ALTERNATING CURRENT . II

1- **Definition:-** Alternating current (A.C) is that which is produced by a voltage source whose polarity keeps on reversing with time.

2- **Explanation:-**

(a)- **Advantage of A.C**

The main reason for the world wide use of A.C. is that it can be increased or decreased by transformers, it can be transmitted to long distances easily at a very low cost and with very small power losses.

(b)- **Flow of A.C through a circuit**

Consider an alternating voltage source which is connected across a resistor as shown in fig (a). The terminal A of the source is positive with respect to terminal B and it remains so during a time interval 0 to $T/2$. During this time interval, current flows through the circuit from A to B i-e in clockwise direction as shown in fig. (a)

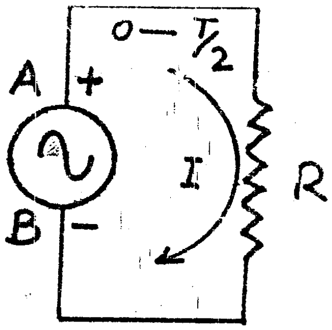


fig. (a)

At $t = T/2$, the terminals change their polarity. 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 change of polarity during $T/2$ to T, the direction of flow of current in the circuit also changes i-e it flows from B to A (anticlockwise

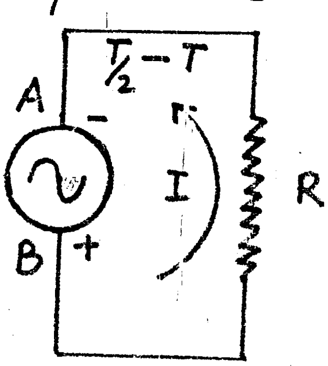


fig. (b)

(c). Different Terms Of A.C

(i). Time Period :- This is the time interval during which the voltage source changes its polarity once is known as period of alternating current or voltage. It is denoted by 'T'.

(ii). Frequency :- The number of cycles per second is called frequency. $f = \frac{1}{T}$

In Pakistan the frequency of A.C or alternating voltage is 50 Hz.

(iii). Alternating Voltage :- The most common source of alternating voltage is an A.C. generator. The output voltage of this A.C. generator at any instant is given by

$$V = V_0 \sin \omega t = V_0 \sin \frac{2\pi}{T} t$$

where T is the period of rotation of the coil and is equal to the period of A.C. and $\frac{2\pi}{T} = 2\pi f = \omega$ is the angular frequency of rotation of the coil. Thus $\frac{2\pi}{T} t = \omega t = \theta$ the angle through which the coil rotates in time 't'.

(d). Variation of Voltage with time :-

As $$V = V_0 \sin \theta = V_0 \sin \omega t = V_0 \sin \frac{2\pi}{T} t \quad \text{——— (1)}$$

This equation shows that the alternating voltage V is not constant. It changes with time t.

- When $t = 0$, $\theta = \omega t = \frac{2\pi}{T} t = 0$ and $V = 0$
- When $t = T/4$ $\theta = \frac{2\pi}{T} \times T/4 = \frac{\pi}{2}$, and V attains its maximum value V_0 at this instant.
- When $t = T/2$, $\theta = \frac{2\pi}{T} \times \frac{T}{2} = \pi$ and $V = 0$

At this instant V changes its polarity and becomes −ve henceforth.

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

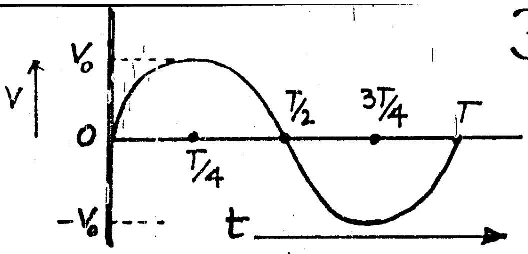
Finally at the end of the cycle

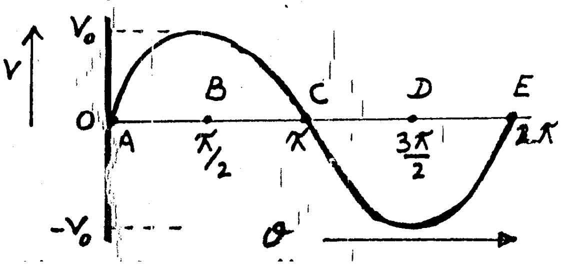
- When $t = T$, $\theta = 2\pi$ and $V = 0$.

Graphical Representation

The variation of V with time 't' and 'θ' is shown

The graph between voltage and time or between voltage and θ Fig.(c) is known as waveform of alternating voltage. It is a sine curve. Thus output voltage of an A.C. generator Fig(d) varies sinusoidally with time.

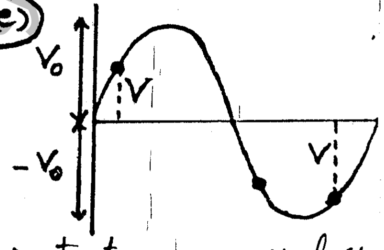




(e). Different Values of Alternating Voltage

(i). 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 $-V_0$ as shown in figure (e). It is denoted by V. The waveform of alternating voltage is actually a set of all the instantaneous values that exist during a period T.

Fig(e)

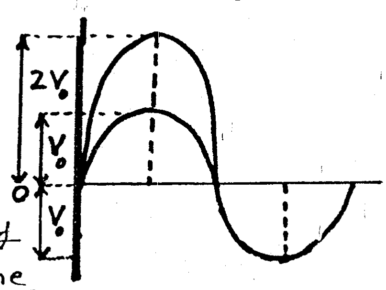


Mathematically it is given as

$$V = V_0 \sin\theta = V_0 \sin\omega t = V_0 \sin\frac{2\pi}{T}t = V_0 \sin 2\pi f t$$

(ii). Peak Value :- It is the highest value reached by the voltage or current in one cycle. For example voltage shown in fig (c) has a peak value of V_0.

(iii). Peak to Peak Value :- It is the sum of the positive and negative peak values i.e $V_0 + V_0 = 2V_0$. It is written as p-p value. It is shown graphically as fig(f)



(iv). Root Mean Square (rms) Value :-

Root mean square value of an alternating current is that steady current which produces the same heating effect in a resistance in a given time as

The alternating current does in the same resistance in the same time.

When an ordinary D.C ammeter is connected in a circuit to measure A.C, it would measure its value as averaged over a cycle i-e zero. It can be seen in fig (c) that the average value of voltage or A.C over a cycle is zero, but power delivered or power dissipated as heat for a cycle is not zero, because $P = I^2 R = \frac{V^2}{R}$.

Therefore, the average of square of current or voltage will not be zero because the values of V^2 or I^2 are positive even for the negative values of V or I. Since alternating voltage or A.C has no steady magnitude so, the power delivered at any instant will be proportional to the square of the instantaneous value of voltage or A.C.

Thus the effective value of an alternating voltage is defined as its rms value i-e

$$V_{rms} = \sqrt{\text{average value of } V^2}$$

Expression :-

In order to derive an expression for V_{rms} value over a cycle, consider figure (g) which shows an alternating voltage or A.C and the way its V^2 values vary. The values of V^2 are +ve on the negative half cycle.

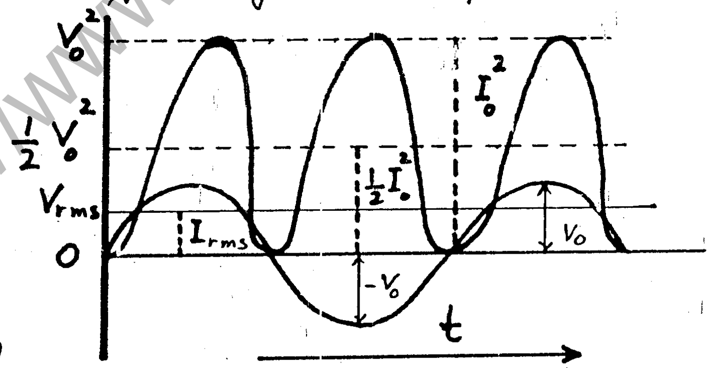


Fig (g)

From figure (g) it can be seen that

Min.) Initial value of $V^2 = 0$

Max.) Final value of $V^2 = V_0^2$

Average value of $V^2 = \frac{0 + V_0^2}{2} = \frac{1}{2} V_0^2$

So the root mean square value of V is obtained by taking the square root on both the sides

$$\sqrt{\text{Average value of } V^2} = \sqrt{\frac{V_0^2}{2}}$$

$$\boxed{V_{rms} = \frac{V_0}{\sqrt{2}} = 0.707\, V_0}$$

Similarly

$$\boxed{I_{rms} = \frac{I_0}{\sqrt{2}} = 0.707\, I_0}$$

(f)- Phase of Alternating Voltage or A.C

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

As we have $V = V_0 \sin\theta = V_0 \sin\omega t$

The figure (d) shows that phase at the points A, B, C, D and E is $0, \pi/2, \pi, 3\pi/2$ and 2π respectively. Thus each point on the A.C waveform corresponds to a certain phase. The phase at the positive peak is $\pi/2 = 90^\circ$ and it is $\frac{3\pi}{2} = 270^\circ$ at the negative peak. The points where the waveform crosses the time axis correspond to phase $0, \pi$ and 2π.

