UEC747: ANTENNA AND WAVE PROPAGATION

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Lecture 11: Antenna Parameters

Dr Rajesh Khanna, Professor ECE

and

Dr Amanpreet Kaur, Assistant Professor, ECE

2.2 Radiation Pattern

Antenna (radiation) pattern

- A mathematical function or a graphical representation of the radiation properties of the antenna as a function of space coordinates.
- Determined in the far-field region
- Represented as a function of the directional coordinates.

Radiation properties

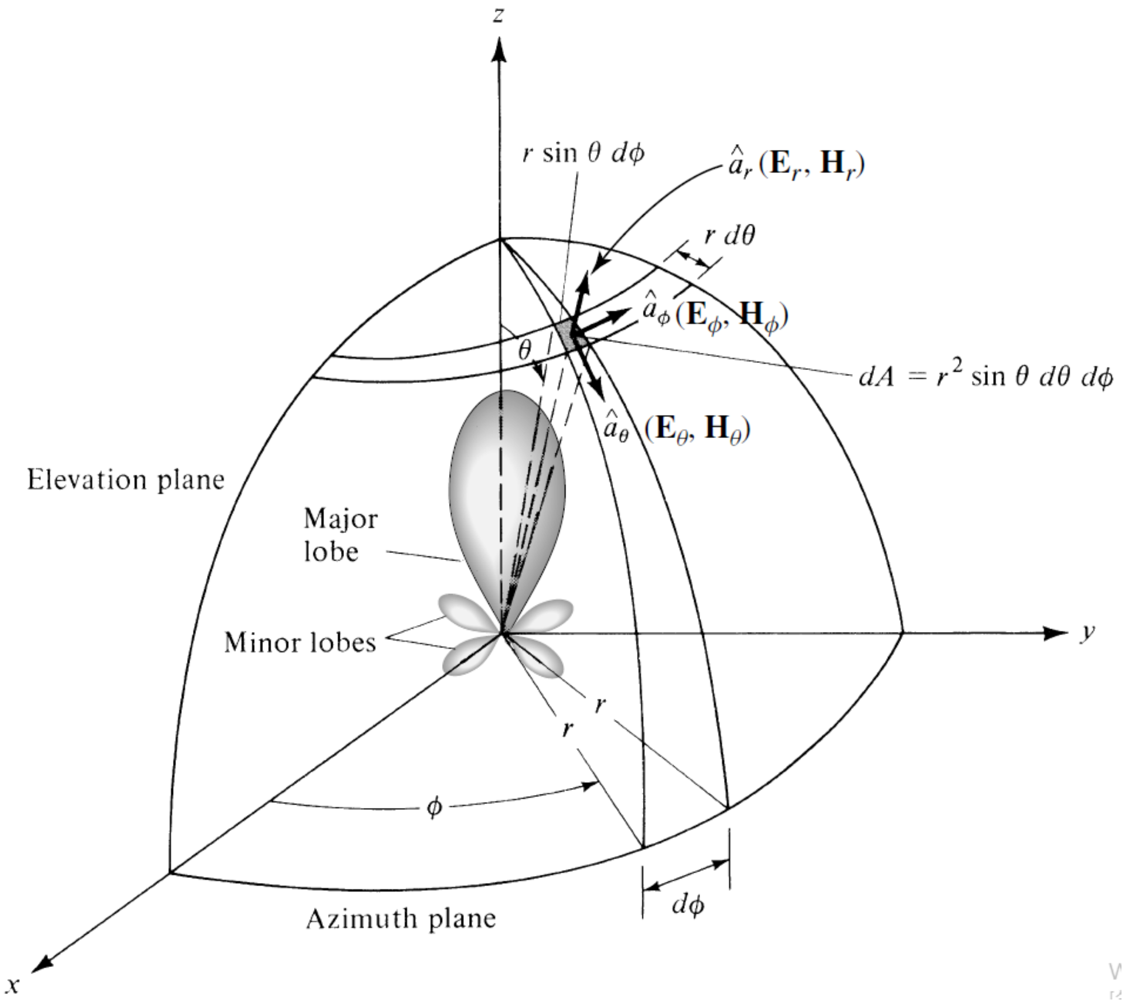
- power flux density
- Radiation intensity
- Field strength
- Directivity
- Phase
- Polarization
- The radiation property of most concern is the two- or three dimensional spatial distribution of radiated energy as a function of the observer's position along a path or surface of constant radius.

2.2 Radiation Pattern

An antenna radiation pattern is defined as "a mathematical function or a graphical representation of the radiation properties of the antenna as a function of space coordinates. (θ and ϕ).

In most cases, the radiation pattern is determined in the far field region.

Radiation properties include power flux density, radiation intensity, field strength, directivity, phase or polarization."



- **Field pattern** : E & H fields' magnitude (Linear scale. Angular Space)

- **Power pattern** : Square of magnitude's of E&H fields (Linear scale. Angular Space)

- **Power pattern** : Magnitude of E & H fields (dB scale)

Amplitude Radiation Pattern

- Field Pattern:

  A plot of the field (either electric $|\underline{E}|$ or magnetic $|\underline{H}|$) on a *linear* scale

- Power Pattern:

  A plot of the power (proportional to either the electric $|\underline{E}|^2$ or magnetic $|\underline{H}|^2$ fields) on a *linear* or *decibel (dB)* scale.

1.2 RADIATION PATTERN

- Amplitude Field pattern

  : A trace of the received electric (magnetic) field at a constant radius
- Amplitude Power pattern

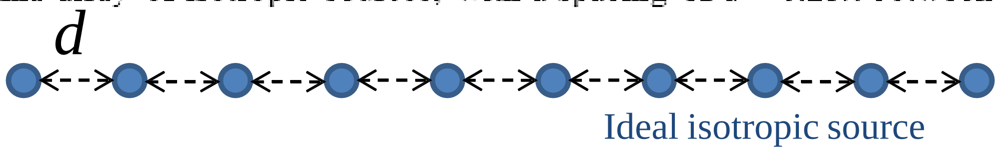
  : A graph of the spatial variation of the power density along a constant radius
- Often this patterns are normalized with respect to their maximum value.

- Power pattern is usually plotted on a logarithmic scale or more commonly in decibels (dB).

To demonstrate this three radiation pattern, the two-dimensional normalized field pattern (*plotted in linear scale*), power pattern (*plotted in linear scale*), and power pattern (*plotted on a logarithmic dB scale*) of a 10-element linear antenna array of isotropic sources, with a spacing of $d = 0.25\lambda$ between the elements, are shown in Figure 1.2. 1

free-space

Figure 1.2.1 10-element linear antenna array of isotropic sources, with a spacing of $d = 0.25\lambda$ between the elements



To find the points where the pattern achieves its half-power (−3 dB points), relative to the maximum value of the pattern, you set the value of

2-D Normalized *Field* $|E_n|$ Pattern of a Linear Array

(a) $\text{dB} = 20\log(x) = -3$

$$x = \frac{1}{\sqrt{2}} = 0.707$$

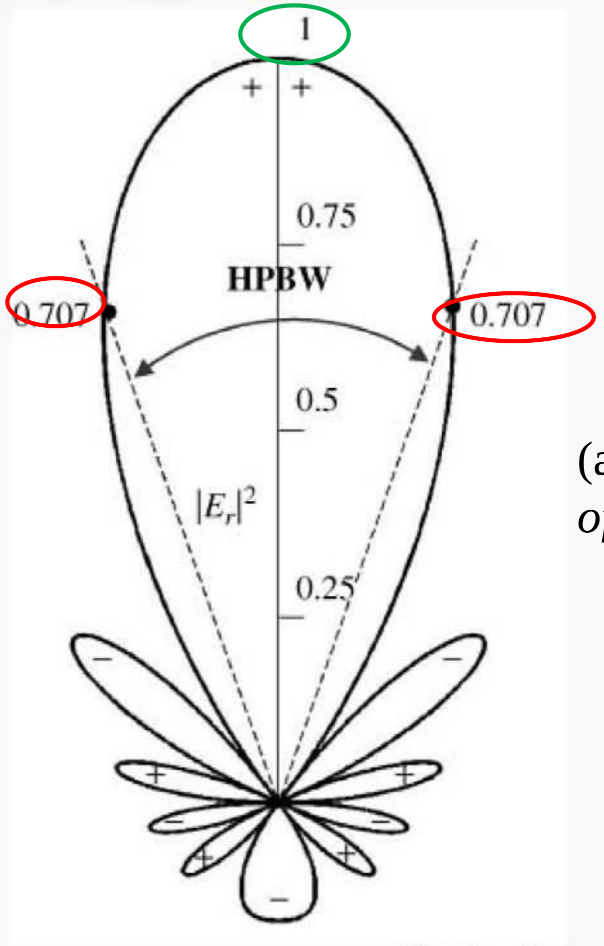
Linear Scale

$N = 10$ elements

$d = \lambda/4$ spacing

HPBW = 38.64°

Fig. 2.2(a)



