天线与电波传播
ANTENNAS AND WAVE PROPAGATION

Lecture 2
Fundamental Antenna Parameters

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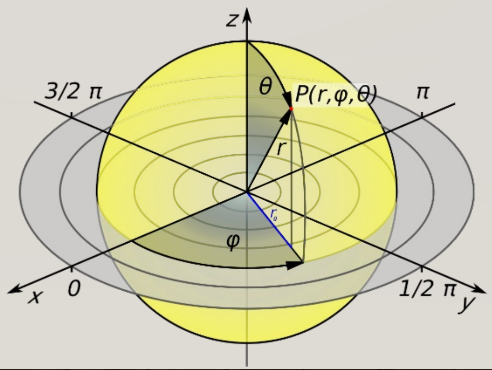
CHAPTER 2 FUNDAMENTAL ANTENNA PARAMETERS

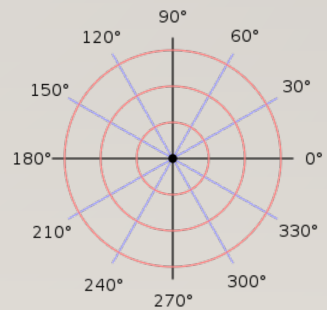
Many definitions are from the IEEE Standard Definitions of Terms for Antennas (IEEE Std 145-1983).

- Radiation patterns
- Radiation power density
- Radiation intensity
- Beam efficiency
- Beam width
- Antenna efficiency
- Directivity and gain
- Polarization
- Bandwidth
- Input impedance
- Radiation efficiency

Radiation Patterns

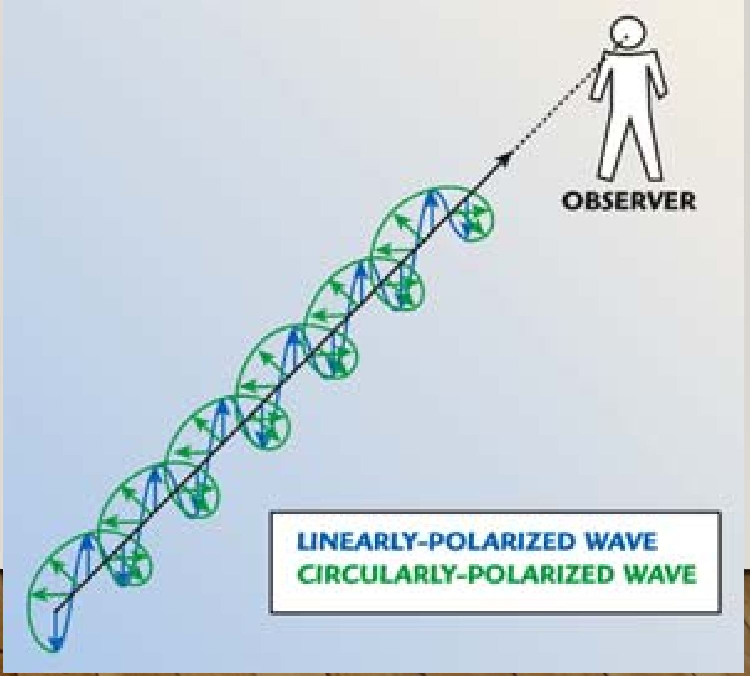
- antenna radiation pattern or antenna pattern
- "a **mathematical function** or a **graphical representation** of the **radiation properties** of the antenna as a function of **space coordinates**."
- " In most cases, the **radiation pattern** is determined in the **far field region** and is represented as a function of **the directional coordinates."**





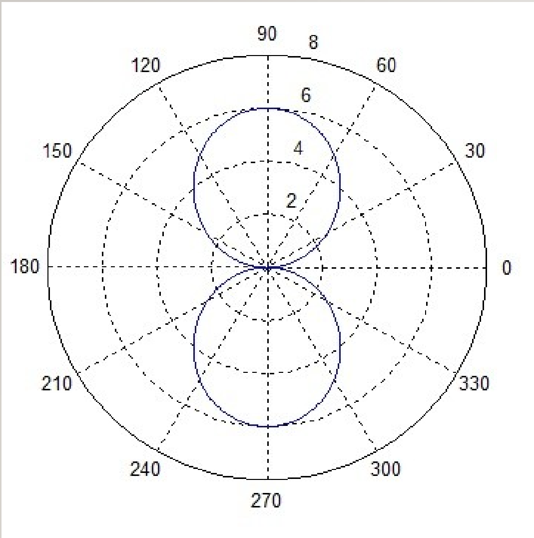
Radiation Patterns

- include **power flux density**, **radiation intensity**, **field strength**, **directivity**, **phase** or **polarization**."
- **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**.

