VTU eNotes On

Antennas and Propagation

(Electronics and Communication)

Unit – 1

Antenna Basics: Introduction, basic Antenna parameters, patterns, beam area, radiation intensity, beam efficiency, directivity and gain, antenna apertures, effective height, bandwidth, radiation efficiency, antenna temperature and antenna filed zones.

Introduction:-

It is a source or radiator of EM waves, or a sensor of EM waves. It is a transition device or transducer between a guided wave and a free space wave or vice versa. It is an electrical conductor or system of conductors that radiates EM energy into or collects EM energy from free space. is an impedance matching device, coupling EM waves between Transmission line and free space or vice versa.

Some Antenna Types

- Wire Antennas- dipoles, loops and Helical
- Aperture Antennas-Horns and reflectors
- Array Antennas-Yagi, Log periodic
- Patch Antennas- Microstrips, PIFAs

Principle- Under time varying conditions , Maxwell's equations predict the radiation of EM energy from current source(or accelerated charge). This happens at all frequencies , but is insignificant as long as the size of the source region is not comparable to the wavelength. While transmission.lines are designed to minimize this radiation loss, radiation into free space becomes main purpose in case of Antennas . For steady state harmonic variation, usually we focus on time changing current For transients or pulses ,we focus on accelerated charge The radiation is perpendicular to the acceleration. The radiated power is proportional to the square of .

I L or Q V

Where

I = Time changing current in Amps/sec

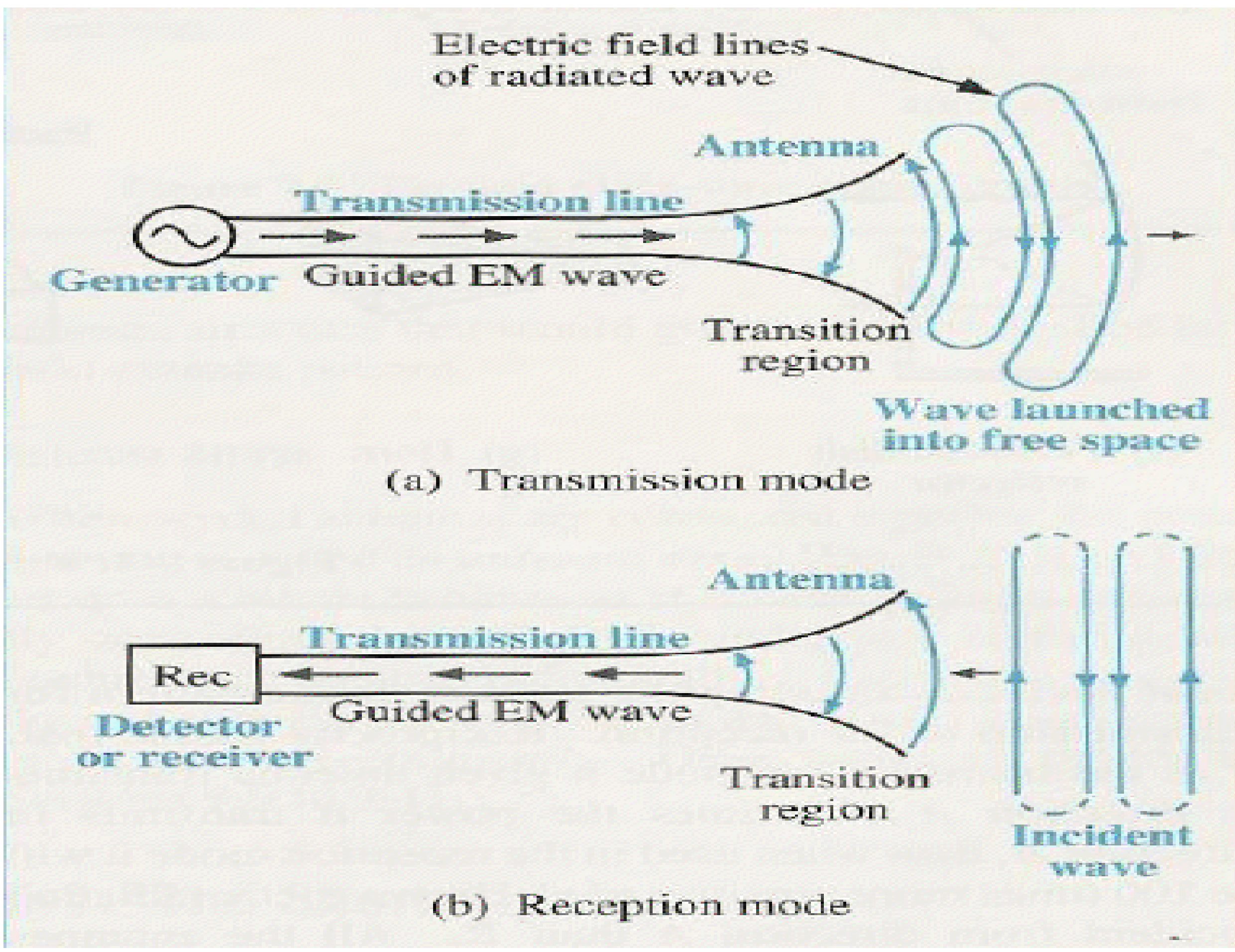
L = Length of the current element in meters