(a) *the field pattern at 0.707 value of its maximum.*

2-D Normalized *Power* $|\underline{E}_n|^2$ Pattern of a Linear Arra

Linear Scale

$N = 10$ elements

$d = \lambda/4$ spacing

HPBW = 38.64°

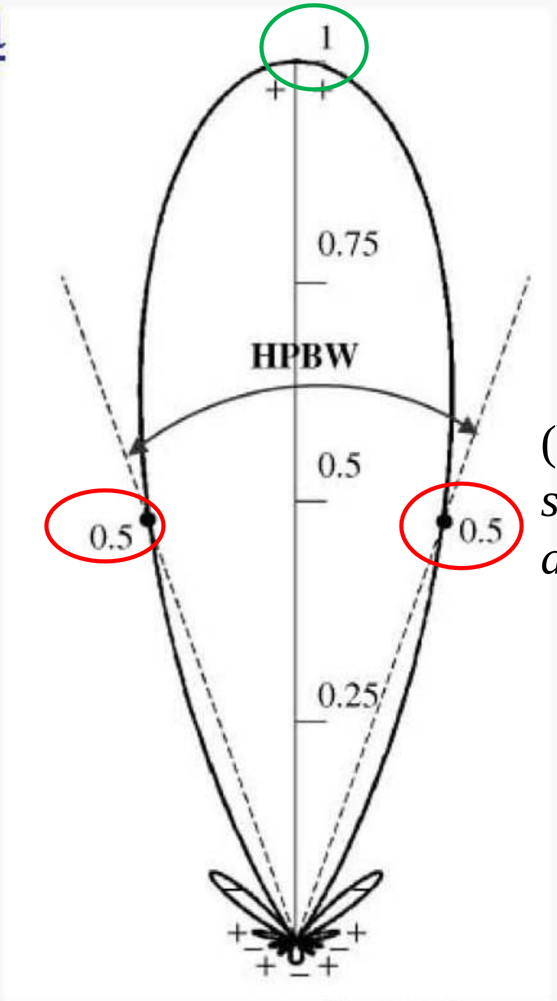


Fig. 2.2(b)

(b) $\text{dB} = 10\log(x) = -3$

$x = \frac{1}{2} = 0.5$

(b) *the power pattern (in a linear scale) at its* 0.5 value *of its maximum, as shown in Figure 1.2b;*

2-D Normalized *Power* $|E_n|^2$ Pattern of a Linear Array

HPBW = 38.64° at all the three patterns

(b) $\text{dB} = 10\log(x) = -3$

$x = \frac{1}{2} = 0.5$

dB Scale

$N = 10$ element

$d = \lambda/4$ spacing

HPBW = 38.64°

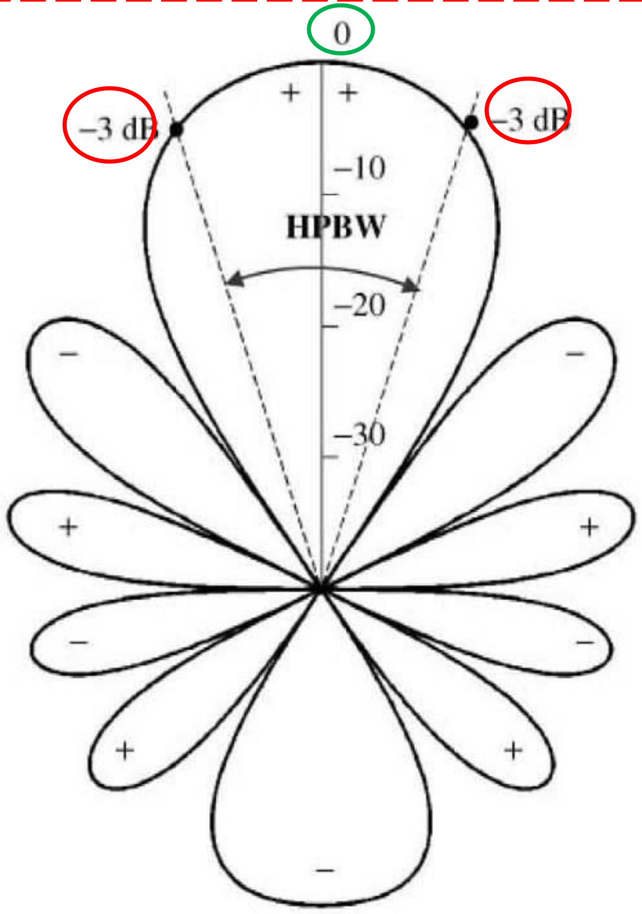


Fig. 2.2(c)

and (c) *the power pattern (in dB) at −3 dB value of its maximum.*

Polar Pattern

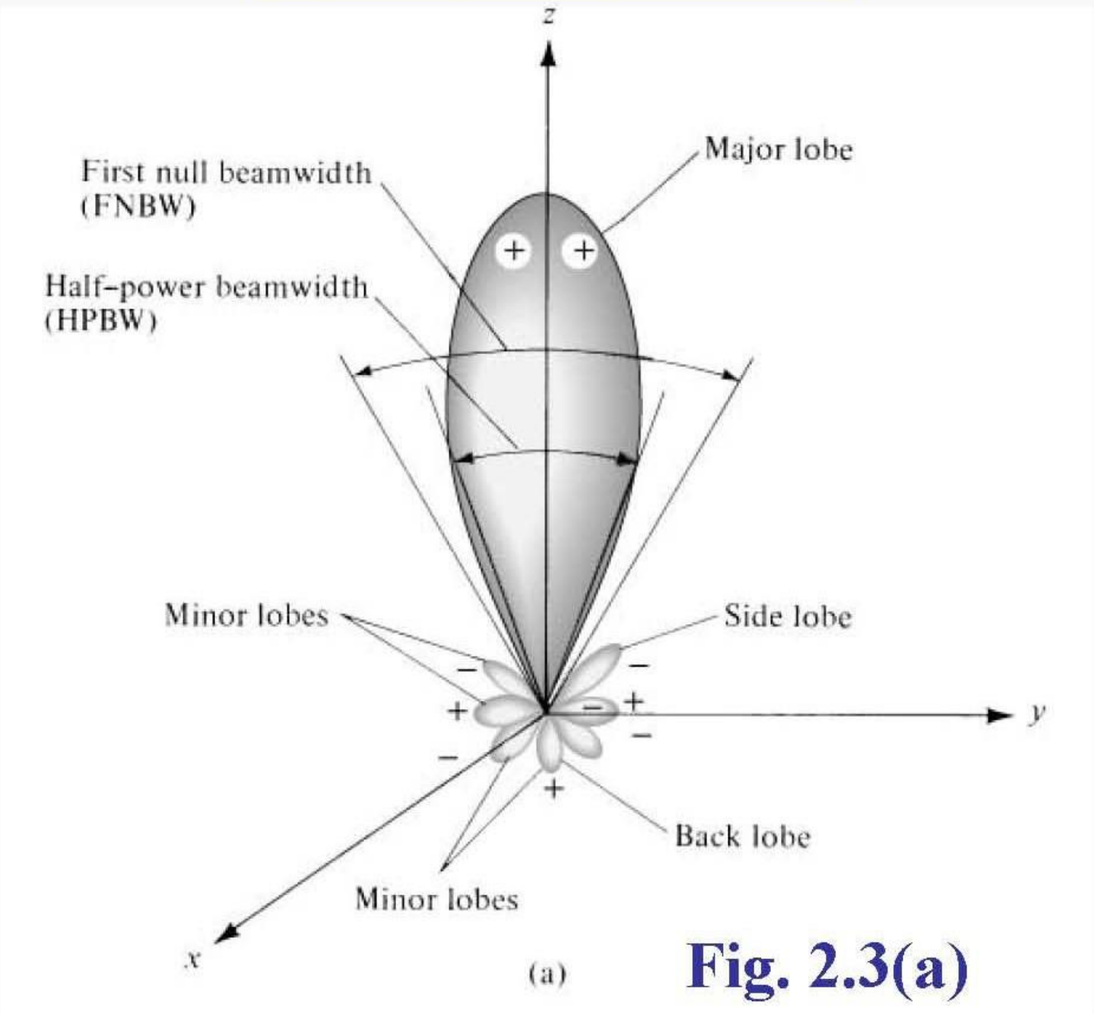


Fig. 2.3(a)

