Antenna parameters

Radio antennas have a two-fold function. The first of these functions is to 'radiate' the RF energy that is generated in the transmitter and guided to the antenna by the Tx-line. In this capacity the antenna acts as an impedance-transforming device to match the impedance of the Tx-line to that of free space. The other function of the antenna is to direct the energy into desired directions, and what is often more important, to suppress the radiation in other directions where it is not wanted.

A completely non-directional radiator radiates uniformly in all directions and is known as an Isotropic radiator.

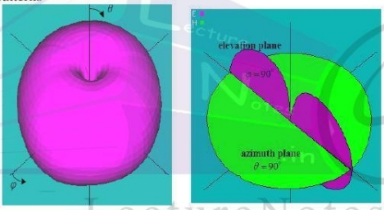
Ex: A point source of sound is an example of an isotropic radiator in Acoustics.

* There is no such thing as an isotropic radiator of electromagnetic energy, since all radio antennas have some directivity. However, it is useful, especially for gain comparison purposes. So Isotropic antenna is used as reference antenna. But it doesn't exist anywhere (hypothetical antenna).

ckt quantities	physical quantities	space quantities
• Antenna Impedance, Z_A	• size	• Field pattern $\left\{\begin{array}{l} E_\theta \\ E_\phi \\ \delta \end{array}\right. \left\{\begin{array}{l} (\theta,\phi) \\ (\theta,\phi) \\ (\theta,\phi) \end{array}\right.$
• Radiation resistance, R_r	• weight	• polarization
• Antenna Temperature, T_A		• power pattern $P_n(\theta,\phi)$
		• Beam Area, Ω_A
		• Directivity, D
		• Gain, G
		• Effective Apperture, A_e

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

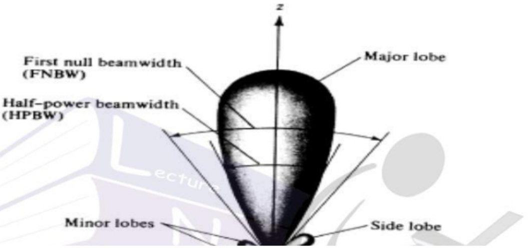
Half power level occurs at those angles $(\theta,\Phi)$for which $E_\theta(\theta,\Phi)_n = 0.707$
At distance d>>λ and d>> size of the antenna, the shape of the field pattern is independent of the distance

$$_n = \frac{S(\theta,\phi)}{S(\theta,\phi)_{max}}$$

Normalized Power Pattern =

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 $(\theta,\Phi)$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.

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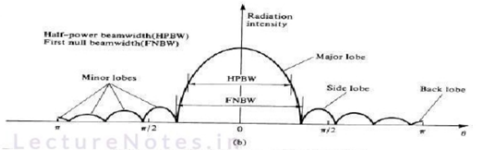


Pattern in Cartesian co-ordinate system

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 $0^\circ \leq \theta \leq 90^\circ$ Find the Half power beamwidth(HPBW)

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

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

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

$HPBW=2\theta=66^\circ$

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

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

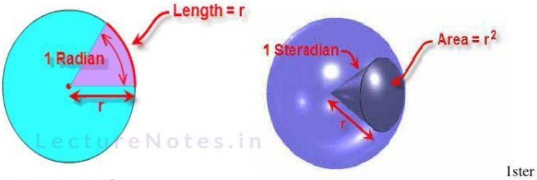
soln: In the x-y plane, $\theta=\pi/2$ and power pattern is given by $U(\pi/2,\Phi)=\sin\Phi$

- Therefore half power points are at $\sin\Phi=0.5$, i.e., at $\Phi=30^\circ$ and $\Phi= 150^\circ$
- Hence 3dB beamwidth in x-y plane is $(150-30)=120^\circ$
- 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 $\theta =45^\circ$ and $\theta =135^\circ$
- Hence 3dB beamwidth in y-z plane is $(135-45)= 90^\circ$

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



steadian= $(1\text{radian})^2$
$= (180/\pi)^2$
$=$ 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 $0^\circ \leq \theta \leq 90^\circ$. Find the Beam area of the pattern. Also find Approximate beam area using Half Power Beamwidths