Q= Charge in Coulombs

V= Time changing velocity

Transmission line opened out in a Tapered fashion as Antenna:

a) As Transmitting Antenna: –Here the Transmission Line is connected to source or generator at one end. Along the uniform part of the line energy is guided as Plane TEM wave with little loss. Spacing between line is a small fraction of λ. As the line is opened out and the separation b/n the two lines becomes comparable to λ, it acts like an antenna and launches a free space wave since currents on the transmission Line flow out on the antenna but fields associated with them keep on going. From the circuit point of view the antennas appear to the tr. lines As a resistance R_r, called Radiation resistance



(a) Transmission mode

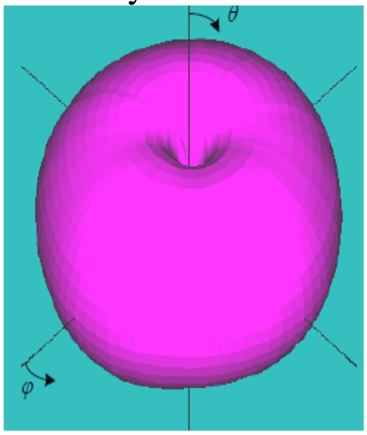
(b) Reception mode

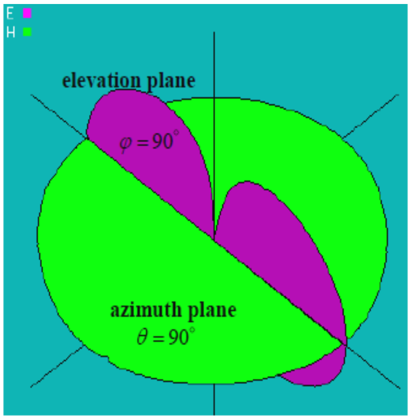
b) As Receiving Antenna –Active radiation by other Antenna or Passive radiation from distant objects raises the apparent temperature of R_r. This has nothing to do with the physical temperature of the antenna itself but is related to the temperature of distant objects that the antenna is looking at. R_r may be thought of as virtual resistance that does not exist physically but is a quantity coupling the antenna to distant regions of space via a virtual transmission .line

Reciprocity-An antenna exhibits identical impedance during Transmission or Reception, same directional patterns during Transmission or Reception, same effective height while transmitting or receiving **.** Transmission and reception antennas can be used interchangeably. Medium must be linear, passive and isotropic(physical properties are the same in different directions.) Antennas are usually optimised for reception or transmission, not both.

Patterns

The radiation pattern or *antenna pattern* is the graphical representation of the radiation properties of the antenna as a function of space. That is, the antenna's pattern describes how the antenna radiates energy out into space (or how it receives energy. It is important to state that an antenna can radiate energy in all directions, so the antenna pattern is actually three-dimensional. It is common, however, to describe this 3D pattern with two planar patterns, called the *principal plane patterns*. These principal plane patterns can be obtained by making two slices through the 3D pattern ,through the maximum value of the pattern . It is these principal plane patterns that are commonly referred to as the antenna patterns





Radiation pattern or Antenna pattern is defined as the spatial distribution of a 'quantity' that characterizes the EM field generated by an antenna.

