hz

(a) Reactance of capacitor = X_c = ?

(b) Current in the circuit = I = ?

(a) The reactance of the capacitor:

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

$$X_c = \frac{1}{2 \times 3.14 \times 50 \times 100 \times 10^{-6}} = 31.8\ \Omega$$

(b) Since

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

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

$$I = \frac{24}{31.8} = 0.75\ A$$

Example 16.3: **When 10 V are applied to an A.C. circuit, the current following in it is 100 mA. Find its impedance.**

Solution:

rms value of applied voltage = V_{rms} = 10 V

rms value of current = I_{rms} = 100 mA

rms value of current = 100×10^{-3} A

Impedance = Z = ?

Since

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

$$Z = \frac{10}{100 \times 10^{-3}} = 100\ VA^{-1} = 100\ \Omega$$

Example 16.4: **At what frequency will an inductor of 1.0H have a reactance of 500 Ω?**

Solution:

Inductance of inductor = L = 1.0 H

Reactance of inductor = X_L = 500 Ω
Frequency = f = ?

Reactance of the inductor:

$X_L = \omega L$

$X_L = 2\pi f L$ $(\because \omega = 2\pi f)$

$f = \frac{X_L}{2\pi L}$

$f = \frac{500}{2\times3.14\times1.0} = 80\ Hz$

Example 16.5: **An iron core coil of 2.0 H and 50 Ω, is applied in series with a resistance of 450 Ω. An A.C. supply of 100 V, 50 Hz is connected across the circuit. Find (i) the current flowing in the coil, (ii) phase angle between the current and voltage.**

Solution:

Since resistance are connected in series

Resistance = R = 50 Ω + 450 Ω = 500 Ω
Inductance = L = 2.0 H
Supplied voltage = V_{rms} = 100 V
Frequency = f = 50 Hz
(i) Current in the coil = I = ?
(ii) Phase angle = θ = ?

$X_L = 2\pi f L$

$X_L = 2 \times 3.14 \times 50 \times 2.0 = 628\ \Omega$

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

$Z = \sqrt{(500)^2 + (628)^2} = 803\ \Omega$

Also, $I_{rms} = (\frac{V_{rms}}{Z})$

$I_{rms} = \frac{100}{803} = 0.01245\ A = 12.45 \times 10^{-3}\ A$

$I_{rms} = 12.45\ mA$

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

$\theta = \tan^{-1}(\frac{628}{500}) = \tan^{-1}(1.256) = 51.5^0$

Example 16.6: **A circuit consists of a capacitor of 2 μF and a resistance of 1000 Ω connected in series. An alternating voltage of 12V and frequency 50Hz is applied. Find (i) the current in the circuit, and (ii) the average power supplied.**

Solution:

Capacitance = C = 2 μF = 2×10^{-6} F
Resistance = R = 1000 Ω
Alternating Voltage = V = 12 V
Frequency = f = 50 Hz
(i) Current = I_{rms} = ?
(ii) Average power = P = ?

Since $X_c = \frac{1}{2\pi f C}$

$X_c = \frac{1}{2\times3.14\times50\times2\times10^{-6}} = 1592\ \Omega$

Also

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

$Z = \sqrt{(1000)^2 + (1592)^2} = 1880\ \Omega$

Now

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

$I_{rms} = \frac{12}{1880} = 0.0064\ A = 6.4 \times 10^{-3} A = 6.4\ mA$

Phase difference $= \theta = \tan^{-1} (\frac{X_C}{R})$

$\theta = \tan^{-1} (\frac{1592}{1000}) = \tan^{-1} (1.592) = 57.87°$

Average power $= P_{av} = V_{rms}\ I_{rms} \cos\theta$

$P_{av} = 12 \times 0.0064\ A \times \cos 57.87°$

$P_{av} = 12V \times 0.\ 00064\ A \times 0.532 = 0.04\ W$

Example 16.7: Find the capacitance required to construct a resonance circuit of frequency 1000 kHz with an inductor of 5 mH.

Solution:

Resonance frequency $= f_r = 100\ kHz = 1000 \times 10^3\ Hz = 10^6$

Hz Inductance $= L = 5\ mH = 5 \times 10^{-3}\ H$

Capacitance $= C = ?$

The formula for resonance frequency is,

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

Squaring both sides, we get

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

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

$C = \frac{1}{4\times(3.14)^2\times(10^6)^2\times5\times10^{-3}} = 5.09 \times 10^{-12}\ F$

$C = 5.09\ pF$ (Since $1\ pF = 10^{-12}\ F$)

SOLUTION OF PROBLEMS

16.1. An alternating current is represented by the equation $I = 20 \sin 100\pi t$. Compute its frequency and the maximum and rms values of current.

