UNIT-1

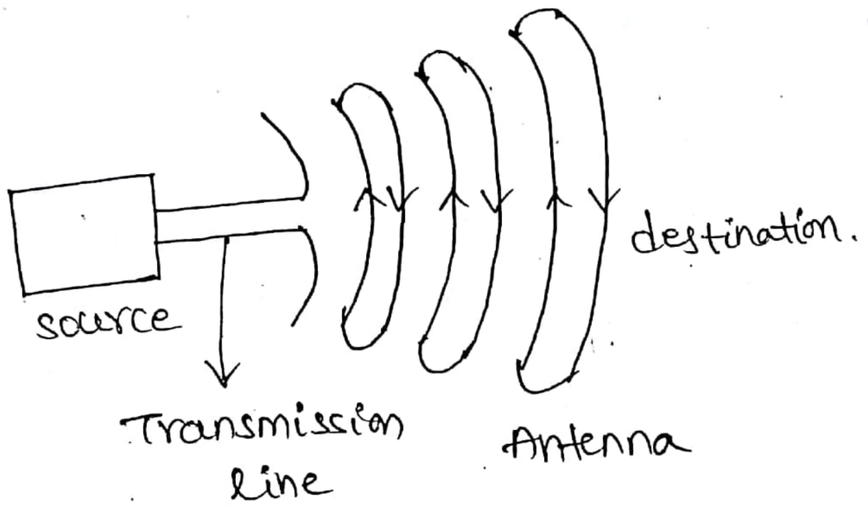
ANTENNA FUNDAMENTALS

Antenna:- An Antenna is a metallic device which converts electrical signals to electromagnetic waves and electro magnetic waves to electrical signals.

→ An Antenna is in the form of a wire (or) rod which can be used as both Transmitting antenna and receiving antenna.

→ The first radio antenna was discovered by "Henrich hertz" in 1886.

Ex:- Transmitting antenna, Receiving antenna, Cellsite antenna mobile antenna, Radio antenna.



Antenna Functions :-

1. Antenna acts as a Transducer
2. Antenna acts as an impedance matching device between Transmission and freespace.
3. It acts as a coupling device.
4. The antenna acts as a remote sensing, temperature measuring device.

properties of Antenna :-

The antenna properties are applicable for Both Transmitting antenna. and Receiving. antenna.

1. Equality of Impedances.
2. equality of effective lengths
3. Equality of directional patterns.

Antenna elements :-

1. Hertzian dipole (current element)
2. short dipole
3. short monopole
4. Halfwave dipole
5. quarter wave monopole

1. Hertzian dipole :- It is a basic linear antenna whose current distribution is constant. This is also called as "current element".

2. Short Dipole :- It is a basic linear antenna with a length is less than $\frac{\lambda}{4}$. The current distribution is triangular

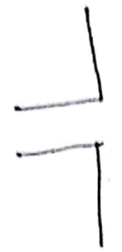
3. short monopole :- It is a basic linear antenna with a length is less than $\frac{\lambda}{8}$. The current distribution is Triangular.

4. Half wave dipole :- It is a linear antenna, with a length is equal to $\frac{\lambda}{2}$. The current distribution is sinusoidal.

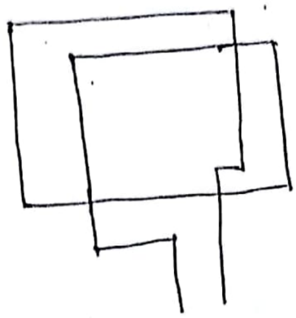
5. quarter wave monopole :- It is a linear antenna, with a length is equal to $\frac{\lambda}{4}$. The current distribution is sinusoidal.

ypes of Antennas :-

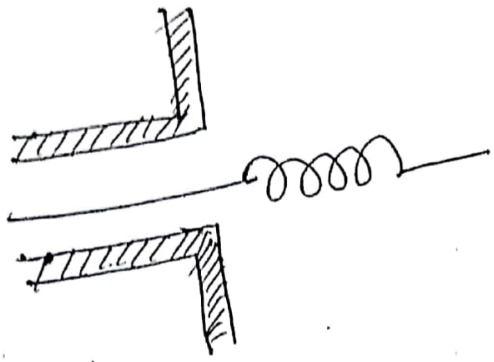
(i) dipole antenna



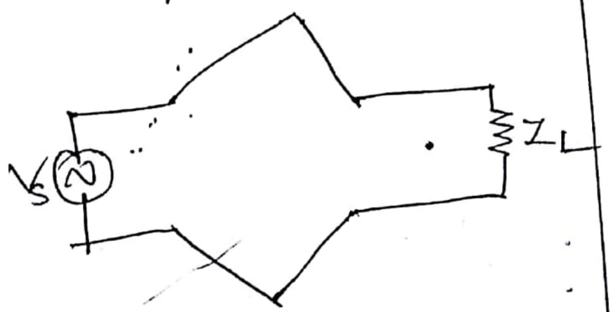
(ii) Loop antenna



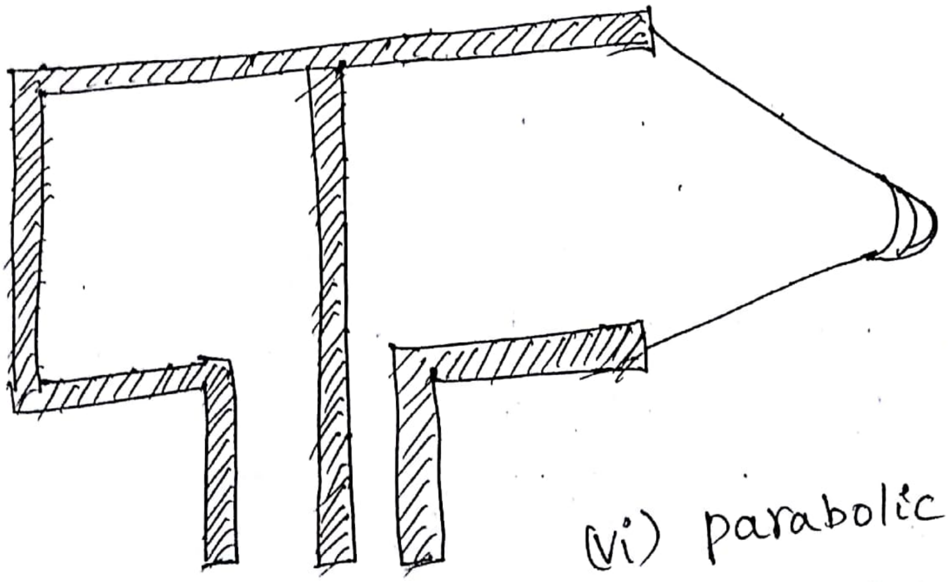
(iii) Helical antenna



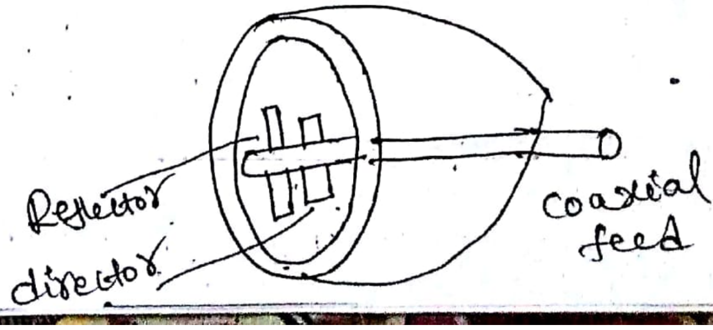
(iv) Rhombic antenna



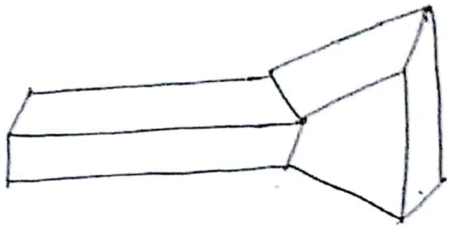
(V) dielectric antenna



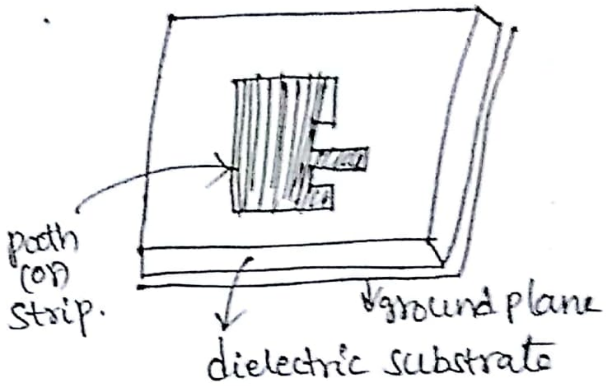
(Vi) parabolic antenna



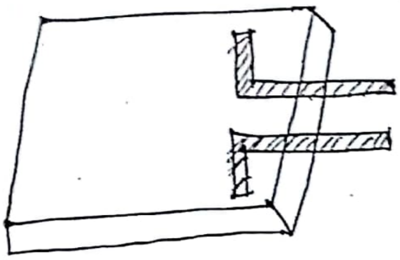
(vii) Horn antenna.