The 'quantity' may be Power, Radiation Intensity, Field amplitude, Relative Phase etc.

Normalized patterns

It is customary to divide the field or power component by it's maximum value and plot the normalized function.Normalized quantities are dimensionless and are quantities with maximum value of unity

Normalized Field Pattern = $E_\theta(\theta,\phi)_n = \dfrac{E_\theta(\theta,\phi)}{E_\theta(\theta,\phi)_{max}}$

Half power level occurs at those angles (θ,Φ)for which $E_\theta(\theta,\Phi)_n = 0.707$

At distance d>>λ and d>> size of the antenna, the shape of the field pattern is independent of the distance

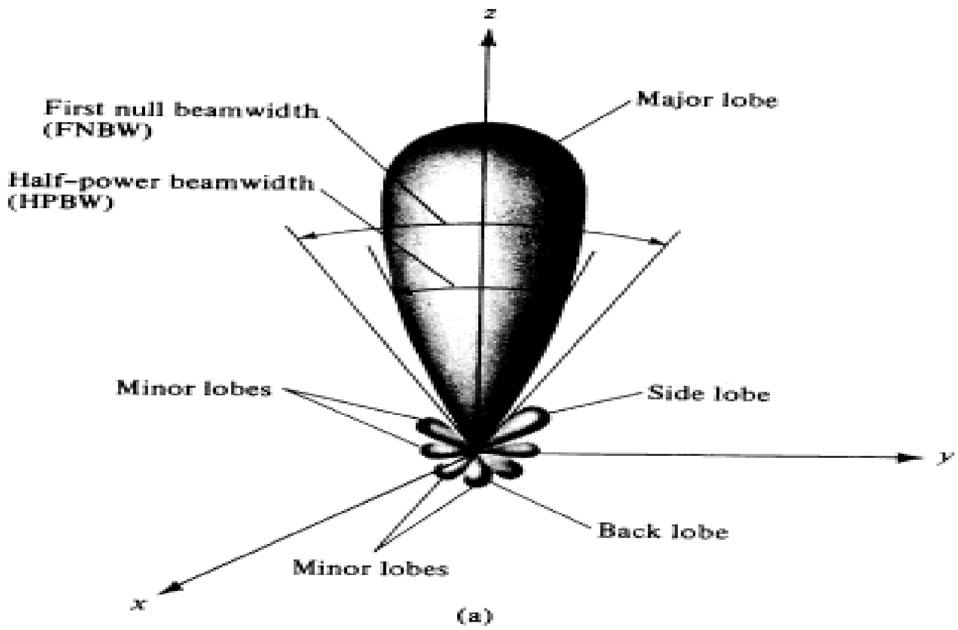
Normalized Power Pattern = $P_n(\theta,\phi)_n = \dfrac{S(\theta,\phi)}{S(\theta,\phi)_{max}}$

where

$$S(\theta,\phi) = \frac{\left[E_\theta^2(\theta,\phi) + E_\phi^2(\theta,\phi)\right]}{Z_0} W/m^2$$

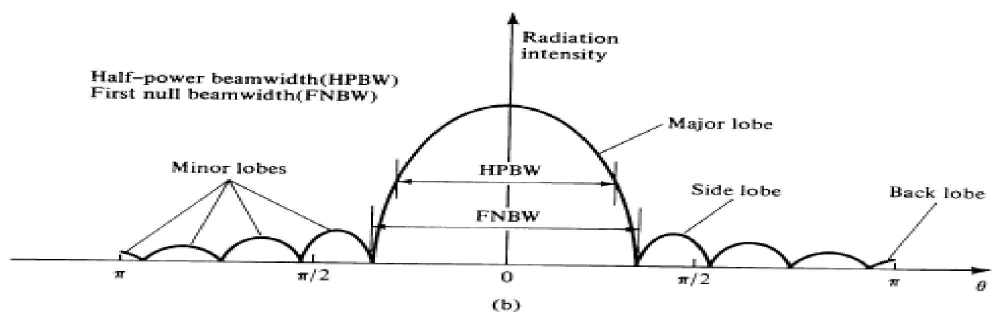
is the poynting vector. Half power level occurs at those angles (θ,Φ)for which $P(\theta,\Phi)_n = 0.5$

