Antenna & Propagation

Antenna Parameters

by

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Chapter Synopsis

In this chapter, the student will be exposed to the parameters of antenna such as radiation pattern, impedance, directivity, gain, polarization and more.

Teaching Outcome

At the end of this chapter student should be able to:

- ❑ Characterize the fundamentals of antenna.
- ❑ Know how to calculate and analyzed the related antenna parameters.

Antenna Parameter (1)

- Frequency
- Radiation Pattern
- Field Regions
- Directivity
- Antenna Efficiency

Antenna Parameter (2)

- Antenna Gain
- Beamwidths and Sidelobes
- Radiation Intensity
- Polarization

Introduction

- To design an antenna... “We need to know what is the desired frequency, gain, bandwidth, impedance, and polarization?“

- Before we can design an antenna or discuss antenna types, we must understand the basics of antennas, which are the fundamental parameters that characterize an antenna.

- So let us learn something about antenna parameters. We'll start with frequency and step through radiation patterns, directivity and gain, and so on..

Let’s get started..

Frequency (*f*)

- The basics of sinusoids are wavelength, frequency and the speed of light.
- All electromagnetic waves propagate at the same speed in air or in space.
- The speed of light will be denoted as *c* in the equations that follow.
- While length measured in meters and time in seconds.
- The **wavelength (λ)** of an electromagnetic wave is related to its **frequency (*f*)** by:

$$\lambda = \frac{c}{f}$$

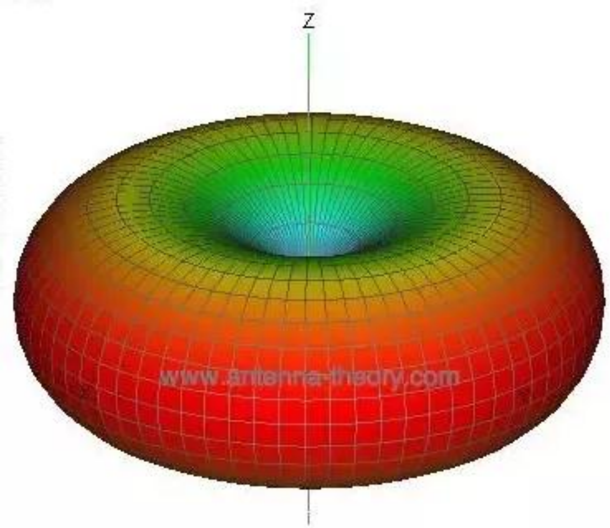
Where; $c = 3x10^8\ m/s$ (speed of light in vacuum)

λ = wavelength in meter

f = frequency in Hz or 1/s

Radiation Pattern

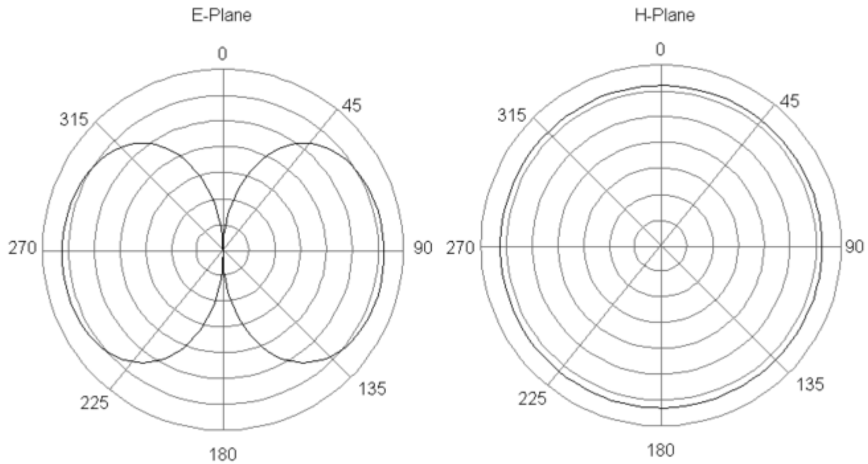
- Radiation pattern provide information that describe how an antenna directs the energy it radiates.
- It determine in the far field region.
- Figure here shows the radiation pattern in 3-D for dipole antenna.



Source: www.antenna-theory.com

Radiation Pattern (2)

- Figure below shows the radiation pattern in 2-D for dipole in E-Plane and H-Plane.
- Normalised radiation pattern can be plotted in:
  - polar and rectangular (Cartesian) plots.
  - linear (ratio) and logarithmic (dB) scales.



