Module 7 : Antenna

Lecture 49 : Radiation Characteristics of an Antenna

Objectives

In this course you will learn the following

- Radiation pattern.
- E and H-plane radiation pattern.
- Main beam and nulls of an antenna.
- Side lobe level of antenna.
- HPBW and BWFN for an antenna.
- Directivity.
- Gain and efficiency of an antenna.
- Effective aperture of antenna.
- Relative between Directivity and effective aperture.

- An antenna has dual nature. When seen from the space side, it has properties of electromagnetic waves like the radiation pattern, polarization, Poynting vector etc, and when seen from the terminal side it has circuit like properties like the impedance, bandwidth and so on.

- The antenna therefore has to be characterized from circuit as well as the waves perspective. Following parameters are used for characterizing an antenna.

Radiation Pattern

- Radiation pattern is one of the important characteristic of an antenna as tells the spatial relative distribution of the electromagnetic wave generated by the antenna.

- The radiation pattern is a plot of the magnitude of the radiation field as a function of direction (θ, ϕ) .

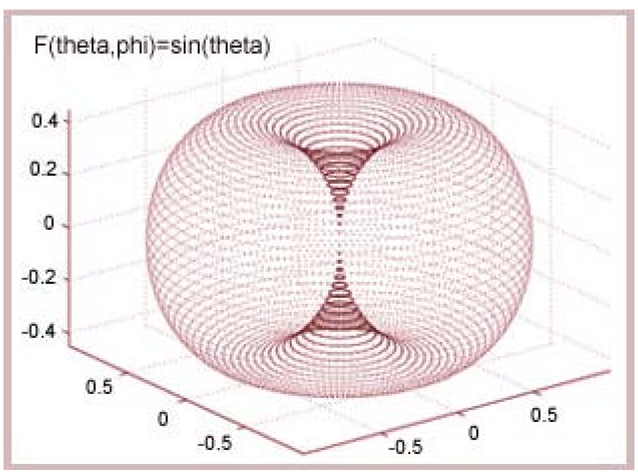
- The radiation pattern is essentially a 3-D surface.

- Since the radiation pattern is supposed to provide relative distribution of the fields, the absolute size of the 3-D surface does not have any significance. In practice therefore the maximum amplitude is normalized to unity.

- The radiation pattern for the Hertz dipole is

$$F(\theta, \phi) = \sin\theta$$

- The above equation when plotted in the spherical coordinate system ((r, θ, ϕ) with $r = |F(\theta, \phi)|$ we get a three dimensional figure as shown in Fig.

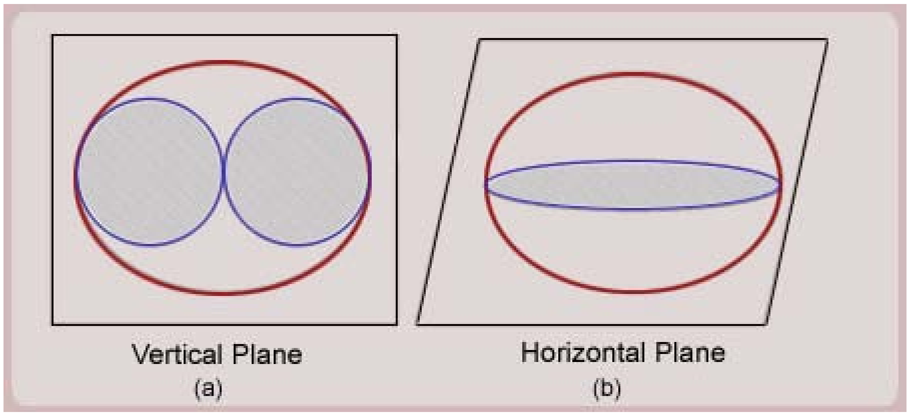


- The radiation pattern of the Hertz dipole is like an apple.

- At times a full 3-D description of the radiation pattern may not be needed. Invariably therefore two principal sections of the 3-D radiation patterns are given as the radiation patterns.

- The two principle sections are obtained by planes one containing the electric field vector and the other containing the magnetic field vector. Consequently, the two planar radiation patterns are called the E-plane and H-plane radiation patterns respectively.

- For the Hertz dipole any vertical plane passing through the z-axis is the E-plane and a horizontal plane passing through the antenna is the H-plane. The two radiation patterns for the Hertz dipole are shown in Fig.