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

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

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

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

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

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

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

4Π

$$\frac{1}{4\Pi}\int_0\int_0 P_n(\theta,\varphi)d\Omega$$

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

Directivity is the ratio of total solid angle of the sphere to beam solid angle. For antennas with rotationally symmetric lobes, the directivity D can be approximated as $D \approx \frac{4\pi}{\theta_{HP}\varphi_{HP}}$

- Directivity of isotropic antenna is equal to unity , for an isotropic antenna Beam area $\Omega A = 4\pi$
- Directivity indicates how well an antenna radiates in a particular direction in comparison with an isotropic antenna radiating same amount of power
- Smaller the beam area, larger is the directivity

Gain: Any physical Antenna has losses associated with it. Depending on structure both ohmic and dielectric losses can be present. Input power P_{in} is the sum of the Radiated power P_{rad} and losses P_{loss}

$$P_{in} = P_{rad} + P_{loss}$$

The Gain G of an Antenna is an actual or realized quantity which is less than Directivity D due to ohmic losses in the antenna. Mismatch in feeding the antenna also reduces gain The ratio of Gain to Directivity is the Antenna efficiency factor k(dimensionless)

$$\therefore G = kD$$

$$0 \le k \le 1$$

In practice, the total input power to an antenna can be obtained easily, but the total radiated power by an antenna is actually hard to get. The *gain of an antenna is introduced to solve* this problem. This is defined as the ratio of the radiation intensity in a given direction from the antenna to the total input power accepted by the antenna divided by 4π. *If the direction* is not specified, the direction of maximum radiation is implied. Mathematically, the gain (dimensionless) can be written as

$$G = \frac{4\pi U}{Pin}$$

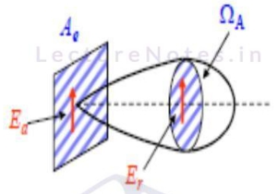
Directivity and Gain: Directivity and Gain of an antenna represent the ability to focus it's beam in a particular direction

Directivity is a parameter dependant only on the shape of radiation pattern while gain takes ohmic and other losses into account

Effective Aperture

Aperture Concept: Aperture of an Antenna is the area through which the power is radiated or received. Concept of Apertures is most simply introduced by considering a Receiving Antenna. Let receiving antenna be a rectangular Horn immersed in the field of uniform plane wave as shown

Ω_A, assuming uniform field E_a over the aperture, power radiated is $P = \frac{E_a^2}{z_0} A_e$



Assuming a uniform field E_r in far field at a distance r, Power Radiated is also given by $P = \frac{E_r^2}{z_0} r^2 \Omega_A$

Equating the two and noting that $E_r = E_a A_e / r\lambda$ we get Aperture –Beam area relation

$$\lambda^2 = A_e \Omega_A$$

At a given wavelength if Effective Aperture is known, Beam area can be determined or vice- versa

Directivity in terms of beam area is given by $D = \frac{4\Pi}{\Omega_A}$

Aperture and beam area are related by $\lambda^2 = A_e \Omega_A$

Directivity can be written as $D = \frac{4\Pi}{\lambda^2} A_e$

Other antenna equivalent areas :

Scattering area : *It is the area, which when multiplied with the incident wave power density, produces the re-radiated (scattered) power*

Loss area : *It is the area, which when multiplied by the incident wave power density, produces the dissipated (as heat) power of the antenna*

Capture area: It is the area, which when multiplied with the incident wave power density, produces the total power intercepted by the antenna.

Effective height

The effective height is another parameer related to the apertures. Multiplying the effective height, h_e(meters), times the magnitudeof the incident electric field E (V/m) yields the voltage V induced. Thus $V = h_e E$ or $h_e = V/E$ (m). Effective height provides an indication as to how much of the antenna is involved in radiating (or receiving. To demonstrate this, consider the current distributions a dipole antenna for two different lengths.

If the current distribution of the dipole were uniform, it's effective height would be *l* Here the current distribution is nearly sinusoidal with average value $2/\pi = 0.64$(of the maximum) so that it's effective height is 0.64*l* .It is assumed that antenna is oriented for maximum response.

If the same dipole is used at longer wavelength so that it is only 0.1λ long, the current tapers almost linearly from the central feed point to zero at the ends in a triangular distribution. The average current is now 0.5 & effective height is 0.5*l*