(viii) micro strip antenna



(ix) co planar antenna

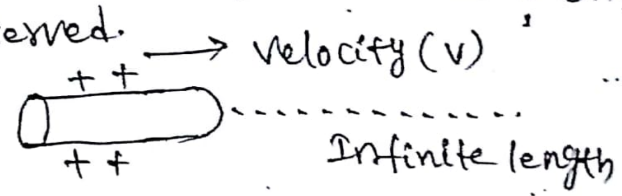


Radiation mechanism :-

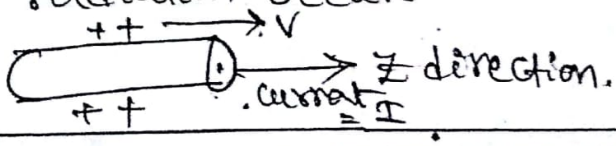
Radiation mechanism is the process of transmitting energy. The radiation occurs due to a source of electric charge.

(a) If a charge is static charge, then there was no current generated. ∴ No radiation will be takes place

(b) If a charge is moving with a uniform velocity along the infinite length wire then only no radiation will be observed.



(c) When a pulse of charge is moving with a uniform velocity along a straight conductor in the z-direction. so the radiation occurs.



(∵ pulse of charge means finite length of charge)

Let us consider a charge per unit length is $\frac{q}{l}$ coulomb/m

The momentary current is $I = \frac{q}{l} \cdot \frac{dz}{dt} \rightarrow ①$

Where $\frac{dz}{dt}$ is velocity 'V'

$\therefore I = \frac{q}{l} \cdot V \rightarrow ②$

$\therefore I \cdot l = qV \rightarrow ③$

differentiate eq ③ w.r.t 't' on both sides

$l \frac{dI}{dt} = q \frac{dv}{dt}$

($\because$ Acceleration $a = \frac{dv}{dt} = \frac{d}{dt}\left(\frac{dz}{dt}\right)$

$a = \frac{d^2z}{dt^2}$)

$\Rightarrow \boxed{l \frac{dI}{dt} = qa}$

(OR)

$\boxed{l \frac{dI}{dt} = q \frac{d^2z}{dt^2}}$

(or)

$\boxed{\frac{dI}{dt} = \frac{qa}{l}}$

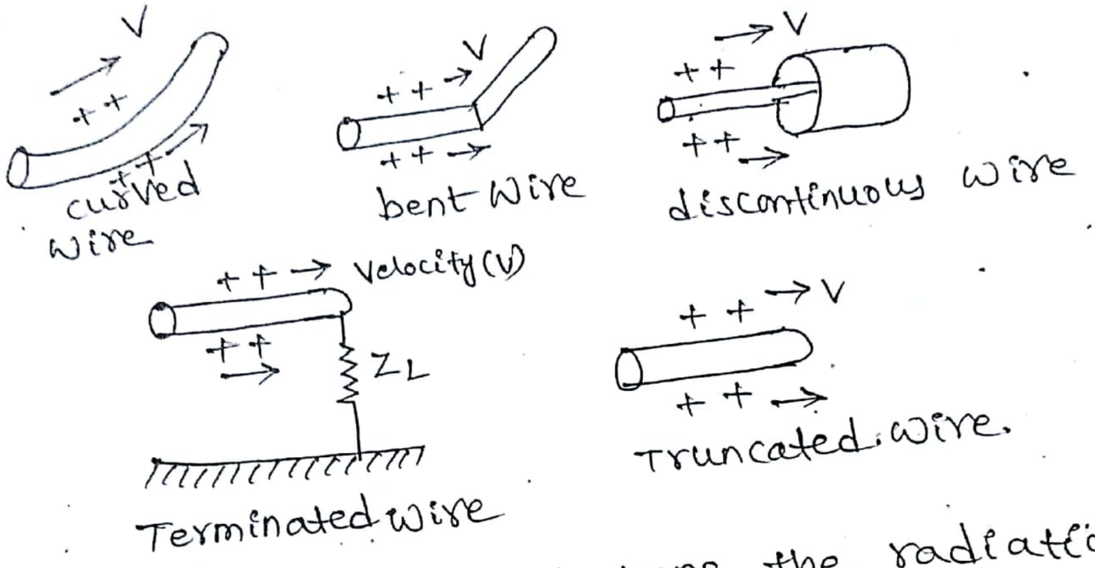
This equation represents a fundamental electro-magnetic radiation, that gives relationship between charge and current.

Radiation Mechanism for single Wire:-

→ If a charge is stationary then there was no current will be generated. No radiation is occurs.

→ If a charge is moving with a uniform velocity along an Infinite length wire then only No radiation will be observed.

→ The radiation occurs only when a wire is curved, bent, discontinuous, terminated, truncated.



→ Due to the force of electrons the radiation is ~~pattern~~ Increased.

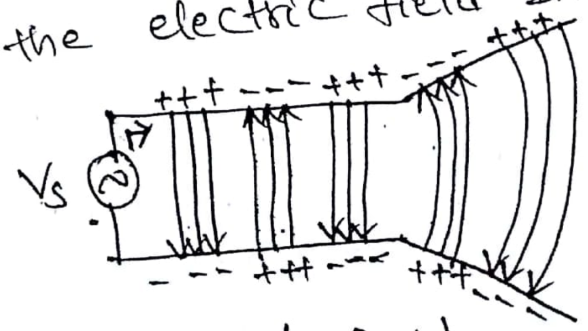
→ At the source end the Velocity is increased, at the destination end, Velocity is decreases.

→ Finally we conclude that the radiation is accelerated at source end and de-accelerated at destination end.

Radiation Mechanism for Two Wires :-

› When a Voltage source is applied, the electric field can be produced between two conductors (or) wires.

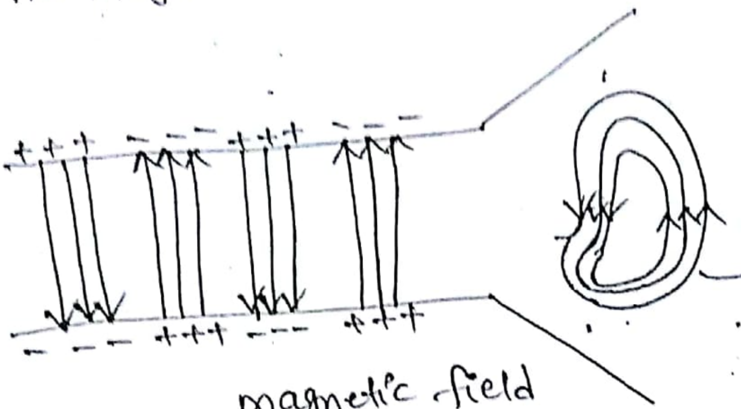
› The electric lines of force is parallel to the electric field that means the electric flux is directly proportional to the electric field Intensity



electric field

→ Due to the movement of charge carriers, the current will be produced, this current will generate a magnetic lines of force.

∴ The magnetic field forms the closed loops.

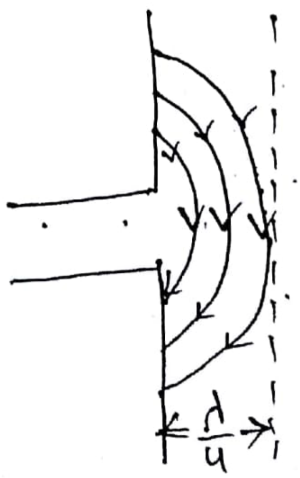


magnetic field

→ The electric lines travelling from positive charge carriers to Negative charge carriers. While the magnetic lines form a closed loop.

Radiation Mechanism for dipoles:-

Consider a small dipole is center in the first quarter period of time. (ie) $t = \frac{T}{4}$, at this time the charge gets a maximum value. Assume that the three electric lines, these lines are radially outwards at distance of $\frac{\lambda}{4}$.