Pattern lobes and beam widths



Pattern in spherical co-ordinate system

Beamwidth is associated with the lobes in the antenna pattern. It is defined as the angular separation between two identical points on the opposite sides of the main lobe. The most common type of beamwidth is the half-power (3 dB) beamwidth (HPBW). To find HPBW, in the equation, defining the radiation pattern, we set power equal to 0.5 and solve it for angles. Another frequently used measure of beamwidth is the first-null beamwidth (FNBW), which is the angular separation between the first nulls on either sides of the main lobe.



Pattern in Cartesian co-ordinate system

Beamwidth defines the resolution capability of the antenna: i.e., the ability of the system to separate two adjacent targets

Examples :

1.An antenna has a field pattern given by $E(\theta)=\cos^2\theta$ for $0^o \le \theta \le 90^o$. Find the Half power beamwidth(HPBW)

$E(\theta)$ at half power=0.707

Therefore, $\cos^2\theta = 0.707$ at Halfpower point

i.e., $\theta = \cos^{-1}[(0.707)^{1/2}] = 33^o$

$HPBW = 2\theta = 66^o$

2.Calculate the beamwidths in x-y and y-z planes of an antenna, the power pattern of which is given by

$$U(\theta,\phi) = \begin{cases} \sin^2\theta \sin\phi; 0 \le \theta \le \pi, 0 \le \phi \le \pi \\ 0; \pi \le \theta \le 2\pi, \pi \le \phi \le 2\pi \end{cases}$$

soln: In the x-y plane, $\theta=\pi/2$ and power pattern is given by $U(\pi/2,\Phi)=\sin\Phi$

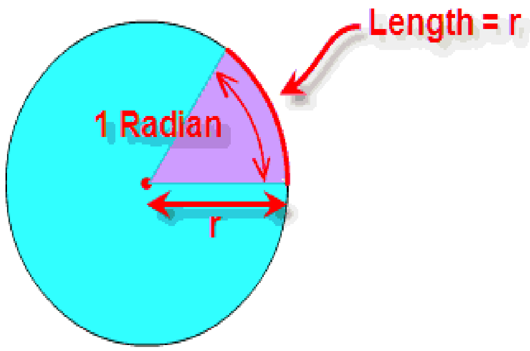
- Therefore half power points are at $\sin\Phi=0.5$, i.e., at $\Phi=30^o$ and $\Phi=150^o$
- Hence 3dB beamwidth in x-y plane is $(150-30)=120^o$
- In the y-z plane, $\Phi=\pi/2$ and power pattern is given by $U(\theta,\pi/2)=\sin^2\theta$
- Therefore half power points are at $\sin^2\theta=0.5$, i.e., at $\theta=45^o$ and $\theta=135^o$
- Hence 3dB beamwidth in y-z plane is $(135-45)= 90^o$

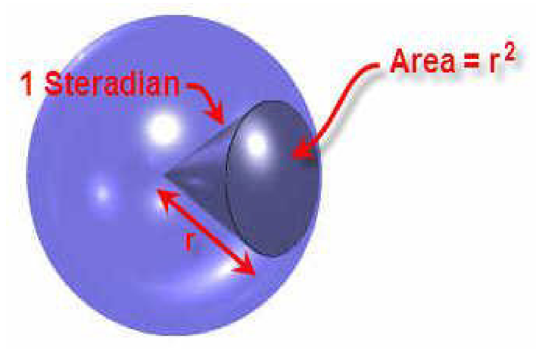
Beam area or Beam solid angle Ω_A

Radian and Steradian: Radian is plane angle with it's vertex a the centre of a circle of radius r and is subtended by an arc whose length is equal to r. Circumference of the circle is $2\pi r$ Therefore total angle of the circle is 2π radians.