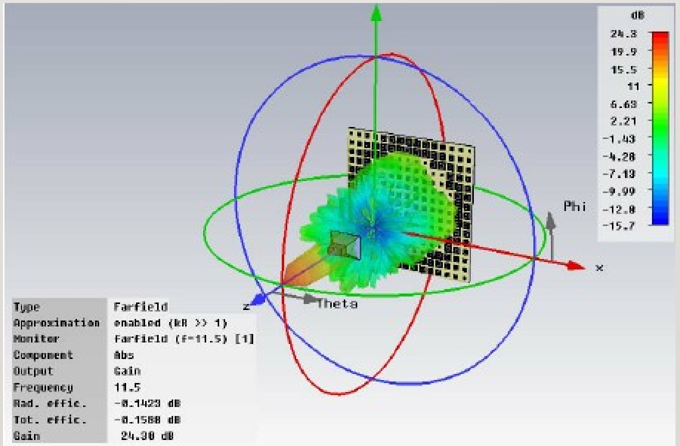


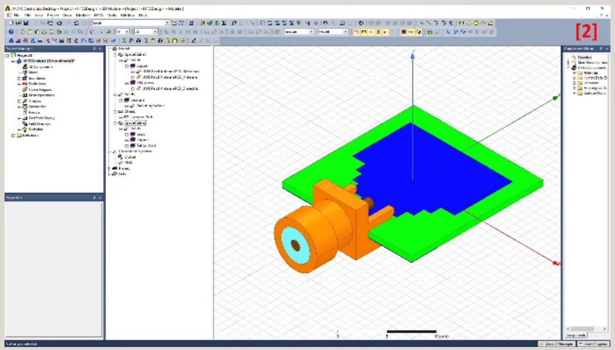
Radiation Patterns

Calculated

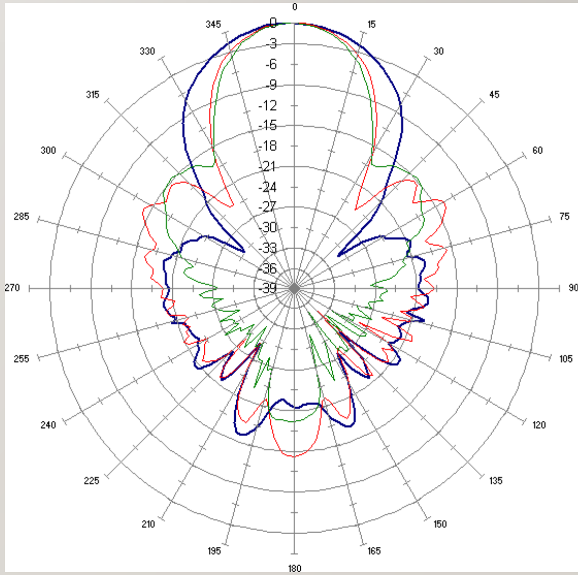


Simulated





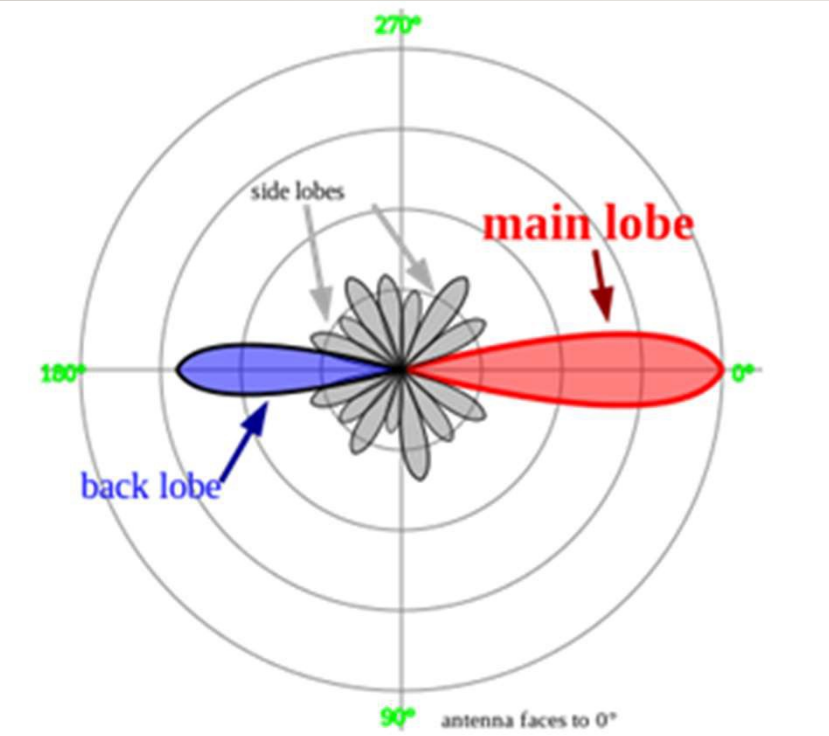
Measured



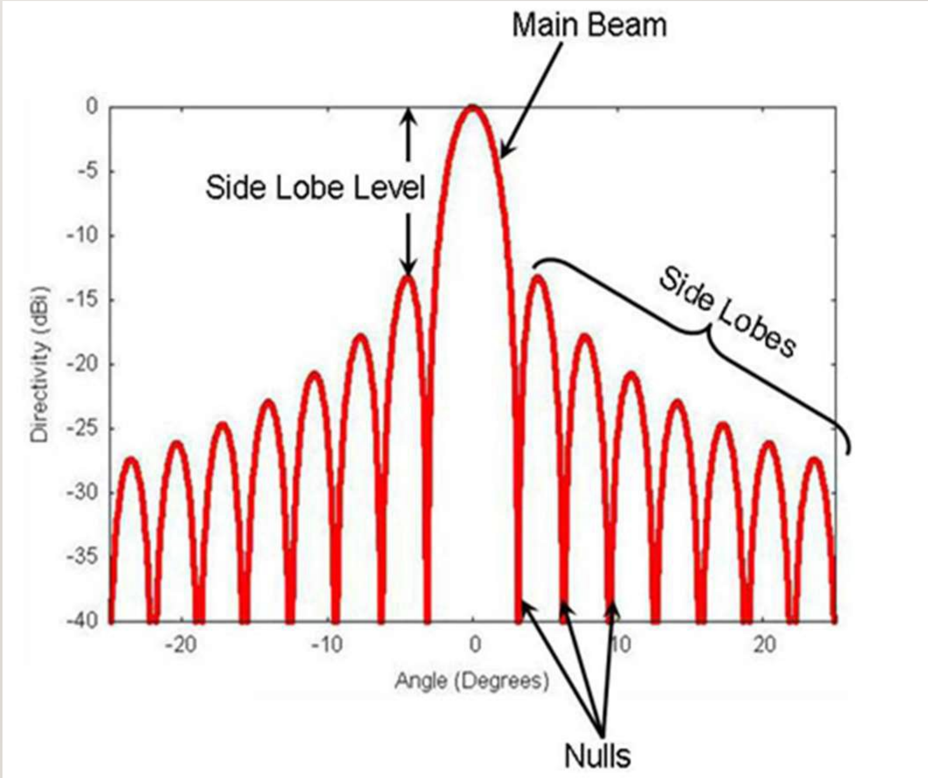
Radiation Patterns

2D radiation pattern

Polar

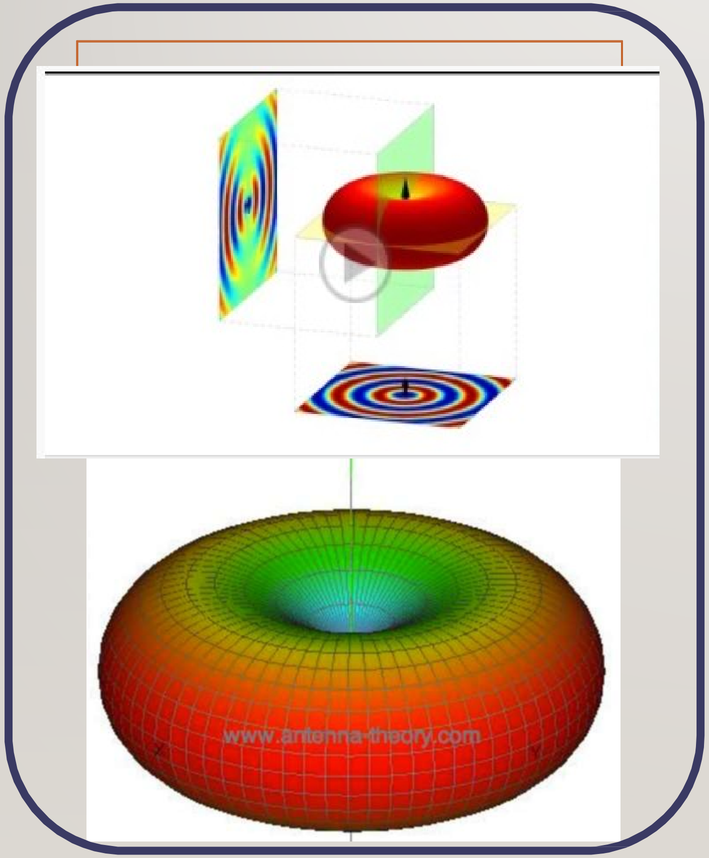


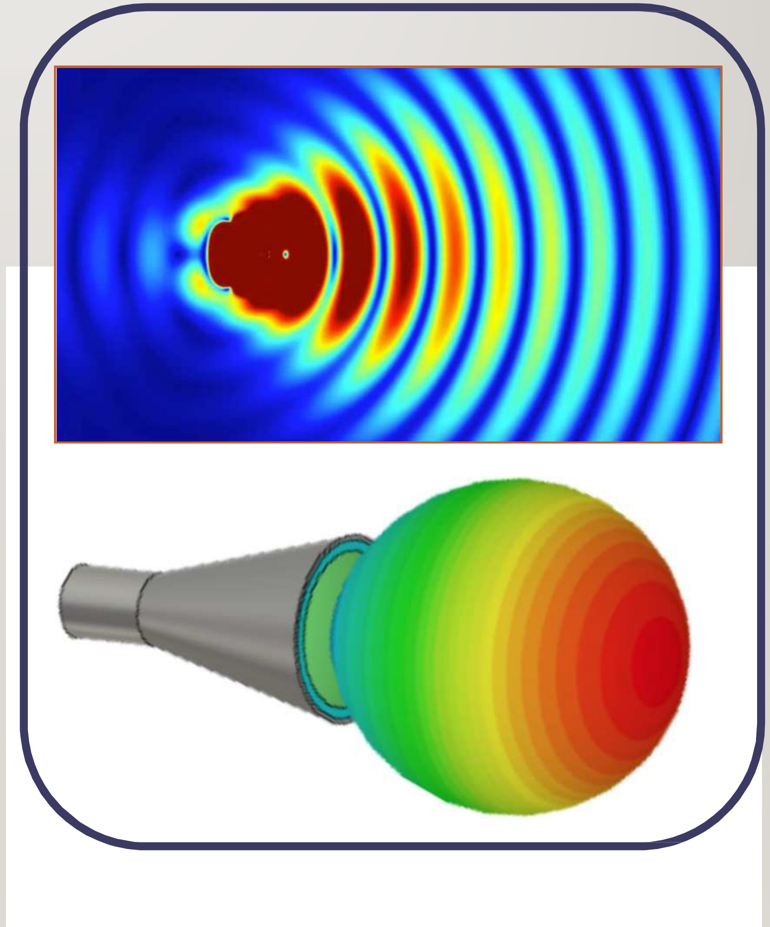
Cartesian



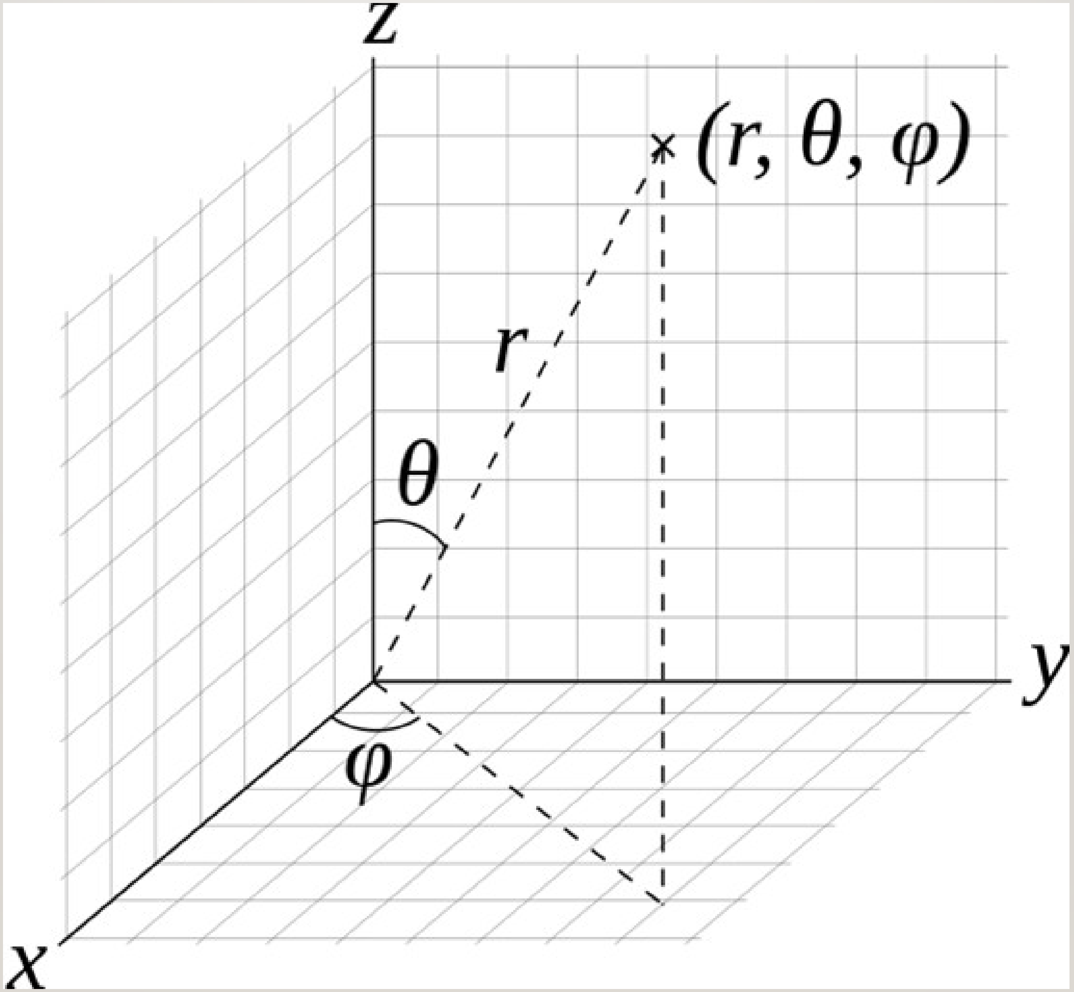
Radiation Patterns

3D radiation pattern



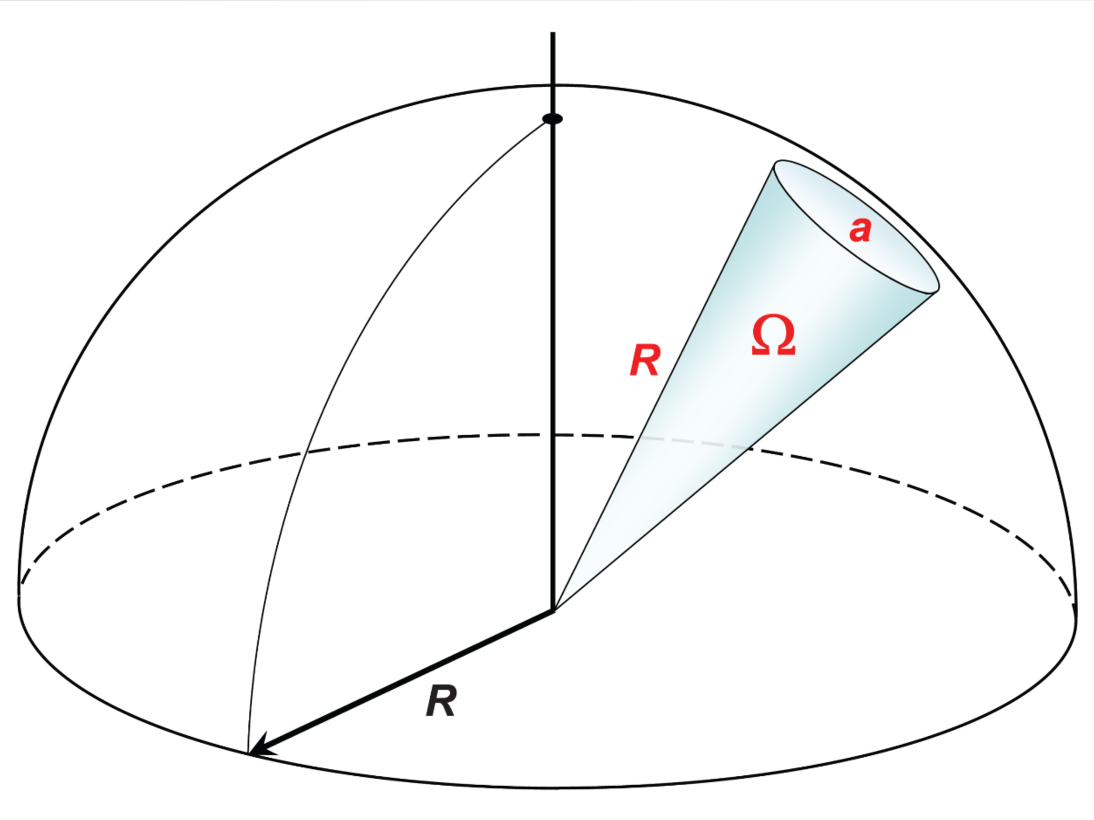


3-D Coordinate System for Antenna Analysis



spherical coordinates are used to study antenna patterns.

3-D Coordinate System for Antenna Analysis

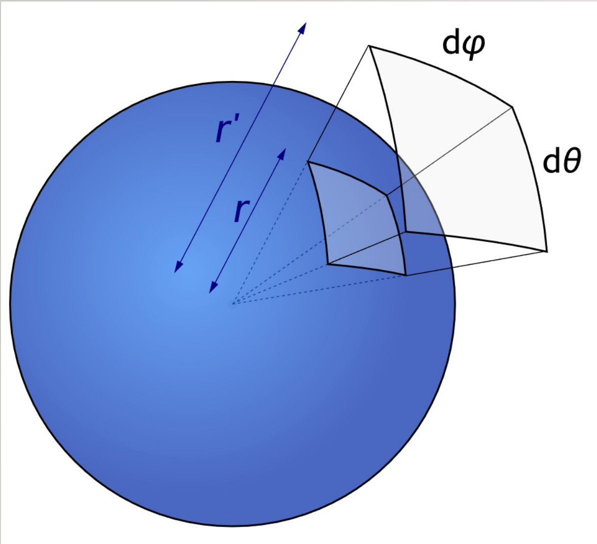


Solid angle:

- a measure of the **amount of the field of view** from some particular point that **a given object covers**.

- a measure of **how large the object appears** to an observer looking from that point.

3-D Coordinate System for Antenna Analysis



Solid angle:

An object's solid angle in **steradians** (Ω , sr) is equal to the area of the segment of a unit sphere ($r = 1$), centered at the angle's vertex, that a given object covers.

a measure of how large the object appears to an observer looking from the center of the sphere.

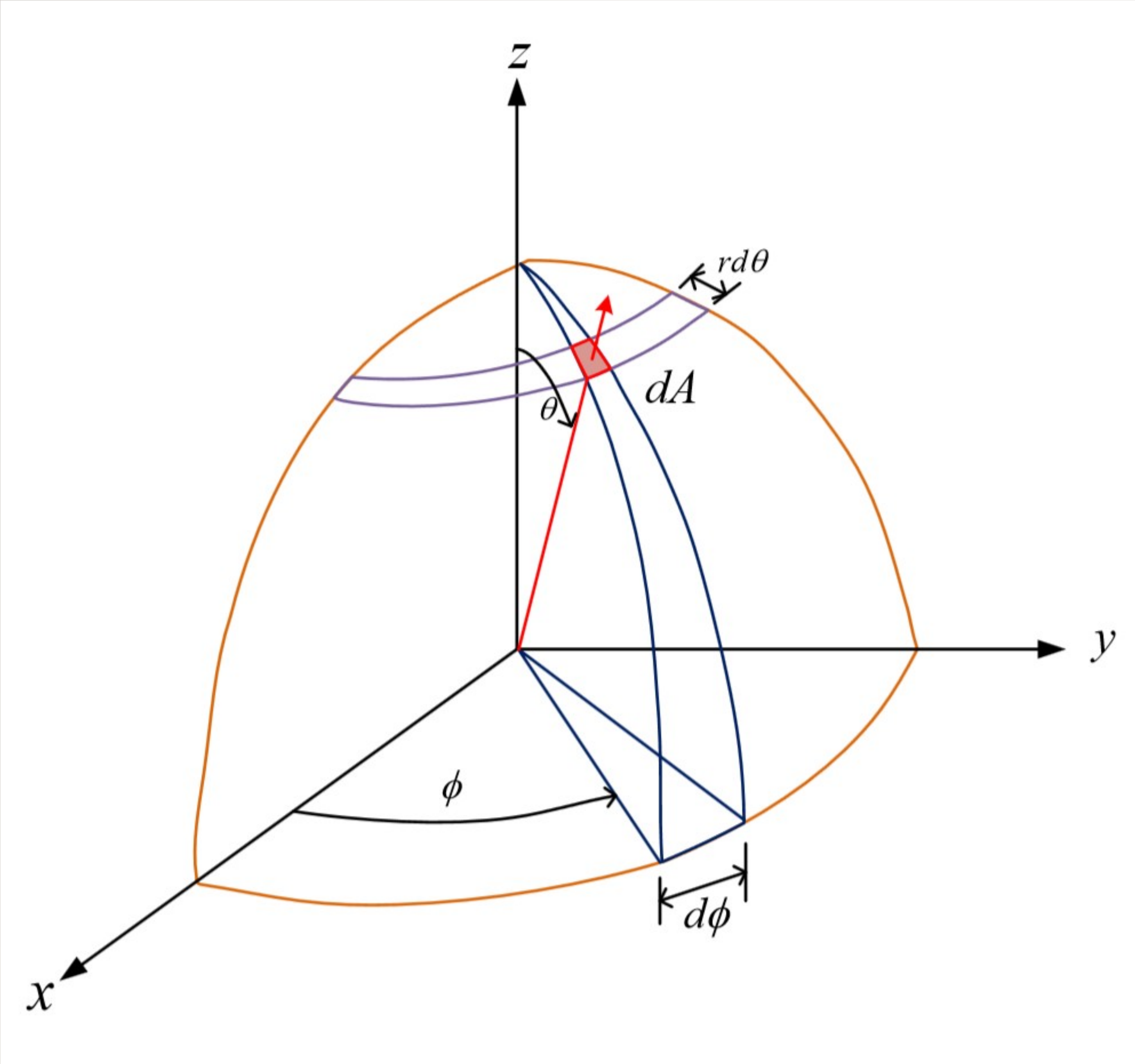
Many antenna pattern parameters are defined **per unit solid angle**

How many steradians are in a complete sphere?

3-D Coordinate System for Antenna Analysis

Object	**Solid Angle (steradians)**
Entire Sphere	4π
Half Sphere	2π
27-inch Monitor (1 m away)	0.1677
Movie Screen (10m by 5 m, 20 m away)	0.125
Sun	6.794×10^{-5} (Approximately)
Moon	6.418×10^{-5} (Approximately)
Saturn	4.42E-10

3-D Coordinate System for Antenna Analysis

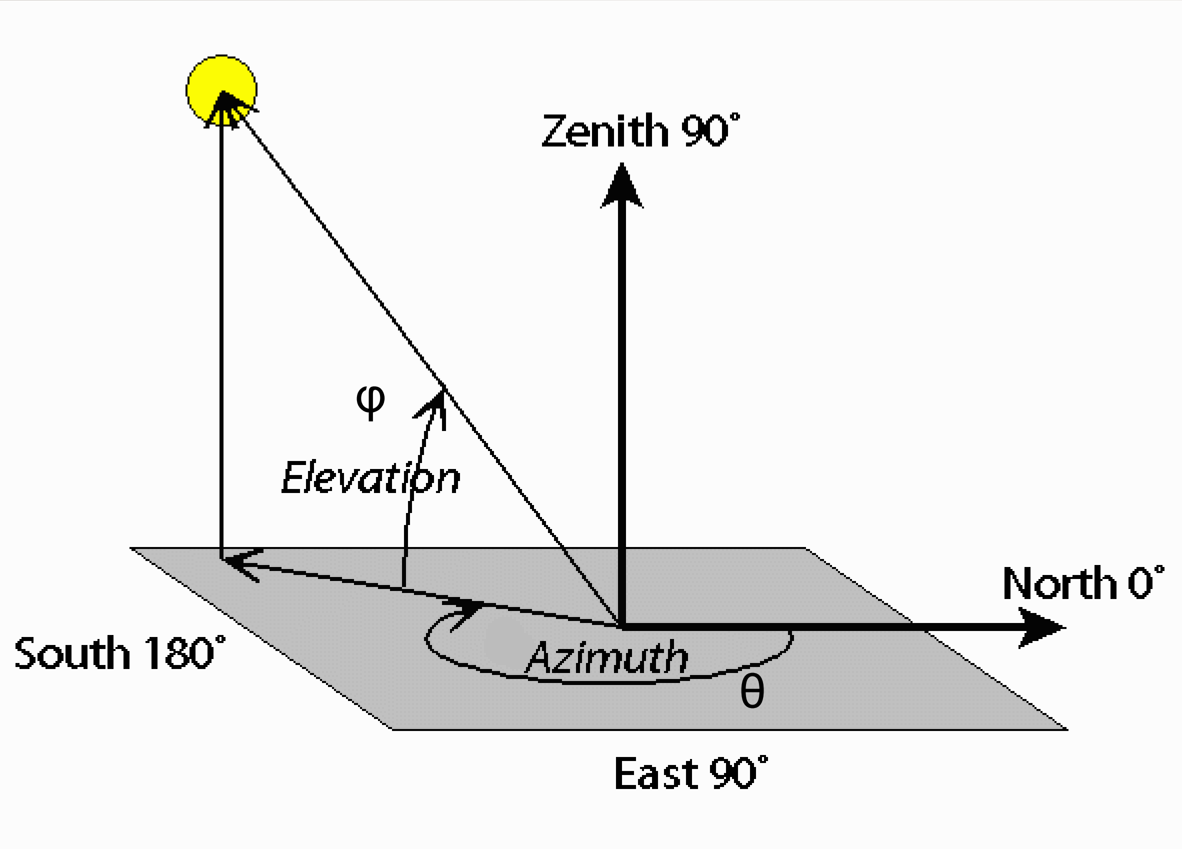


Many antenna pattern parameters are also defined per unit area

$$dA = r^2 \sin\theta \, d\theta \, d\phi.$$

- dA is the differential area element,
- r is the radius of the sphere,
- θ is the elevation angle,
- ϕ is the azimuth angle.