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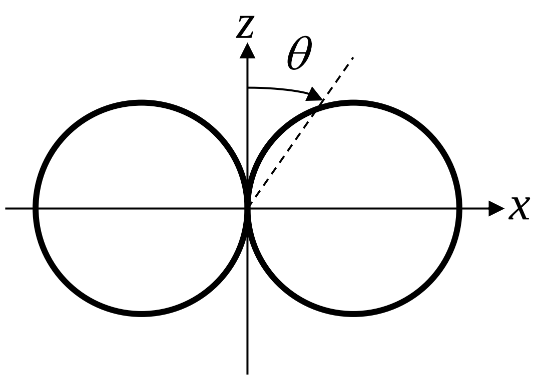
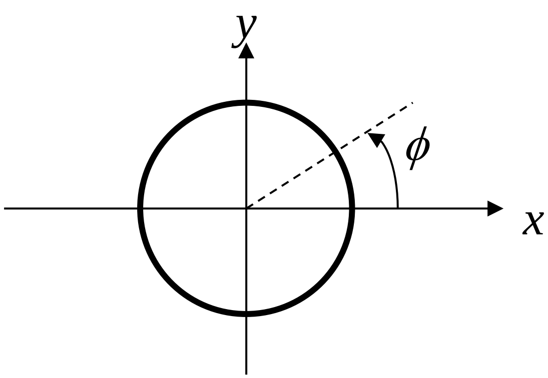
E-Plane and H-Plane

E plane (elevation)	H plane (azimuth)
• Electromagnetic field is in vertical plane	• Electromagnetic field is in horizontal plane
• $\theta = 90°$	• $0° < \theta < 180°$
• $0° < \Phi < 90°$, $270° < \Phi < 360°$	• $\Phi = 0°$