(g)- Phase Lag and Phase Lead

– Phase Lag :-

Figure (h) shows two waveforms 1 and 2. The phase angles of the waveform 1 at the points A,B,C,D and E has been shown above the axis and those of 2 below the axis.

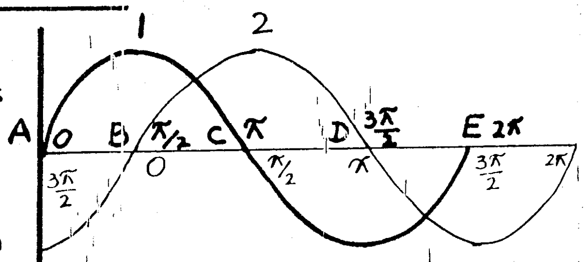
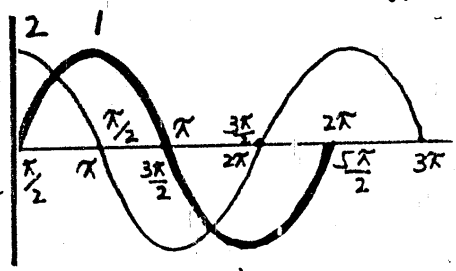


fig (h)

At point B, the phase of 1 is $\pi/2$ and that of 2 is 0. 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 a phase $\pi/2$. It means that at each point or instant, the phase of A.C. 2 is less than phase of A.C. 1 by $\pi/2$.

Phase Lead



fig(i)

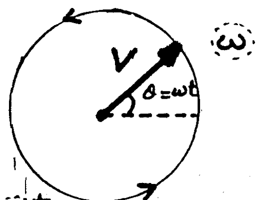
It can be seen in fig(i) that phase at each point of waveform 2 is greater than that of waveform 1 by an angle $\pi/2$. In this case it is said that A.C.2 is leading the A.C 1 by $\pi/2$. It means that at each instant of time, the phase of A.C. 2 is greater than that of 1 by $\pi/2$.

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

(h). Vector Representation of an Alternating Qty.

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

1. The length of the vector is according to certain scale which represents the peak or rms value of the alternating quantity.
2. A vector will be 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.



$V = V_o \sin \omega t$

Example :-

Consider fig (j) which shows a sinusoidal voltage waveform leading an alternating current waveform by $\pi/2$. The same effect has been shown vectorially in figure (k) as :

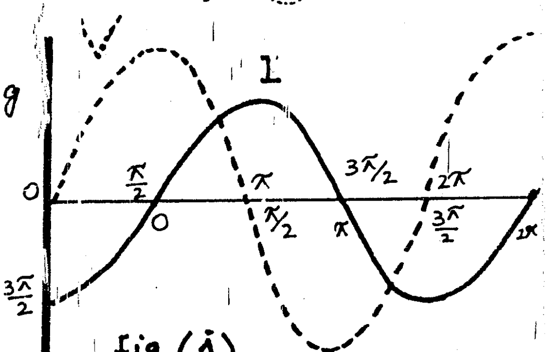
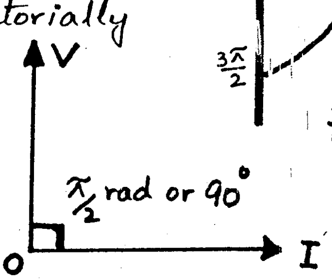


fig (j)



fig(k)

Here vector $\overrightarrow{OI}$ represents the peak or rms value of the current which is taken as reference quantity. Similarly $\overrightarrow{OV}$ represents the rms or peak value of the alternating voltage which is leading the current by 90°.
Both vectors are supposed to be rotating in counter clockwise direction at the angular frequency ω of the two alternating quantities.

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

Solution :- $f = 50\,Hz$

$V_{rms} = 250\,V$

As $V_{rms} = V_o/\sqrt{2}$

Then $V_o = \sqrt{2}\,V_{rms} = \sqrt{2} \times 250\,V = 353.5\,V$

Also

$$V = V_o \sin\omega t = V_o \sin 2\pi f t$$

$$V = 353.5\,V \sin(2\pi \times 50 \times t)$$

$$V = 353.5 \sin(100\pi t) \text{ Volts.}$$

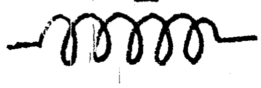
16.2 A.C. CIRCUITS

In D.C Circuit :- 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 $V = IR$

R

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

L



C

16.3 A.C. THROUGH A RESISTOR

Consider a resistor of resistance R connected with an alternating voltage source, as shown in figure (a)

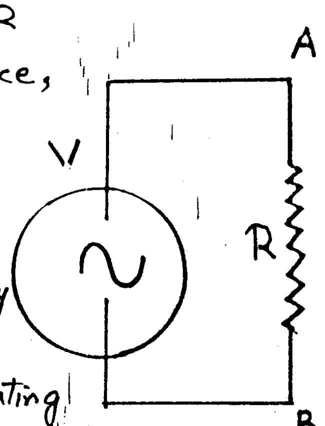


fig.(a)

1. Instantaneous Voltage :-

At any time 't' the potential difference across the terminals of the resistor is given by

$$V = V_0 \sin \omega t \quad \text{—— (1)}$$

Where 'V_0' is the peak value of the alternating voltage.

2. Instantaneous Current :-

The current 'I' flowing through the circuit is given by Ohm's law $V = IR$

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

$$I = I_0 \sin \omega t \quad \text{—— (2)} \qquad \because I_0 = \frac{V_0}{R}$$

Where I is the instantaneous current and I_0 is the peak value of the current.

3. Graphical Representation :-

It can be seen from eq (1) and (2) that the instantaneous values of both voltage and current are sine functions which vary with time. The graphical representation of voltage and current are shown in figure (b). This figure shows that when voltage rises, current also rises. If the voltage falls, the current also falls. Both pass the maximum and minimum values at the same instant.

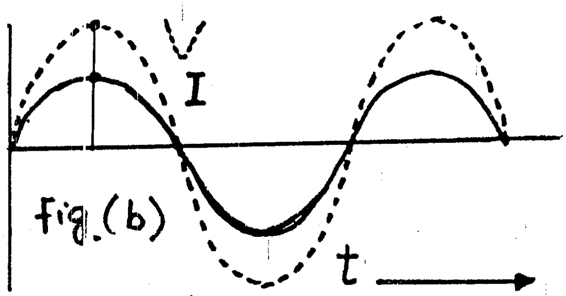


fig.(b)

Thus in purely resistive A.C. circuit, instantaneous values of voltage and current are in phase.

4. Vector Representation :-

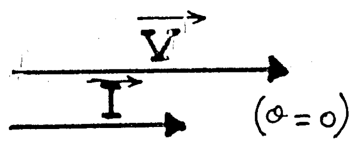


fig.(c)

The behaviour of voltage and current with respect to phase is shown in figure (c) vectorially. Phase diff. is zero.

5- **RESISTANCE** :-
The opposition to A.C. which the circuit presents is the resistance.

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

The figure (c) shows $\vec{V}$ and $\vec{I}$ vectors for resistance. i-e resistance can be shown along $\vec{V}$ or $\vec{I}$ for resistive A.C. circuit as shown in figure (d).

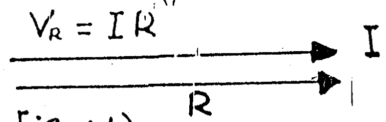


fig.(d)

6- **Power** :-
The electrical power supplied by the source or power dissipated in the resistor is given as

$$P = VI = I^2R = \frac{V^2}{R} \quad \text{———} \quad (4)$$

The power P is in watt, V is in volts, I is in amperes and R is in ohms. It is very important to note that eq. (4) holds only when current and voltage are in phase.

16.4 A.C. THROUGH A CAPACITOR

1- **Introduction** :- A.C. can flow through a resistor. In order to observe the flow of A.C. through a capacitor, consider a low power bulb which is connected in series with 1 μF capacitor and supply mains through a switch as shown in fig.(a). When the switch is closed, the bulb lights up showing that the current is flowing through the capacitor. Direct current cannot flow through a capacitor continuously because of the presence of an insulating medium between the plates of capacitor.

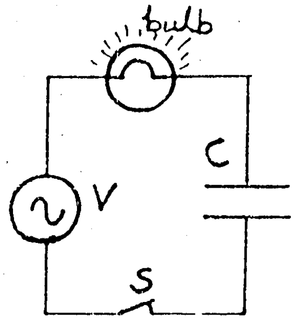


fig.(a)

2- **Flow of A.C. Through a Capacitor** :-
Consider a capacitor of capacitance C is connected in series with an alternating voltage source. Though the plates of the capacitor are separated by an insulating medium (through which current cannot pass) an alternating current flows in the circuit as plates

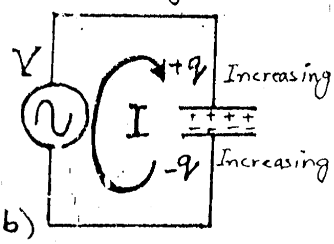


Fig.(b)

are being continuously charged (for the half of +ve cycle of A.C), discharged (for the next half of +ve cycle of A.C) and charged the other way round, as shown in fig.(b) and fig.(c).

