ANTENNA PATTERN CHARACTERISTICS

To describe the performance of an antenna, definitions of various parameters are necessary. Some of the parameters are interrelated and not all of them need be specified for complete description of the antenna performance.

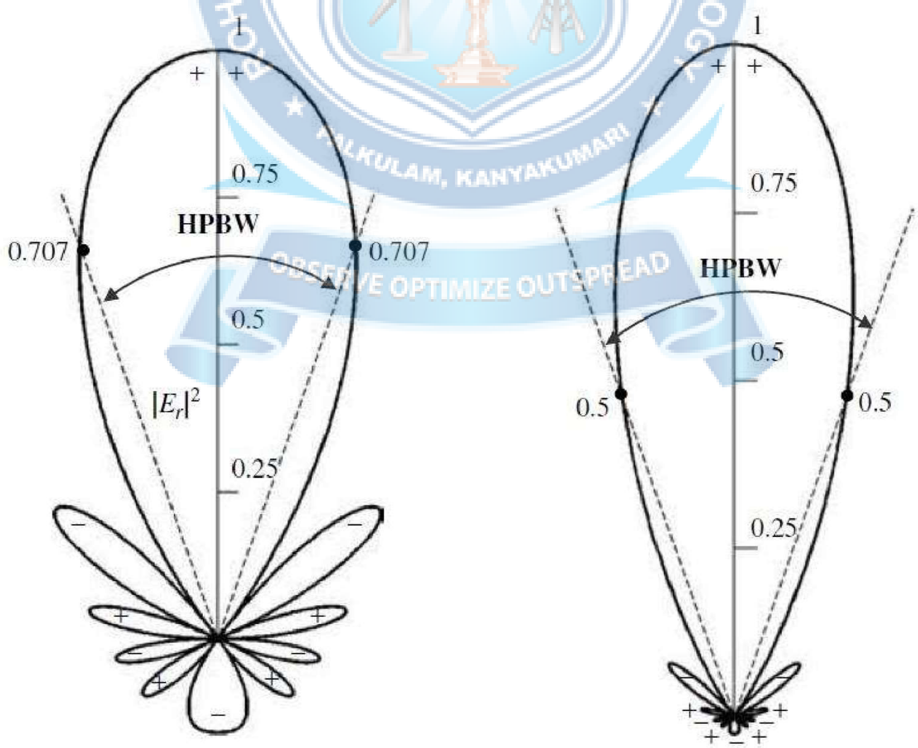
5.1 Radiation Pattern

Definition: "a mathematical function or a graphical representation of the radiation properties of the antenna as a function of space coordinates. In most cases, the radiation pattern is determined in the far field region and is represented as a function of the directional coordinates. Radiation properties include power flux density, radiation intensity, field strength, directivity, phase or polarization."

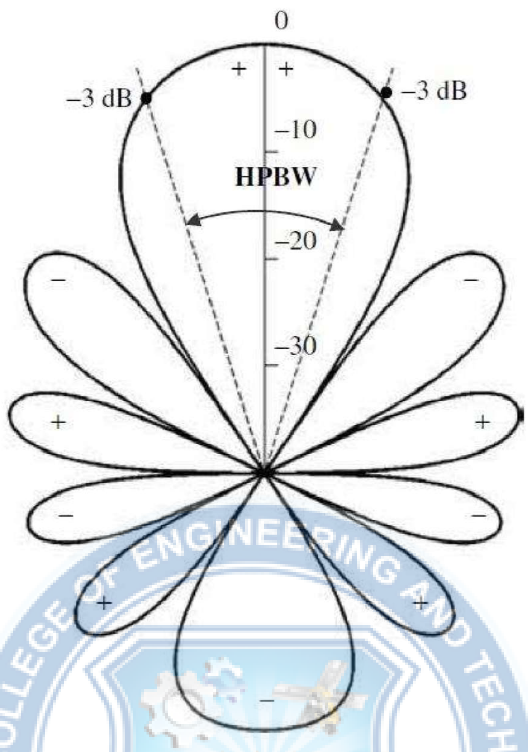
a. *field* pattern(*in linear scale*) typically represents a plot of the magnitude of the electric or magnetic field as a function of the angular space.

b. *power* pattern(*in linear scale*) typically represents a plot of the square of the magnitude of the electric or magnetic field as a function of the angular space.

c. *power* pattern(*in dB*) represents the magnitude of the electric or magnetic field, in decibels, as a function of the angular space.