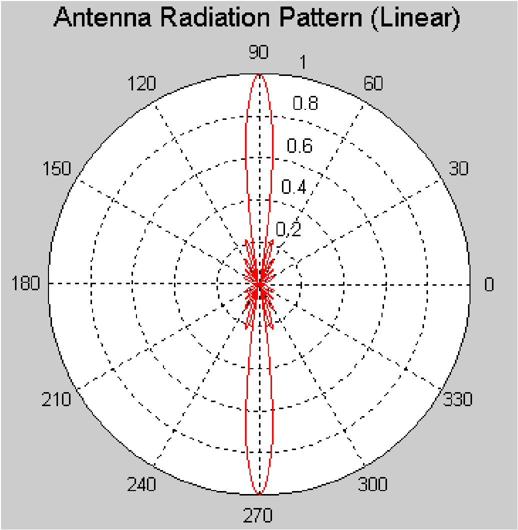
E-plane

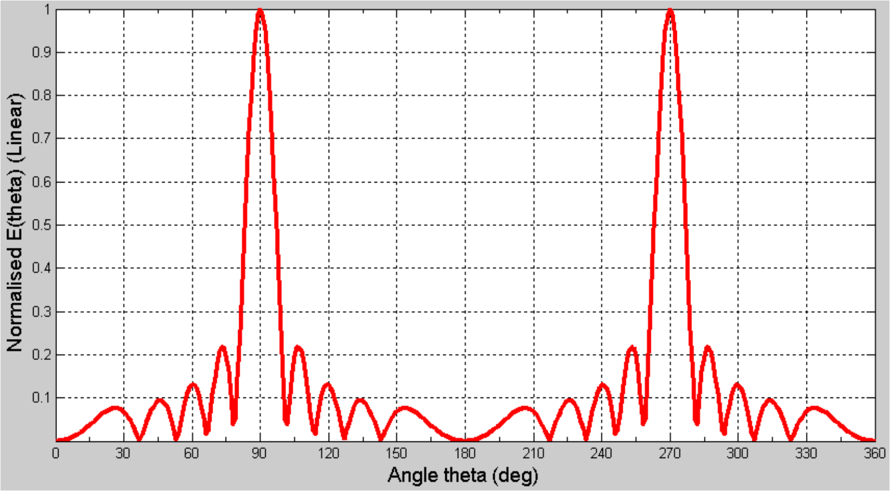


H-plane

Polar and Rectangular (Cartesian) Plots

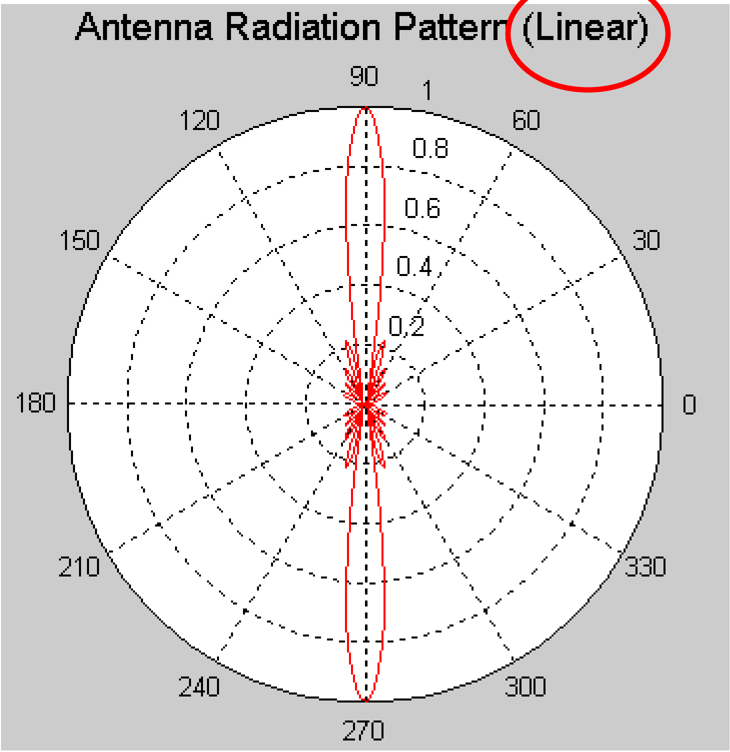
- Figure below shows the plots of radiation pattern in Polar and Cartesian.

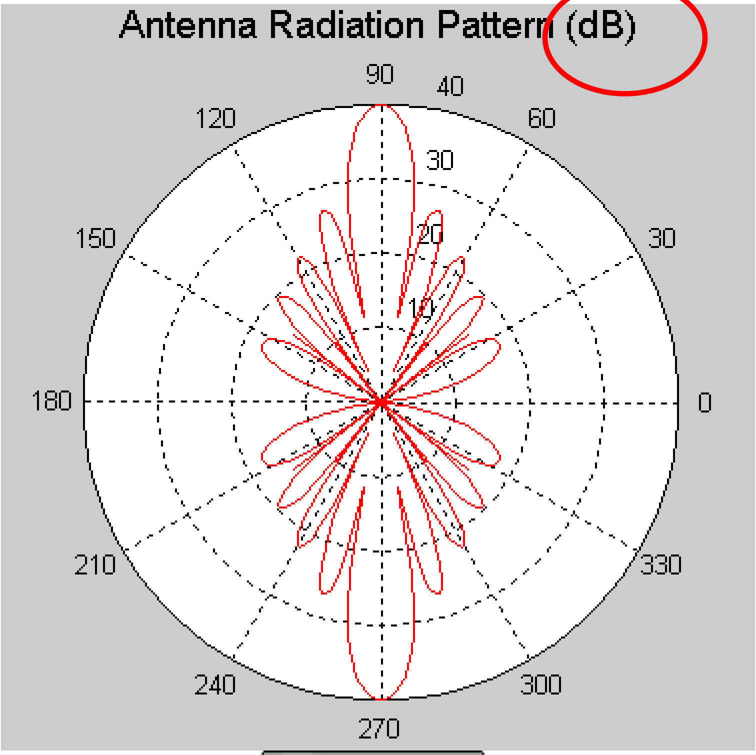




Linear (ratio) and Logarithmic (dB) Scales

- Figure below shows the polar plot radiation pattern in Linear and in Logarithmic scales





Field Regions

The fields surrounding an antenna are divided into 3 principle regions:

Distance

$0.62\sqrt{\frac{D^3}{\lambda}}$

- Reactive Near Field

$2D^2/\lambda$

- Radiating Near Field or Fresnel Region

$> 2D^2/\lambda$

- Far Field or Fraunhofer Region

Note: The far field region is the most important, as this determines the antenna's radiation pattern.