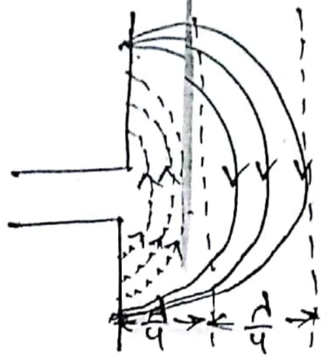


(a) at $t = \frac{T}{4}$

→ In the next qter period of time ($t = \frac{T}{4}$) the three electric es are produced at a distance of $\frac{d}{4}$. so the opp^te charge lines are produced.

∴ The total me period is $t = \frac{T}{2}$, and total distance is $\frac{d}{2}$ ($\frac{d}{4}+\frac{d}{4}$) ... ... ($\because t = \frac{T}{4}+\frac{T}{4}$)

→ Due to the opsite charges, the charge density on the conductor is Zero. ∴ The charge is Neutral.

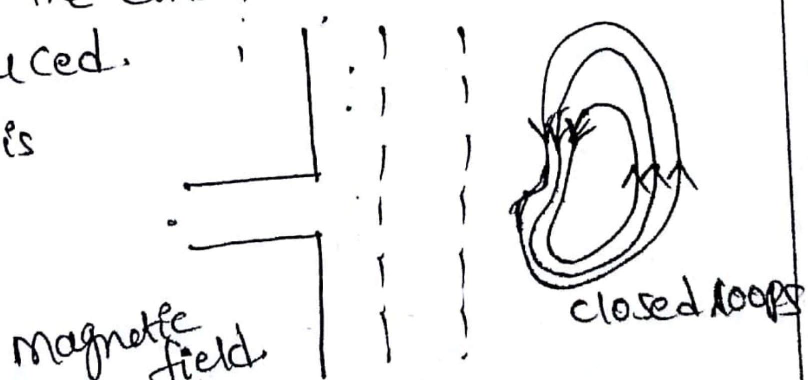


(b) at $t = \frac{T}{2}$ (ie first quarter and second quarter period $t = \frac{T}{4}+\frac{T}{4} = \frac{T}{2}$)

→ finally We ~~Conclu~~ conclude that the three electric lines are outward direction during the first quarter period of time, while the other three electric lines are in inward direction during second quarter period of time.

→ By Applying external force, these opposite charge lines are seperated by the conductor then the closed loops are produced.

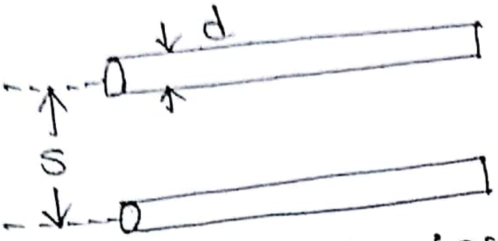
∴ The magnetic field is observed



Current distribution on thin linear wire antenna :- (5)

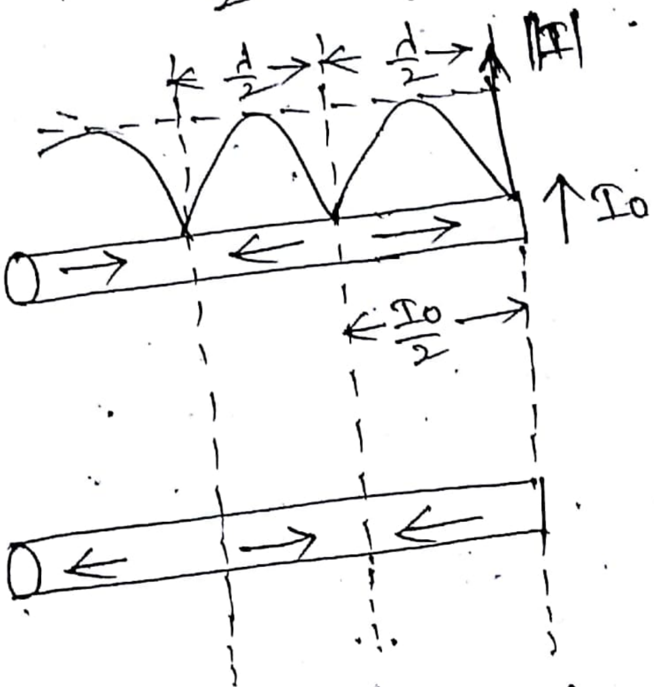
(i) For a two wire lossless Transmission line :-

Let us consider a two wire lossless Transmission line with the distance of seperation is 's' and diameter is 'd'.



(a) Two Wire Lossless Transmission line

When a free electrons are moving on the each conductor the travelling wave current is generated along each conductor. The magnitude of incident wave current is $\frac{I_0}{2}$.



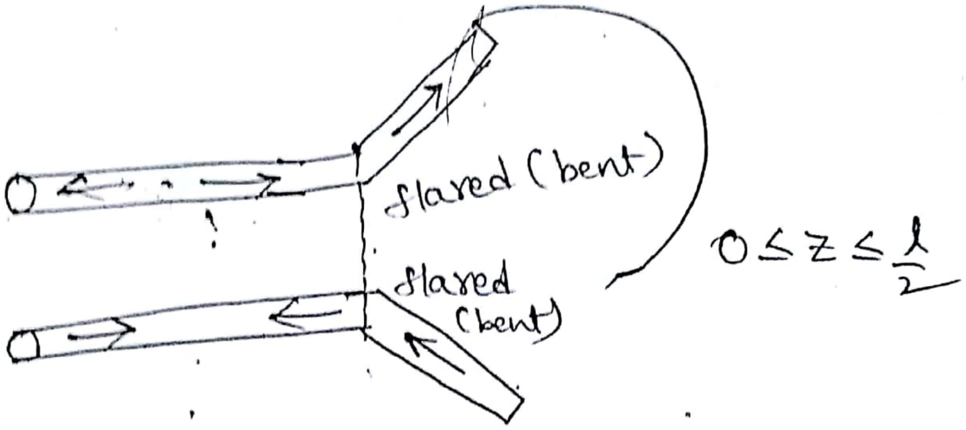
(b) Current distribution for a two wire Transmission line.

→ At the end of each conductor the current will be reflected completely. The magnitude of this reflected current is also $\frac{I_0}{2}$ and phase shift is 180°

> When this reflected current is combined with a incident current, the standing wave pattern generated.
> In the adjcent half cycle the time period is varying. Also the current is varying.
∴ The radiation will be observed along each conductor.

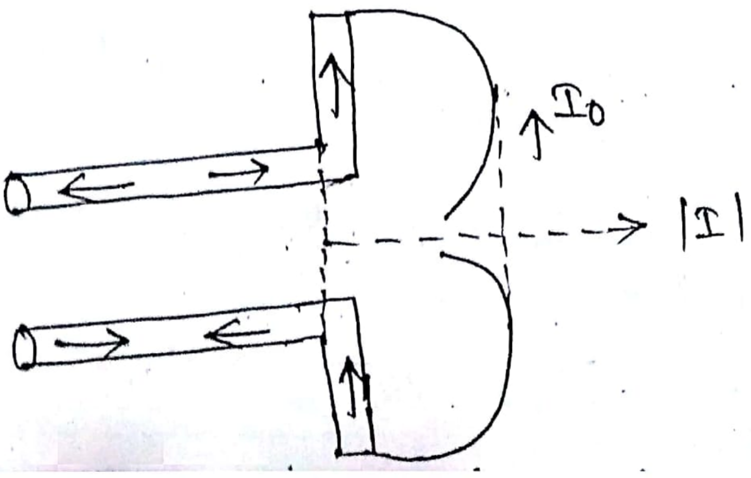
(ii) For a Flared Transmission Line :-

If both the conductors between $0 \leq z \leq \frac{\lambda}{2}$ are bended (flared) then the current distribution will be no changes. (i.e) current distribution is same as in the first case. ∴ The radiation will be takes place.



(iii) For a Linear dipole :-

When a flared Transmission line is again bending, the linear dipole will be generated, this is called as dipole Antenna. dipole antenna also called as "Standing wave Antenna".



Isotropic Radiator (or) Hypothetical (or) fictitious radiator

→ Isotropic radiator is a radiator which radiates the energy in all directions uniformly. It can be used as reference antenna because the practical antenna can't radiate in all directions.

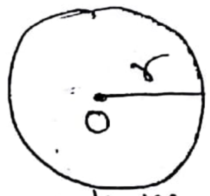
∴ Isotropic radiator is also used as Ideal Antenna.