(a) Field pattern (in linear scale) (b) Power pattern (in linear scale)



(c) Power pattern (in dB)

Figure 1.13 Two-dimensional normalized field pattern(linear scale), power pattern(linear scale), and power pattern(in dB)

5.1.1 Radiation Pattern Lobes

Various parts of a radiation pattern are referred to as *lobes*, which may be subclassified into *major* or *main, minor, side*, and *back* lobes.

A ***radiation lobe*** is a "portion of the radiation pattern bounded by regions of relatively weak radiation intensity."

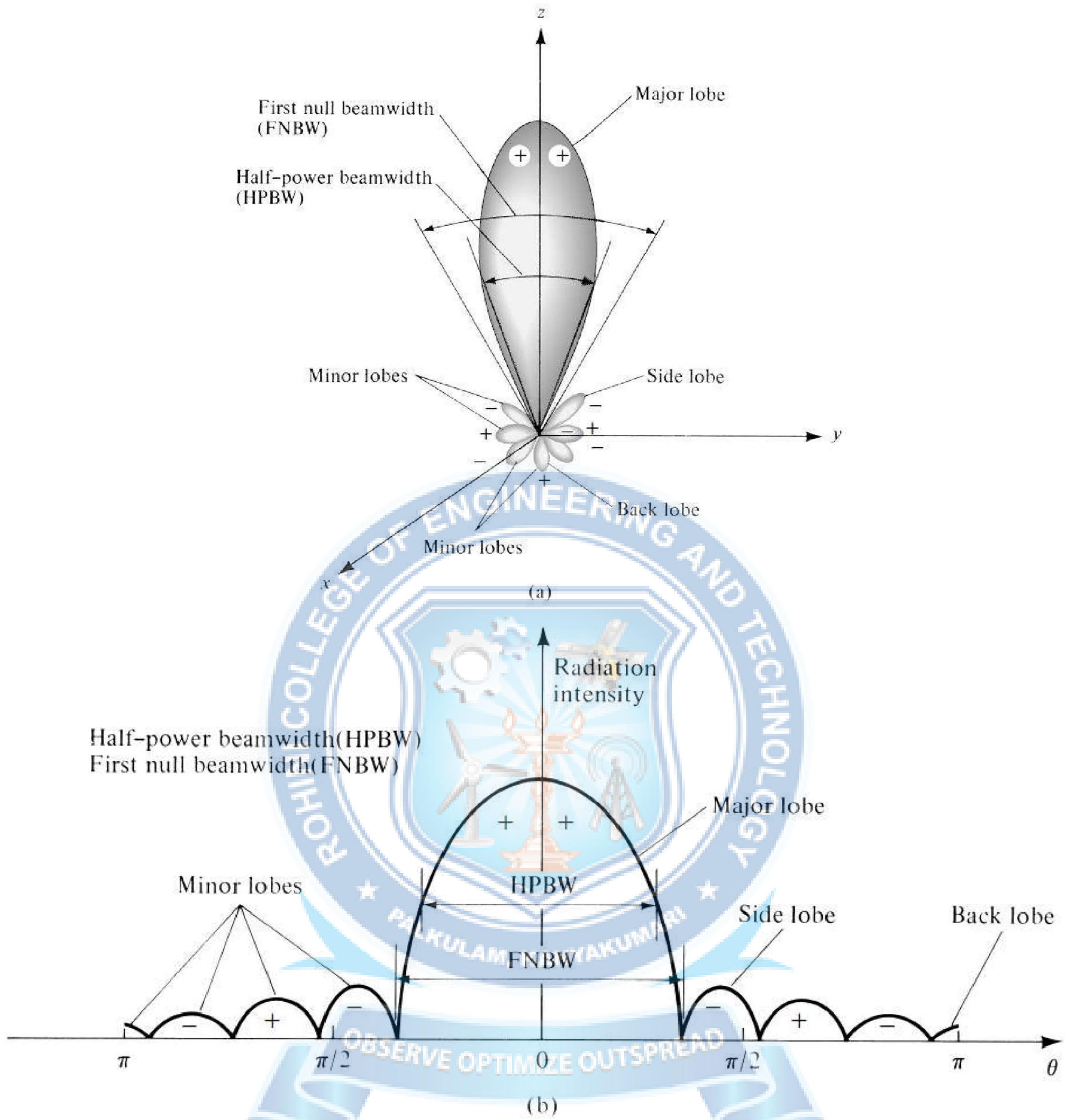


Figure 1.14 (a) Radiation lobes and beamwidths of an antenna pattern. (b) Linear plot of power pattern and its associated lobes and beamwidths.

5.1.2 Isotropic, Directional, and Omnidirectional Patterns

Isotrophic - "a hypothetical lossless antenna having equal radiation in all directions."