NOTE:

- In a radiation pattern the physical shape and size of the antenna do not get reflected. The antenna is merely a point at the origin of the radiation pattern

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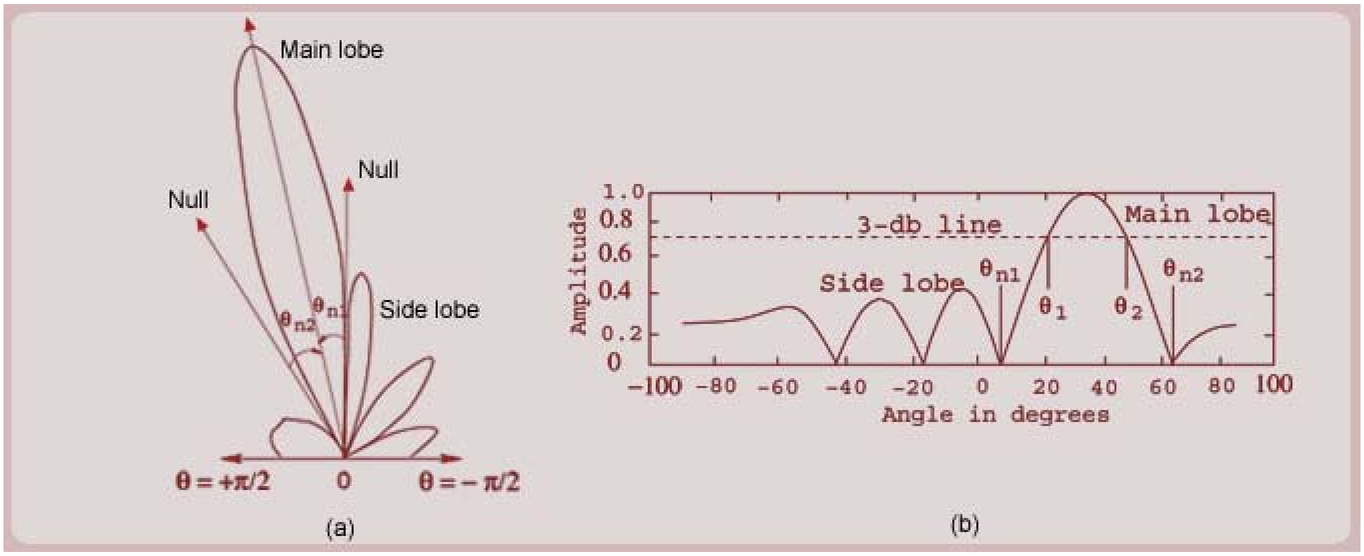
- A typical radiation pattern for a general antenna is shown in Fig.



Direction of Maximum Radiation (Main Beam)

- The direction along which the field strength is maximum is called the direction of maximum radiation. The angular zone around the direction of maximum radiation is called the main beam of the antenna.

- For the Hertz dipole, the direction of maximum radiation is $\theta = \pi/2$ for all ϕ. The maximum radiation goes in a plane perpendicular to the dipole.

Direction of Nulls

- The directions along which the field strength is zero, i.e. along which no power is radiated are called the directions of nulls.

- For the Hertz dipole there are two nulls one along $\theta = 0$ direction and other along $\theta = \pi$ direction.

Beam Width between First Nulls(BWFN)

- At times the effective width of the main beam is given by the angular separation between the nulls around the direction of the maximum radiation is called the BWFN.

- For any antenna the BWFNs are to be defined in E and H-planes.

- For the Hertz dipole the BWFN in the E-plane is 180^o, and the BWFN for the H-plane is not defined since there is no null in the H-plane radiation pattern.

Half Power Beam Width(HPBW) of an antenna

- The main beam is the angular region where primarily the radiation goes. The effective width of the antenna main beam called the HPBW is defined as the angular separation between directions where the field strength reduces to $1/\sqrt{2}$ of its maximum value.

- Since the power density of a wave is proportional to the square of the electric field, when the electric field reduces to $1/\sqrt{2}$ of its maximum value, the power density reduces to $1/2$ of its maximum value. That is, the power density reduces by 3-dB. The HPBW therefore is also referred to as the 3-dB Beam width.

- There two HPBWs, one for the E-plane pattern and other for the H-plane pattern.

- For the Hertz dipole, the E-plane HPBW is 90° and the H-plane HPBW is not defined since the radiation pattern is constant in the H-plane.

- **The HPBW is a better measure of the effective width of the main beam of the antenna compared to BWFN** because there are situations when the effective width of the antenna beam changes but the BWFN remains same.

Side-Lobe Level(SLL)

- The local maxima in the radiation pattern are called the side-lobes of the radiation pattern.

- Since ideally the antenna should radiate along the direction of the main beam the side-lobes essentially indicate the leakage of power in undesired directions. **The side-lobes in general is an undesirable feature in a radiation pattern**.

- The ratio of the main beam to the highest side-lobe is called the SSL of the radiation pattern. For a good communication antenna the SLL lies in the range of 30-40 dB

- Since the Hertz dipole has only one maximum in the radiation pattern, there are no side-lobes for the Hertz dipoles.