Radiation Intensity (U)

- Radiation intensity in a given direction is defined as the power radiated from an antenna per unit solid angle.
- The radiation intensity is a far-field parameter.
- Total Prad, Radiated Power (in Watt) Using U, Radiation Intensity (in w/sr) is obtained by integrating the radiation intensity over the entire solid angle of 4π. Thus,

$$P_{rad} = \iint U d\Omega = \int_0^{\pi} \int_0^{2\pi} U \sin\theta d\theta d\Phi$$

where dΩ is the element of solid angle = sinθdθdϕ (in sr)

Directivity

- It is a measure of how 'directional' an antenna's radiation pattern is.
- The ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions.

$$D(unitless) = D(\theta, \Phi) = \frac{U(\theta, \Phi)}{U_0} = \frac{4\pi U(\theta, \Phi)}{P_{rad}}$$

- If the direction is not specified, the direction of maximum radiation intensity is implied.

$$D_{max}(unitless) = D_{o=} \frac{U}{U_0} = \frac{U_{max}}{U_0} = \frac{4\pi U_{max}}{P_{rad}}$$

Antenna Efficiency

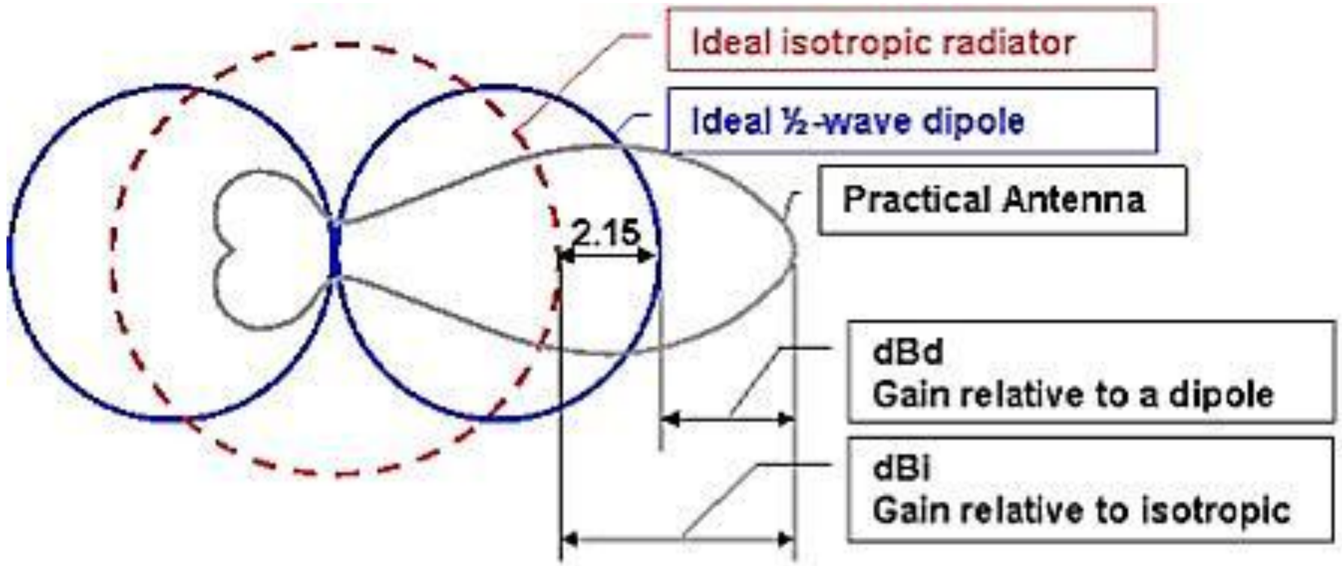
- The efficiency of an antenna is a ratio of the power delivered to the antenna relative to the power radiated from the antenna.
- A **high efficiency** antenna has most of the power present at the antenna's input radiated away.
- A **low efficiency** antenna has most of the power absorbed as losses within the antenna, or reflected away due to impedance mismatch.
- The antenna efficiency (or radiation efficiency) can be written as the ratio of the radiated power to the input power of the antenna:

$$\eta = \frac{P_r}{P_t} \quad \frac{\text{(Radiated power)}}{\text{(Transmitted power)}}$$

- Antenna efficiency is a range number between 0 and 1. And commonly antenna efficiency is presented in terms of a percentage.

Antenna Gain

- The gain shows how much power is transmitted in the direction of peak radiation to that of an isotropic source.
- Therefore, the gain of an antenna referenced to an isotropic radiator is G(dBi) = G(dBd) + 2.15 dB



Units for Antenna Gain

- dB – decibels. Ex: 10 dB means 10 times the energy relative to an isotropic antenna in the peak direction of radiation.