Directional Antenna - "having the property of radiating or receiving electromagnetic waves more effectively in some directions than in others. This term is usually applied to an antenna whose maximum directivity is significantly greater than that of a half-wave dipole."

Omnidirectional Antenna - "having an essentially nondirectional pattern in a given plane (in this case in azimuth) and a directional pattern in any orthogonal plane (in this case in elevation)."

5.1.3 Principal Patterns

E Plane - "the plane containing the electric field vector and the direction of maximum radiation,"

H Plane - "the plane containing the magnetic-field vector and the direction of maximum radiation."

5.1.4 Field Regions

The space surrounding an antenna is usually subdivided into three regions:

(a) reactive near-field

(b) radiating near-field (Fresnel)

(c) far-field (Fraunhofer) regions

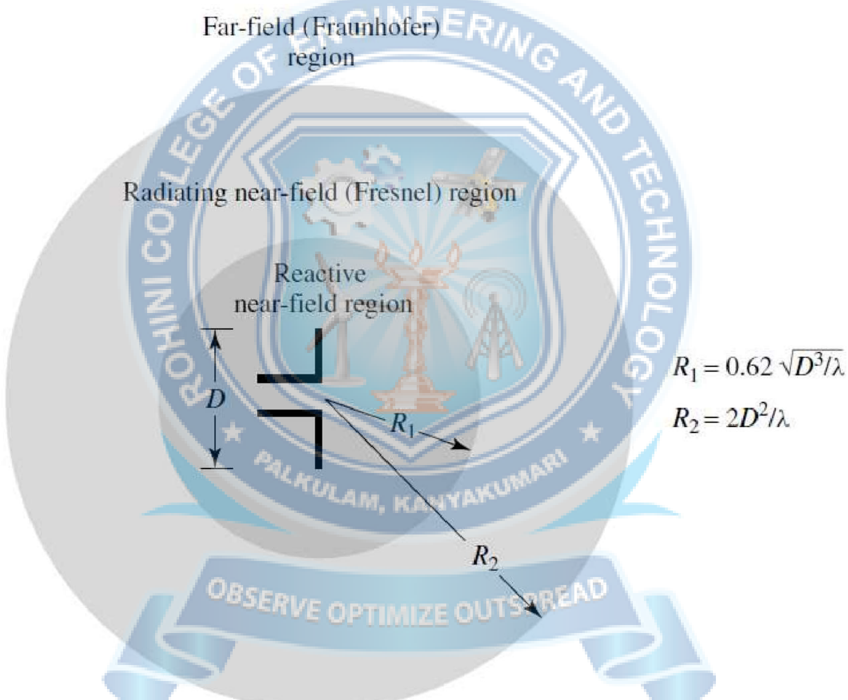


Figure 1.15 Field regions of an antenna.