Linear Pattern

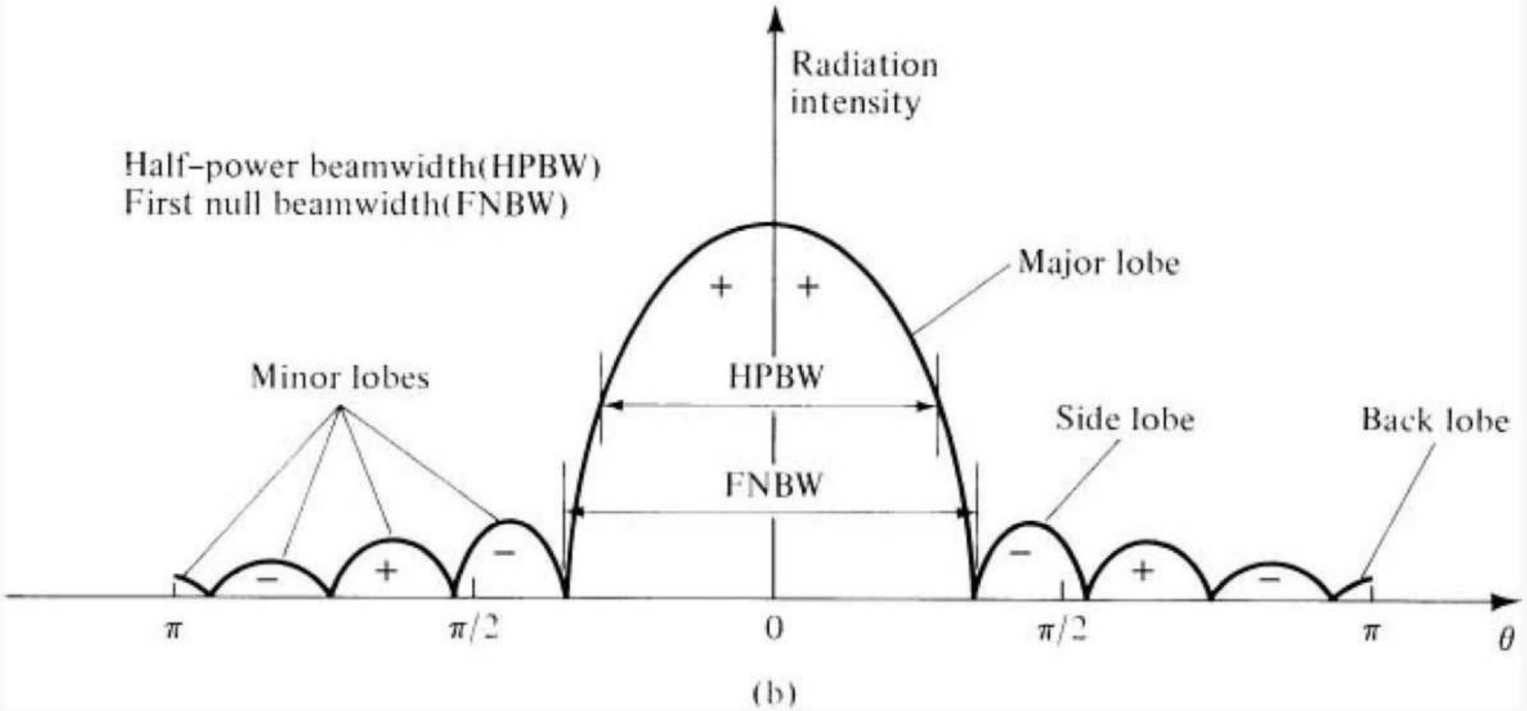
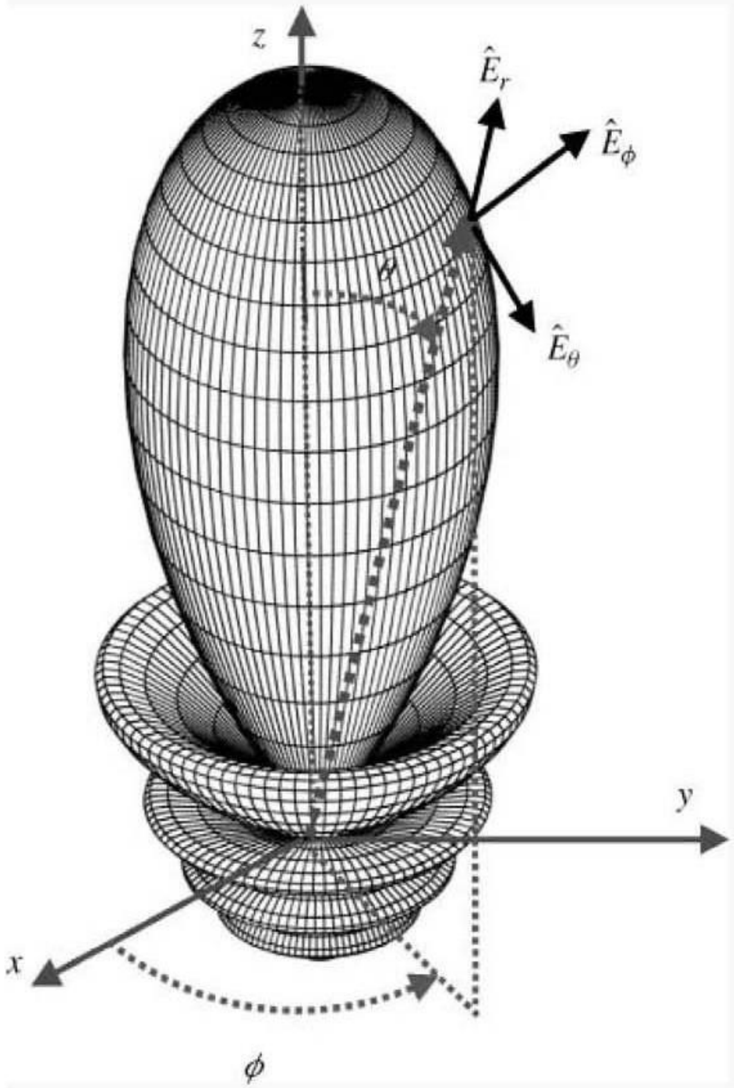


Fig. 2.3(b)



Normalized 3-D Amplitude *Field* Pattern of Linear Array

Linear Scale

$N = 10,\ d = \lambda/4$

$$\underline{E}(r,\theta,\phi)\,|_{r=r_c} = \hat{a}_r E_r(r_c,\theta,\phi) + \hat{a}_\theta E_\theta(r_c,\theta,\phi) + \hat{a}_\phi E_\phi(r_c,\theta,\phi)$$

$$|\,\underline{E}\,| = \sqrt{|\,E_r\,|^2 + |\,E_\theta\,|^2 + |\,E_\phi\,|^2}$$

Fig. 2.4

Amplitude Radiation Pattern

1. Isotropic,
   Directional,
   Omnidirectional
2. Principal patterns
3. Pattern lobes

1.2.2 Isotropic, Directional, and Omnidirectional Patterns

1) Isotropic pattern

- A hypothetical lossless antenna having equal radiation in all directions.
- Although it is ideal and not physically realizable, it is often taken as a reference for expressing the directive properties of actual antennas. Ex) dBi

2) Directional Pattern

- A directional antenna is one having the property of radiating or receiving electro-magnetic waves more effectively in some directions than in others.