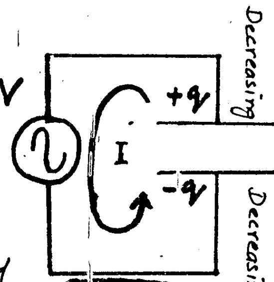


Fig.(c)

3. Electric Charge :-

The basic relation between the charge q on the capacitor and voltage V across the plates i.e $q = CV$ holds at every instant. If $\boxed{V = V_0 \sin\omega t}$ is the applied voltage, then charge on the capacitor at any instant is given as

$$q = CV$$

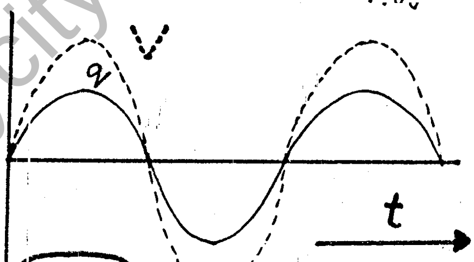
$$\boxed{q = CV_0 \sin\omega t} \text{ ——— } (1)$$

Since C, V_0 are constants, it can be seen that q and V both are sine functions which vary the same way with time i.e V and q are in phase as shown in Fig.(d)

4. Electric Current :-

The current is the rate of change of charge with time.

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



Fig(d)

At any point on the curve the rate of change is given by the slope of the tangent line at that point. So the value of I at any instant is obtained by the slope of the $q-t$ curve as shown in fig (e). i.e

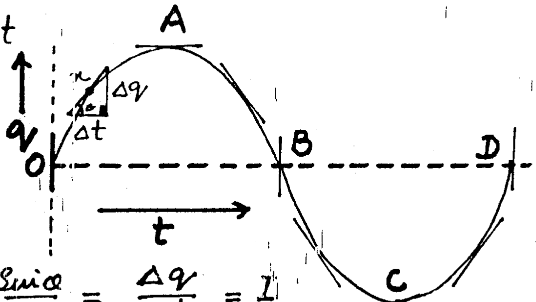
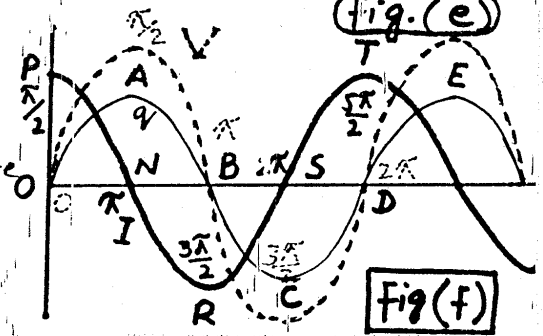


Fig.(e)

<u>slope of $q-t$ curve at a point 'x'</u> = <u>tangent at that point</u> $= \tan\theta = \frac{\sin\theta}{\cos\theta} = \frac{\Delta q}{\Delta t} = I$

At O when $q = 0$, the slope is max. (as shown in fig.(e)), so I is then maximum (as shown in fig(f)).

From O to A, slope of the q-t curve decreases to zero. So I decreases and becomes zero at N.



Fig(f)

16.5 A.C. THROUGH AN INDUCTOR

1- Inductor :-

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.

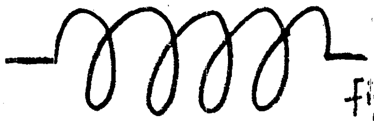


fig (a)

2. Flow of A.C. through an inductor :-

Consider an inductor, connected with an alternating voltage source. As we know that self inductance of a coil opposes the change of current. Therefore inductor must oppose the flow of A.C, which is continuously changing.

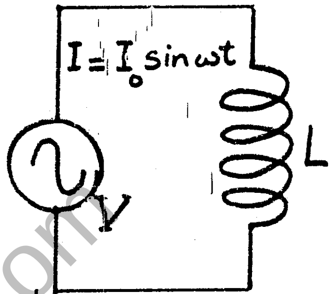


fig (b)

For simplicity, we first consider the current and then finding the potential difference across inductor which will cause this current.

3. Electric Current :-

Suppose the current flowing through the inductor is

$$I = I_0 \sin\omega t = I_0 \sin 2\pi f t \quad \text{———} \quad (1)$$

Where I is the instantaneous value and I_0 is the peak value of current.

4- Voltage :-

If L is the inductance of the coil, the changing current sets up a back emf in the coil of magnitude $\qquad \mathcal{E}_L = L \frac{\Delta I}{\Delta t}$

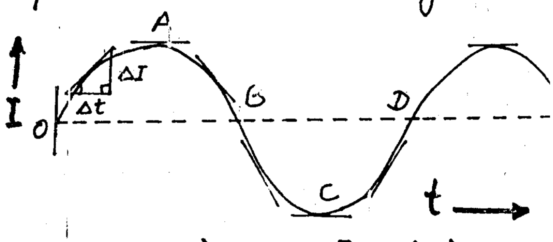
To maintain the current, the applied voltage must be equal to the back e.m.f.

So applied voltage $= V = L \frac{\Delta I}{\Delta t}$ ——— (2)

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

From eq (1) current is a sine function which vary with time as shown in figure (c).

The value of $\frac{\Delta I}{\Delta t}$ is given by the slope of the I-t curve at various instants of time.



i.e Voltage $= L\frac{\Delta I}{\Delta t} = L$ (slope of I-t curve)

fig (c)

(e). Factors

According to equation ②, certain capacitors will have a large reactance at a 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.

$$I = CV_o \frac{d}{dt}(\sin \omega t)$$

$$I = CV_o \omega \cos \omega t$$

at $t = 0$ $\qquad I = I_o$

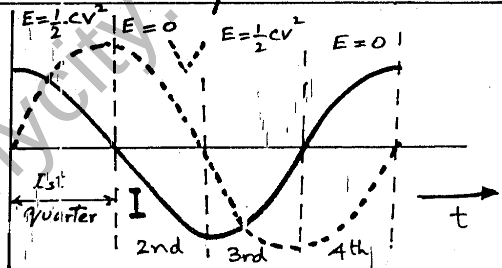
$$I_{max} = I_o = CV_o \omega \cos 0^\circ = CV_o \omega$$

As $X_c = \frac{V_o}{I_o} = \frac{V_o}{CV_o \omega}$

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

NOTE **Energy Dissipation in a Capacitive Circuit**

The power loss in the circuit can be investigated by referring to given figure. As it can be seen that the current (+ve) is leading the voltage (+ve) by $\frac{1}{4}$ cycle or by a phase 90°. The capacitor therefore charges for a quarter cycle and energy $(\frac{1}{2}CV^2)$ is stored in it. During the next quarter cycle the current (-ve) is flowing in a direction opposite to applied voltage (+ve). In otherwards the capacitor discharges and returns the energy to the generator. This action is repeated again and again. It is, therefore, apparent that <u>the average power delivered to a capacitor is zero. So there is no dissipation of energy in a pure capacitive circuit.</u>



EXAMPLE 16.2:- A $100\mu F$ capacitor is connected to an alternating voltage of 24 V and frequency 50 Hz. Calculate X_c and I.

SOLUTION:- $C = 100\mu F$, $V = 24V$ and $f = 50 Hz$.

(a) Reactance of a capacitor $X_c = \frac{1}{2\pi f C}$

$$X_c = \frac{1}{2 \times 3.14 \times 50 s^{-1} \times 100 \times 10^{-6} F} = \underline{31.8\ \Omega} \quad \text{Answer}$$

(b) As $X_c = \frac{V}{I} \Rightarrow I = \frac{V}{X_c}$

$$I = \frac{24V}{31.8\Omega} = \underline{0.75 A} \quad \text{Answer.}$$

(c)- Expression

For an inductive circuit the inductive reactance is given as

$$X_L = \frac{V}{I} = \omega L = 2\pi f L$$

(d). Factors

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.

As $I = I_o \sin \omega t$

and $V = L\frac{\Delta I}{\Delta t} = L\frac{dI}{dt}$

$$V = L\frac{d}{dt}(I_o \sin \omega t)$$

$$= L I_o \frac{d}{dt} \sin \omega t$$

$$V = L I_o \omega \cos \omega t$$

when $t = 0$ then $V = V_o$

$\therefore \quad V_o = L I_o \omega \cos 0°$

$V_o = L I_o \omega$

$\therefore \quad X_L = \frac{V_o}{I_o} = \frac{I_o L \omega}{I_o}$

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

(e). Units L is expressed in henry, f in hertz and X_L in ohms.

(f). Comparision of X_c and X_L :-

For a purely capacitive circuit

$$X_c = \frac{1}{\omega C} = \frac{1}{2\pi f C} \quad \text{i.e} \quad X_c \propto \frac{1}{f}$$

and for a purely inductive circuit

$$X_L = \omega L = 2\pi f L \quad \text{i.e} \quad X_L \propto f$$

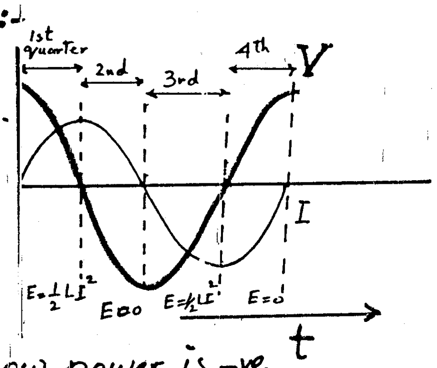
It can be noted that inductance and capacitance behave oppositely as a function of frequency.