Reactive near-field region: "that portion of the near-field region immediately surrounding the antenna wherein the reactive field predominates."

$$R < 0.62\sqrt{D^3/\lambda}$$

$$\lambda - Wavelength, D - Largest\ dimension\ of\ the\ Antenna$$

Radiating near-field (Fresnel) region: "that region of the field of an antenna between the reactive near-field region and the far-field region wherein radiation fields predominate and wherein the angular field distribution is dependent upon the distance from the antenna. If the antenna has a maximum dimension that is not large compared to the wavelength, this region may not exist. For an antenna focused at infinity, the radiating near-field region is sometimes referred to as the Fresnel region on the basis of analogy to optical terminology. If the antenna has a maximum overall dimension which is very small compared to the wavelength, this field region may not exist."

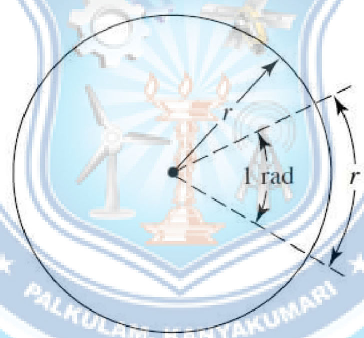
$$\text{Inner Boundary } R \geq 0.62\sqrt{D^3/\lambda}$$

$$\text{Outer Boundary } R < 2D^2/\lambda$$

Far-field (Fraunhofer) region: "that region of the field of an antenna where the angular field distribution is essentially independent of the distance from the antenna. If the antenna has a maximum∗ overall dimension D, the far-field region is commonly taken to exist at distances greater than $2D^2/\lambda$ from the antenna, λ being the wavelength."

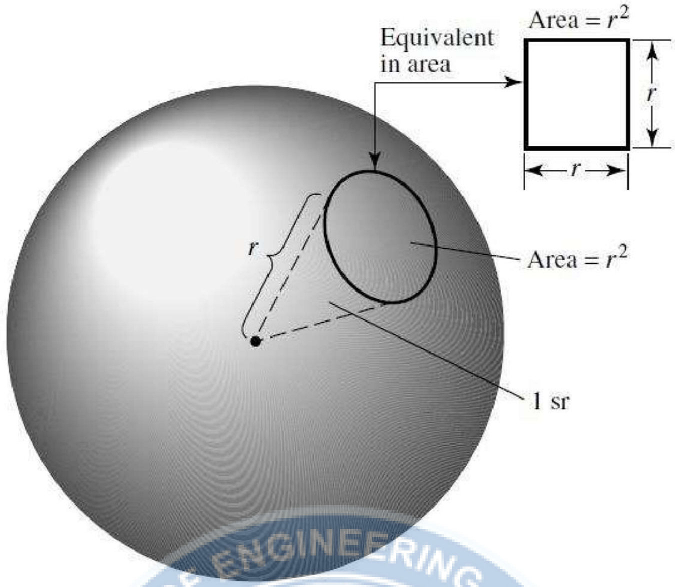
5.1.5 Radian and Steradian

One ***radian*** is defined as the plane angle with its vertex at the center of a circle of radius *r* that is subtended by an arc whose length is *r*.



(a) Radian

One ***steradian*** is defined as the solid angle with its vertex at the center of a sphere of radius *r* that is subtended by a spherical surface area equal to that of a square with each side of length *r*.