Directional Pattern of a Horn

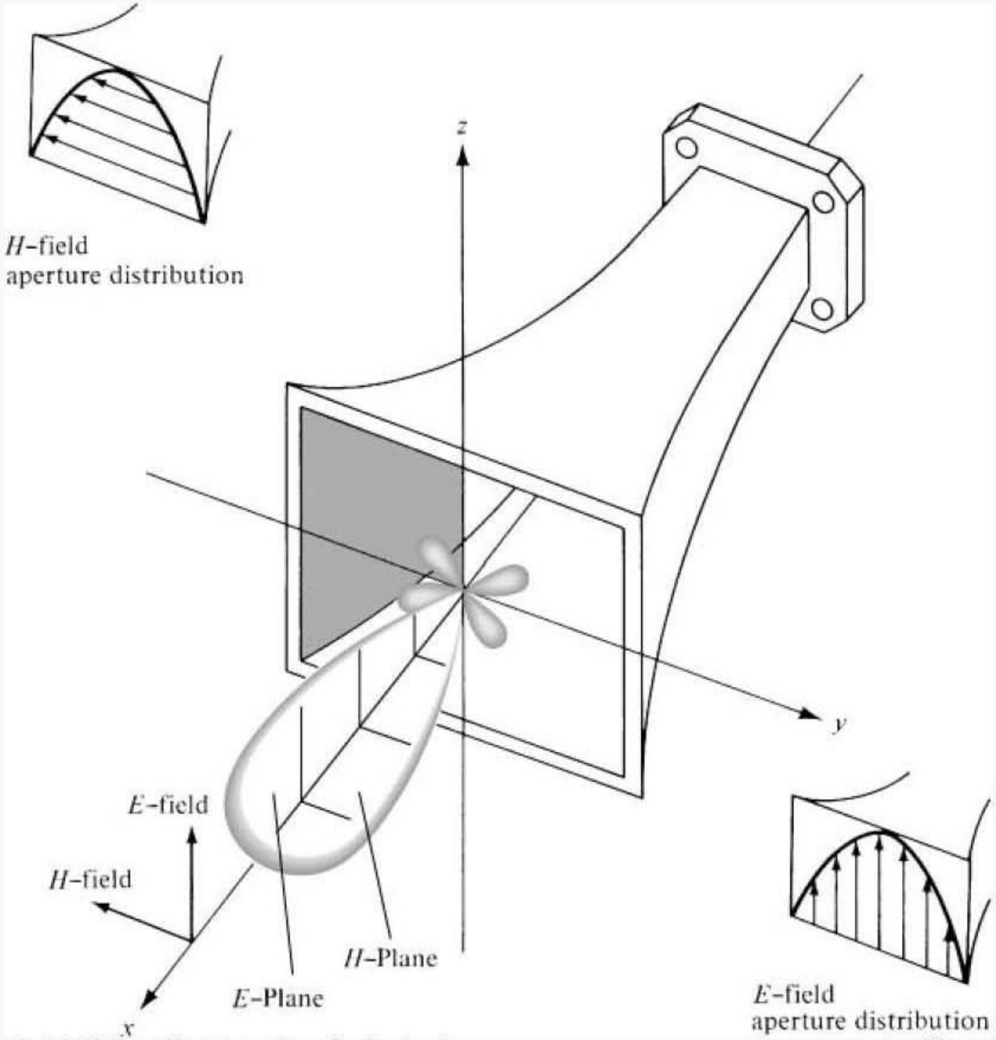
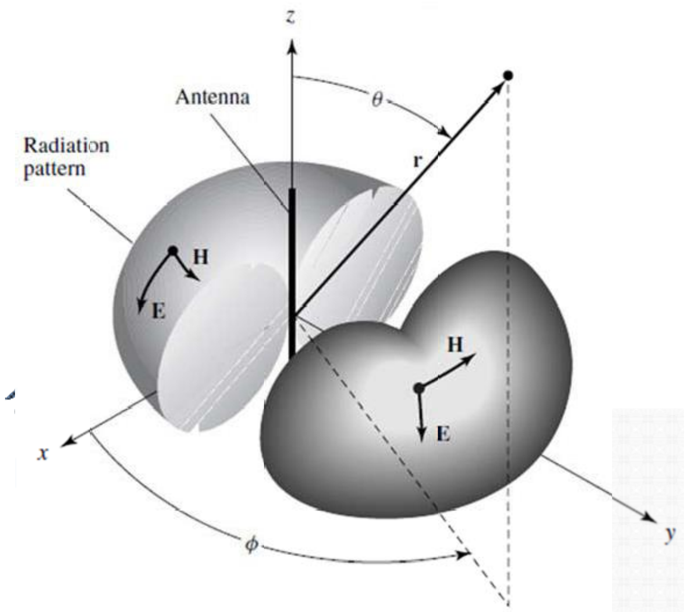


Fig. 2.5

) Omnidirectional Pattern

- having an essentially non-directional pattern in a given plane (in this case in azimuth) and a directional pattern in any orthogonal plane.



principal E-planes (elevation planes; $\phi = \phi_c$) and one principal H-plane (azimuthal plane; $\theta = 90^o$).

An illustration is shown in Figure 2.5. For this example, the x-z plane (elevation plane; $\phi = 0$) is the principal E-plane and the x-y plane (azimuthal plane; $\theta = \pi/2$) is the principal H-plane. Other coordinate orientations can be selected. The omnidirectional pattern of Figure 2.6 has an infinite number of

1.2.3 Principal Patterns

- The Three-dimensional pattern is measured and recorded in a series of two-dimensional patterns.

- For most practical applications, a few plots of the pattern as a function of θ for some particular values of ϕ, plus a few plots as a function of ϕ for some particular values of θ, give most of the useful and needed information.

- For a linearly polarized antenna, performance is often described in terms of its principal E- and H-plane 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

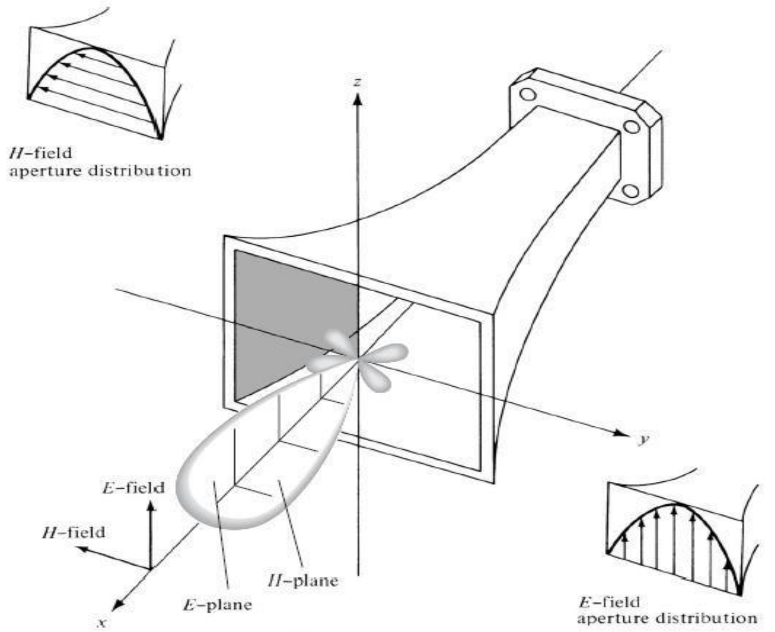


Figure 1.5 Principal E- and H-plane patterns for a pyramidal horn antenna.

Radiation Pattern Lobes

- Radiation lobe : portion of the radiation pattern bounded by regions of relatively weak radiation intensity
- major lobe (main beam, front lobe*) : the radiation lobe containing the direction of maximum radiation
- minor lobe : any lobe except a major lobe.

usually represent radiation in undesirable directions.
★should be minimized
(for careful design, side lobe ratio(level) < -30 dB)
** Especially, In most radar system, low side lobe ratios are very important

- side lobe : a radiation lobe in any direction other than the intended lobe.
- back lobe : a radiation whose axis makes an angle of 180° with respect to the beam of an antenna.