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.

The behaviour of resistance is independent of the frequency.

9- Energy Stored in Inductor :-



From figure it can be seen that no power is dissipated in a pure inductor. In the first quarter of cycle both V and I are positive, so power (VI) is +ve which means energy is supplied to inductor. In the second quarter V is −ve but I is +ve. Now power is −ve. which means that energy is returned by the inductor. Again in third quarter inductor receives energy but returns the same amount in the fourth quarter. Thus there is no net

5. Graphical Representation

At O, the value of slope is max. as shown in fig (c), so the maximum value of V equals to V_0 occurs at O and is represented by OP as shown in fig (d). From O to A the slope of I-t curve decreases to zero so the voltage decreases from V_0 to zero at Q. From A to B, the slope of It curve 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.

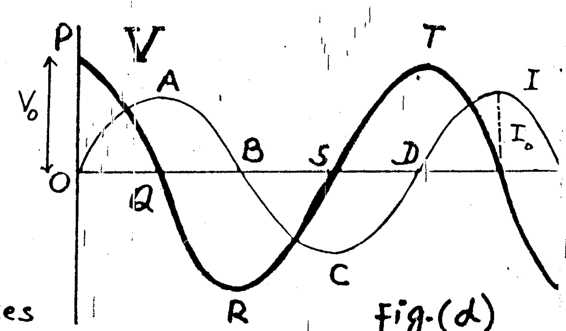


fig.(d)

6. Phase Difference :-

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 $\pi/2$.

7. Vector Representation :-

As in this case applied voltage leads the current by a phase of 90° or $\pi/2$, so vectorially it is shown in fig (e).

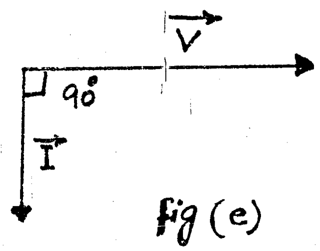


fig (e)

8. Inductive Reactance :-

(a). **Definition** :- It is a measure of the opposition offered by the inductance coil to the flow of A.C. It is represented by X_L.

(b). **Mathematically** :- If V is the rms value of the alternating voltage across an inductance and I is the rms value of current passing through it, the value of X_L is given as

$$X_L = \frac{V}{I} = \frac{V_0}{I_0} \qquad (3)$$

$\because V_{rms} = \frac{V_0}{\sqrt{2}}$ and $I_{rms} = \frac{I_0}{\sqrt{2}}$

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change of energy in a complete cycle. 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.

16.6 IMPEDANCE

1- **Introduction** :-

We know that resistance R offers opposition to the flow of current. In case of A.C. an inductance L or a capacitance C also offer opposition to the flow of A.C. which is measured by reactances X_L and X_C respectively. An A.C. circuit may consist of a resistance R, an inductance L, a capacitance C or a combination of these elements.

2- **Definition** :- The combined effect of resistance, reactances of inductor and capacitor in an A.C. circuit is known as Impedance.

It is denoted by Z.

3- **Formula** :- It is measured by the ratio of the rms value of the applied voltage to the rms value of resulting A.C.

$$Z = \frac{V_{rms}}{I_{rms}} = \frac{V_0/\sqrt{2}}{I_0/\sqrt{2}} = \frac{V_0}{I_0}$$

4- **Unit** :-

It is expressed in ohms.

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

Solution :-

rms value of applied voltage $= V = 10\,V$

rms value of Current $= I = 100\,mA = 100\times10^{-3}\,A$

Impedance $= Z = \frac{V}{I} = \frac{10\,V}{100\times10^{-3}\,A} = \underline{100\,\Omega}$

Answer

16.7 R-C AND R-L SERIES CIRCUITS

1- R-C SERIES CIRCUIT

(a). Definition :- It is a circuit inwhich resistance R and a capacitor C are connected in series with each other and also with an alternating voltage source.

(b). Explanation :-

Consider a series network of resistance R and a capacitor C excited by an alternating voltage as shown in fig.(a).

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

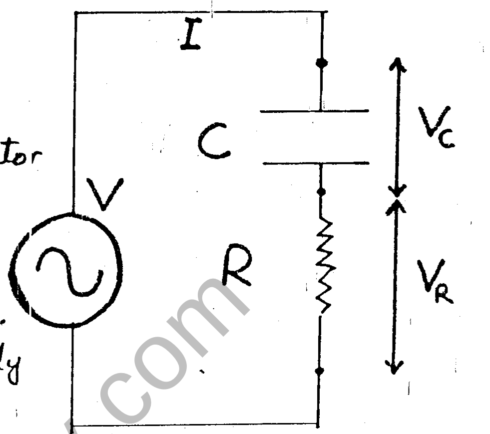


fig.(a)

If I is the value of current, the potential difference across resistance R would be IR and it would be in phase with current I.

Let X_c be the reactance of capacitor, the potential difference across capacitor C would be $V_c = IX_c$, and this voltage lags the current by a phase of 90°.

(c). Vector Diagram of the voltage and Current

The vector diagram of voltage and current is shown in fig.(b).

Taking current as a reference line, the potential difference across resistance $V_R = IR$ is represented along the current line because it is in phase with the current. The potential difference across capacitor $V_c = IX_c$ lags behind the current, so it is represented by a line at a right angle to the current line.

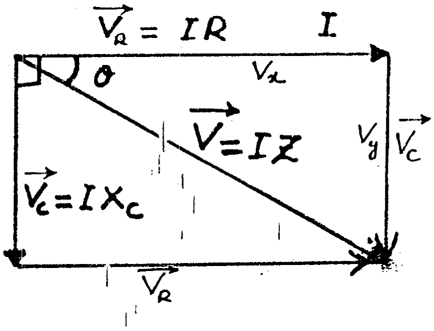


fig.(b)

(d). Applied Voltage

The applied voltage V that will send the current I through the circuit is obtained by the resultant of vectors $\vec{V_R}$ and $\vec{V_c}$. i.e $\vec{V} = \vec{V_R} + \vec{V_c} = V_R\hat{i} + V_c\hat{j}$

As from fig.(b) V_R is considered to be x- component

and V_c " " " " y- component.

then **Magnitude** is

$$V = \sqrt{V_x^2 + V_y^2} = \sqrt{V_R^2 + V_c^2}$$

$$V = \sqrt{(IR)^2 + (IX_c)^2} = \sqrt{(IR)^2 + (I/\omega C)^2}$$

$$\boxed{V = I\sqrt{R^2 + (1/\omega C)^2}} \quad \text{——— } ① \quad \left(\because X_c = \frac{1}{\omega C}\right)$$

Direction (Phase)

From fig.(b)

$$\tan\theta = \frac{V_y}{V_x} = \frac{I/\omega C}{IR}$$

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

It can be seen in fig (b) that the current and the applied voltage are not in phase. The current leads the voltage by an angle $\theta = \tan^{-1}(1/\omega CR)$.

(e). **Impedance**

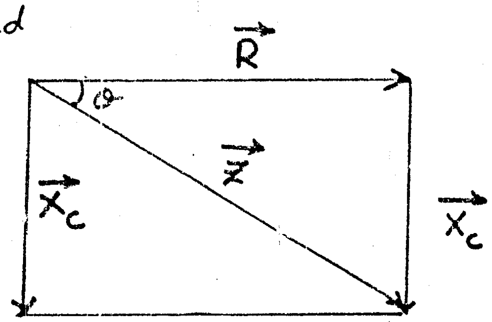
Impedance can be calculated from eq ① as

$$\text{Impedance} \quad \boxed{Z = \frac{V}{I} = \sqrt{R^2 + \left(\frac{1}{\omega C}\right)^2}} \quad \text{——— } ③$$

Equation ③ suggests that we can find the impedance of a series A.C. circuit by vector addition. It can be obtained by impedance diagram.

Impedance Diagram:-

The R resistance is represented by a horizontal line in the direction of current which is taken as reference. The reactance $X_c = \frac{1}{\omega C}$ is shown by a line lagging R



line by 90 as shown in fig(c). The impedance Z of the circuit is obtaind by vector summation of R and X_C i.e

$$\vec{Z} = \vec{R} + \vec{X_c} = R\hat{i} + X_c\hat{j}$$

The fig. (c) is known as Impedance diagram of the circuit. The magnitude of the impedance is

$$Z = \sqrt{R^2 + (X_c)^2} \qquad \left(|\vec{A}| = \sqrt{A_x^2 + A_y^2}\right)$$

$$Z = \sqrt{R^2 + \frac{1}{(\omega C)^2}} \qquad \left(\theta = \tan^{-1} A_y/A_x\right)$$

The angle which the line representing the impedance Z makes with R line gives the phase difference b/w the voltage and current. Fig. (c) shows that the current is leading the voltage across a capacitor by an angle

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

2. R - L Series Circuit

(a) Definition :- A circuit inwhich resistance R and an inductor L are connected in series with eachother and are excited by an alternating voltage is called R-L series circuit.