Directivity of an Antenna (D)

- The directivity is a parameter which quantifies the radiation focusing capability of an antenna. It is a measure of how the antenna guides power in the desired direction compared to the other directions.

- The directivity is one of the very important parameters used for comparing the performance of different antennas.

- The directive gain of an antenna is defined as

$$G(\theta,\phi) = \frac{U(\theta,\phi)}{U_{av}} = \frac{4\pi U(\theta,\phi)}{\iint U(\theta,\phi)\, d\Omega}$$

- Where $U(\theta,\phi)$ is the radiation intensity defined as the power per unit solid angle, and U_{av} is the average value the radiation intensity over 4π solid angle. We then have

$$U(\theta,\phi) = \frac{|E(\theta,\phi)|^2}{\eta} r^2 = P(\theta,\phi) r^2$$

$$U_{av} = \frac{W}{4\pi} = \frac{1}{4\pi} \iint U(\theta,\phi)\, d\Omega$$

- The maximum value of the directive gain is called the directivity of an antenna. The Directivity therefore is

$$D = \frac{U_{\max}}{U_{av}} = \frac{4\pi U_{\max}}{\iint U(\theta,\phi)\, d\Omega}$$

$$D = Max\left(G(\theta,\phi)\right)$$

$$D = \frac{4\pi E^2 \max}{\int_{\theta=0}^{\pi}\int_{\phi=0}^{2\pi} |E(\theta,\phi)|^2 \sin\theta d\theta d\phi}$$

- The directivity is parameter solely defined by the radiation pattern of an antenna.
- If the radiation pattern is normalized, the maximum field strength is unity and the directivity can be written as

$$D = \frac{4\pi}{\int_{\theta=0}^{\pi}\int_{\phi=0}^{2\pi} |E_n(\theta,\phi)|^2 \sin\theta d\theta d\phi}$$

- For the Hertz dipole the directivity is

$$G = D = \frac{4\pi}{\int_{\theta=0}^{\pi}\int_{\phi=0}^{2\pi} \sin^2\theta . \sin\theta d\theta d\phi}$$

$$G = \frac{3}{2}$$

- For the large antennas with single main beam like the parabolic dishes, the main beam is very narrow and the directivity can be approximately written as

$$D = \frac{4\pi}{\Omega_{MB}} = \frac{4\pi}{\theta_{HP}\phi_{HP}}$$

- The directivity is generally given in dB (= 10 log D).

- For an antenna with 1° circular beam, the directivity is approximately

$$D \approx \frac{4\pi}{\pi(\pi/180)^2/4} = 16\left(\frac{180}{\pi}\right)^2 = 52528 = 47.2\text{dB}$$

Antenna Gain

- Due to Ohmic losses on the antenna surface a part of the power supplied to the antenna terminals is lost in heating of the antenna. The full power supplied to the antenna is then not radiated. The efficiency of an antenna is

$$\eta = \frac{\text{Total power radiated}}{\text{Total power supplied to the antenna}}$$

- The antenna gain is

G = Directivity X Antenna efficiency

Effective Aperture

- It can be shown by the reciprocity theorem that an antenna has same radiation characteristics while transmitting and receiving. That is

(1) The direction in which an antenna radiates maximally, and the direction from which the antenna receives maximum power are the same.

(2) The antenna does not receive any power from the radiation arriving from the direction of a null.

(3) An antenna maximally responds to that polarization which it generates while transmitting.

- Effective aperture of an antenna is a parameter defined for the receiving antenna. It tells the capability of an antenna to tap power from a radiation arriving from certain direction.

- If an antenna is placed in a radiation field with power flow density S, and if the power transferred to a matched load connected to the terminals of a receiving antenna under matched polarization condition is P_L, the effective aperture is given as

$$A_e = \frac{P_L}{S}$$

- Effective aperture in general is direction dependent, however when there is no specific mention, it is its maximum value.

- The effective aperture has dimensions of area and generally has units m^2.

- The Effective aperture and the Directivity of an antenna are related through a relation,

$$G = \frac{4\pi A_e}{\lambda^2}$$

- The effective aperture is directly proportional to the directivity. Higher the directivity higher is the effective aperture.

- The effective aperture has no direct relation to the physical aperture of an antenna. However, for aperture type antenna like horns, parabolic dishes, the effective aperture is equal to the physical aperture weighted by the aperture field distribution.

- Since the directivity of the Hertz dipole is 1.5, its effective aperture is

$$A_e = \frac{D\lambda^2}{4\pi} = \frac{1.5\lambda^2}{4\pi} = 0.12\lambda^2$$

- **Note that the effective aperture of a Hertz dipole is independent of its length.**

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Recap

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