- Radiation Pattern Lobes

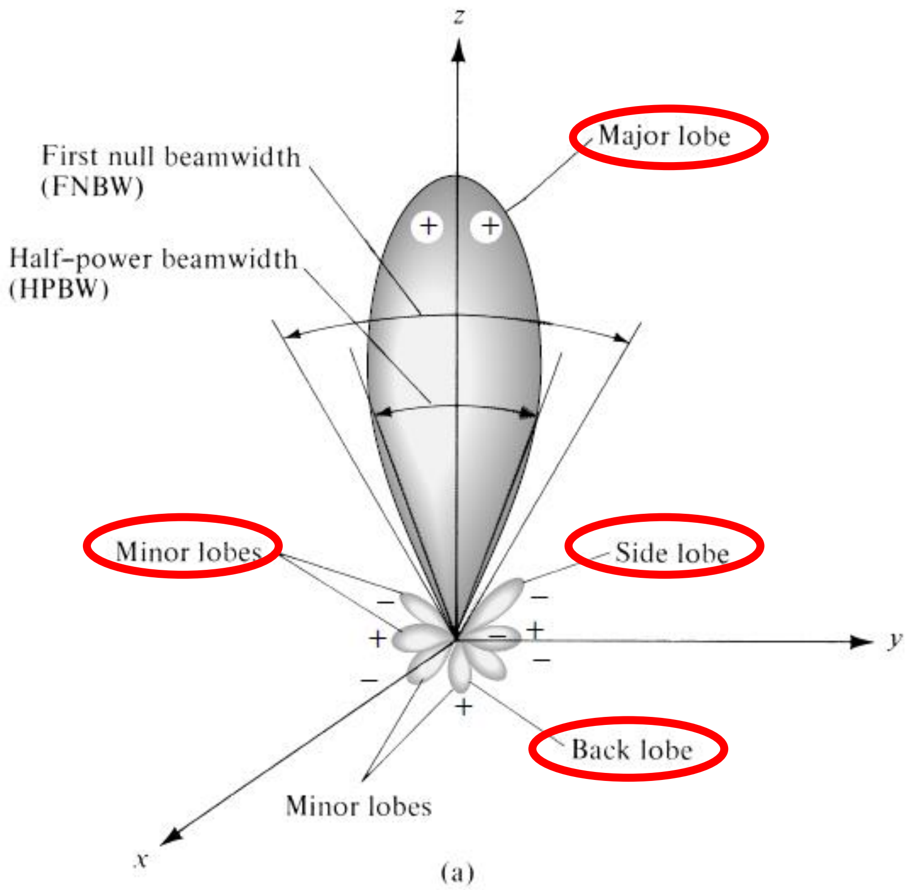
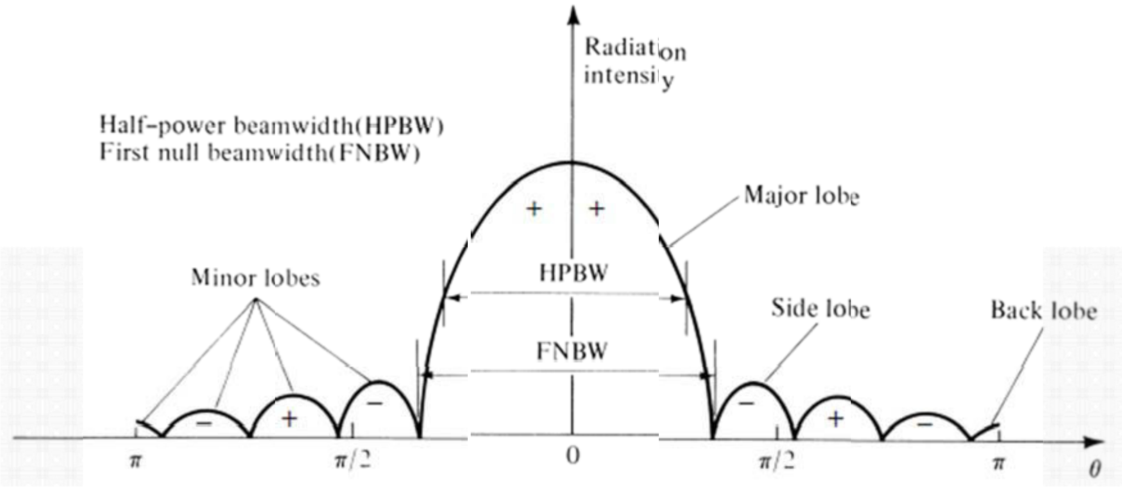


Figure 1.3 (a) Radiation lobes and beamwidths of an antenna pattern. (b) Linear plot of Power pattern and its associated lobes and beamwidths.

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.

Some are of greater radiation intensity than others, but all are classified as lobes. Figure 2.3(b) illustrates a linear two-dimensional pattern where the same pattern characteristics are indicated.



●A major lobe (**main beam**) is defined as "the radiation lobe containing the direction of maximum radiation." In Figure 2.3 the major lobe is pointing in the $\theta = 0$ direction. In some antennas, such as split-beam antennas, there may exist more than one major lobe.

●A minor lobe is any lobe except a major lobe.

●A side lobe is "a radiation lobe in any direction other than the intended lobe." Usually a side lobe is adjacent to the main lobe

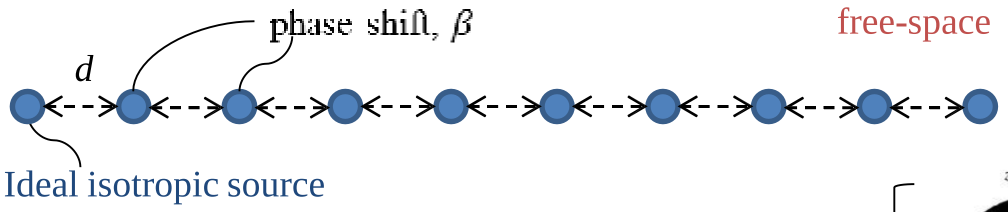
●A back lobe is "a radiation lobe whose axis makes an angle of approximately 180^{o} with respect to the beam of an antenna."

Minor lobes usually represent radiation in undesired directions and should be minimized. Side lobes are the largest minor lobes.

1.2.1 Radiation Pattern Lobes

Examples)

A normalized three-dimensional far-field amplitude pattern, plotted on a linear scale, of a 10-element linear antenna array of isotropic sources with a spacing of d = 0.25λ and progressive phase shift β= -0.6π between the elements is shown Figure 1. 4.



- This pattern has one major lobe, five minor lobes, and one back lobe.
- Three electric-field components (E_r, E_θ, E_ϕ) at $\boxed{\text{each observation point}}$ on the surface of constant radius r
- In the far field, the radial E_r component is zero, or vanishingly small compare to either on, or both, of the other two components.

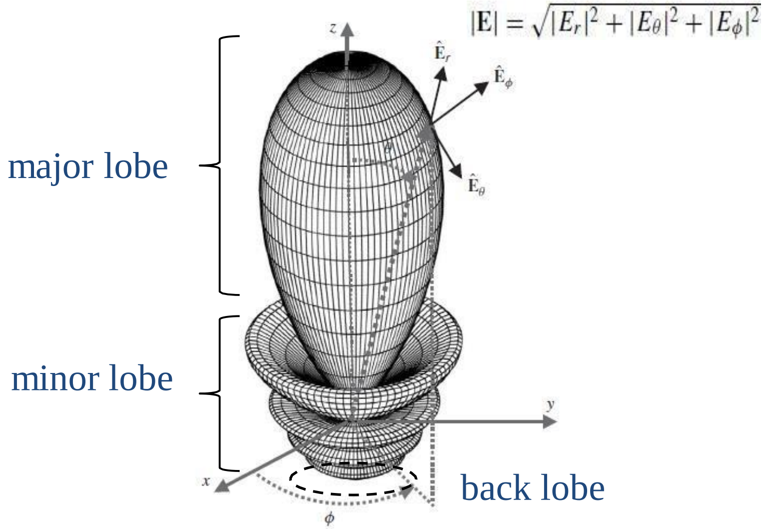


Figure 1.4 Normalized three-dimensional amplitude *field* pattern (in *linear scale*) of a 10-element linear array antenna with a uniform spacing of $d = 0.25\lambda$ and progressive phase shift $\beta = -0.6\pi$ between the elements.