→ Isotropic Radiator also called as hypothetical (or) fictitious radiator.

→ Consider an Isotropic radiator (Antenna) placed at the center of sphere with radius 'r'.

Let $\bar{P}$ be the poynting vector gives average power density

$$\therefore |\bar{P}| = P_r \rightarrow ①$$



sphere
o = point source
r = radius.

The total power radiated is

$$P_{rad} = \iint |\bar{P}| \cdot d\bar{s} \qquad (\because |\bar{P}| = P_r)$$

$$\Rightarrow P_{rad} = \iint P_r \cdot d\bar{s} \rightarrow ②$$

where $P_r = P_{avg}$ = average power density

$$\therefore P_{rad} = \iint P_{avg}\, d\bar{s}$$

$$= P_{avg} \iint d\bar{s} \qquad (\because \iint d\bar{s} = \text{surface area of sphere} = 4\pi r^2)$$

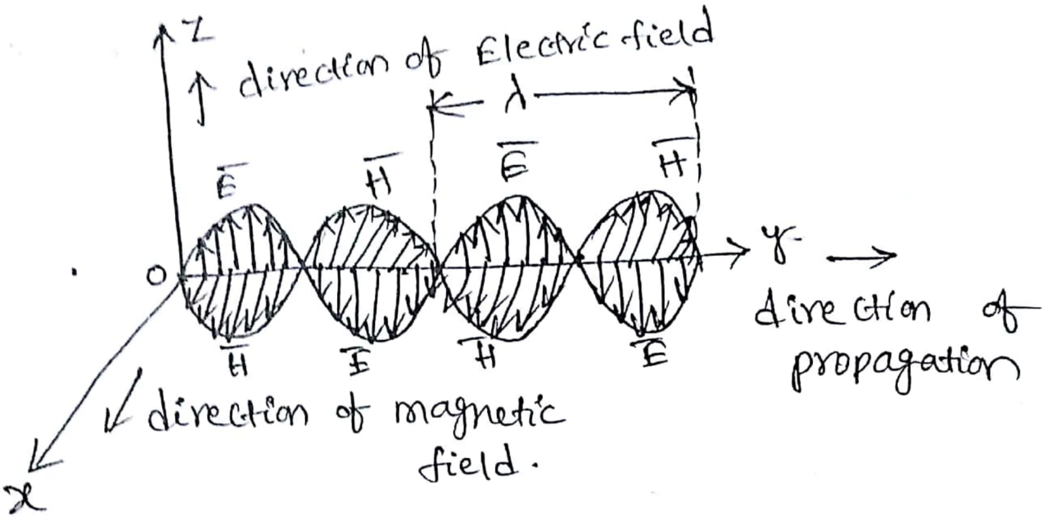
$$P_{rad} = P_{avg} \cdot 4\pi r^2$$

$$\therefore \boxed{P_{avg} = \frac{P_{rad}}{4\pi r^2}} \text{ Watts}/m^2$$

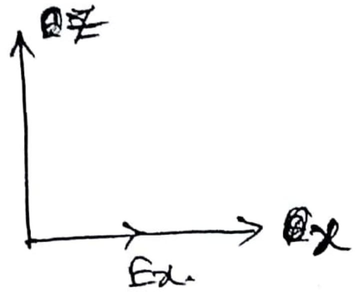
Polarization :- It is defined as to estimate the time varying behavior of the electric field strength.

(or)

The electric field is aligned with the one complete full cycle. There are three types of polarization.

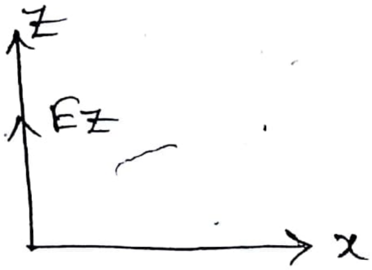


1. Linear polarization :- It is defined as the electro magnetic waves located in the complete space (or) total space.



Ex present
Ez Absent (zero)

(a) Horizontal polarization.



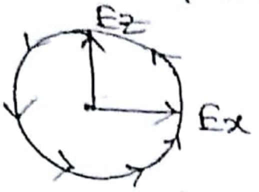
Ex Absent (zero)
Ez present

(b) Vertical polarization.

2. Circular polarization :-

Two linear polarized waves having equal magnitudes and 90° phase shift then the wave is circularly polarized. (ie) $\boxed{E_x^2 + E_z^2 = E_a^2}$ (or) $\frac{E_x^2}{E_a^2} + \frac{E_z^2}{E_a^2} = 1$

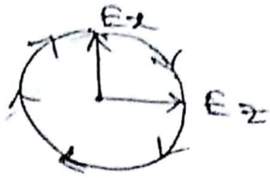
Left circular polarization.



E_z leads E_x by $90°$

($\phi = 90°$)

Right circular polarization



E_z lags E_x by $90°$

($\phi = -90°$)

(3) Elliptical polarization :- Two linear polarized waves having different magnitudes and $90°$ phase shift then the wave is said to be "elliptically polarized".

(ie) $$\boxed{\frac{E_x^2}{E_a^2} + \frac{E_z^2}{E_b^2} = 1}$$

Left elliptical polarization

Right elliptical polarization.

ANTENNA PARAMETERS

An Antenna is a basic element of communication system. It provides link between Transmitter to free space and free space to Receiver.

1. Radiation pattern
   (a) field radiation pattern
   (b) power radiation pattern.
2. Beam Width
3. Beam Area
4. Radiation Intensity
5. Directivity (or) maximum directive gain.

6. Power gain
7. Antenna Band width.
8. Beam efficiency
9. Antenna Aperture (effective area)
10. Effective length (effective height)
11. Antenna Temperature
12. Radiation efficiency.

<u>Radiation pattern</u> :- The radiation from Antenna can be measured in any direction interms of field strength.

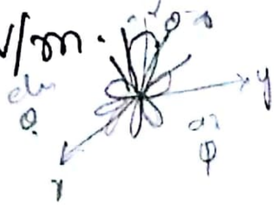
→ The field strength can be calculated by measuring voltages at two points on an electrical lines of force and then dividing by distance between two points.

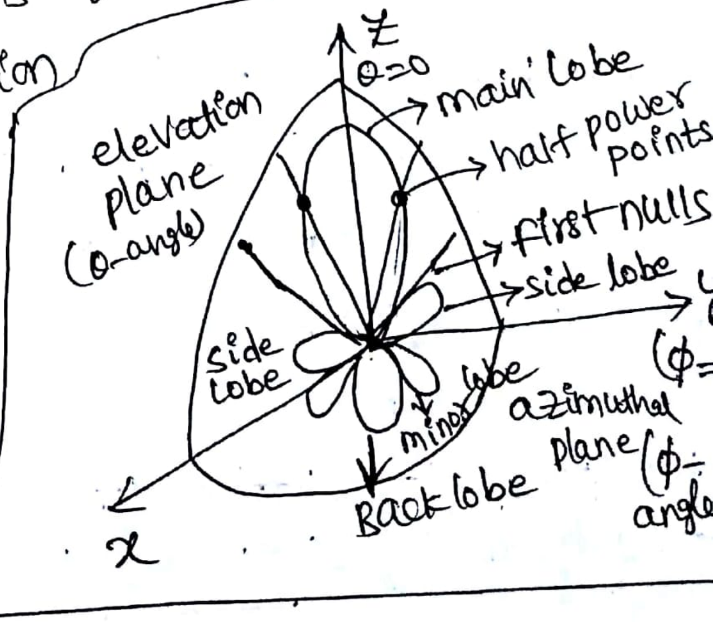
The radiation pattern can be classified into two types.
(a) field radiation pattern
(b) power radiation pattern.

<u>Definition of Radiation pattern</u> :- The radiation from an antenna is represented by graphically (or) Mathematically, interms of direction.

<u>(a) field radiation pattern</u> :- The field radiation pattern is defined as the radiation from antenna can be represented interms of electric field strength. $E(\theta,\phi)$. The field radiation is a graph which shows the direction of radiation.

→ The units of field radiation pattern are V/m.





→ It is a three dimensional pattern. So the spherical coordinate system is suitable

∴ The normalized field strength is given by

$$\boxed{E_{\theta n} = \frac{E_\theta(\theta,\phi)}{E_\theta(\theta,\phi)_{max}}} \qquad \boxed{E_{\phi n} = \frac{E_\phi(\theta,\phi)}{E_\phi(\theta,\phi)_{max}}}$$

→ Where $E_\theta(\theta,\phi)$ is 'θ' component of electric field in the direction of θ and ϕ. $E_\phi(\theta,\phi)$ is ϕ component of electric field in the direction of θ and ϕ.