- dBi - "decibels relative to an isotropic antenna". This is the same as dB as we have been using it. 3 dBi means twice the power relative to an isotropic antenna in the peak direction.

- dBd - "decibels relative to a dipole antenna". Note that a half-wavelength dipole antenna has a gain of 2.15 dBi. Hence, 7.85 dBd means the peak gain is 7.85 dB higher than a dipole antenna; this is 10 dB higher than an isotropic antenna.

Directivity and Gain

- Directive Gain: $D(\theta,\phi)$ or $G_D(\theta,\phi)$
- Directivity: D

Antenna	D (ratio)	D (dB)
isotropic	1	0
Hertzian dipole	1.5	1.76
λ/2 dipole	1.64	2.15

$$G = \eta D$$

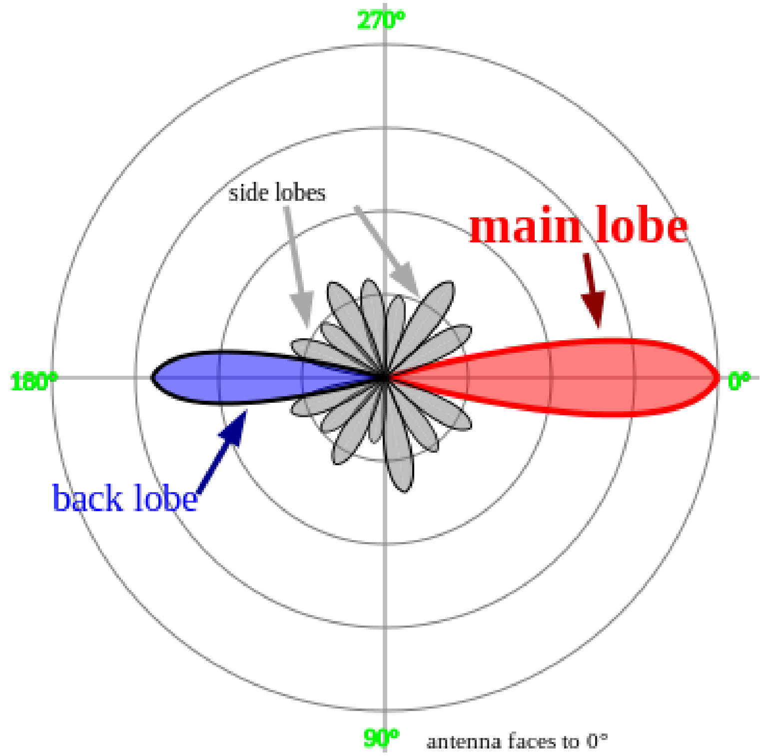
G = *gain*

D = *Directivity (dimensionless)*

η = *antenna efficiency*

Beamwidths and Sidelobes

- Figure below shows the sidelobes of antenna radiation pattern.



Source: https://commons.wikimedia.org

Sidelobes

Major Lobe

- containing the direction of maximum radiation. The major lobe is pointing in the $\vartheta = 0$ direction. In some antennas, there may exist more than one major lobe.

Minor Lobe

- any lobe except a major lobe. Minor lobes usually represent radiation in undesired directions, and they should be minimized.

Side Lobes

- Usually a side lobe is adjacent to the main lobe. Side lobes are normally the largest of the minor lobes.

Back Lobe

- an angle of approximately 180◦ with respect to the beam of an antenna. Usually it refers to a minor lobe in a direction opposite to that of the major lobe.