(b) Explanation :- Consider an inductor of inductance 'L', a resistor of resistance 'R' are connected in series and are excited by an A.C. source of frequency 'ω'.

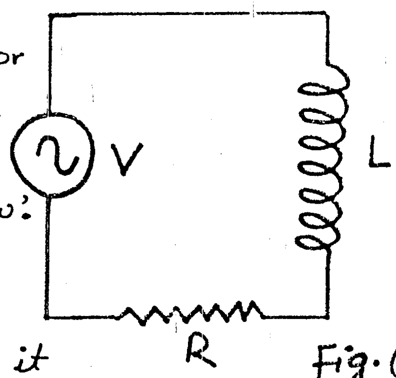


Fig. (a)

(i) Impedance Diagram

The current flowing through the circuit is taken as reference, so it is represented by a horizontal line. Resistance R is drawn along this line because the potential drop IR is in phase with current. As potential across the inductance $V_L = IX_L = I(\omega L)$ leads the current by 90°, so the vector line of

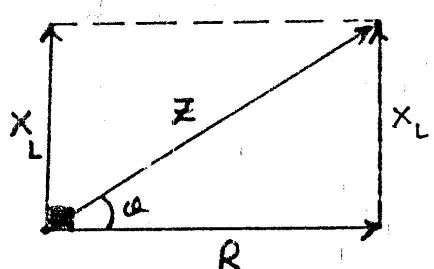


fig. (b)

reactance $X_L = \omega L$ is drawn at right angle to R line as shown in fig. (b).

(ii). **Impedance** The impedance of the circuit is obtained by the vector sum of R and X_L lines i-e

$$\vec{Z} = \vec{R} + \vec{X_L} = R\hat{i} + X_L\hat{j}$$

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

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

(iii) **Phase difference b/w voltage and current.**

As from fig.(b)

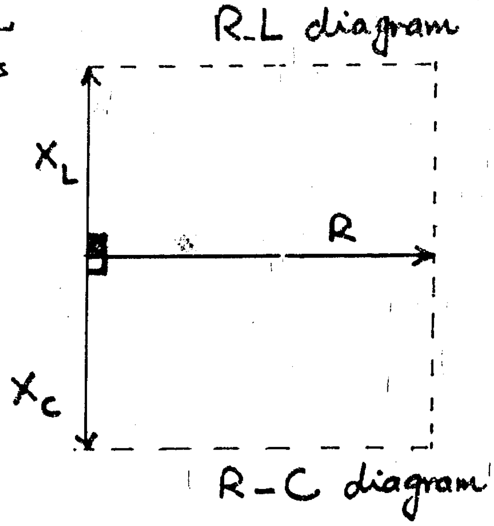
$$\tan\theta = \frac{X_L}{R} = \frac{\omega L}{R}$$

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

The angle 'θ' which Z makes with R-line gives the phase difference between voltage and current ($\because Z = \frac{V}{I}$). In this case the voltage across inductance leads the current by 90°.

★- **Comparision b/w impedance diagrams of R-C and R-L circuits.**

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



16.8 POWER IN A.C. Circuits

The expression for power 'P' is

$$P = VI$$

where V = applied voltage and

I = current flowing through the circuit.

1. For Resistive Circuit

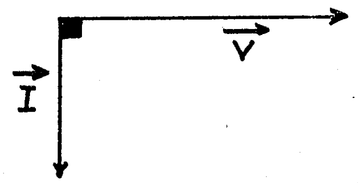
The above expression is true in case of A.C. circuits only when V and I are in phase as in case of a purely resistive circuit.

$\xrightarrow{\quad I \quad}$

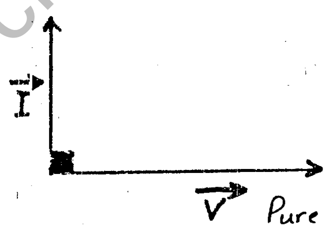
$\xrightarrow{\quad V \quad}$

2. For Pure Inductive or Pure Capacitance Circuit

We know that the power dissipation 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 $\vec{V}$ along the current vector $\vec{I}$ is zero. (i.e $V\cos\theta = 0$) $\because \theta = 90^\circ$



Pure Inductive Circuit



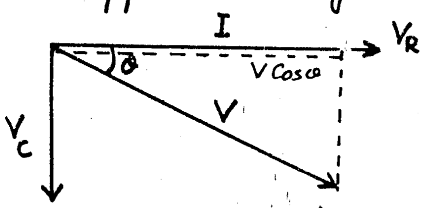
Pure Capacitance Circuit.

($\because$ Power dissipation $= 0$ because $V\cos 90^\circ = 0$

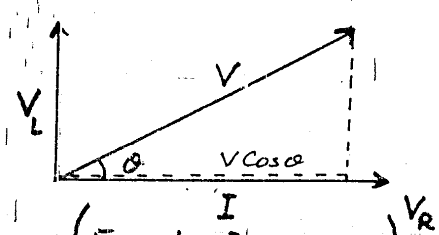
$P = IV\cos 90^\circ = 0$)

3. For R-C and L-R Circuits

In R-C and L-R A.C. circuits the phase difference between applied voltage V and the current I is 'θ'



(For R-C circuit)



(For L-R circuit)

The component of $\vec{V}$ along $\vec{I}$ is $V\cos\theta$.
Actually it is this component of voltage vector which is in phase with current.

Power Dissipated in A.C circuit is

$$\boxed{P = IV\cos\theta}$$

Power Factor The factor $\cos\theta$ is known as power factor.
Power factor for a resistive circuit is $\cos 0^\circ = 1$
Power factors for pure inductive and pure capacitance circuits are $\cos 90^\circ = \text{Zero}$.

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

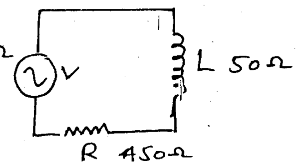
Solution :- $L = 1.0\,H$, $X_L = 500\,\Omega$

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

$\therefore$ $f = \dfrac{X_L}{2\pi L} = \dfrac{500\,\Omega}{2\times 3.14\times 1.0\,H} = 80\,Hz$ Answer.

Example 16.5 An iron core coil of 2.0 H and 50 Ω is placed 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 b/w the current and voltage.

Solution :-



Total Resistance of circuit $= 50\,\Omega + 450\,\Omega$
$R = 500\,\Omega$
Inductance $L = 2.0\,H$
applied voltage $V = 100$ Volts.
Frequency $f = 50\,Hz$.

(i). The reactance $= X_L = \omega L = 2\pi f L$
$= 2\times 3.14\times 50\,s^{-1}\times 2.0\,H$
$X_L = 628\,\Omega$

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

As $Z = \dfrac{V}{I} \Rightarrow$ Current $I = \dfrac{V}{Z} = \dfrac{100\,V}{803\,\Omega} = 0.01245\,A$
$= 12.45\,mA$ Answer

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

$$\theta = \tan^{-1}\left(\frac{628\,\Omega}{500\,\Omega}\right) = \underline{51.5^\circ} \text{ Answer.}$$

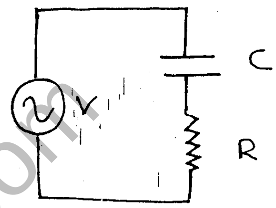
Example 16.6 A circuit consists of a capacitor of $2\mu F$ and a resistance of 1000Ω connected in series. An alternating voltage of 12 V and frequency 50 Hz is applied. Find (i) the current in the circuit and phase. (ii) the average power supplied.

Solution :-

Resistance $= R = 1000\,\Omega$

Capacitance $= C = 2\mu F = 2\times10^{-6} F$

Frequency $= f = 50\ Hz$.



(i)- Reactance $= X_c = \frac{1}{\omega C} = \frac{1}{2\pi f C}$

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

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

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

$$Z = 1880\,\Omega$$

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

$$= \frac{12\ V}{1880\,\Omega} = 0.0064\ A$$

$$\underline{I = 6.4\ mA} \text{ Answer}$$

phase difference $= \theta = \tan^{-1}\frac{X_c}{R} = \tan^{-1}\left(\frac{1592\,\Omega}{1000\,\Omega}\right)$

$$\theta = 57.87^\circ$$

(ii)- Average Power

$$P = VI\cos\theta$$

$$= 12\ V\times0.0064\ A\times\cos(57.87^\circ)$$

$$\underline{P = 0.04\ W}$$

RESONANCE :- A condition existing when an oscillatory electric circuit responds with maximum amplitude to an external signal of angular frequency ω.

RESONANCE CIRCUIT :- A circuit that contains both inductance and capacitance so arranged that the circuit is capable of RESONANCE, is called Resonance circuit.

16.9 SERIES RESONANCE CIRCUIT

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

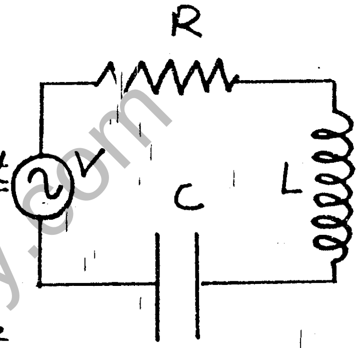


Fig.(a)

1- **Behaviour of circuit as R-C circuit**

The capacitor reactance is

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

When the frequency of A.C. source is very small then $X_c = \frac{1}{\omega C}$ is much larger than inductive reactance $X_L = \omega L$.
So the capacitance dominates at low frequency and the circuit behaves like an R-C circuit.