(b) Steradian

5.2 Radiation Power Density

Electromagnetic waves are used to transport information through a wireless medium or a guiding structure, from one point to the other. It is then natural to assume that power and energy are associated with electromagnetic fields. The quantity used to describe the power associated with an electromagnetic wave is the instantaneous Poynting vector defined as

$$W = E * H$$

$$W - \text{instantaneous Poynting vector } (W/m^2)$$

$$E - \text{instantaneous electric} - \text{field intensity } (V/m)$$

$$H - \text{instantaneous magnetic} - \text{field intensity } (A/m)$$

5.3 Radiation Intensity

Definition: "the power radiated from an antenna per unit solid angle."

$$U = r^2 W_{rad}$$

$$U - Radiation\ Intensity\ (\frac{W}{unit}solid\ angle)$$

$$W_{rad} - Radiation\ Intensity\ (\frac{W}{m^2})$$

5.4 Beamwidth

Beamwidth: **"**the angular separation between two identical points on opposite side of the pattern maximum."

Half-Power Beamwidth (HPBW): "In a plane containing the direction of the maximum of a beam, the angle between the two directions in which the radiation intensity is one-half value of the beam."

5.5 Directivity

Definition: "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 power radiated by the antenna divided by 4π. If the direction is not specified, the direction of maximum radiation intensity is implied."

$$D = \frac{U}{U_o} = \frac{4\pi U}{P_{rad}}$$

If the direction is not specified, it implies the direction of maximum radiation intensity (maximum directivity) expressed as

$$D_{max} = D_o = \frac{U_{max}}{U_o} = \frac{4\pi U_{max}}{P_{rad}}$$

$$D - Directivity\ (dimensionless)$$

$$D_o - maximum\ directivity\ (dimensionless)$$

$$U - radiation\ intensity\ (\frac{W}{unit} solid\ angle)$$

$$U_{max} - maximum\ radiation\ intensity\ \left(\frac{W}{unit} solid\ angle\right)$$

$$U_o - \text{radiation intensity of isotropic source}\ (\frac{W}{unit} solid\ angle)$$

$$P_{rad} - total\ radiated\ power\ (W)$$

5.6 Antenna Efficiency

The total antenna efficiency e_o is used to consider losses at the input terminals and within the structure of the antenna. Such losses may be due

1. reflections because of the mismatch between the transmission line and the antenna
2. I^2R losses (conduction and dielectric)

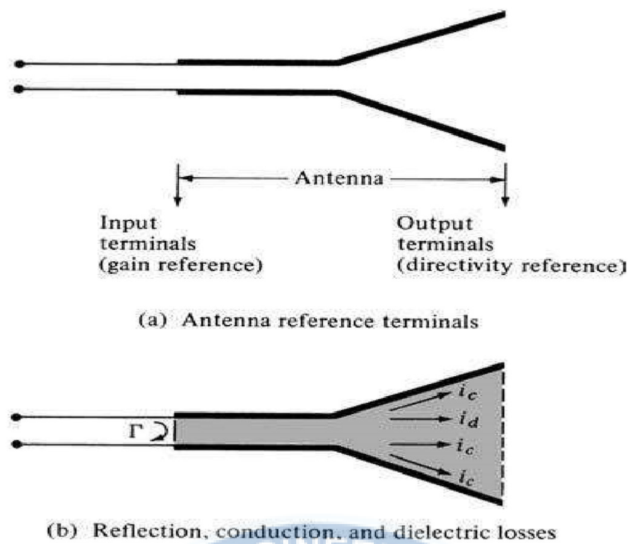


Figure 1.16 Reference terminals and losses of an antenna.

In general, the overall efficiency can be written as

$$\boldsymbol{e_0 = e_r e_c e_d}$$

Where

$$e_o - total\ efficiency\ (dimensionless)$$

$$e_r - reflection\ (mismatch) efficiency\ (dimensionless)$$

$$e_c - conduction\ efficiency\ (dimensionless)$$

$$e_d - dielectric\ efficiency\ (dimensionless)$$

$$\Gamma - Voltage\ reflection\ coefficient\ at\ the\ input\ terminals\ of\ the\ antenna$$

$$[\Gamma = (Z_{in} - Z_o)/(Z_{in} + Z_o)]$$

$$Z_{in} - Antenna\ Input\ Impedance$$

$$Z_o - Characteristic\ impedance\ of\ the\ transmission\ line$$

$$VSWR = Voltage\ Standing\ Wave\ Ratio = \frac{1 + |\Gamma|}{1 - |\Gamma|}$$

5.7 Gain

Definition: "the ratio of the intensity, in a given direction, to the radiation intensity that would be obtained if the power accepted by the antenna were radiated isotropically. The radiation intensity corresponding to the isotropically radiated power is equal to the power accepted (input) by the antenna divided by 4π."