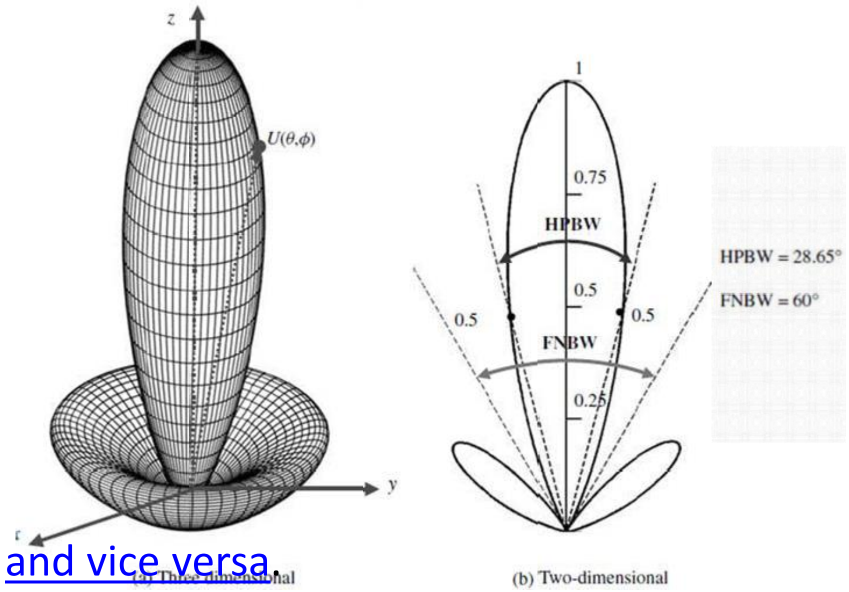
BEAMWIDTH

The beamwidth of a pattern is defined: the angular separation between two identical points on opposite side of the pattern maximum.

1. Half-Power Beamwidth (HPBW).
2. First-Null Beamwidth (FNBW).

● Often, the term beamwidth usually refers to HPBW.

● The beamwidth is a trade-off between it and the side lobe level. The beamwidth decreases, the side lobe increases and vice versa.

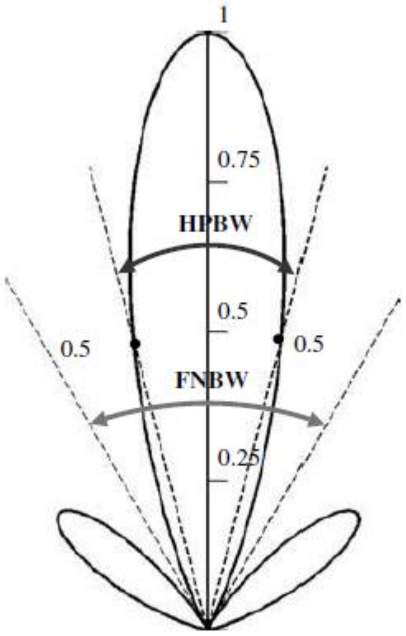


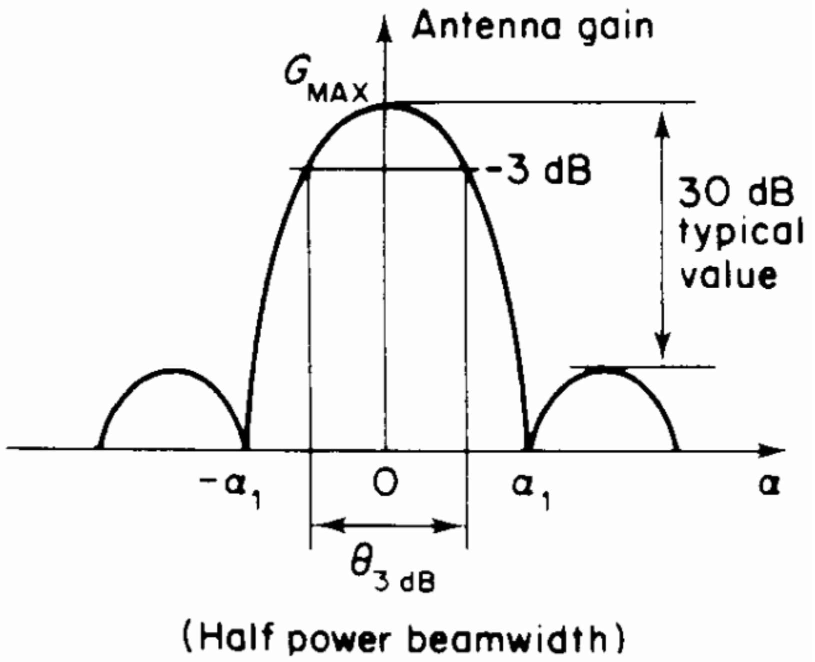
●The beamwidth of the antenna is also used to describe the **resolution capabilities to distinguish** two adjacent radiating sources or targets.

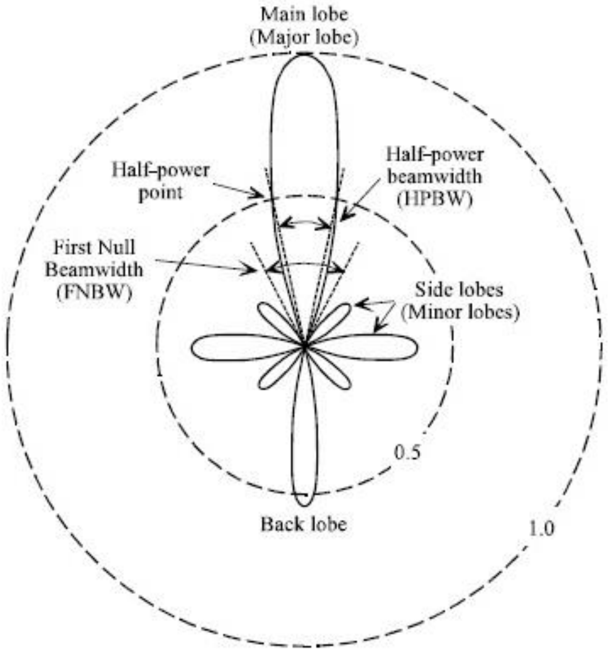
2.5 Beamwidth

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.
First-Null Beamwidth (FNBW) - The angular separation between the first nulls of the pattern.







2.5 Beamwidth

Beamwidth of the antenna is used to describe the resolution capabilities of the antenna to distinguish between two adjacent radiating sources or radar targets.

$$FNBW/2 \approx HPBW$$

Ex) $U(\theta) = \cos^2(\theta)\cos^2(3\theta), \quad (0^\circ \le \theta \le 90^\circ, \ \ 0^\circ \le \phi \le 360^\circ)$

a. HPBW

$$U(\theta)\big|_{\theta=\theta_h} = \cos^2(\theta)\cos^2(3\theta)\big|_{\theta=\theta_h} = 0.5$$

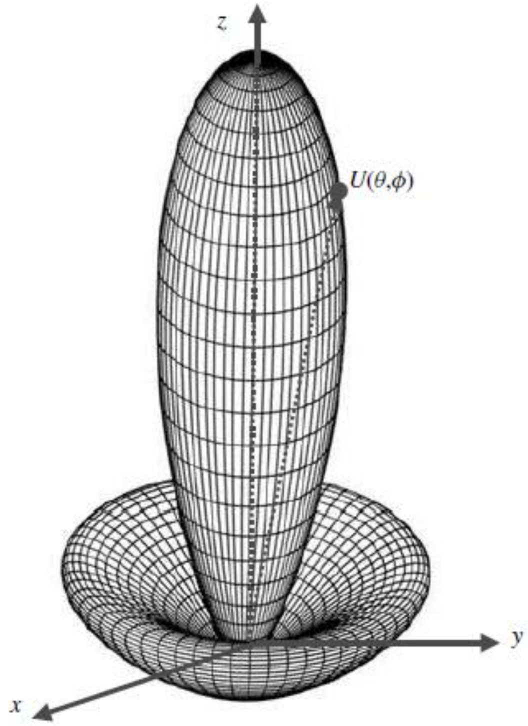
$$\cos(\theta_h)\cos(3\theta_h) = 0.707$$

$$\theta_h = \cos^{-1}\left(\frac{0.707}{\cos 3\theta_h}\right)$$

$$\theta_h \approx 0.25\, radians = 14.325^\circ$$

$$HPBW = 2\theta_h$$

$$\approx 0.5\, radians = 28.65^\circ$$



2.5 Beamwidth

Ex) $U(\theta) = \cos^2(\theta)\cos^2(3\theta), \quad (0^\circ \le \theta \le 90°, \quad 0^\circ \le \phi \le 360^\circ)$