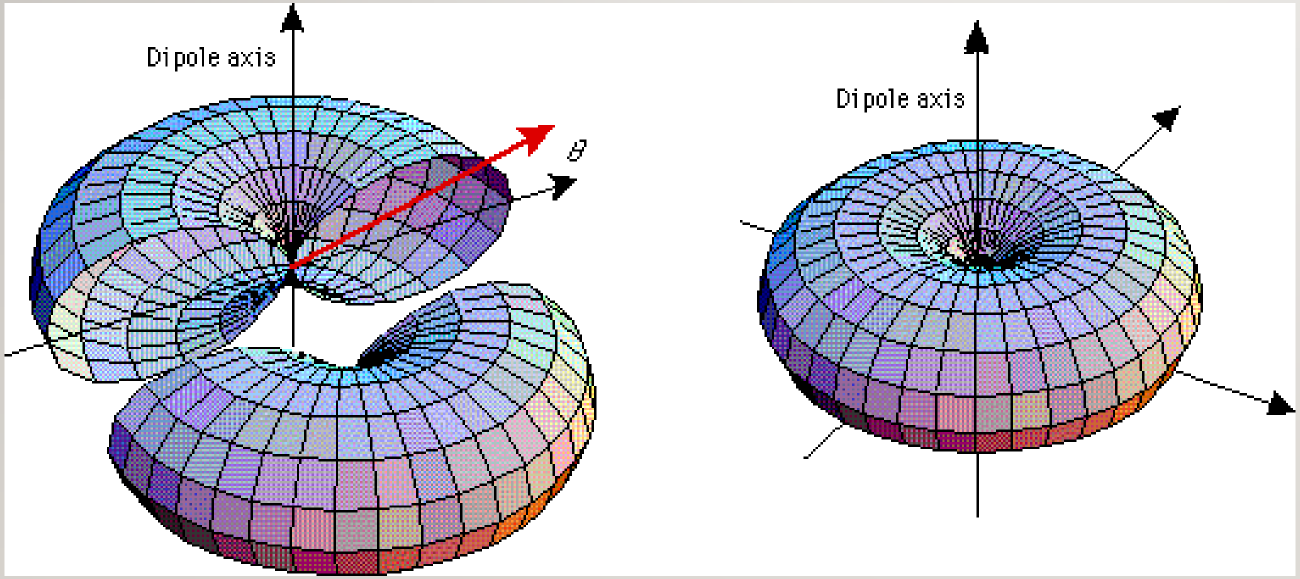
3-D Coordinate System for Antenna Analysis



Azimuth vs. Elevation

- Azimuth (φ) tells you what direction to face
- Elevation(θ) tells you how high up in the sky to look.

3-D Coordinate System for Antenna Analysis



For most practical applications, **a few plots of the pattern as a function** of θ for **some particular values** of φ (0 or 90 degree), plus **a few plots as a function** of φ for **some particular values** of θ, give most of the useful and needed information.

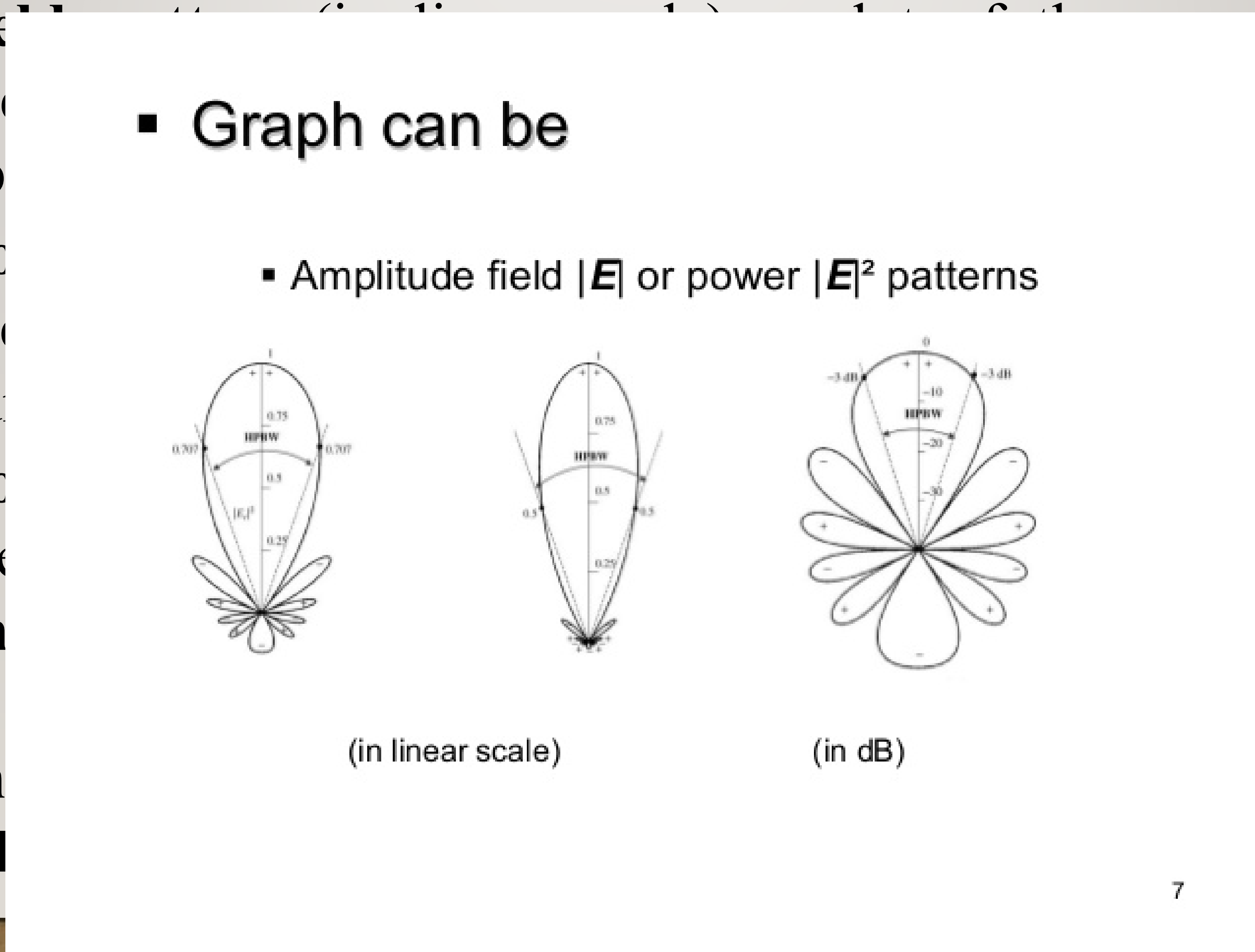
Spherical Coordinates

Antenna Patterns

- **field pattern** (in linear scale): a plot of the magnitude of the electric or magnetic field as a function of the angular space. (volt/meter)
- **power pattern** (in linear scale): a plot of the square of the magnitude of the electric or magnetic field as a function of the angular space. (W/sr)
- **power pattern**(in dB): the (normalized) magnitude of the electric or magnetic field, in decibels, as a function of the angular space. **This scale is usually desirable because a logarithmic scale can accentuate in more details those parts of the pattern that have very low values, which later we will refer to as minor lobes.**

Antenna Patterns

- **fie** ... itude of the ... angular sp
- **po** ... quare of the ... ld as a fu
- **po** ... of the ele ... on of the an ... **because a** ... **details th** ... **values, wh**



Antenna Patterns

Dividing a field/power component by its **maximum value**, we obtain a **normalized** or relative field/power pattern which is a dimensionless number with maximum value of unity.

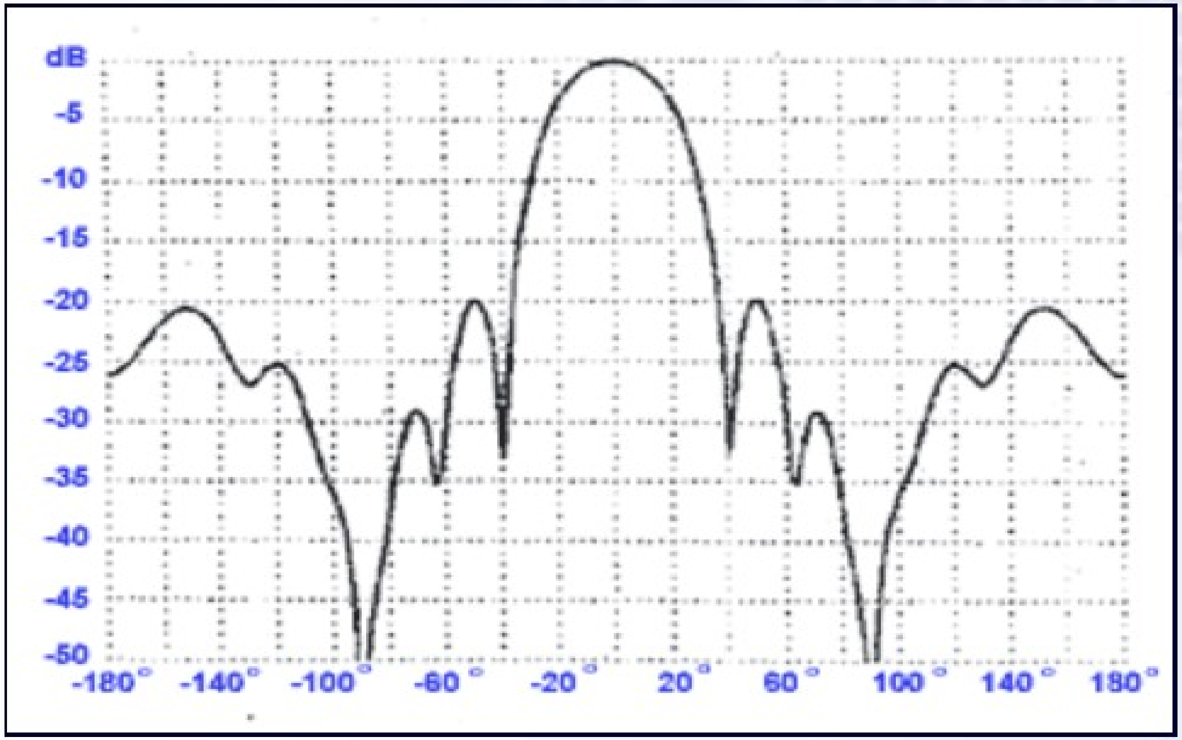
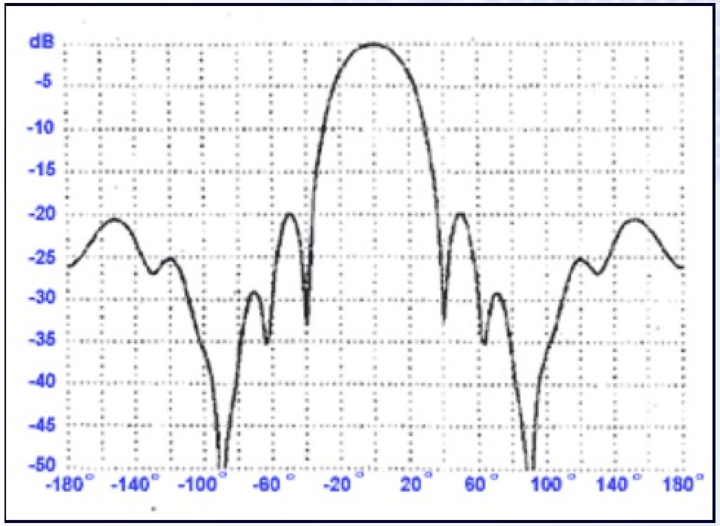


Figure 1.
This figure shows a rectangular azimuth ("E" plane) plot presentation of a typical 10 element Yagi. The detail is good but the pattern shape is not always apparent.

Antenna Patterns (Linear)



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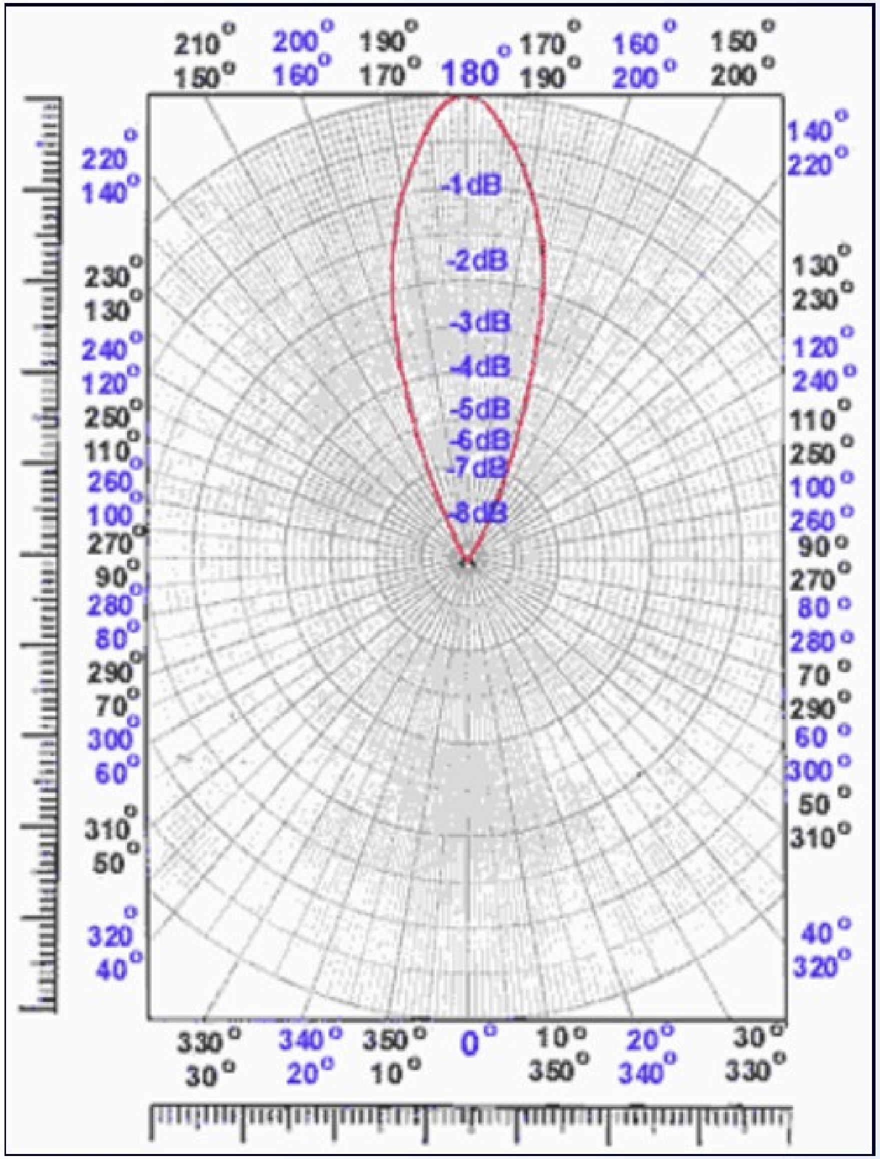
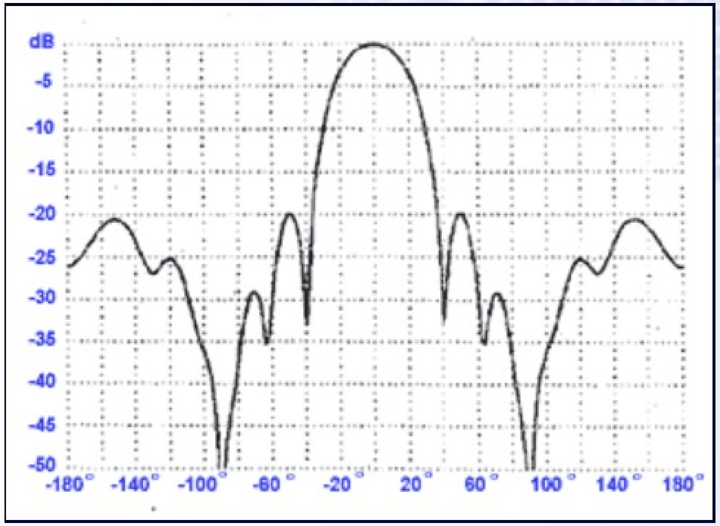


- emphasizes the shape of the main radiation lobe of the antenna
- suppressing all side lobes
- radiation pattern look better than it really is!

linear

Antenna Patterns (dB)