→ Normalized field pattern is defined as the ratio of field strength to its maximum value.

Main lobe :- It is a radiation lobe, which gives the maximum direction of radiation.

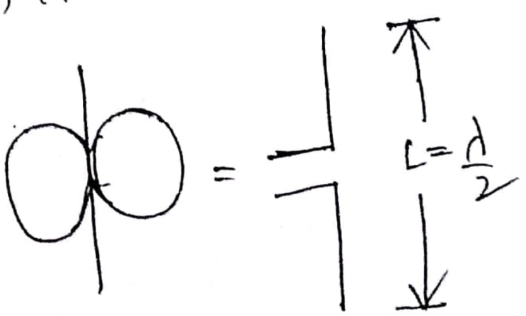
Side lobe :- Side lobes are lobes adjacent to the main lobe

Minor lobe :- The lobes other than side lobes called as "minor lobes".

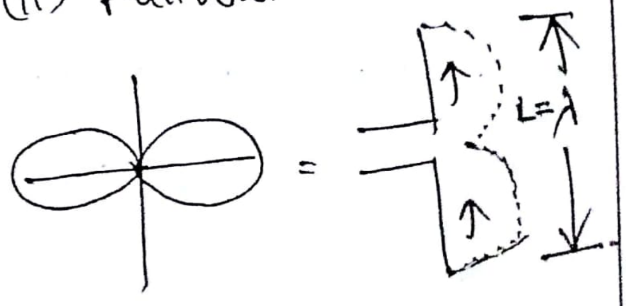
Back lobe :- The lobe opposite to the main lobe is called as back lobe. The angle between main lobe and ~~side~~ Back lobe is 180°.

Examples of field strength pattern (Field Radiation pattern)

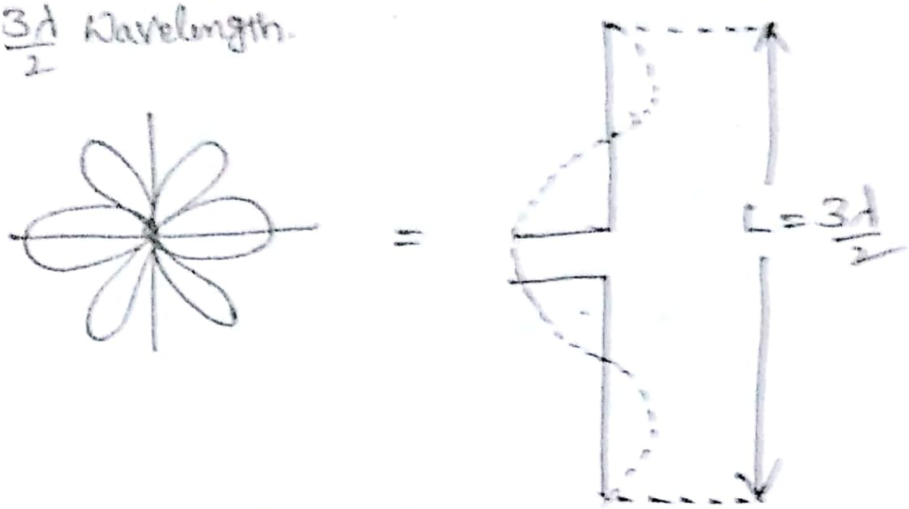
(i) Half Wavelength $(\frac{\lambda}{2})$



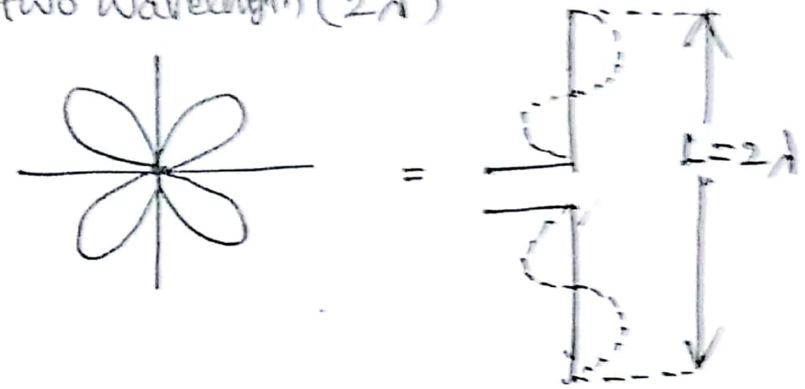
(ii) Full Wavelength (λ)



(iii) $\frac{3\lambda}{2}$ Wavelength.



(iv) two Wavelength (2λ)



(b) power Radiation pattern:-

→ power radiation pattern is defined as the radiation of antenna can be represented interms of power per unit solid angle.

→ The power radiation pattern explained by power density. The power density is defined as power flow per unit area. It is given by $P_d(\theta, \phi)$

But we know that poynting vector

$$\bar{P} = \bar{E} \times \bar{H} \quad (\text{or}) \quad P = E \times H$$

$$= E \times \frac{E}{\eta_0}$$

$$P = \frac{E^2}{\eta_0}$$

$\left(\because \text{for free space } \frac{E}{H} = 120\pi = \eta_0 \right.$

$\left. H = \frac{E}{\eta_0} \right)$

→ The power density is

$$\boxed{P_d(\theta,\phi) = \frac{1}{2}\frac{|E(\theta,\phi)|^2}{\eta_0}} \text{ Watts}/m^2$$

$\frac{1}{2}\frac{|E(\theta,\phi)|^2}{\eta_0}$

$E(\theta,\phi) = E_\theta^2(\theta,\phi) + E_\phi^2(\theta,\phi)$

Where $|E(\theta,\phi)| = \sqrt{E_\theta^2(\theta,\phi) + E_\phi^2(\theta,\phi)}$

η_0 = characteristic Impedance for free space

When $E(\theta,\phi)$ is maximum, the power density $P_d(\theta,\phi)$ is also maximum.

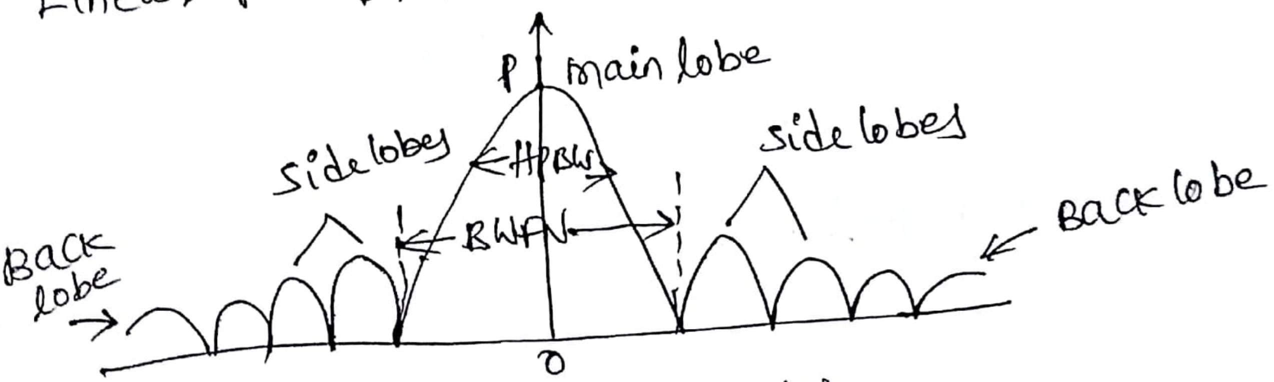
The normalized power pattern is given by

$$\boxed{P_{dn}(\theta,\phi) = \frac{P_d(\theta,\phi)}{P_d(\theta,\phi)_{max}}}$$

$$P_{dn}(\theta,\phi) = \frac{\frac{1}{2}\frac{|E(\theta,\phi)|^2}{\eta_0}}{\frac{1}{2}\frac{|E(\theta,\phi)|^2_{max}}{\eta_0}} = \frac{|E(\theta,\phi)|^2}{|E(\theta,\phi)|^2_{max}}$$

$$\therefore \boxed{P_{dn}(\theta,\phi) = f_n^2(\theta,\phi)}$$

Linear plot of power pattern.