2. **Behaviour of circuit as R-L circuit**

The inductive reactance is

$$X_L = \omega L$$

When the frequency of A.C. source is very high then $X_L = \omega L$ is much larger than capacitance reactance $X_c = \frac{1}{\omega C}$. So in this case the inductance dominates and the circuit behaves like R-L circuit.

3. **FOR RESONANCE** (a)- Condition

In between low and high frequencies there will be a moderate frequency ω_r at which $X_L = X_c$.
This condition is called resonance.

As we know that, the inductive reactance X_L and capacitive reactance X_c are directed opposite to each other as shown in impedance diagram (Fig.b) (b). Impedance Diagram

Thus at resonance the inductive reactance being equal and opposite to capacitor reactance, cancel each other and the impedance diagram assumes the form fig. (c). i.e. $\vec{X_L} - \vec{X_c} = 0$

The impedance of circuit is

$$\therefore \; Z = R \quad \text{for resonance}$$

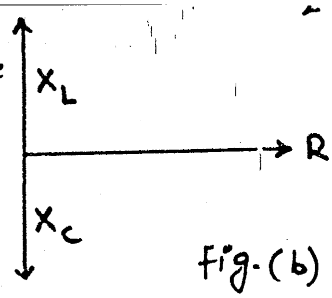


fig. (b)

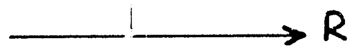


fig. (c)

(c). Resonance Frequency

(i). Definition:- The frequency at which resonance occurs in a particular circuit or network is called resonance frequency. It is denoted by f_r.

(ii). Expression

The resonance will occur under the condition

$$X_L = X_c$$

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

$$\omega_r^2 = \frac{1}{LC}$$

As

$$\omega_r = 2\pi f_r$$

Therefore

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

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

4. PROPERTIES :-

The following are the properties of the series resonance circuit.

(a) The resonance frequency is given by

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

(b) The impedance of the circuit is resistive so current and voltage are in phase.

The Power Factor $= V\cos\theta$

$= V\cos 0^\circ$

$= 1$

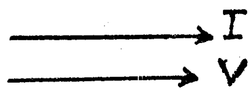


fig (d)

(c). The impedance of the circuit is minimum at resonance frequency (because X_L and X_C cancel out each other) and it is equal to R.

(d). If the peak value (amplitude) of source voltage V_o is kept constt., the current is maximum at the resonance frequency $\left(\because I = \frac{V_o}{Z} \Rightarrow I \propto \frac{1}{Z}\right.$ and Z is min. so I will be max.$\left.\right)$ and its value is

$$I_r = V_o/Z = V_o/R$$

The variation of current with the frequency is shown in fig.(e).

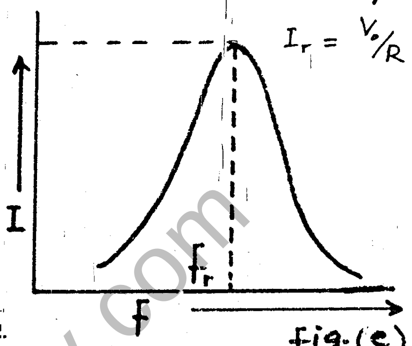
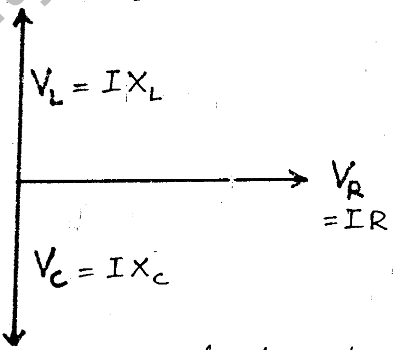


fig.(e)

(e). 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

Because

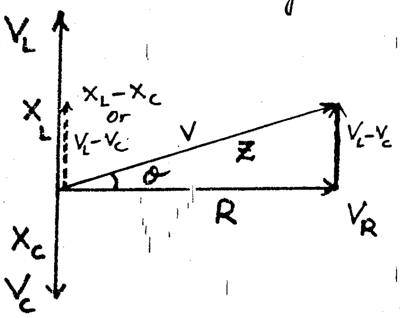
At resonance the combined impedance is purely resistive and is minimum. In this case the current flowing through the circuit will be high. Since current flowing is due to voltages developed across individual elements. Therefore large voltages are developed across the individual elements. Since V_L and V_C are out of phase with each other so that the total voltage developed across the circuit is relatively low.



NOTE $\left\{\begin{array}{l} \text{As } V = IZ = IR \Rightarrow I = V/R \text{ and } V_C = IX_C \\ V_C = \frac{V}{R}X_C = V\left(\frac{X_C}{R}\right) \because X_C > R \therefore V_C > V \\ \text{and } V_C = V_L \text{ so } V_L > V \end{array}\right\}$

In general

RLC-Series circuit, the impedance diagram is shown which gives circuit impedance and applied voltage as:



$$\vec{Z} = \vec{R} + (\vec{X_L} - \vec{X_C})$$
$$= R\hat{i} + (X_L - X_C)\hat{j}$$

And $Z = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}$

applied voltage $V = \sqrt{(V_R)^2 + (V_L - V_C)^2} = \sqrt{(IR)^2 + (IX_L - IX_C)^2}$

16.10 PARALLEL RESONANCE CIRCUIT:

Consider a LC circuit in which L and C are connected in parallel to each other as shown in figure (a). It is excited by an alternating source of voltage whose frequency could be varied.

The inductance coil L has a negligibly small resistance R_L. The capacitor draws a leading current where as the coil draws a lagging current (as from artical a.c. through capacitor and inductor).

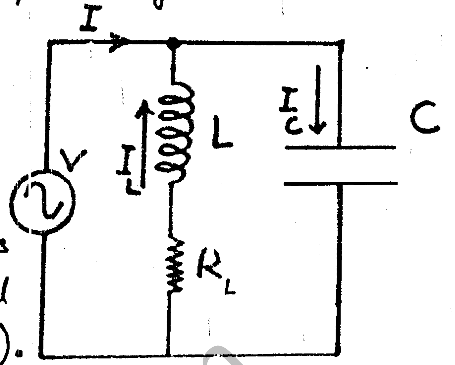


Fig (a)

1- For Resonance

The circuit resonates at a frequency $\omega = \omega_r$ which makes $X_L = X_C$, so that two branch currents i.e through capacitor and through inductor are equal but opposite. Hence they cancel out with the result that the current drawn from supply is zero. But in actual practice, the current is not zero, has a minimum value due to small resistance 'R' of the coil.

Resonance frequency f_r is calculated by $X_L = X_C$

2- Properties

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

(b)- At resonance frequency, the circuit impedance is maximum. It is resistive and its value is given L/CR_L. Because the source current through the circuit is very small at resonance condition

$$Z = \frac{V}{I} \Rightarrow Z \propto \frac{1}{I}$$

(c) At the resonance the current is minimum and it is in phase with the applied voltage.

The Power Factor $= V\cos 0^\circ = 1$.

The variation of current with the source is shown in Fig.(b).

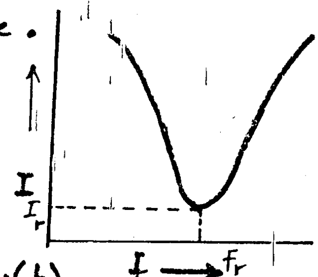


Fig.(b)

(d)- At resonance, the branch current I_L and I_C may each be larger than the source current I_r.

Because :- At resonance the circuit impedance is high, the overall current is low but the voltage developed across the parallel circuit is high. The individual currents developed in the inductance I_L and capacitance I_C at resonance can be very large but are out of phase with each other, resulting in low combined current. As $Z = \frac{L}{CR}$ and $V = IZ \Rightarrow V = I\frac{L}{CR}$

Now $I_C = \frac{V}{X_C} = \frac{IL}{CR} \times \omega C = I\frac{L\omega}{R}$ Since $\frac{\omega L}{R} > 1 \therefore I_C > I$

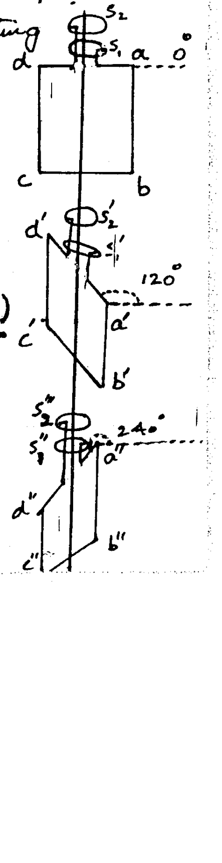
and $I_C = I_L$ So $I_L > I$

NOTE L-C circuit as an electrical oscillator

Electrical oscillator is a device in which electrical charges (electrons) can move to and fro repeatedly with a certain frequency or in which energy oscillates between capacitor and inductor.