Steradian is solid angle with it's vertex at the centre of a sphere of radius r, which is subtended by a spherical surface area equal to the area of a square with side length r

Area of the sphere is $4\pi r^2$. Therefore the total solid angle of the sphere is 4π steradians





1stersteadian= $(1 \text{radian})^2$

= $(180 / \pi)^2$

= 3282.8 Square degrees

The infinitesimal area *ds on a surface of a sphere of radius r in spherical* coordinates(with θ as vertical angle and Φ as azimuth angle) is

$$ds = r^2 \sin\theta d\theta d\phi$$

By defnition of solid angle $ds = r^2 d\Omega$

$$\therefore d\Omega = \sin\theta d\theta d\phi$$

Beam area is the solid angle Ω_A for an antenna, is given by the integral of the normalized power pattern over a sphere(4π steradians)

i.e.,

$$\Omega_A = \int_0^{2\Pi}\int_0^{\Pi} P_n(\theta,\phi)d\Omega$$

$$d\Omega = Sin\theta d\theta d\phi$$

Beam area is the solid angle through which all of the power radiated by the antenna would stream if P(θ,Φ) maintained it's maximum value over Ω_A and was zero elsewhere.

i.e., Power radiated= P(θ,Φ) Ω_A watts

Beam area is the solid angle Ω_A is often approximated in terms of the angles subtended by the Half Power points of the main lobe in the two principal planes(Minor lobes are neglected)

$$\Omega_A \approx \theta_{HP}\phi_{HP}$$

Example

An antenna has a field pattern given by $E(\theta)=\cos^2\theta$ for $0^o \le \theta \le 90^o$. Find the Beam area of the pattern. Also find Approximate beam area using Half Power Beamwidths

$$\Omega_A = \int_0^{2\Pi}\int_0^{\Pi} P_n(\theta,\phi)d\Omega$$

$$d\Omega = Sin\theta d\theta d\phi$$

$$\Omega_A = \int_0^{2\Pi}\int_0^{\Pi} \cos^4(\theta) Sin\theta d\theta d\phi$$

$$\Omega_A = -2\pi\left[\frac{1}{25}\cos^5(\theta)\right]_0^{\frac{\pi}{2}} = \frac{2\pi}{5} = 1.26\ Sr$$

Radiation Intensity

Definition: The power radiated from an Antenna per unit solid angle is called the Radiation Intensity. **U** Units: Watts/Steradians

Poyting vector or power density is dependant on distance from the antenna while Radiation intensity is independent of the distance

Beam efficiency

The total beam area Ω_A consists of Main beam area Ω_M and minor lobe area Ω_m

$$\therefore \Omega_A = \Omega_M + \Omega_m$$

'Beam efficiency' is defined by $\varepsilon_M = \frac{\Omega_M}{\Omega_A}$

And 'stray factor' is $\varepsilon_m = \frac{\Omega_m}{\Omega_A}$

$$\therefore \varepsilon_M + \varepsilon_m = 1$$

Directivity and Gain

From the field point of view, the most important quantitative information on the antenna is the directivity, which is a measure of the concentration of radiated power in a particular direction. It is defined as the ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions. The average radiation intensity is equal to the total radiated power divided by 4π. If the direction is not specified, the direction of maximum radiation is implied. Mathematically, the directivity (dimensionless) can be written as

$$D = \frac{U(\theta,\phi)_{\max}}{U(\theta,\phi)_{average}}$$

The directivity is a dimensionless quantity. The maximum directivity is always ≥ 1

Directivity and Beam area

$$P(\theta,\phi)_{Av} = \frac{1}{4\Pi}\int_0^{2\Pi}\int_0^{\Pi} P(\theta,\phi) Sin\theta d\theta d\phi$$

$$= \frac{1}{4\Pi}\int_0^{2\Pi}\int_0^{\Pi} P(\theta,\phi) d\Omega$$

$$\therefore D = \frac{P(\theta,\phi)_{\max}}{\frac{1}{4\Pi}\int_0^{2\Pi}\int_0^{\Pi} P(\theta,\phi) d\Omega}$$

$$D = \frac{1}{\frac{1}{4\Pi}\int_0^{2\Pi}\int_0^{\Pi} P_n(\theta,\phi) d\Omega}$$

$$i.e., D = \frac{4\Pi}{\Omega_A}$$

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