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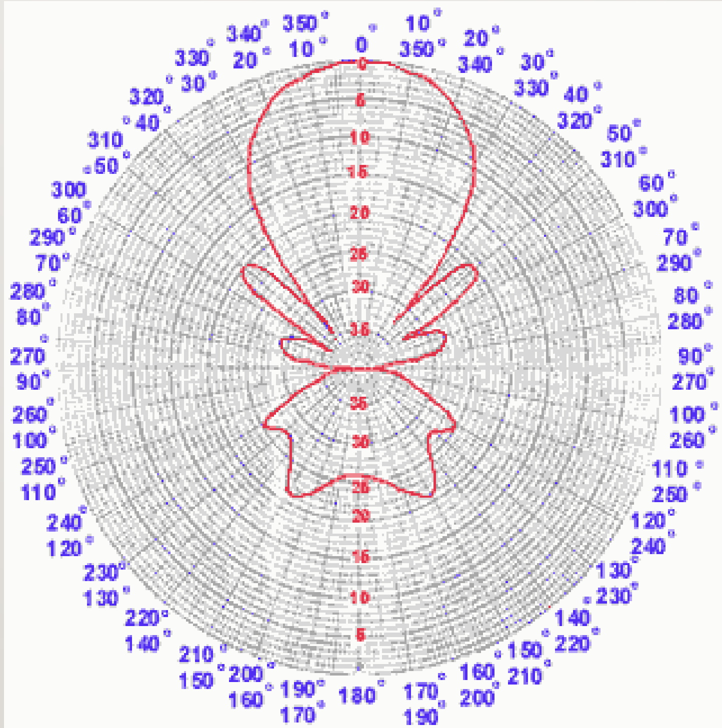
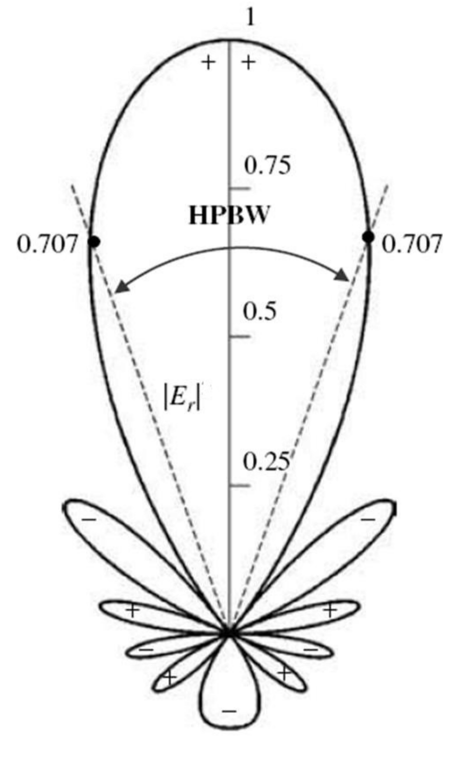


- shows the sidelobes of the antenna relative to the main beam in decibels.
- preferred when the exact level of the sidelobes is important.

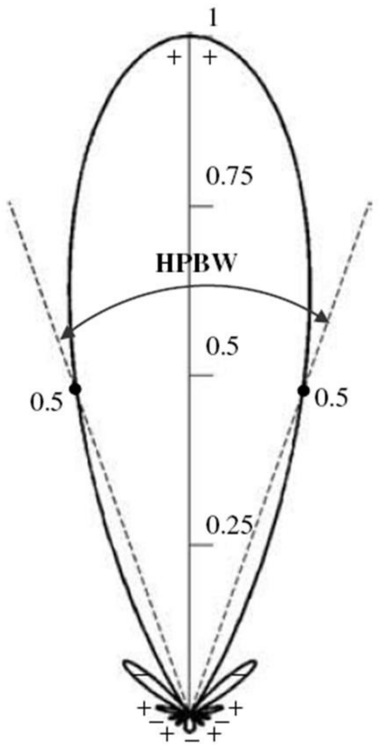
Exact the same plot in dB

Antenna Patterns

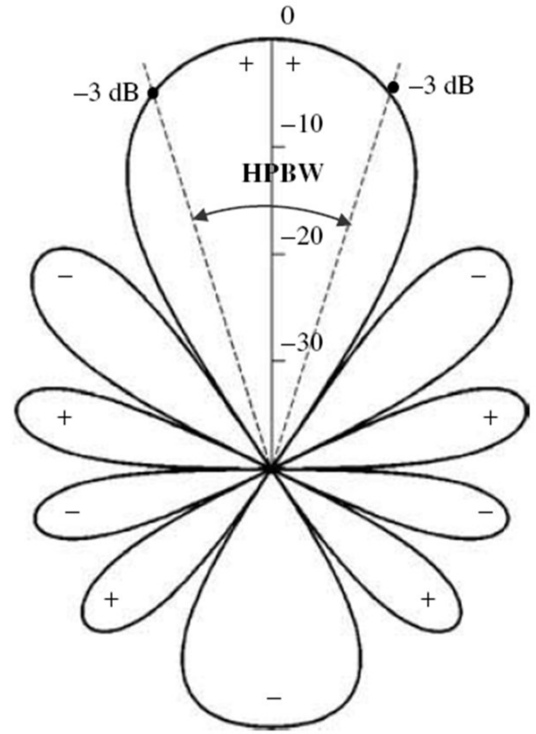
All three patterns yield the same angular separation between the two half-power points, on their respective patterns, referred to as **HPBW** *(Half Power Beamwidth discussed later in this lecture)*



(a) Field pattern (in linear scale)



(b) Power pattern (in linear scale)



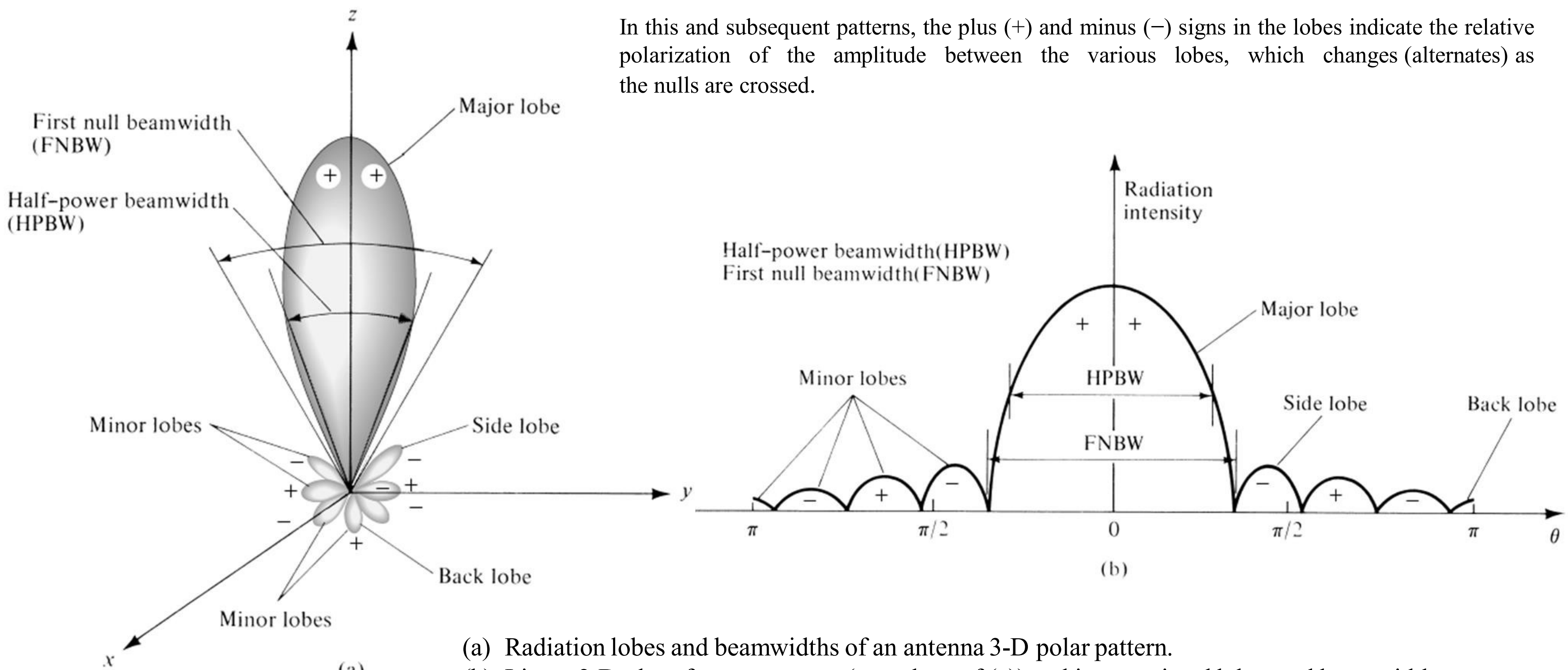
(c) Power pattern (in dB)

All three patterns yield the same angular separation between the two half-power points, 38.64º←.

Radiation Pattern Lobes

- various parts of a radiation pattern referred to as **lobes**
- subclassified into **major** or **main**, **minor**, **side**, and **back** lobes.
- radiation lobe: a "portion of the radiation pattern **bounded** by regions of **relatively weak radiation intensity**."

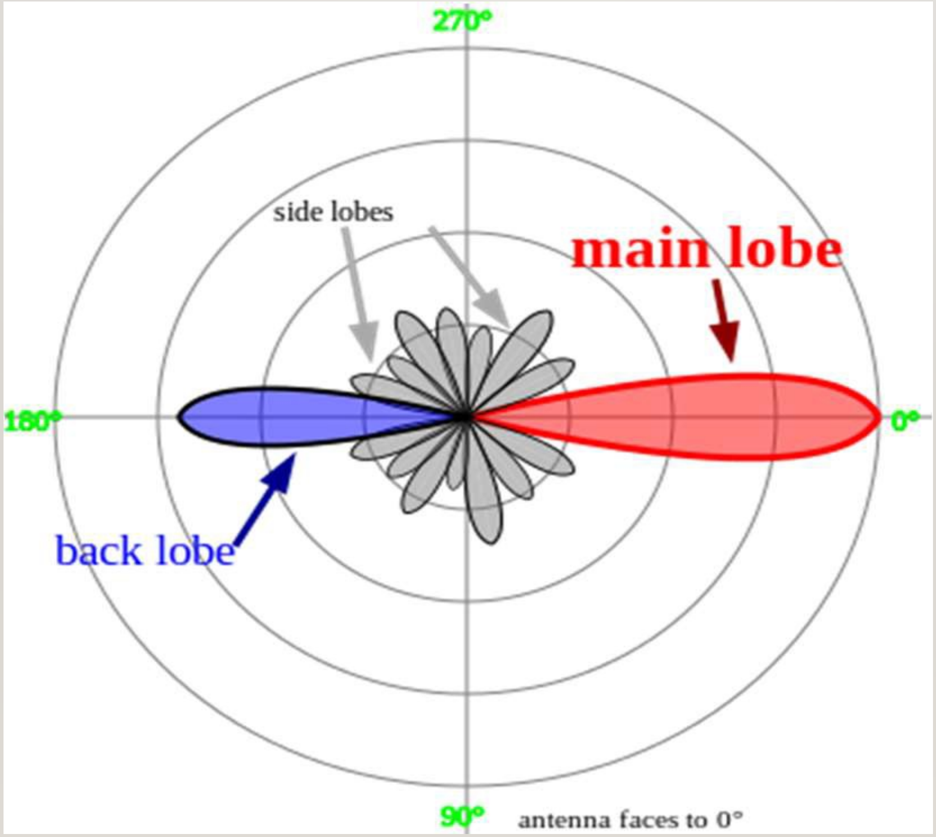
In this and subsequent patterns, the plus (+) and minus (−) signs in the lobes indicate the relative polarization of the amplitude between the various lobes, which changes (alternates) as the nulls are crossed.



(a) Radiation lobes and beamwidths of an antenna 3-D polar pattern.
(b) Linear 2-D plot of power pattern (one plane of (a)) and its associated lobes and beamwidths.

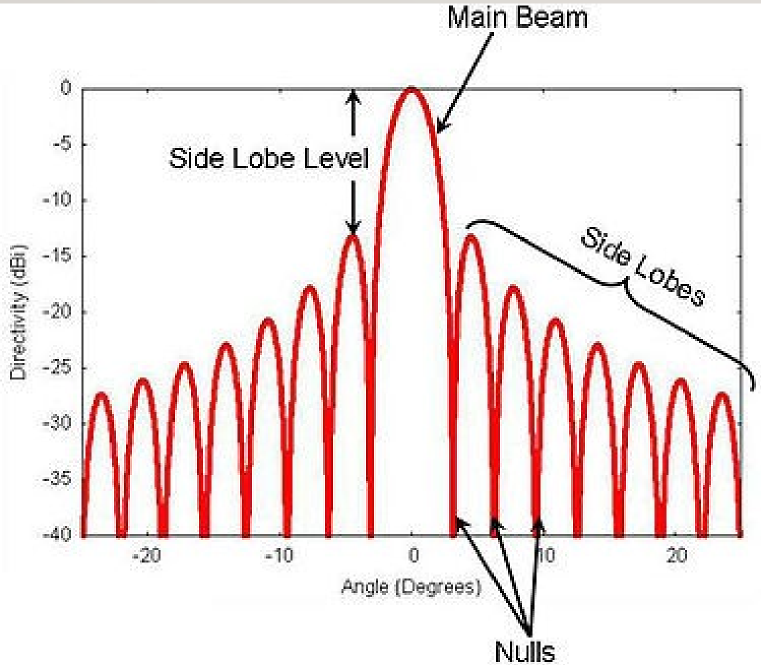
Radiation Pattern Lobes

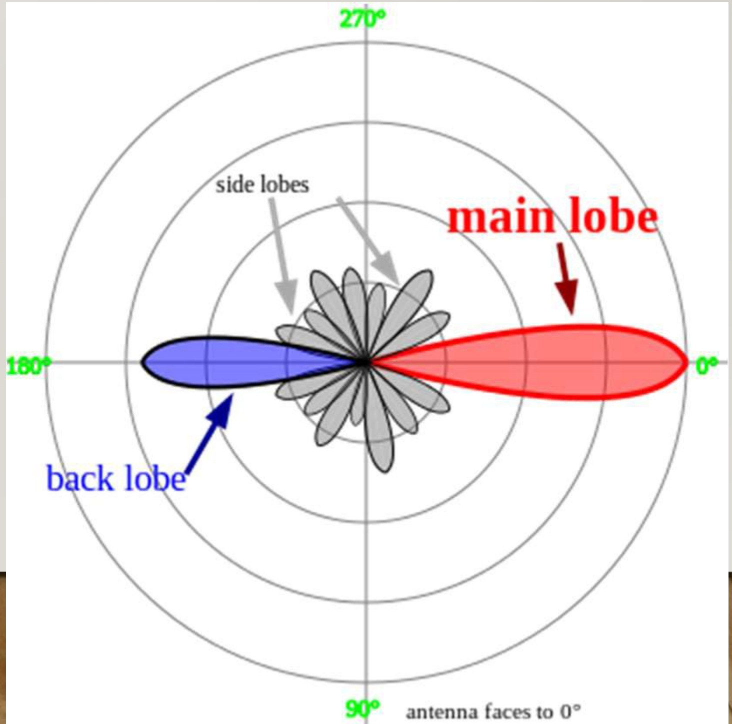
- **major lobe** (also called main beam): the radiation lobe containing the direction of **maximum radiation**.
- **minor lobe**: any lobe **except a major lobe**. Usually radiation in undesired directions, and should be minimized



Radiation Pattern Lobes

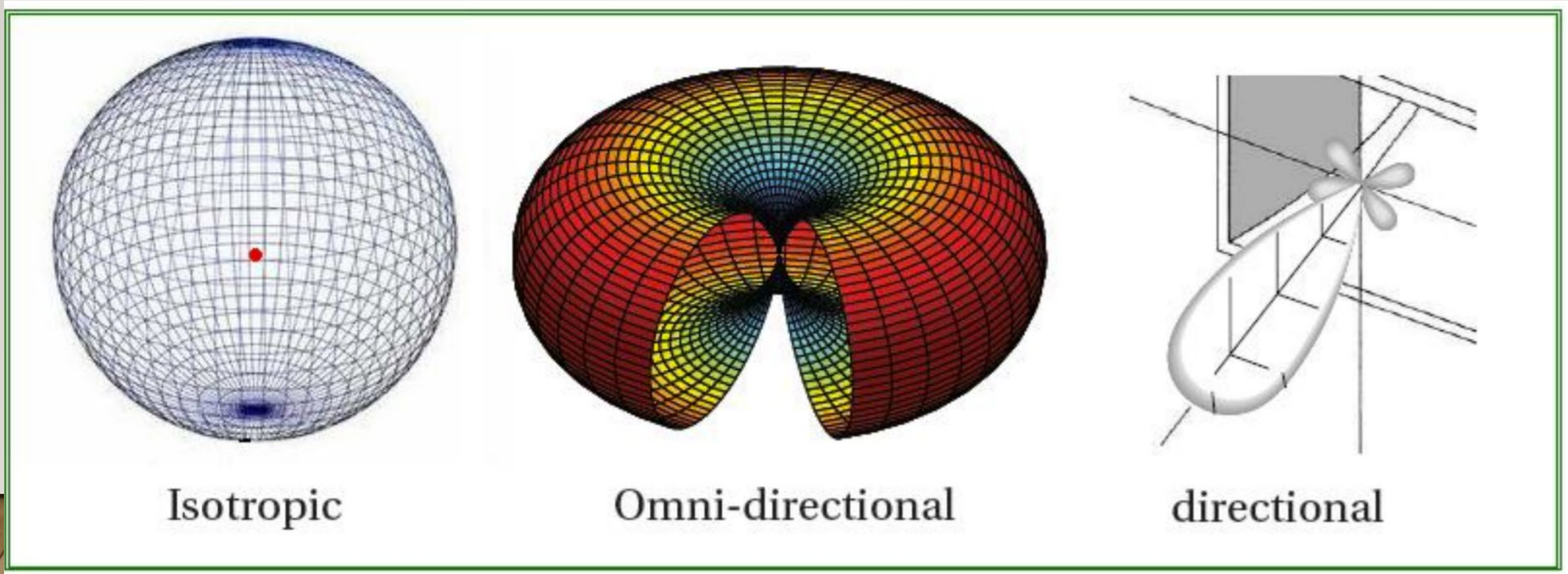
- **back lobe**: lobe axis making an angle of approximately 180º with respect to the beam of an antenna. Usually a minor lobe that occupies the hemisphere in a direction **opposite** to that of the major (main) lobe.
- **side lobes**: radiation lobes in any direction other than the intended lobe. (Usually a side lobe adjacent to the main lobe and occupying the hemisphere in the direction of the main beam.)
- The level of minor lobes is usually expressed as a ratio of the power density in the lobe in question to that of the major lobe. This ratio is often termed the ***side lobe ratio*** or ***side lobe level***.