When capacitor is charged by applied source, the electrons are given to one plate of C. The work done in charging the capacitor will be stored as energy $(\frac{1}{2}CV^2)$. As capacitor is charged electrons flow along the wire as electronic current. When capacitor discharges, maximum current will now be flowing in the circuit and original energy will be stored in the form of magnetic field of inductor $(\frac{1}{2}LI^2)$. The self inductance of the coil will oppose the growth of current at first and afterwards will oppose its decay so that the electrons will accummulate on other plate. The energy will be restored in the capacitor. So energy is oscillating b/w C and L.

16.11 THREE PHASE A.C. SUPPLY



As we know that an A.C. generator consists of a coil with a pair of slip rings. As the coil rotates an alternating voltage is generated across the slip rings. 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. 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°. It means that when voltage across the first pair of slip ring 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°.

These alternating voltages are shown in fig (b).

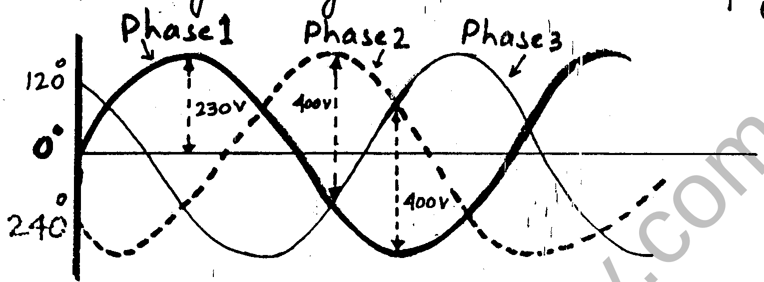


fig (b).

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 coil 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 (c).

The voltage across each of the 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 as shown in fig(b).

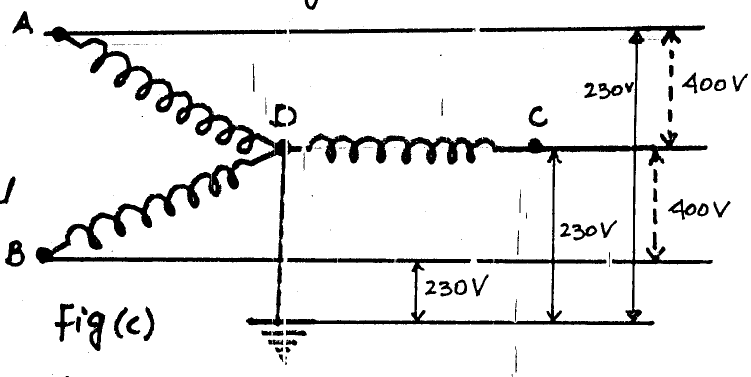


fig (c)

Advantages

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

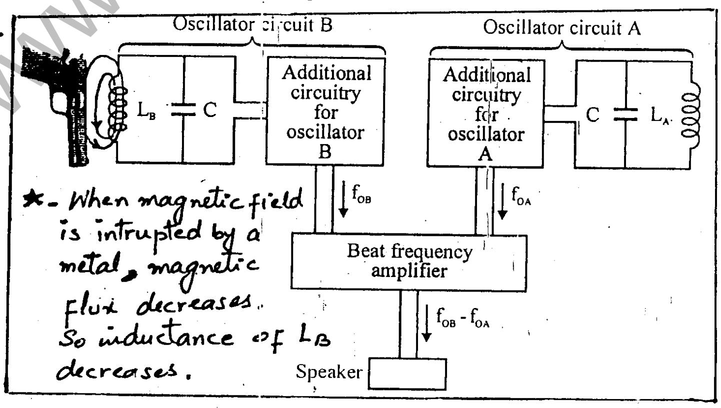
2. The three phase supply also provides 400 V which can be used to operate some special appliances requiring 400 V for their operation.

16.12 PRINCIPLE OF METAL DETECTORS

1- **Electrical Oscillator**:- A coil and a capacitor are electrical components which together can produce oscillations of current. 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.

2- **Metal Detector**:- Two electrical oscillators A and B are used for the operation of common type of metal detector as shown in its principle diagram.

Working Principle:- 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 circuit is the same.



★- When magnetic field is intrupted by a metal, magnetic flux decreases. So inductance of L_B decreases.

When the inductor B called the search coil comes near a metal object, its inductance L_B decreases★ ($\because N\phi_m = LI \Rightarrow L \propto \phi_m$) and corresponding oscillatory frequency increases ($f_B = \frac{1}{2\pi\sqrt{L_B C}}$) and thus a beat note is heared in the attached speaker.

Uses:- (a)- Such detectors are extensively used for various security checks.

(b)- To locate buried metal objects.

16.13 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. This makes the inductance L of the coil quite large where as its resistance R is very small. Thus it consumes extremely small power.

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

16.14 ELECTROMAGNETIC WAVES

1. **Introduction**:- In 1864 British physicist James Clark Maxwell formulated a set of equations known as Maxwell's equations which explained the various electromagnetic phenomena. According to these equations, a changing magnetic flux creates an electric field and a changing electric flux creates a magnetic field.

(These equations are given as
$$E = \frac{1}{2\pi r}\frac{\Delta\phi_m}{\Delta t} \quad \text{and} \quad B = \frac{\mu_0}{2\pi d}\varepsilon_0\frac{\Delta\phi_e}{\Delta t}).$$

2. **Definition**:- A package of changing electric and magnetic fields induced due to charge oscillation, which travel perpendicular to each other in the form of wave with velocity of light is called electromagnetic waves.

3. **Explanation**:- Consider a region of space as shown in fig (a). Suppose a change of magnetic flux is taken place through it. This changing magnetic flux will set up a changing electric flux in the surrounding region. The creation of electric field in the region CD will cause a change of electric flux

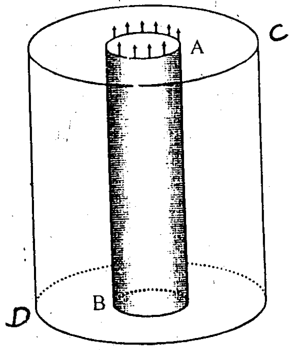


fig (a)

through it due to which a magnetic field would be set up in 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.
The electric field, magnetic field and the direction of their propagation are mutually orthogonal as shown in fig.(b).

It can be seen in this figure that the electromagnetic waves are periodic, hence they have a wave length λ which is given by the relation

$$c = f\lambda$$

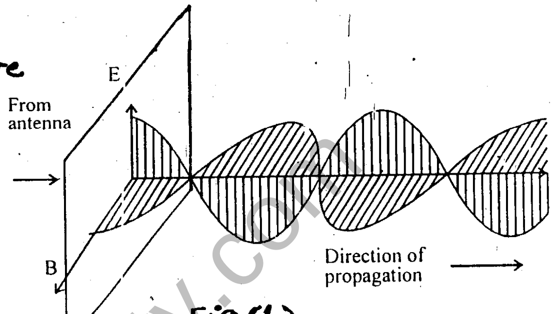


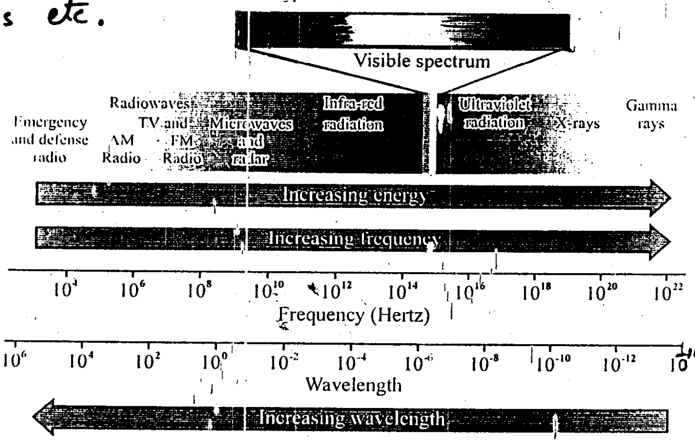
Fig.(b)

where 'f' is the frequency and c is the speed of the wave. In free space the speed of electromagnetic waves is $3 \times 10^{8} m s^{-1}$.

4- Types of em waves

Depending upon the values of wave length and frequency, the electromagnetic waves have been classified into different types of waves as radiowaves, microwaves, infrared rays, visible light, ultraviolet radiations, X-rays and γ-rays etc.

The figure (c) shows the complete spectrum of electromagnetic waves from low radio waves (in which energy of photon is only about 10^{-10} eV.) to high frequency gamma rays (in which energy of photon is about 1 Mev)



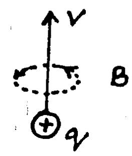
The Electromagnetic spectrum

Fig(c).

16.15 PRINCIPLE OF GENERATION, TRANSMISSION AND RECEPTION OF ELECTROMAGNETIC WAVES

1- Introduction :- As we know that electromagnetic waves are generated when electric or magnetic flux is changing through a certain region of space. 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 surrounding space, but such a field also does not radiate out, because no changes of magnetic flux are involved.