b. FNBW

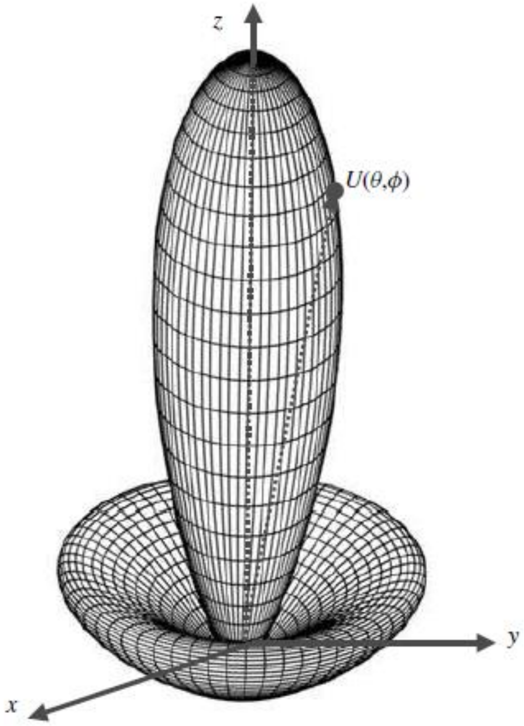
$$U(\theta)\Big|_{\theta=\theta_n} = \cos^2(\theta)\cos^2(3\theta)\Big|_{\theta=\theta_n} = 0$$

$$i.\ \cos\theta_n = 0 \Rightarrow \theta_n = \cos^{-1}(0) = \frac{\pi}{2}\,radians = 90^\circ$$

$$ii.\ \cos 3\theta_n = 0 \Rightarrow \theta_n = \frac{1}{3}\cos^{-1}(0) = \frac{\pi}{6}\,radians = 30^\circ$$

The one with the smallest value leads to the FNBW.

$$FNBW = 2\theta_n = \frac{\pi}{3}\,radians = 60^\circ$$



Field Regions

The space surrounding an antenna is usually subdivided into three regions: reactive near-field, radiating near-field (Fresnel) region and far-field (Fraunhofer) regions

1. Reactive near-field region

For most antennas, the outer boundary of this region is $R < 0.62\sqrt{D^3/\lambda}$, λ is the wavelength and D is the largest dimension of the antenna.

a. The reactive field predominates

b. For a very short dipole, or equivalent radiator, the outer boundary is commonly taken to $\lambda/2\pi$.

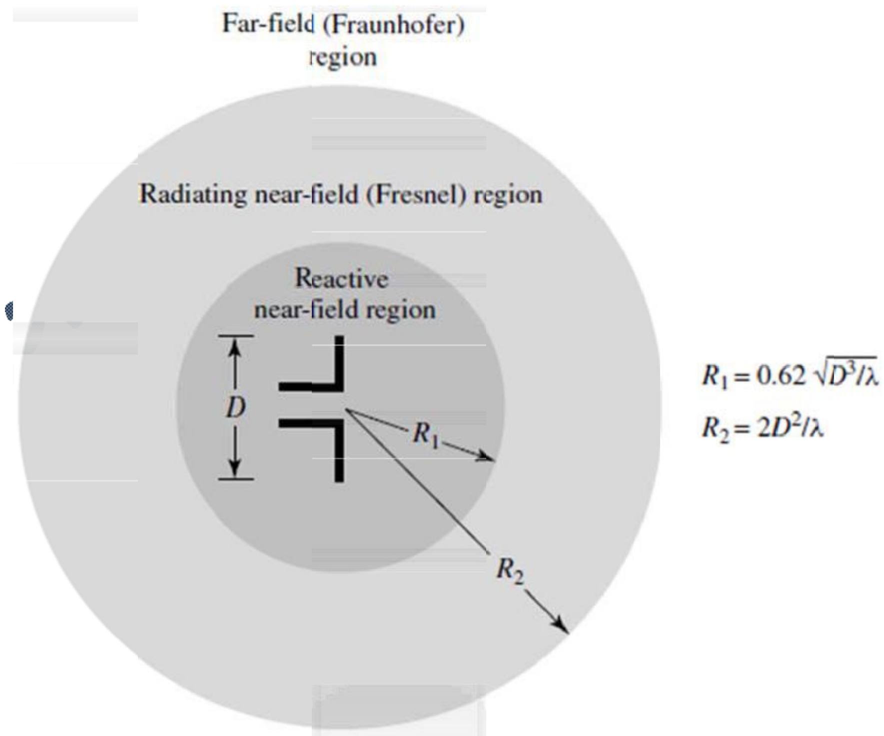


Figure 2.7 Field regions of an antenna.

2. Radiating near-field (Fresnel) region

Defined as "that region of the field of an antenna between the reactive near-field region and the far-field region

a. Radiation fields predominate

b. The angular field distribution is <u>dependent upon</u> the distance from the antenna.

c. If the antenna has a maximum overall dimension which is very small compared to the wavelength, this field region may not exist.

The region is limited by

.

$$0.62\sqrt{D^3/\lambda} < R < 2D^2/\lambda.$$

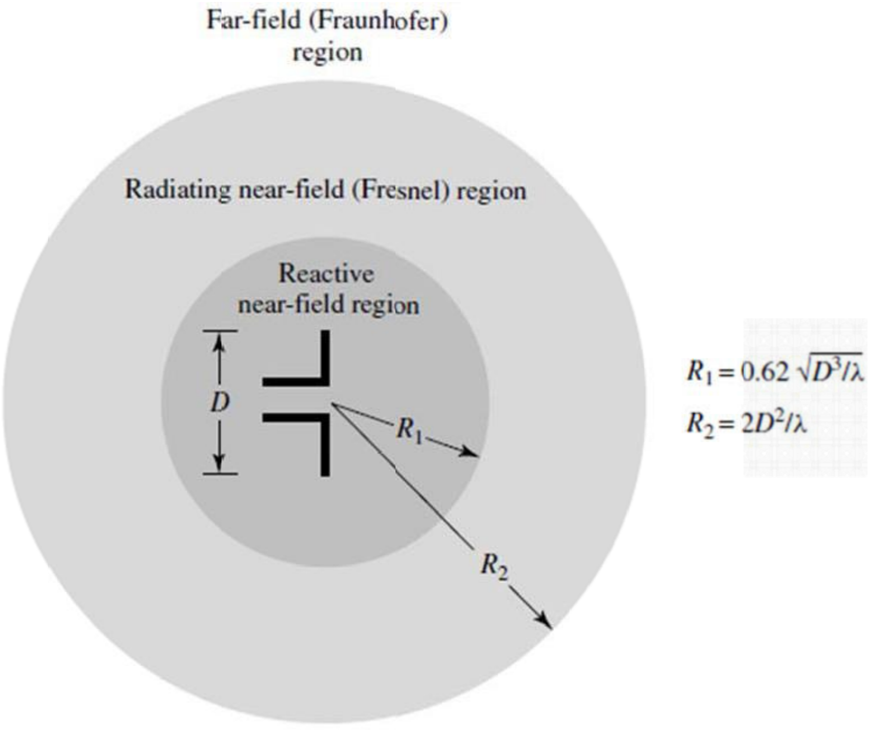


Figure 2.7 Field regions of an antenna.

3. Far-field (Fraunhofer) region

a. The angular field distribution is essentially independent of the distance from the antenna.

b. The far-field region is taken to exist at distances greater than $2D^2/\lambda$ from the antenna.

As the observation is moved to the radiating near-field region, **the pattern begins to smooth and form lobes**. In **the** far-field region, the **pattern is well formed**, usually consisting of few minor lobes and one, or more, major lobes.