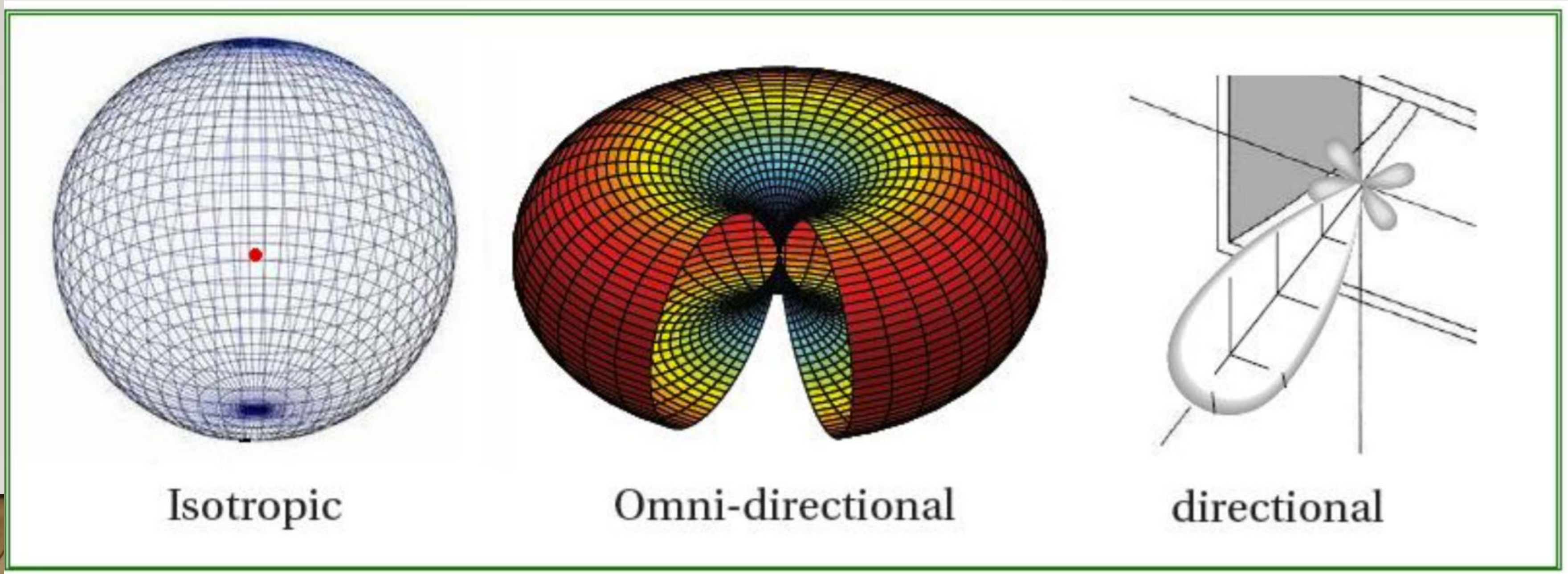
Isotropic, Directional, and Omnidirectional Patterns

- An **isotropic** radiator: a **hypothetical lossless** antenna having equal radiation in all directions.
- A **directional** antenna: having the property of radiating or receiving electromagnetic waves **more effectively in some directions** than in others. Usually applied to an antenna whose maximum directivity significantly greater than that of a half-wave dipole."



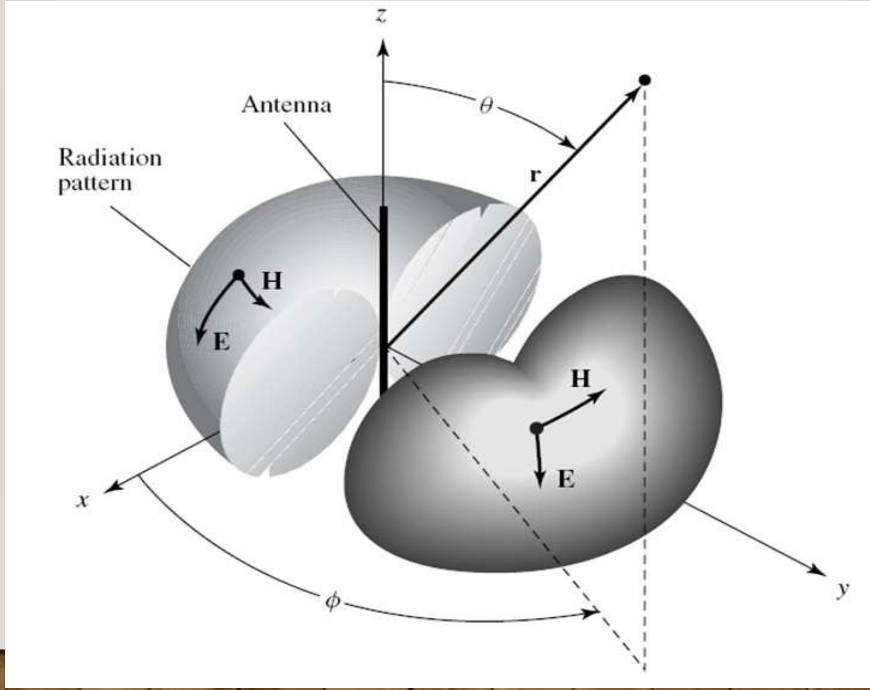
Isotropic, Directional, and Omnidirectional Patterns

- An **omnidirectional** antenna: having an essentially nondirectional pattern **in a given plane** (in this case in azimuth plane) and **a directional pattern** in any orthogonal plane (in this case in elevation plane). It is a special type of a directional pattern.



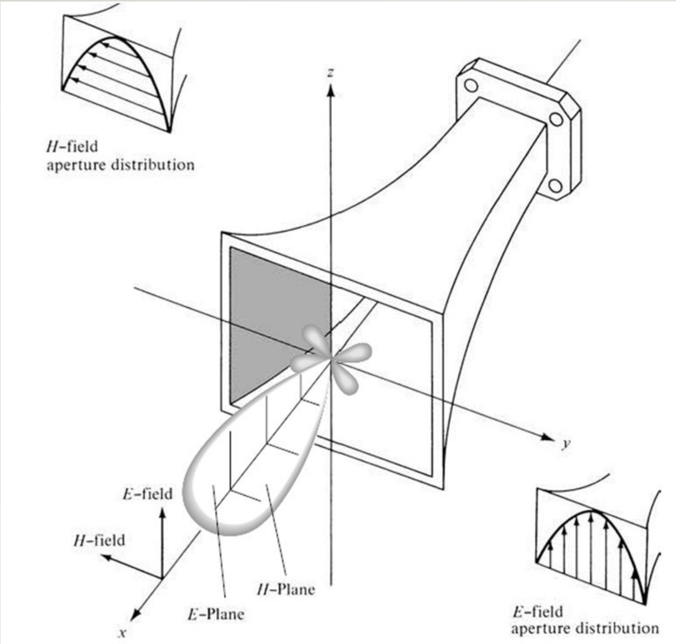
Isotropic, Directional, and Omnidirectional Patterns

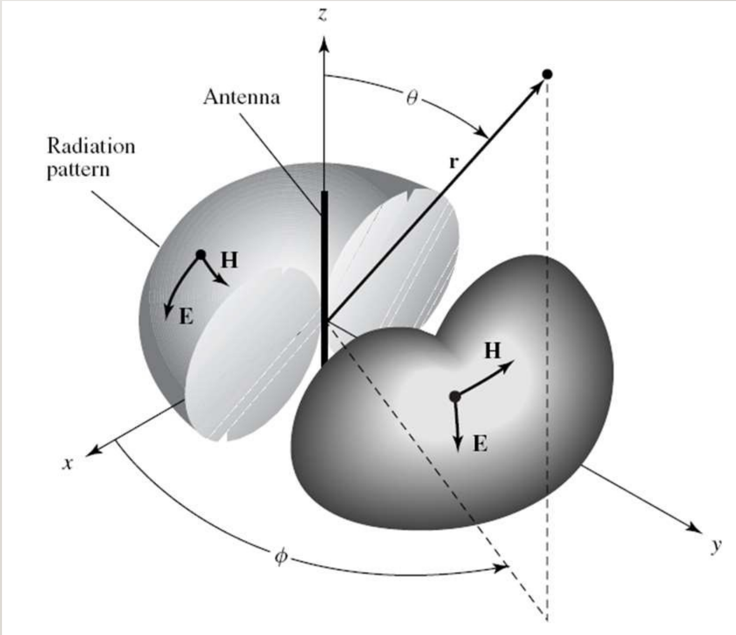
- An **omnidirectional** antenna: having an essentially nondirectional pattern **in a given plane** (in this case in azimuth, f (φ), θ = π/2) and **a directional pattern** in any orthogonal plane (in this case in elevation, g(θ), φ = any constant). It is a special type of a directional pattern.



PRINCIPAL PATTERNS

- E-plane: the plane containing the electric field vector and the direction of maximum radiation (linear polarization)
- H-plane: the plane containing the magnetic-field vector and the direction of maximum radiation (linear polarization)





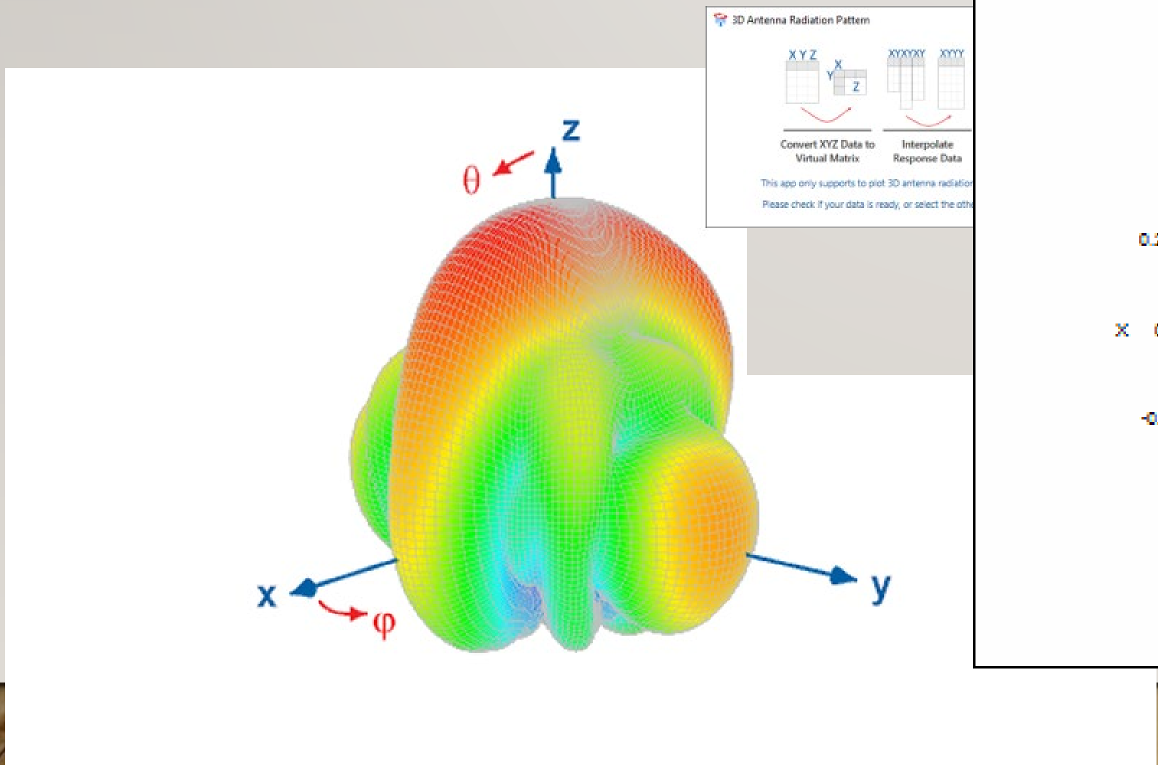
the x-z plane (elevation plane; φ =0) is the principal E-plane and the x-y plane (azimuthal plane; θ = π/2) is the principal H-plane.

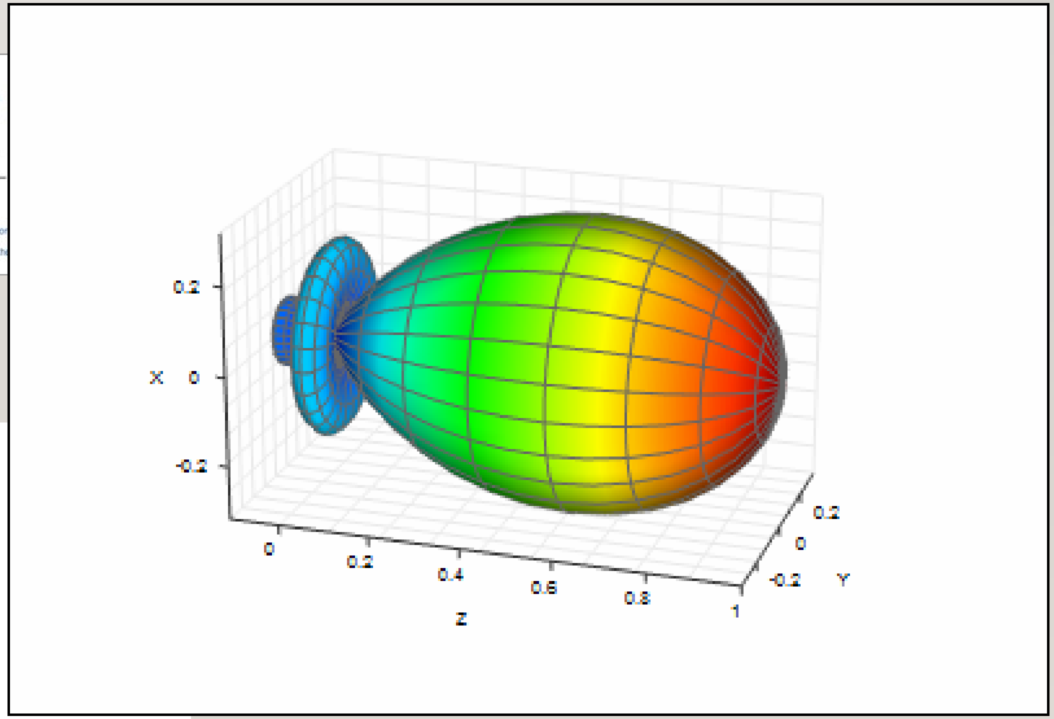
The omnidirectional pattern has an infinite number of principal E-planes (elevation planes; φ = ***0***) and one principal H-plane (azimuthal plane; θ = ***90***°)

PRINCIPAL PATTERNS

- the usual practice to orient most antennas:

at least one of the principal plane patterns coincide with one of the geometrical principal planes.