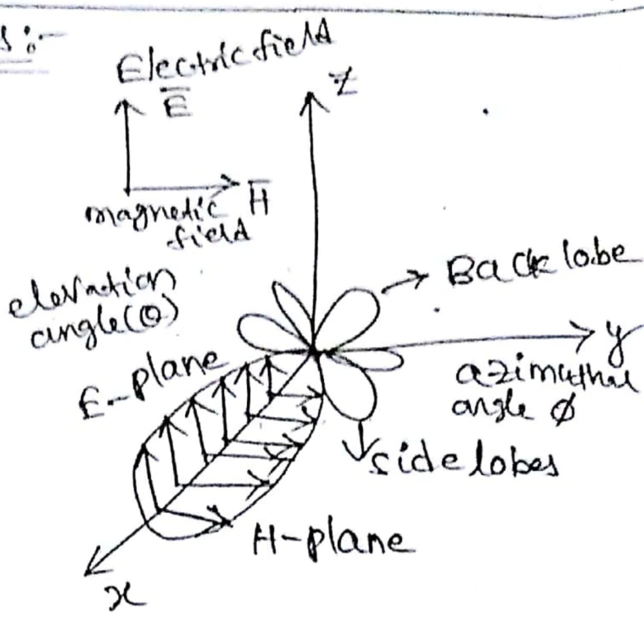
HPBW = Half power Beam Width

BWFN = Beam Width between first nulls.

→ The power radiation pattern doesn't requires 3 dimensional approach. Because power radiation pattern is plane surfaces.

∴ For spherical surfaces only 3-dimensional pattern exists.

Patterns in principal planes:-



→ The performance of Antenna can be described in terms of E-plane and H-plane. These planes are called as "principal" planes.

→ Generally principal plane patterns are two dimensional.

* **E-plane pattern**: It is defined as a plane consists of electric field vector ($\bar{E}$) and the direction of radiation is maximum.

→ It is also called as Vertical plane pattern.

→ E-plane exists in xz-plane.

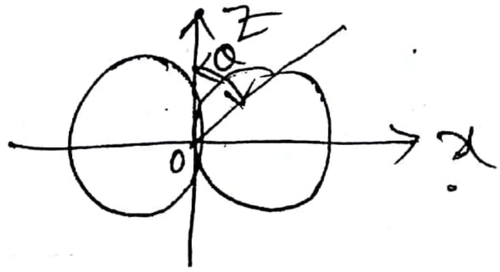
H-plane pattern:- It is defined as a plane consists of magnetic field vector ($\bar{H}$) and the direction of radiation is maximum.

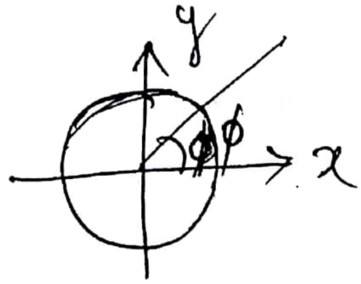
→ It is also called as Horizontal plane pattern.

→ the H-plane exists in xy-plane

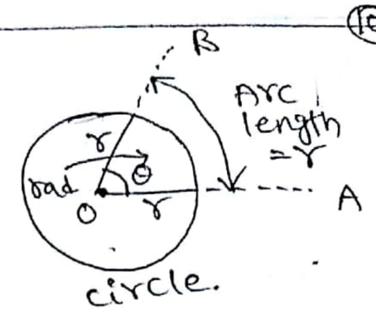
The E-plane and H-planes are perpendicular to each other

Examples of principal planes



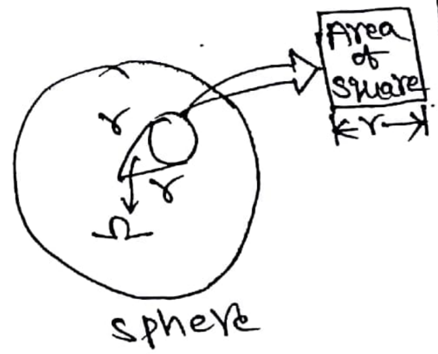


Radian and steradian:-



Radian :- The radian is simply a measure of plane angle. It can be defined as the plane angle with its vertex at the centre of the circle which can be extended by an arc (AB length) whose length is equal to 'r'.
The angle of complete circle is 2π radians ($360°$)
The circumference of circle is $2\pi r$.

steradian :- steradian is measure of solid angle. It is defined as the solid angle with its vertex at the centre of the sphere with radius 'r' which can be extended by area of sphere equivalent to area of square with each side is 'r'.



The area of sphere is $A = 4\pi r^2$

$$1 \text{ steradian} = 1\, sr = \frac{\text{solid angle}}{4\pi}$$

and also $1\,sr = (1\,rad)^2 = (57.3\ deg)^2$

$$\boxed{1\,sr = 3283.3} \text{ square degrees}$$

$$4\pi\, sr = 4\pi \times 3283.3 \text{ square degrees}$$
$$= 41,259 \text{ square degrees}$$

The Infinitesimal area ds on sphere is

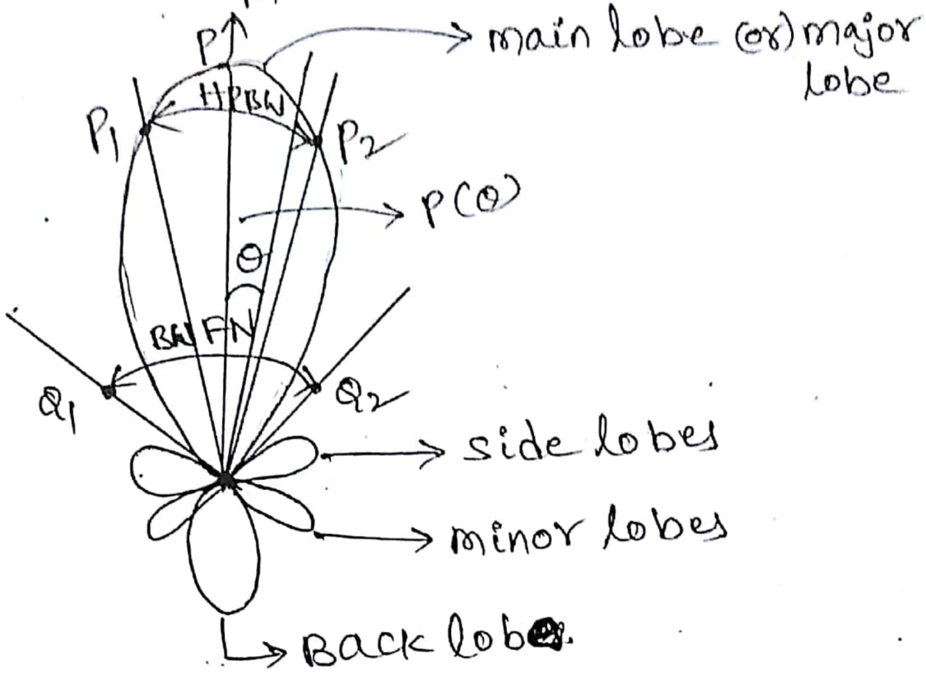
$$ds_r = (r\,d\theta)(r \sin\theta\, d\phi)$$
$$ds = ds_r = r^2 \sin\theta\, d\theta\, d\phi$$