Beamwidths

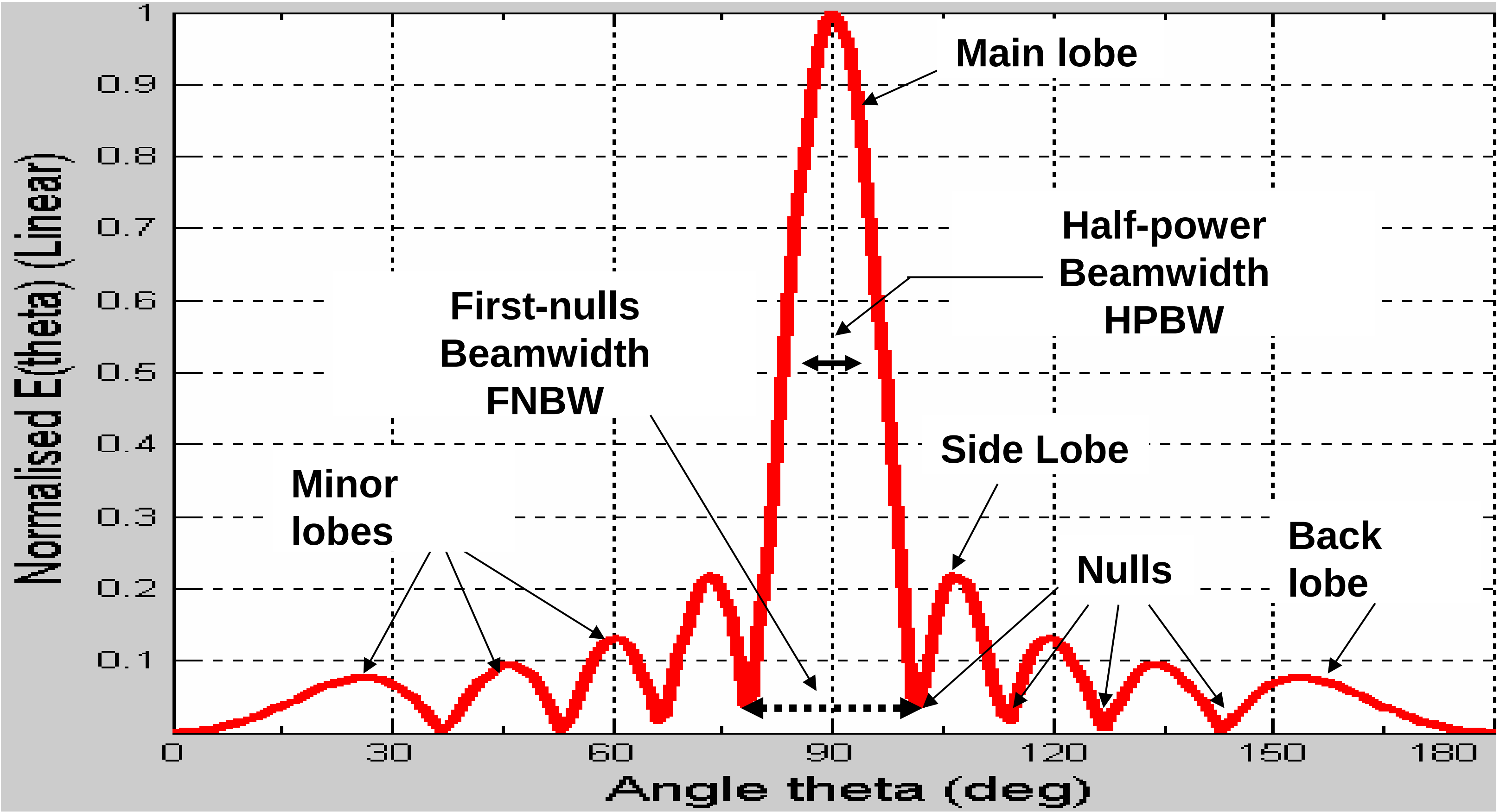
HPBW

- Half Power Beamwidth
- The angular separation in which the magnitude of the radiation pattern decrease by 50% (or -3 dB) from the peak of the main beam.

FNBW

- First Null Beamwidth
- The angular separation from which the magnitude of the radiation pattern decreases to zero (negative infinity dB) away from the main beam.

Figure of Beamwidths and Sidelobes



Polarization

- Defined as the direction of the ***electric field*** of an electromagnetic field.
- There are three (3) types of polarization:
  - Linear polarization: Vertical and Horizontal
  - Circular polarization: left handed circular (LHC) and right handed circular (RHC)
  - Elliptical polarization

Concept of Polarization

- A horizontally polarized antenna will **not** communicate with a vertically polarized antenna.
- Due to the reciprocity theorem, antennas transmit and receive in exactly the same manner.
- Hence, a vertically polarized antenna transmits and receives vertically polarized fields.
- Consequently, if anyhow a horizontally polarized antenna is trying to communicate with a vertically polarized antenna, there will be **no reception**.

References

[1] C.A. Balanis:"Antenna Theory: Analysis & Design", John Wiley & Sons, 2012.

[2] Stutzman and Thiele, *Antenna Theory and Design*, John Wiley, 2012.

[3] T. A. Milligan, "Modern Antenna Design" John Wiley, 2nd edition, 2005.

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