$$Gain = 4\pi \frac{radiation\ intensity}{total\ input\ (accepted)\ power} = 4\pi \frac{U(\theta, \phi)}{P_{in}}\ (dimensionless)$$

Relative Gain

Definition: "the ratio of the power gain in a given direction to the power gain of a reference antenna in its referenced direction."

$$G = \frac{4\pi U(\theta,\phi)}{P_{in}(Lossless\ isotrophic\ source)}\ (dimensionless)$$

When the direction is not stated, the power gain is usually taken in the direction of maximum radiation.

5.8 Beam Efficiency

For an antenna with its major lobe directed along the *z*-axis *(θ* = 0*)*, the beam efficiency (BE) is defined by

$$BE = \frac{\text{power transmitted (received) within cone angle}}{\text{power transmitted (received) by the antenna}}\ (dimensionless)$$

5.9 Bandwidth

Definition: "the range of frequencies within which the performance of the antenna, with respect to some characteristic, conforms to a specified standard."

5.10 Polarization

Polarization of an antenna in a given direction is defined as "the polarization of the wave transmitted (radiated) by the antenna.

Polarization of a radiated wave is defined as "that property of an electromagnetic wave describing the time-varying direction and relative magnitude of the electric-field vector; specifically, the figure traced as a function of time by the extremity of the vector at a fixed location in space, and the sense in which it is traced, *as observed along the direction of propagation*."

Polarization may be classified as

- Linear
- Circular
- Elliptical

"*Co-polarization* represents the polarization the antenna is intended to radiate (receive) while ***cross-polarization*** represents the polarization orthogonal to a specified polarization, which is usually the co-polarization."

5.10.1 Linear Polarization

A *time-harmonic wave is linearly polarized at a given point in space if the electric-field (or magnetic-field) vector at that point is always oriented along the same straight line at every instant of time*. This is accomplished if the field vector (electric or magnetic) possesses:

a. Only one component, or

g

b. Two orthogonal linear components that are in time phase or 180◦ (or multiples of 180◦) out-of-phase.

5.10.2 Circular Polarization

A time-harmonic wave is circularly polarized at a given point in space if the electric (or magnetic) field vector at that point traces a circle as a function of time.

The *necessary and sufficient* conditions to accomplish this are if the field vector (electric or magnetic) possesses *all* of the following:

a. The field must have two orthogonal linear components, and

b. The two components must have the same magnitude, and

c. The two components must have a time-phase difference of odd multiples of 90◦.

5.10.3 Elliptical Polarization

A time-harmonic wave is elliptically polarized if the tip of the field vector (electric or magnetic) traces an elliptical locus in space. At various instants of time the field vector changes continuously with time at such a manner as to describe an elliptical locus. It is right-hand (clockwise) elliptically polarized if the field vector rotates clockwise, and it is left-hand (counter clockwise) elliptically polarized if the field vector of the ellipse rotates counter clockwise.

A wave is elliptically polarized if it is not linearly or circularly polarized. Although linear and circular polarizations are special cases of elliptical, usually in practice elliptical polarization refers to other than linear or circular. The *necessary and sufficient* conditions to accomplish this are if the field vector (electric or magnetic) possesses *all* of the following:

a. The field must have two orthogonal linear components, and

b. The two components can be of the same or different magnitude.

c. (1) If the two components are not of the same magnitude, the time-phase difference between the two components must not be 0◦ or multiples of 180◦ (because it will then be linear). (2) If the two components are of the same magnitude, the time-phase difference between the two components must not be odd multiples of 90◦ (because it will then be circular).