∴ solid angle is

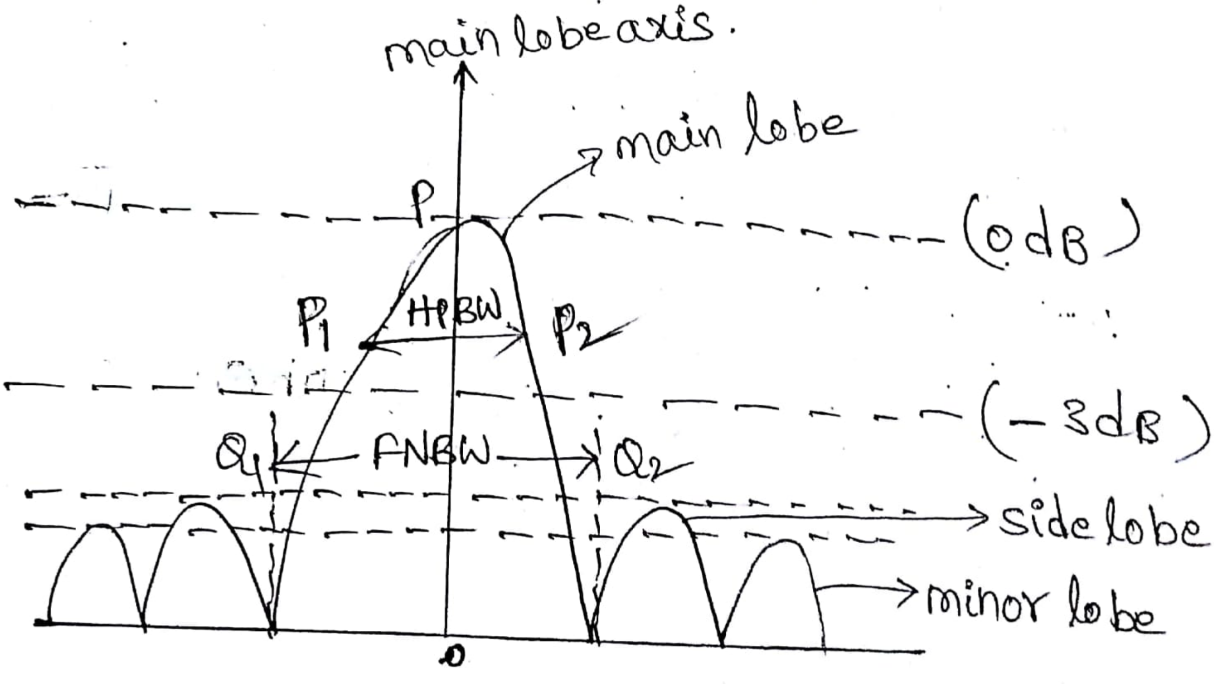
$$\boxed{d\Omega = \frac{ds}{r^2} = \sin\theta\, d\theta\, d\phi} \text{ steradian.}$$

Beam width :-

The beam width is defined as the angular width in degrees between two point on a main lobe (or) major lobe of radiation pattern.



(a) Beam width on polar coordinates



(b) Beam Width on rectangular coordinates.

→ The Beam width is also called as half power beam width because at two half power points the power is reduced to half of its maximum power value.

→ The half power beam width is defined as the angular width in degrees between two half power points on the main lobe of radiation pattern.

→ It is also called as 3dB beam width from the above diagrams at point P, the power is maximum. At points P_1 and P_2 the power is reduces to half of its maximum power value.

<u>BWFN</u> :- (Beam width between First Nulls)

The angular width in degrees between two first nulls is called as first nulls beam width (or) Beam width between first nulls.

The directivity and Beam area can be related as

$$D = \frac{4\pi}{\Omega_A} = \frac{4\pi}{B} \longrightarrow (1)$$

Where D = directivity

Ω_A = B = Beam area (or) Beam solid angle

= Beam width in E-plane x Beam width in H-plane.

= Beam width in vertical plane x Beam width in Horizontal plane

$$\therefore B = \Omega_A = \theta_E \times \phi_H \text{ steradians} \longrightarrow (2)$$

$$D = \frac{4\pi}{\theta_E \times \phi_H} \text{ in steradians.}$$

$$D = \frac{4\pi}{\theta_E \times \phi_H}(57.3\,\text{deg})^2 = \frac{4\pi}{\theta_E \times \phi_H}(57.3)^2 \text{ degrees square}$$

$$\therefore \boxed{D = \frac{41,259}{\theta_E^0 \times \phi_H^0}} \text{ square degrees.}$$

Beam Area (or) Beam solid angle :-

Beam area is defined as the Integral of normalized power patterns over the sphere. It is denoted by Ω_A. It is measured in steradians.

Beam area can be expressed as

$$\Omega_A = \oint_S P_{dn}(\theta,\phi)\, d\Omega \text{ steradians.}$$

$$= \int_{\phi=0}^{2\pi}\int_{\theta=0}^{\pi} P_{dn}(\theta,\phi)\, d\Omega \text{ steradians}$$

$$\boxed{\Omega_A = \int_{\phi=0}^{2\pi}\int_{\theta=0}^{\pi} P_{dn}(\theta,\phi)\sin\theta\, d\theta\, d\phi} \text{ steradians.}$$

Where $d\Omega = \sin\theta\, d\theta\, d\phi$

Also Ω_A = HPBW in E-plane × HPBW in H-plane

= Beam width in vertical plane × Beam width in horizontal plane.

$$\boxed{\Omega_A = \theta_E \times \phi_H} \text{ steradians.}$$

Radian Intensity :- It is defined as the power per unit solid angle. It is denoted by 'U'.

Radiation Intensity can be expressed as

$$U(\theta,\phi) = r^2 P_d(\theta,\phi) \longrightarrow (1)$$

The total power radiated is

$$P_{rad} = \oint_S P_d(\theta,\phi)\, ds$$

$$= \int_{\phi=0}^{2\pi}\int_{\theta=0}^{\pi} P_d(\theta,\phi)\, r^2 \sin\theta\, d\theta\, d\phi$$

$$= \int_{\phi=0}^{2\pi}\int_{\theta=0}^{\pi} [r^2 P_d(\theta,\phi)][\sin\theta\, d\theta\, d\phi]$$

$$\boxed{P_{rad} = \int_{\phi=0}^{2\pi}\int_{\theta=0}^{\pi} U(\theta,\phi)\, d\Omega \text{ steradians.}}$$

The average Radiation Intensity is

$$U_{avg} = r^2 P_a(\theta,\phi)_{avg}$$

$$= r^2 \cdot \frac{P_{rad}}{4\pi r^2}$$

$$\boxed{U_{avg} = \frac{P_{rad}}{4\pi}}$$

Beam efficiency:- Beam efficiency is defined as the ratio of power transmitted (or) received in one cone angle (θ_1) to the power transmitted (or) received by an antenna. The Beam efficiency also defined as

$$\varepsilon_M = \frac{\text{Main beam area}}{\text{Total beam area}} = \frac{\Omega_M}{\Omega_A} \longrightarrow ①$$

Where Ω_M = main beam area

Ω_A = Total beam area.

$\Rightarrow \Omega_A = \Omega_M + \Omega_m \rightarrow ②$ Where Ω_m = minor lobe area

Dividing equation ② by Ω_A on both sides

$$\frac{\cancel{\Omega_A}}{\cancel{\Omega_A}} = \frac{\Omega_M + \Omega_m}{\Omega_A} \Rightarrow \frac{\Omega_M}{\Omega_A} + \frac{\Omega_m}{\Omega_A} = 1$$

$$\therefore \boxed{\varepsilon_M + \varepsilon_m = 1}$$

Where $\varepsilon_M = \frac{\Omega_M}{\Omega_A}$ = Beam efficiency

$\varepsilon_m = \frac{\Omega_m}{\Omega_A}$ = Stray factor.

Gain(G) :- The gain is defined as the ratio of maximum radiation intensity from Test Antenna (practical antenna) to the maximum radiation intensity from the reference antenna (Ideal Antenna). It is denoted by G.

$$\boxed{G = \frac{U_{max}}{U_0}}$$

The gain is measured in dB.

→ generally Isotropic antenna used as reference antenna

Directive Gain (G_D) :- The directive gain is defined as the ratio of radiation intensity in particular direction (θ, ϕ) to the average radiation intensity.

It is denoted by G_D.

$$\boxed{G_D = \frac{U(\theta, \phi)}{U_{avg}}}$$

(or)

Directive gain is also defined as the ratio of power density in particular direction (θ, ϕ) to the average power density.