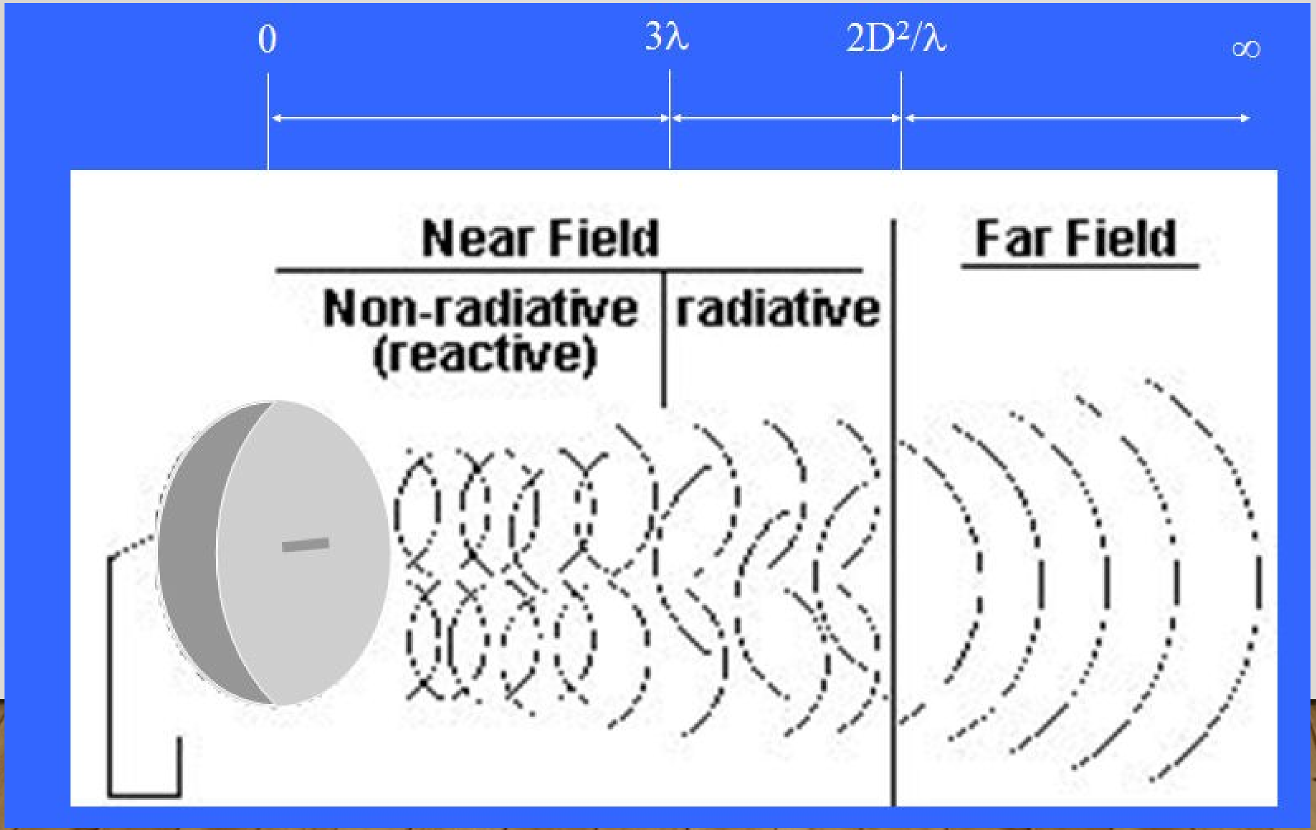




FILED REGIONS

The space surrounding an antenna usually subdivided into three regions:

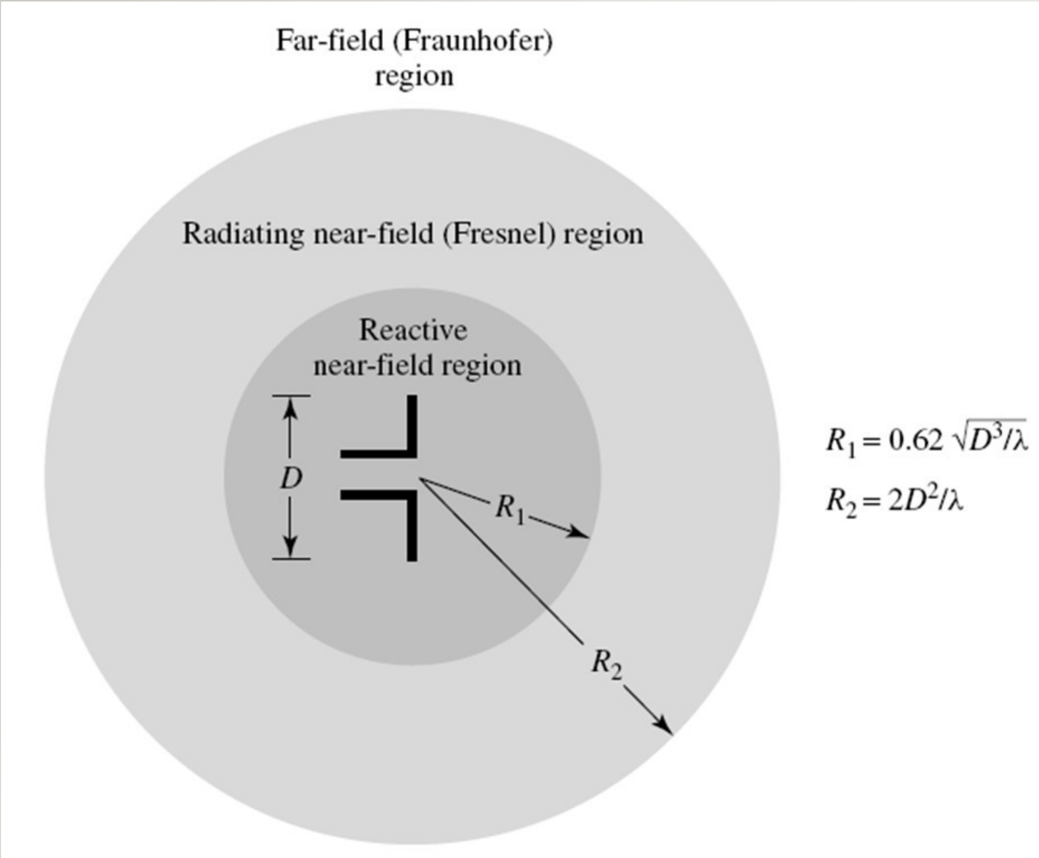
- (a) reactive near-field,
- (b) radiating near-field (Fresnel)
- (c) far-field (Fraunhofer) regions.



FILED REGIONS

- no abrupt changes in the field configurations when the boundaries are crossed
- distinct differences among the regions.
- the boundaries separating these regions are not unique
- various criteria established and commonly used to identify the regions.

FILED REGIONS



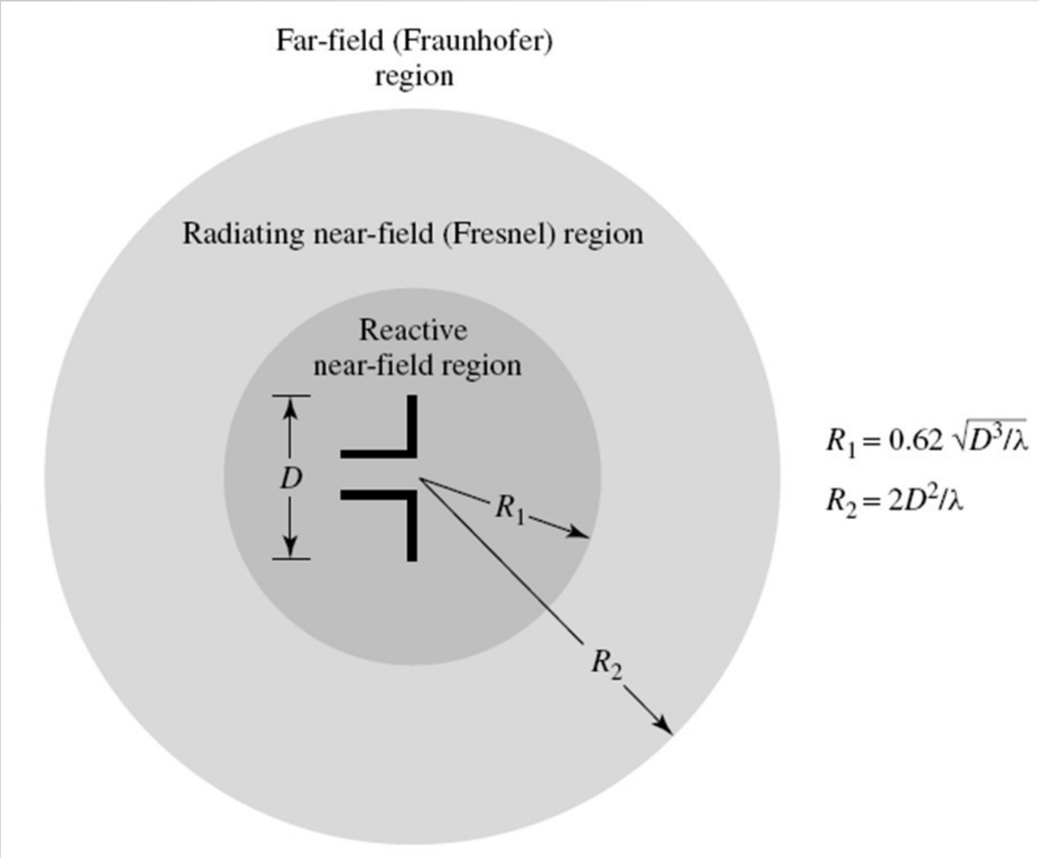
λ is the wavelength ($\lambda = c/f$) and D is the **largest dimension of the antenna**.

1. Reactive near-field region

Very close to the antenna, in the reactive region, energy of a certain amount, if not absorbed by a receiver, is held back and is stored very near the antenna surface.

for a very short dipole, the outer boundary is commonly taken to exist at a distance $\lambda/2\pi$ from the antenna surface.

FILED REGIONS



λ is the wavelength and D is the **largest dimension of the antenna**.

2. Radiating near-field (Fresnel) region

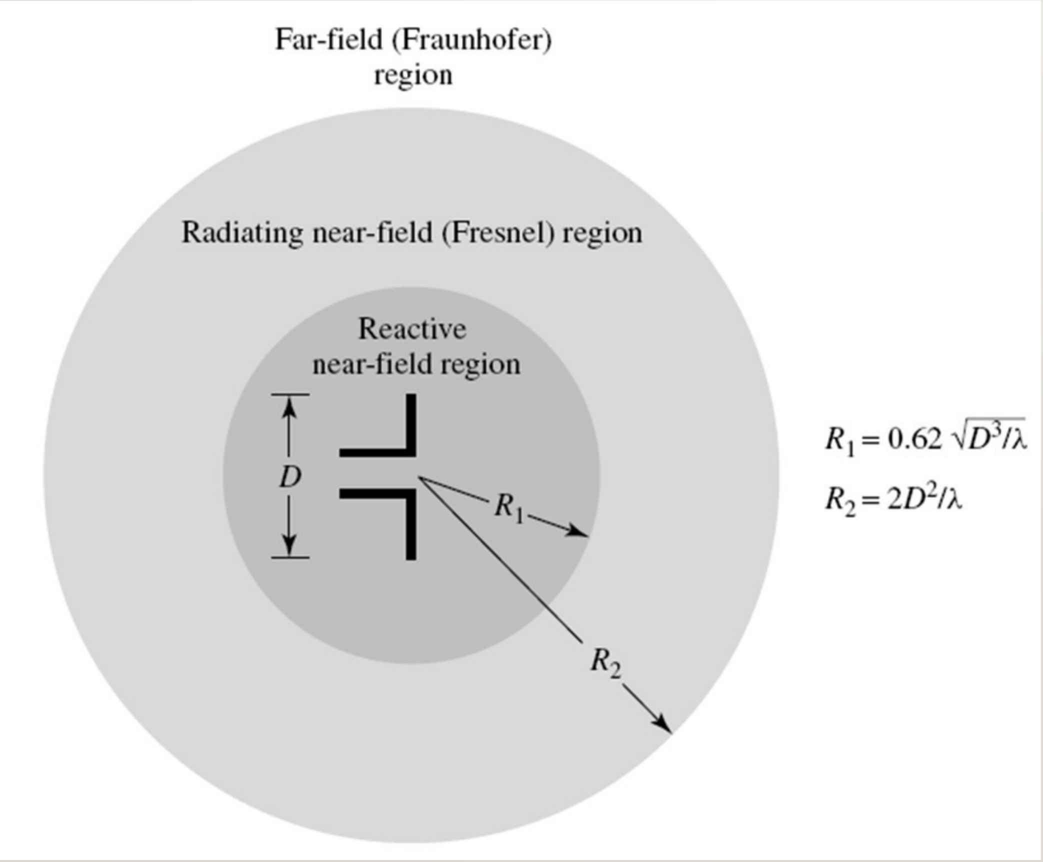
between the reactive near-field region and the far-field region

radiation fields predominate

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**.

FILED REGIONS

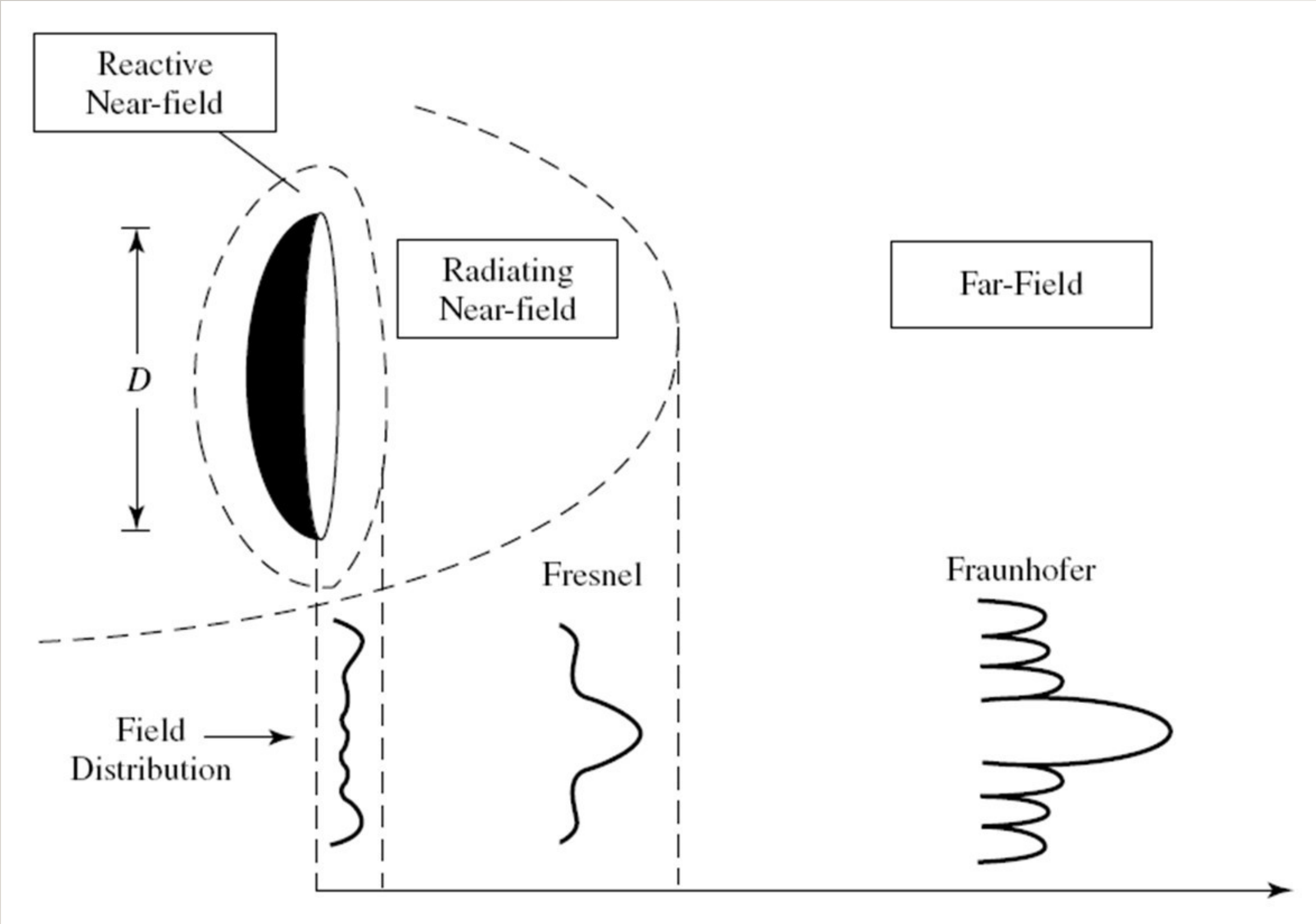


λ is the wavelength and D is the **largest dimension of the antenna**.