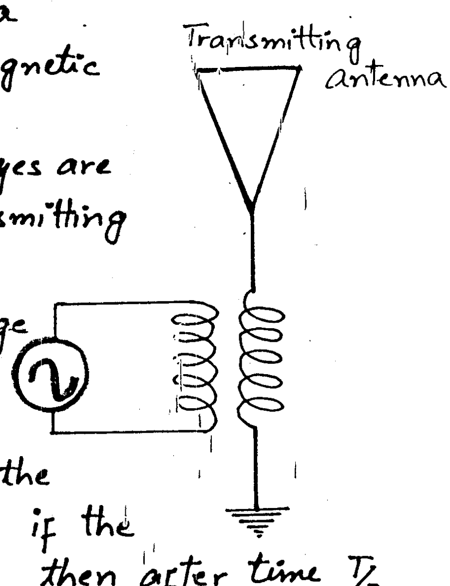


2- Principle of Generation The only chance to generate a wave by changing electrical and magnetic fields is when an electrical charge is accelerated through its oscillation. So this oscillatory charge will radiate a package of electrical and magnetic energies in the form of wave which is known as electromagnetic waves.

3- Generation and Transmission of em waves

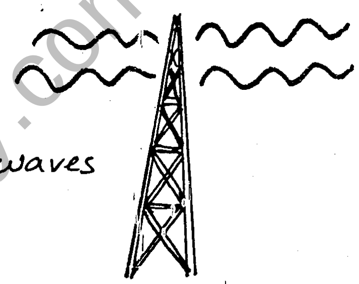
A radio transmitting antenna provides a good example of generating electromagnetic waves by acceleration of charges.

The piece of wire along which charges are made to accelerate is known as transmitting antenna as shown in figure.



It is charged by an alternating voltage source of frequency 'f' and time period 'T'. As the charging potential alternates, the charge on the antenna also reverses. For example if the top has $+q$ charge at any instant, then after time $T/2$ the charge on top will be $-q$. Such regular reversal

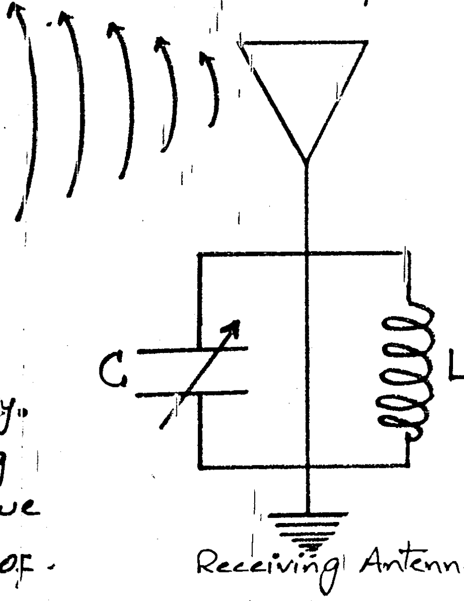
of charges on the antenna gives rise to an electric flux that constantly changes with frequency f. This changing electric flux sets up changing magnetic field, finally both the fields set up electromagnetic waves which propagates out in space away from the antenna.
The frequency with which the fields alternate is always equal to the frequency of the source generating them. These electromagnetic waves which are propagated out in space from antenna of Transmitter are known as radio waves. Since energy carrier in these waves are photons so in free space these waves travel with the speed of light.



For Example When electrons in the transmitting antenna vibrates 94,000 times per second, they produce radio waves having frequency 94 k Hz.

4- Reception of e m waves:-

Suppose the radio waves are intercepted by receiving antenna. The electrons in the wire of receiving antenna move under the action of the oscillating electric field which gives rise to an alternating voltage across the wire. The frequency of this voltage is the same as that of the wave intercepting the wire.



Receiving Antenna

As the electric field of the wave is very weak at a distance of many kilometres from transmitter, the voltage that appear across the receiving antenna is very small. Each transmitter propagates radio waves of one particular frequency. So when a number of transmitting stations operate simultaneously, we have a number of radio waves of different frequencies in space.

Thus the voltage that appears across a receiving antenna placed in space is usually due to the radio waves of large number of frequencies. The voltage of one particular frequency can be picked up by connecting an inductance L and a variable capacitor C in parallel with one end of the receiving antenna as shown in figure above.

Adjustment of frequency for required signal

In order to pick the required signal, the capacitance of the capacitor $\left(C = \frac{A\varepsilon_o\varepsilon_r}{d} \Rightarrow C \propto A\right)$ is so adjusted that the natural frequency $\left(f = \frac{1}{2\pi\sqrt{LC}} \Rightarrow f \propto \frac{1}{\sqrt{C}}\right)$ of LC circuit is the same as that of the required Transmitting station. At this frequency 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.

16.16 MODULATION

1- **Introduction**:- High frequency radio waves are used to carry speech or music signals (sound waves) of low frequency and the scene infront of a television camera to many kilometres away to viewers.
The informations i-e light, sound or other data is impressed on the radio wave and is carried along with it to the destination with velocity of light.

2- **Definition**:- Modulation is the process of combining the low frequency signal with a high frequency radio wave called carrier wave. The resultant wave is called modulated carrier wave.
The low frequency signal is known as modulation signal.

3- **Types**:- Modulation is achieved by changing the amplitude or the frequency of the carrier wave in accordance with the modulating signal.

Thus there are two types of modulations.

(a)- Amplitude Modulation (A.M)

(b)- Frequency Modulation (F.M)

(a). Amplitude Modulation :-

(i) **Def.** In this type of modulation the amplitude of the carrier wave is increased or decreased as the amplitude of the superposing modulating signal increases and decreases.

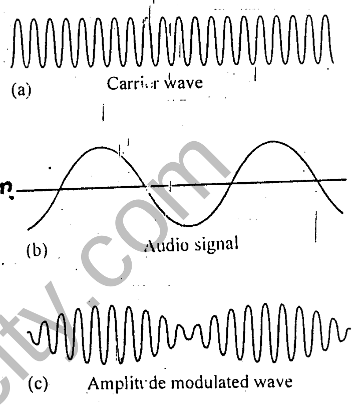
(ii) **Explanation**

Figure (a) represents a high frequency carrier wave of constant amplitude and frequency.

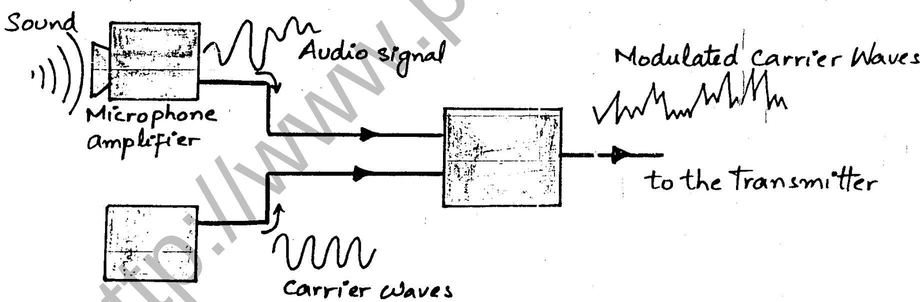
Figure (b) represents a low audio frequency signal of a sine waveform.

Figure (c) shows the result obtained by modulating the carrier wave with the modulating wave.

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


(a) Carrier wave
(b) Audio signal
(c) Amplitude modulated wave

(iii) **Schematic Diagram**

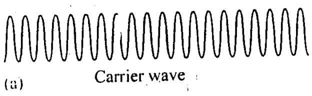


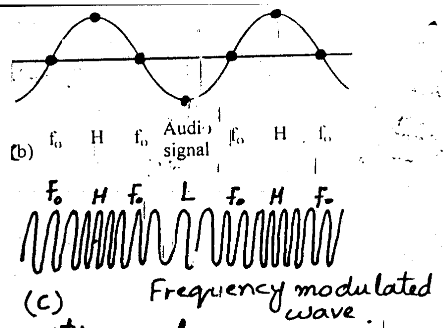
(b). Frequency Modulation

(i)- **Def:-** In this type of modulation the frequency of the carrier wave is increased or decreased as the modulating signal amplitude increases or decreases but the carrier wave amplitude remains constant.

(ii)- **Explanation :-**

Figure (a) shows a high frequency carrier wave of constant amplitude and frequency.


(a) Carrier wave



The figure (b) represents low audio frequency signal.
Figure (c) 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 value. When the signal amplitude is zero, the carrier frequency is at its normal frequency F_0.

Comparision between A.M and F.M

Amplitude Modulation	Frequency Modulation
1- In it amplitude amplitude of carrier wave is varied but frequency is kept constt.	1- In it frequency of carrier wave is varied but amplitude is kept constant.
2- The A.M. transmission frequencie range from 540 kHz to 1600 kHz.	2- The F.M. Transmission frequenck are much higher and ranges between 88 MHz to 108 MHz.
3- A.M. waves are affected greater by electrical interference than F.M. radio waves. So it provide a low quality Transmission of sound than F.M. waves.	3. F.M. radio waves are affected less by electrical interference than A.M. radio waves. So it provide a higher quality transmission of sound.
4- A.M. radio waves have greater range than F.M. waves and are easily able to travel around obstacles such as hills and large buildings	4- F.M. radio waves have a shorter range than A.M. waves and are less able to travel around obstacles.
5- Due to electrical interference it has greater signal-to-noise ratio	5- F.M. radio waves have improved signal-to-noise ratio