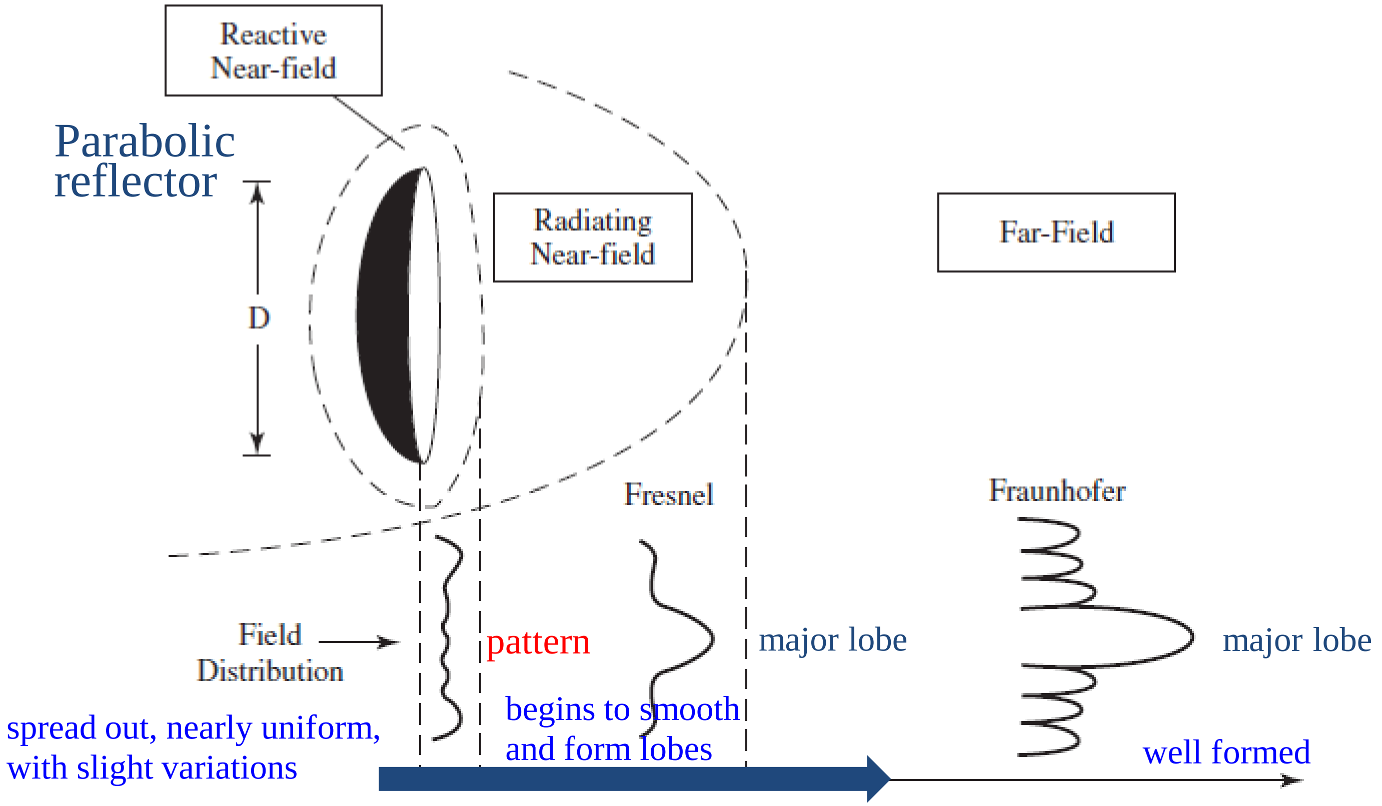
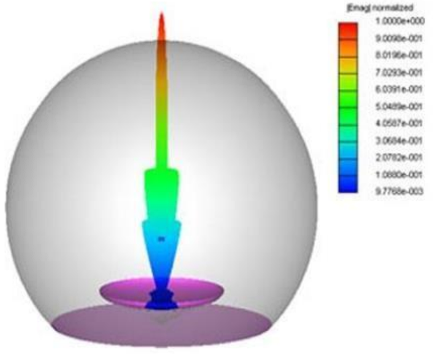


Figure 1.8 Typical changes of antenna amplitude pattern shape from reactive near field toward the far field. (From: Y. Rahmat-Samii, L. I. Williams, and R. G. Yoccarino, The UCLA bi-polar planar-near-field antenna measurement and diagnostics range, *IEEE Antennas Propag. Mag.*, Vol. 37, No. 6, December 1995. Copyright © 1995 IEEE.)

E field pattern of Parabolic Reflector Antenna



Normalized far-zone E-field pattern of a parabolic reflector antenna covered by a radom

Reference : Integrated engineering software
https://www.integratedsoft.com/applications/rf-microwave-antennas/reflector-antennas

Figure 2.9 shows three patterns of a parabolic reflector calculated at distances of $R = 2D^2/\lambda$, $4D^2/\lambda$, and infinity.

It is observed that the patterns are almost identical, except for some differences in the pattern structure around the first null and at a level below 25 dB. Because infinite distances are not realizable in practice, the most commonly used criterion for minimum distance of far-field observations is $2D^2/\lambda$.

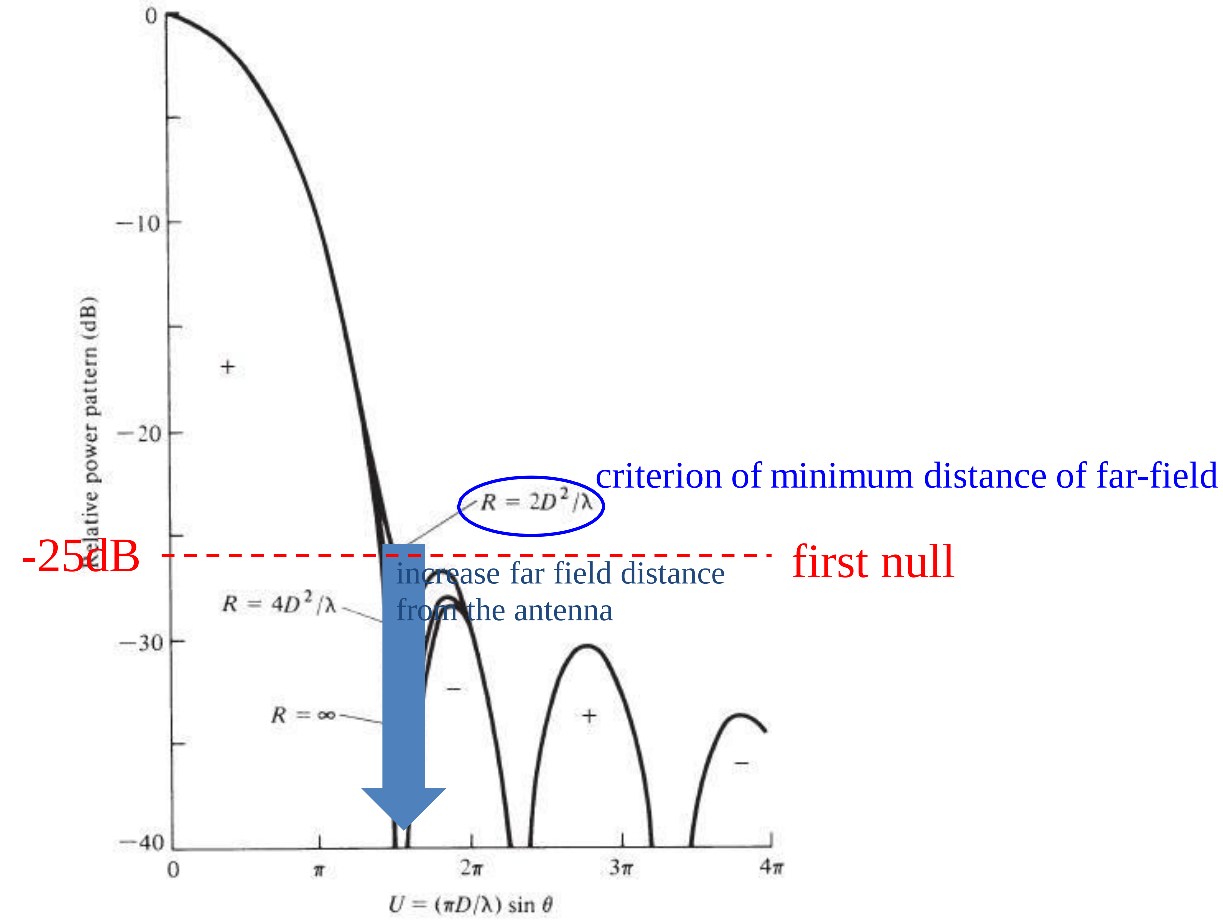


Figure 1.9 Calculated radiation patterns of a paraboloid antenna for different distances from the antenna. (From Ref. 6.)

Thank you