3. Far-field (Fraunhofer) region

the angular field distribution is essentially **independent** of the distance from the antenna

FILED REGIONS



reactive nearfield region
the pattern is more spread out and nearly uniform, with slight variations.

radiating near-field region (Fresnel)
the pattern begins to smooth and form lobes.

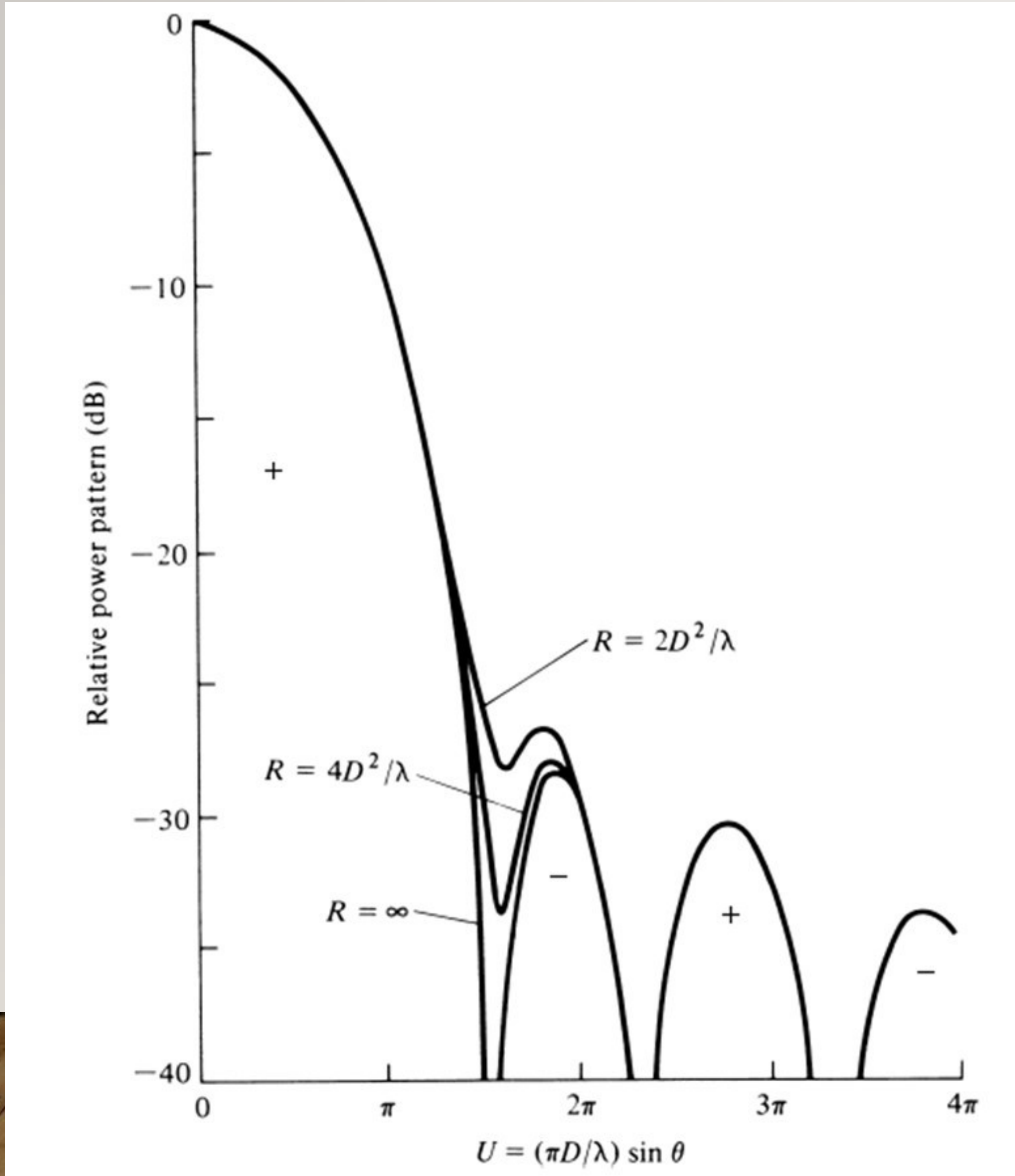
far-field region (Fraunhofer)
the pattern is well formed, usually consisting of few minor lobes and one, or more, major lobes.

Fraunhofer distance $$d = \frac{2D^2}{\lambda}$$

Fraunhofer's most significant discovery: Fraunhofer line 4'03"

FAR-FILED REGIONS

Calculated radiation patterns of a paraboloid antenna for different distances from the antenna.



observation:

- the patterns almost identical
- except for some differences in the pattern structure around the first null and at a level below 25 dB

infinite distances not realizable in practice the most commonly used criterion for **minimum** distance of far-field observations is **Fraunhofer distance**

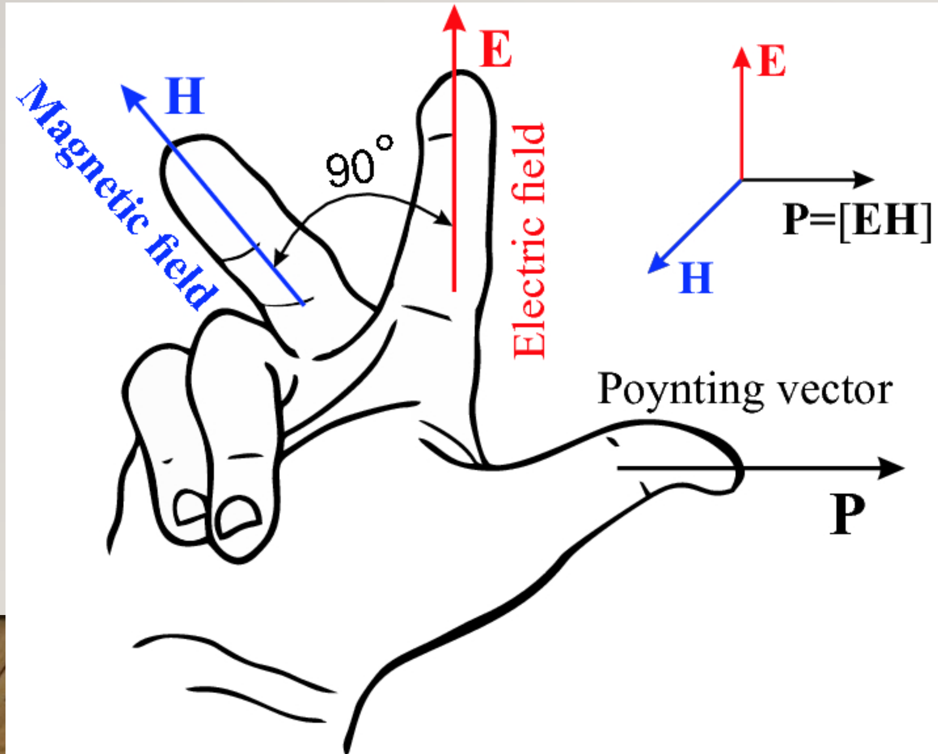
$$2D^2/\lambda.$$

RADIATION POWER DENSITY

- instantaneous Poynting vector defined as:

$$\mathcal{W} = \mathcal{E} \times \mathcal{H}$$

  - $\mathcal{W}$ is the instantaneous Poynting vector (W/m^2)
  - $\mathcal{E}$ is the instantaneous electric-field intensity (V/m)
  - $\mathcal{H}$ is the instantaneous magnetic-field intensity (A/m)



In far field, the electrical and the magnetic field as well as the poynting vector will be perpendicular to each other. Poynting vector points in the direction of the propagation of the wave.

y an antenna

RADIATION POWER DENSITY

- The Poynting vector is a power density.
- The power density associated with the electromagnetic fields of an antenna in its far-field region is predominately real and will be referred to as radiation density (average power density).

$$\mathbf{W}_{av}(x, y, z) = [\mathcal{W}(x, y, z; t)]_{av} = \frac{1}{2}\mathrm{Re}[\mathbf{E} \times \mathbf{H}^*]$$

- Special case, for an isotropic source W_{av} will be independent of the angles θ and φ,

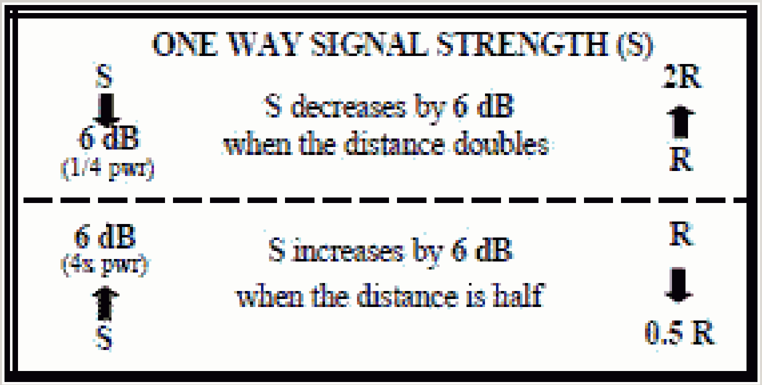
$$W_0 = \hat{a}_r W_0 = \hat{a}_r\left(\frac{P_{rad}}{4\pi r^2}\right) \quad (W/m^2)$$

P_{rad} is radiated power by an antenna

RADIATION POWER DENSITY

theoretical, lossless, omnidirectional (spherical) antenna

$$W_0 = \hat{a}_r W_0 = \hat{a}_r \left(\frac{P_{rad}}{4\pi r^2}\right) \quad (W/m^2)$$



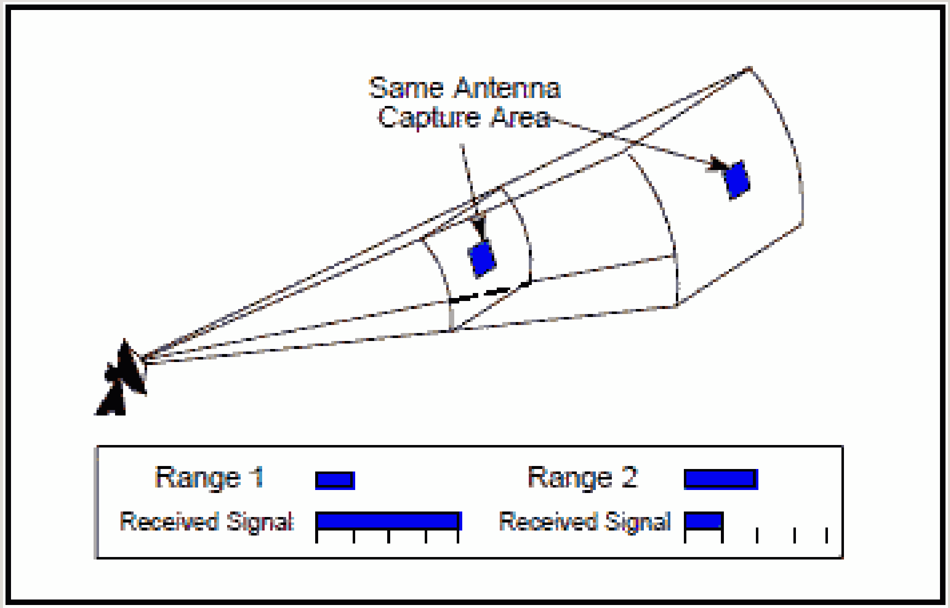


Figure 1. Power Density vs. Range

received signal power decreases by 1/4 (6 dB) as the distance doubles

RADIATION INTENSITY

- power radiated from an antenna per unit **solid angle**
- a far-field parameter
- obtained by simply multiplying the radiation density by the square of the distance. In mathematical form it is expressed as

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

where U is the radiation intensity, (W/unit solid angle)
W_{rad} is the radiation density (W/m^2)

- Special case: For an isotropic source radiation intensity U will be independent of the angles θ and φ,