Solution:

$I = 20 \sin 100\pi t$ .... (1)

$f = ?$

$I_0 = ?$

$I_{rms} = ?$

Since $I = I_0 \sin 2\pi f t$ .... (2)

Comparing equations (1) and (2) we get,

$2f = 100$

$f = \frac{100}{2}\ Hz$

$f = 50\ Hz$

Also

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

$Z = \sqrt{(1000)^2 + (1592)^2} = 1880\ \Omega$

Now

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

$I_{rms} = \frac{12}{1880} = 0.0064\ A = 6.4 \times 10^{-3} A = 6.4\ mA$

Phase difference $= \theta = \tan^{-1}(\frac{X_C}{R})$

$\theta = \tan^{-1}(\frac{1592}{1000}) = \tan^{-1}(1.592) = 57.87°$

Average power $= P_{av} = V_{rms} I_{rms} \cos\theta$

$P_{av} = 12 \times 0.0064\ A \times \cos 57.87°$

$P_{av} = 12V \times 0.\ 00064\ A \times 0.532 = 0.04\ W$

Example 16.7: Find the capacitance required to construct a resonance circuit of frequency 1000 kHz with an inductor of 5 mH.

Solution:

Resonance frequency $= f_r = 100\ kHz = 1000 \times 10^3\ Hz = 10^6$

Hz Inductance $= L = 5\ mH = 5 \times 10^{-3}\ H$

Capacitance $= C = ?$

The formula for resonance frequency is,

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

Squaring both sides, we get

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

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

$C = \frac{1}{4\times(3.14)^2\times(10^6)^2\times5\times10^{-3}} = 5.09 \times 10^{-12}\ F$

$C = 5.09\ pF$ (Since $1\ pF = 10^{-12}\ F$)

SOLUTION OF PROBLEMS

16.1. An alternating current is represented by the equation $I = 20 \sin 100\pi t$. Compute its frequency and the maximum and rms values of current.

Solution:

$I = 20 \sin 100\pi t$ .... (1)

$f = ?$

$I_0 = ?$

$I_{rms} = ?$

Since $I = I_0 \sin 2\pi f t$ .... (2)

Comparing equations (1) and (2) we get,

$2f = 100$

$f = \frac{100}{2}\ Hz$

$f = 50\ Hz$

Also $I_{rms} = 0.707\ I_0$ .... (3)

From Eq 1 $I_0 = 20\ A$

Now, using values in equation (3) we get,

$I_{rms} = 0.707 \times 20 = 14\ A$

16.2 A sinusoidal A.C. has a maximum value of 15A. What are its rms values? If the time is recorded from the instant the current is zero and is becoming positive, what is the instantaneous value of the current after 1/300s, given the frequency is 50 Hz.

Solution:

$I_0 = 15\ A$

$t = \frac{1}{300}$ sec

$f = 50\ Hz$

$I_{rms} = ?$

$I = ?$

As we know that,

$I_{rms} = 0.707\ I_0$

$I_{rms} = 0.70 \times 15 = 10.6\ A$

The standard equation for the instantaneous value of A.C. is,

$I = I_0 \sin (2\pi f)\ t$

$I = 15 \times \text{Sin}\ (2 \times 180 \times 50 \times \frac{1}{300}) = 13\ A$

16.3 Find the value of the current and inductive reactance when A.C. voltage of 220V at 50Hz is passed through an inductor of 10H.

Solution:

$V = 220\ V$

$f = 50Hz$

$L = 10H$

$I_{rms} = ?$

$X_L = ?$

Since $X_L = \omega L = 2\pi f L$

$X_L = 2 \times 3.14 \times 50 \times 10 = 3140\ \Omega$

And $I = \frac{V}{X_L}$

$I = \frac{220}{3140} = 0.07$

16.4 A circuit has an inductance of $\frac{1}{\pi}$ H and resistance of 2000Ω. A 50 Hz A.C. is supplied to it. Calculate the reactance and impedance offered by the circuit.

$L = \frac{1}{\pi} H$

$V = 220\ V$

$f = 50\ Hz$

$R = 2000\ \Omega$

$X_L = ?$

$z = ?$

We know that,

$X_L = 2\pi f L$

$X = 2 \times \pi \times 50 \times \frac{1}{\pi} = 100\ \Omega$

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

$Z = \sqrt{(100)^2 + (2000)^2} = 2002.5\ \Omega$

16.5 An inductor of pure inductance $\frac{3}{\pi}$ H is connected in series with a resistance of 40 Ω. Find

(i) The peak value of the current

(ii) The rms value, and

(iii) The phase difference between the current and the applied voltage

Solution:

$L = \frac{3}{\pi}$ H

$V = 350 \sin(100\pi t)$ (1)

$V_0 = 350$ V (Compare from 1)

$R = 40\ \Omega$

$f = 50$Hz

$I_0 = ?$

$I_{rms} = ?$

$\theta = ?$

The formula for the impedance of an RL circuit is,

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

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

$Z = \sqrt{(40)^2 + (2\pi \times 50 \times \frac{3}{\pi})^2} = \sqrt{1600 + 90000}$