(ie) $$\boxed{G_D = \frac{P_d(\theta, \phi)}{P_{avg}}}$$

$$G_D = \frac{P_d(\theta, \phi)}{\frac{P_{rad}}{4\pi r^2}}$$ $\{U(\theta,\phi) = r^2 P_d(\theta,\phi)\}$

$$G_D = P_d(\theta, \phi) \times \frac{4\pi r^2}{P_{rad}}$$

$$G_D = \frac{4\pi [r^2 P_d(\theta, \phi)]}{P_{rad}} = \frac{4\pi \times U(\theta, \phi)}{P_{rad}}$$ $\left(\because U_{avg} = \frac{P_{rad}}{4\pi}\right)$

$$G_D = \frac{U(\theta, \phi)}{\left(\frac{P_{rad}}{4\pi}\right)} \Rightarrow \boxed{G_D = \frac{U(\theta, \phi)}{U_{avg}}}$$

Directivity (D) :- The directivity is defined as the ratio of maximum radiation Intensity to the average radiation Intensity. It is denoted by D.

$$\boxed{D = G_{Dmax} = \frac{U(\theta,\phi)_{max}}{U_{avg}}}$$

(OR)

The directivity is defined as the ratio of maximum power density to the average power density. It is denoted by 'D'. It can be expressed as

$$D = G_{Dmax} = \frac{P_d(\theta,\phi)_{max}}{P_{avg}}$$

$$= \frac{P_d(\theta,\phi)_{max}}{\left(\frac{P_{rad}}{4\pi r^2}\right)} \qquad \left(\because P_{avg} = \frac{P_{rad}}{4\pi r^2}\right)$$

$$= P_d(\theta,\phi)_{max} \times \frac{4\pi r^2}{P_{rad}}$$

$$\Rightarrow D = \frac{4\pi \times r^2 P_d(\theta,\phi)_{max}}{P_{rad}} \qquad \left(U(\theta,\phi)_{max} = r^2 P_d(\theta,\phi)_{max}\right)$$

$$\Rightarrow \boxed{D = \frac{4\pi \times U(\theta,\phi)_{max}}{P_{rad}}}$$

$$D = \frac{U(\theta,\phi)_{max}}{\left(\frac{P_{rad}}{4\pi}\right)} \qquad \left(\because U_{avg} = \frac{P_{rad}}{4\pi}\right)$$

$$\boxed{D = \frac{U(\theta,\phi)_{max}}{U_{avg}}}$$

The directivity is also defined as maximum directive Gain. (G_{Dmax}).

Relation between directivity (D) and Beam area (Ω_A)

We have to show that $\boxed{D = \frac{4\pi}{\Omega_A}}$.

proof :- We know that directivity $D = \frac{U(\theta,\phi)_{max}}{U_{avg}}$

$$\Rightarrow D = \frac{U(\theta,\phi)_{max}}{\frac{P_{rad}}{4\pi}} = \frac{4\pi \times U(\theta,\phi)_{max}}{P_{rad}} \quad \left(\because U_{avg} = \frac{P_{rad}}{4\pi}\right)$$

$$\Rightarrow D = \frac{4\pi \times r^2 P_d(\theta,\phi)_{max}}{\int_{\phi=0}^{2\pi}\int_{\theta=0}^{\pi} U(\theta,\phi)\,d\Omega \text{ steradians}} \quad \left(\because P_{rad} = \int_{\phi=0}^{2\pi}\int_{\theta=0}^{\pi} U(\theta,\phi) \times d\Omega\right)$$

$$\Rightarrow D = \frac{4\pi r^2 P_d(\theta,\phi)_{max}}{\int_{\phi=0}^{2\pi}\int_{\theta=0}^{\pi} r^2 P_d(\theta,\phi)\,d\Omega \text{ sr}} \quad \left(\because r^2 P_d(\theta,\phi) = U(\theta,\phi)\right)$$

$$\Rightarrow D = \frac{4\pi \cancel{r^2} P_d(\theta,\phi)_{max}}{\cancel{r^2}\int_{\phi=0}^{2\pi}\int_{\theta=0}^{\pi} P_d(\theta,\phi)\,d\Omega \text{ sr}}$$

$$\Rightarrow D = \frac{4\pi}{\int_{\phi=0}^{2\pi}\int_{\theta=0}^{\pi}\left[\frac{P_d(\theta,\phi)}{P_d(\theta,\phi)_{max}}\right] d\Omega \text{ sr}}$$

$$\Rightarrow D = \frac{4\pi}{\int_{\phi=0}^{2\pi}\int_{\theta=0}^{\pi} P_{dn}(\theta,\phi)\,d\Omega \text{ steradians}}$$

$$\left(\because \Omega_A = \int_{\phi=0}^{2\pi}\int_{\theta=0}^{\pi} P_{dn}(\theta,\phi) \times d\Omega\right)$$

$$\therefore \boxed{D = \frac{4\pi}{\Omega_A}}$$

Hence proved

(14)

Resolution :- It is defined as half of the Beam width between first nulls.

$$\text{Resolution} = \frac{BWFN}{2} = \frac{FNBW}{2}$$

Also $HPBW = \frac{BWFN}{2}$

Front to Back Ratio :- It is defined as the ratio of power Transmitted in desired direction to the power transmitted in reverse direction.

$$FBR = \frac{\text{power Transmitted in desired direction}}{\text{power Transmitted in reverse direction}}$$

Antenna Band Width :- Band width is defined as the difference between two band of frequencies. It is denoted by $\Delta\omega$ (or) Δf.

$$\text{Band width} = \Delta\omega = \omega_2 - \omega_1 = \frac{\omega_0}{Q}$$

$$\text{Band width} = \Delta f = f_2 - f_1 = \frac{f_0}{Q}$$

Power gain (G_P) :- power gain is defined as the ratio of power density in particular direction to the actual i/p power.

$$G_P = \frac{P_d(\theta,\phi)}{P_{in}} = \frac{\text{Power density in } (\theta,\phi)}{\text{Actual i/p power}}$$

The relation between G_P and G_D is given by

$$\boxed{G_P = \eta_r G_D}$$

(or)

$$G_{P\max} = \eta_r G_{D\max}$$

$$\boxed{G = \eta_r D}$$

Radiation efficiency (η_r)

It is defined as the ratio of power radiated to the actual input power.

We can express Prad interms of Pin

(i.e) $P_{rad} = \eta_r P_{in}$.

$$\boxed{\eta_r = \frac{P_{rad}}{P_{in}}}$$

where P_{in} = actual input power
$= P_{rad} + P_{Loss}$

$$\boxed{\eta_r = \frac{P_{rad}}{P_{rad} + P_{Loss}}}$$

$$P_{rad} = I^2 R_{rad}$$

$$P_{Loss} = I^2 R_{Loss}$$

$$\eta_r = \frac{I^2 R_{rad}}{I^2 R_{rad} + I^2 R_{Loss}} = \frac{\cancel{I^2} R_{rad}}{\cancel{I^2}[R_{rad} + R_{Loss}]}$$

$$\boxed{\eta_r = \frac{R_{rad}}{R_{rad} + R_{Loss}}}$$

Relation between G_{Pmax} and G_{Dmax} :-

The maximum power gain is

$$G_{Pmax} = \frac{U(\theta,\phi)_{max}}{\left(\frac{P_{in}}{4\pi}\right)} \rightarrow (1)$$

The maximum derective gain is $G_{Dmax} = \frac{U(\theta,\phi)_{max}}{U_{avg}} = \frac{U(\theta,\phi)_{max}}{\left(\frac{P_{rad}}{4\pi}\right)} \rightarrow (2)$

from eq (1), (2)

$$\frac{G_{Pmax}}{G_{Dmax}} = \frac{\frac{\cancel{U(\theta,\phi)_{max}}}{(P_{in}/4\pi)}}{\frac{\cancel{U(\theta,\phi)_{max}}}{\left(\frac{P_{rad}}{4\pi}\right)}}$$

$$\Rightarrow \frac{G_{Pmax}}{G_{Dmax}} = \frac{1}{\left(\frac{P_{in}}{4\pi}\right)} \times \frac{P_{rad}}{4\pi}$$

$$= \frac{\cancel{4\pi}}{P_{in}} \times \frac{P_{rad}}{\cancel{4\pi}}$$

$$= \frac{P_{rad}}{P_{in}}$$

$$= \eta_r.$$

$$\therefore \boxed{G_{Pmax} = \eta_r G_{Dmax}}$$

$$\boxed{G_P = \eta_r G_D}$$

Antenna Aperture (Ae) :- (effective Aperture, capture area, effective area)

It is defined as the ratio of power received at the antenna load terminal to the poynting vector of the antenna. It is denoted by Ae

→ It is also called as effective aperture (or) effective area, capture area.

$$\boxed{A_e = \frac{P_{received}}{\bar{P}}}\ m^2 \qquad (\because \bar{P} = \text{poynting Vector} = \bar{E}\times\bar{H})$$

Aperture efficiency (η_a) :-

It is defined as the ratio of effective aperture to the physical aperture. It is denoted by η_a.

$$\boxed{\eta_a = \frac{\text{effective aperture}}{\text{physical aperture}} = \frac{A_e}{A_p}}$$

$$\boxed{\% \eta_a = \frac{A_e}{A_p} \times 100}$$

Effective Height :- (Leff (or) effective Length)

It is defined as the ratio of Induced voltage at receiving antenna to the under open ckt condition Incident electric field Intensity. It is denoted by Leff.

$$\boxed{L_{eff} = \frac{V_{oc}}{E}}\ \text{meters}$$

$$L_{eff} = \frac{\text{Induced Voltage under open Ckt}}{\text{Incident Electric field Intensity}}$$