$Z = \sqrt{91600} = 302.65\ \Omega$

(i) $I_0 = \frac{V_0}{Z}$

$I_0 = \frac{350}{302.65} = 1.16$ A

(ii) Since $I_{rms} = 0.707\ I_0$

$I_{rms} = 0.707 \times I_0$

$I_{rms} = 0.707 \times 1.16 = 0.81$ A

(iii) Phase difference in RL circuit is,

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

$\phi = \tan^{-1}\left(\frac{2\pi f L}{R}\right) = \tan^{-1}\left(\frac{2\pi \times 50 \times \frac{3}{\pi}}{40}\right) \tan^{-1}\left(\frac{300}{40}\right) = \tan^{-1} 7.5 = 82.4°$

16.6 A 10 mH, 20 Ω coil is connected across 240 V and $\frac{180}{\pi}$ Hz source. How much power does it dissipate?

Solution:

$L = 10$ mH

$R = 20\ \Omega$

$V_{rms} = 240$ volts

$f = \frac{180}{\pi}$ Hz

$P = ?$

Since $X_L = 2\pi f L$

$X_L = 2\pi \times \frac{180}{\pi} \times 10 \times 10^{-3} = 3.6\ \Omega$

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

$Z = \sqrt{(3.6)^2 + (20)^2} = 20.3214\ \Omega$

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

$I_{rms} = \frac{240}{20.3214} = 11.81\ A$

Also $P = V\, I_{rms}$

$P = 240 \times 11.81 = 2834$ Watts

16.7 Find the value of the current flowing through a capacitance 0.5μF when connected to a source of 150V at 50Hz.

Solution:

$C = 0.5\ \mu F = 0.5 \times 10^{-6}\ F$

$V_{rms} = 150\ V$

$f = 50\ Hz$

$I_{rms} = ?$

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

$X_C = \frac{1}{2\pi \times 0.5 \times 10^{-6} \times 50} = \frac{1}{2 \times 3.14 \times 0.5 \times 10^{-6} \times 50} = \frac{10^6}{157} = 6360\ \Omega$

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

$I_{rms} = \frac{150}{6360} = 0.024A$

16.8 An alternating source of emf 12V and frequency 50 Hz is applied to a capacitor of capacitance 3 μF in series with a resistor of resistance 1kΩ. Calculate the phase angle.

Solution:

$V = 12\ V$

$f = 50\ Hz$

$C = 3\ \mu F = 3 \times 10^{-6}\ F$

$R = 1\ k\Omega = 1000\ \Omega$

Since $X_c = \frac{1}{2\pi f c}$

$X_c = \frac{1}{2\pi \times 50 \times 3 \times 10^{-6}} = 1060.89\ \Omega$

$\phi = \tan^{-1} \frac{X_c}{R}$

$\phi = \tan^{-1} \left(\frac{1060.89}{1000}\right) = 46.69° = 46.7^0$

16.9 What is the resonant frequency of a circuit which includes a coil of inductance 2.5 H and a capacitance 40μF?

Solution:

$L = 2.5\ H$

$C = 40\ \mu F = 40 \times 10^{-6}\ F$

$f_r = ?$

Resonance frequency is given by

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

$$f_r = \frac{1}{2\times3.14\sqrt{2.5\times40\times10^{-6}}} = \frac{10^3}{6.28\times10} = \frac{1000}{62.8} = 15.9\ \text{Hz}$$

16.10 An inductor of inductance 150μH is connected in parallel with a variable capacitor whose capacitance can be changed from 500 pF to 20 pF. Calculate the maximum frequency and minimum frequency for which the circuit can be tuned.

Solution:

$L = 150\ \mu H = 150\times10^{-6}\ H$

$C_{max} = 500\ pF = 500\times10^{-12}\ F$ (Since 1 pF = 10^{-12} F)

$C_{min} =$ to 20 pF $= 20\times10^{-12}\ F$

$f_{min} = ?$

$f_{max} = ?$

The formula for resonance frequency is given by,

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

Therefore

$$f_{max} = \frac{1}{2\pi\sqrt{LC_{min}}}$$

$$f_{max} = \frac{1}{2\times3.14\times\sqrt{150\times10^{-6}\times20\times10^{-12}}}$$

$$f_{max} = \frac{1}{6.28\times\sqrt{300\times10^{-18}}} = \frac{1}{343.96}\times10^9 = 2.91\times10^6 = 2.91\ \text{MHz}$$

Now

$$f_{min} = \frac{1}{2\pi\sqrt{LC_{max}}}$$

$$f_{min} = \frac{1}{2\times3.14\times\sqrt{150\times10^{-6}\times500\times10^{-12}}} = \frac{1}{6.28\times\sqrt{75000\times10^{-18}}}$$

$$f_{min} = \frac{1}{6.28\times273.86\times10^{-9}} = 5.814\times10^5 = 0.58\times10^6 = 0.58\ \text{MHz}$$