$$U_0 = \frac{P_{rad}}{4\pi}$$

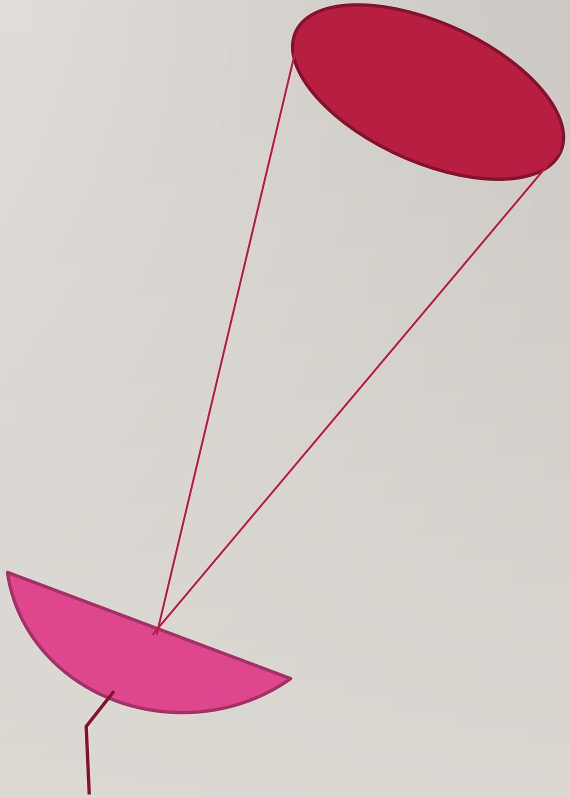
RADIATION POWER DENSITY VS. INTENSITY

$$W = \text{Power Density}$$

$$= \frac{P}{A} \quad \left(\frac{\mathrm{W}}{m^2}\right)$$

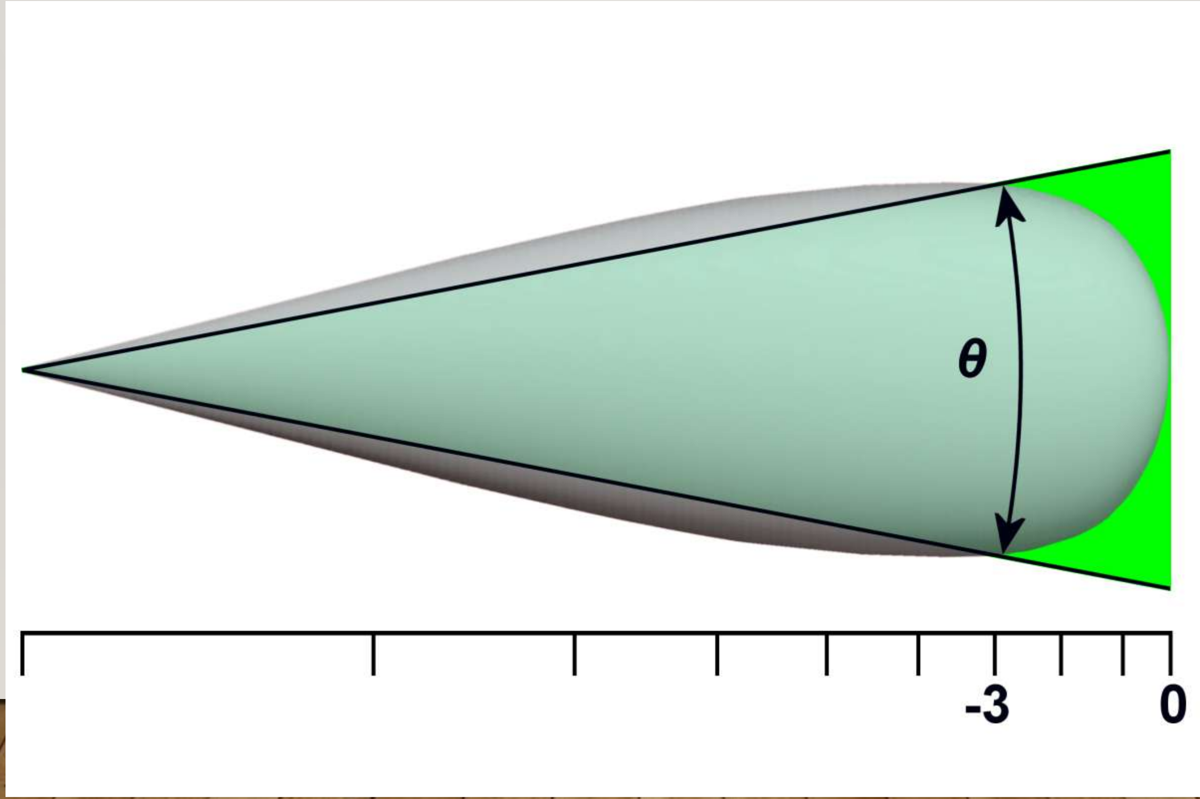
$$U = \text{Radiation Intensity}$$

$$= \frac{P}{\Omega} \quad \left(\frac{\mathrm{W}}{Sr}\right)$$



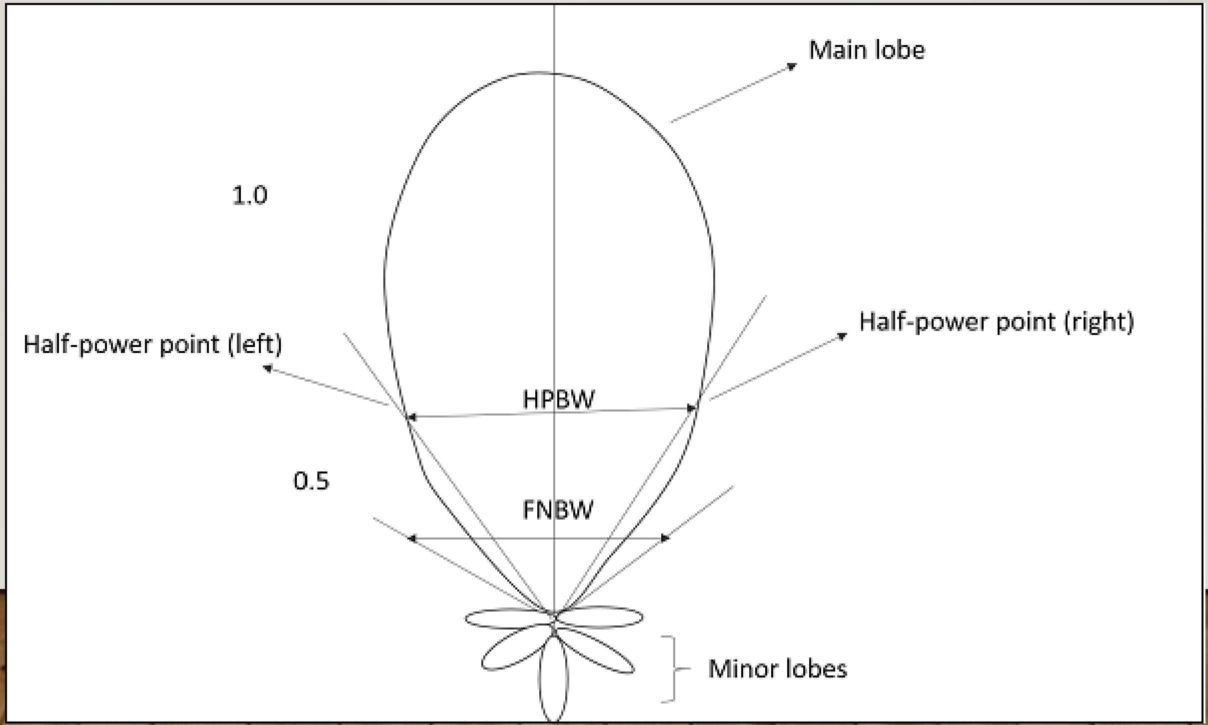
BEAMWIDTH

- associated with the lobes in the antenna pattern
- 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)



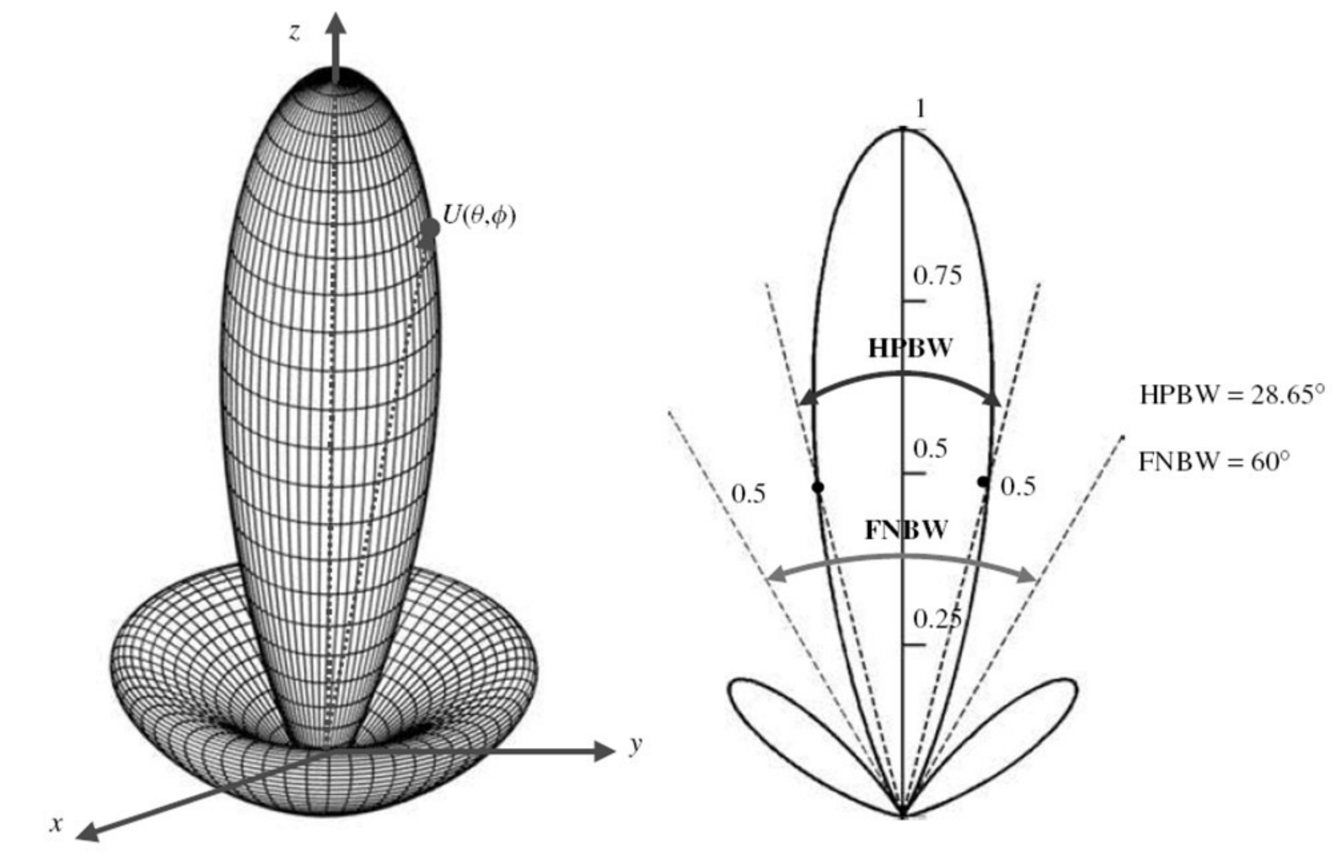
BEAMWIDTH

- associated with the lobes in the antenna pattern
- 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)
- first null beam width (FNBW) is the angular separation between the first nulls of the radiation pattern on either side of the main beam.



BEAMWIDTH

- in practice, **beamwidth** usually refers to **HPBW**.
- a very important figure of merit
- often trade-off between beamwidth and the side lobe level; (as the beamwidth decreases, the side lobe increases and vice versa.)

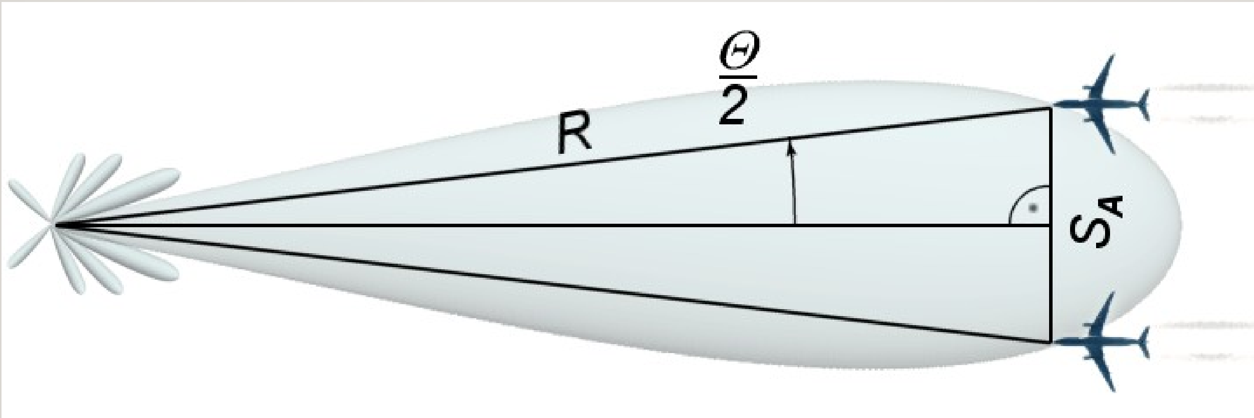


(a) Three dimensional

(b) Two-dimensional

BEAMWIDTH

- also used to describe the resolution capabilities (angular resolution S_A) of the antenna to distinguish between two adjacent radiating sources or radar targets.



$$S_A \geq 2R \cdot \sin \frac{\Theta}{2}$$

with Θ = antenna beam width (Theta)
S_A = angular resolution as a distance between two targets
R = slant range aim - antenna [m]

The air traffic radar ASR-910 calculating the azimuth resolution gives a necessary target distance of 900 m at a distance of 30 km

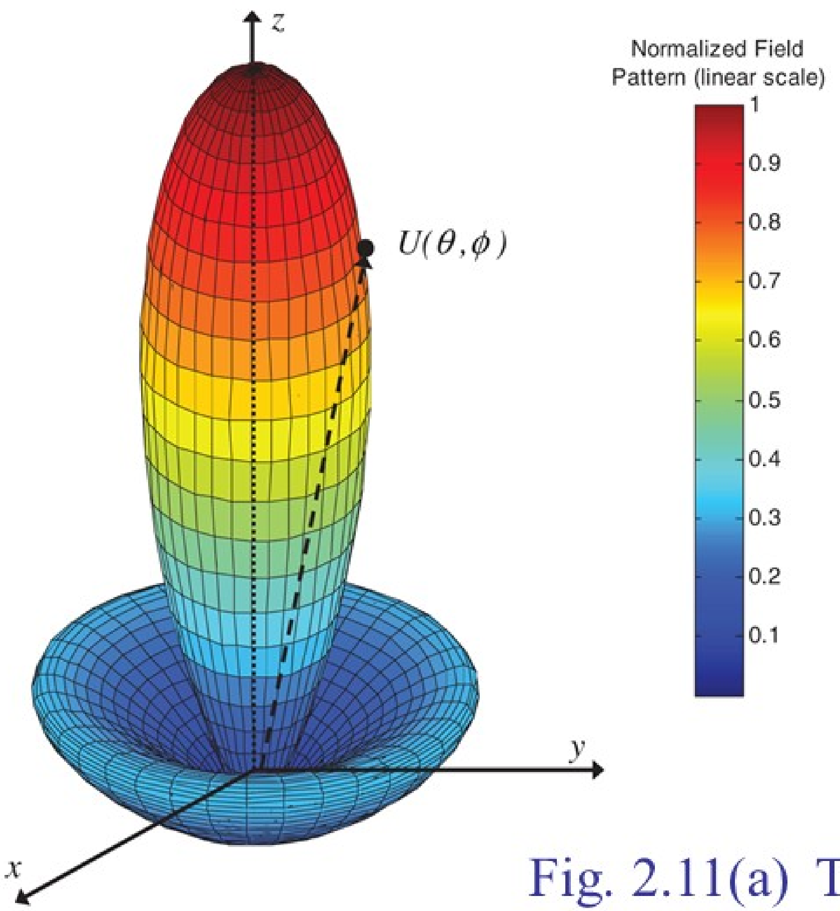
BEAMWIDTH EXAMPLES

Beamwidths

- Half-Power (HPBW)
- First Null (FNBW)

BEAMWIDTH EXAMPLES

HPBW and FNBW of Radiation Intensity U



Linear Scale

$$(\theta,\phi) = \cos^2\theta\cos^2 3\theta$$

Fig. 2.11(a) Three-dimensional

BEAMWIDTH EXAMPLES

Example 2.4:

The normalized radiation intensity of an antenna is represented by

$$U(\theta) = \cos^2(\theta)\cos^2(3\theta),$$

$$(0 \le \theta \le 90^{\circ}, \quad 0^{o} \le \phi \le 360^{o})$$

The three- and two-dimensional plots of this plotted in a linear scale, are shown in the figure. Find the:

a. *HPBW* (*in radians and degrees*)

b. *FNBW* (*in radians and degrees*)

BEAMWIDTH EXAMPLES

Solution:

a. Since the $U(\theta)$ represents the *power* pattern, to find the half-power beamwidth you set the function equal to half of its maximum, or

$$U(\theta)\big|_{\theta=\theta_h} = \cos^2(\theta)\cos^2(3\theta)\big|_{\theta=\theta_h} = 0.5 \quad \Rightarrow \quad \cos\theta_h \cos 3\theta_h = 0.707$$

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

Since the equation is nonlinear, after few iterations it is found that

$$\theta_h \approx 0.25\ radians = 14.32^\circ$$

Since the function $U(\theta)$ is symmetrical about the maximum at $\theta=0$, then the HPBW is

$$HPBW = 2\theta_h = \Theta_h \approx 0.50\ radians = 28.65^\circ$$

BEAMWIDTH EXAMPLES

To find the first-null beamwidth (FNBW), you set the equal to zero, or

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

This leads to two solutions for θ_n.

$$\cos\theta_n = 0 \quad \Rightarrow \quad \theta_n = \cos^{-1}(0) = \frac{\pi}{2}\ radians = 90^o$$

$$\cos 3\theta_n = 0 \quad \Rightarrow \quad \theta_n = \frac{1}{3}\cos^{-1}(0) = \frac{\pi}{6}\ radians = 30^o$$

The one with the smallest value leads to the *FNBW*. Because of the symmetry of the pattern, the *FNBW* is

$$FNBW = 2\theta_{\mathrm{n}} = \Theta_n = \frac{\pi}{3}\ radians = 60^o$$

DIRECTIVITY GAIN (DBi)

the **ratio** of **the radiation intensity *U* in a given direction** from the antenna to the **radiation intensity averaged over all directions**

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

The average radiation intensity U_0 is equal to the total power P_{rad} radiated by the antenna divided by 4π. $U_0 = P_{rad}/4\pi$ equal to the ratio of its radiation intensity in a given direction over that of an **isotropic source**.

DIRECTIVITY

the **maximal** directive gain value found among all possible solid angles:

$$D_{max} = D_0 = \frac{U_{max}}{U_0} = \frac{4\pi U_{max}}{P_{rad}}$$

D = directivity (gain) D_0 = maximum directivity

U = radiation intensity

U_0 = radiation intensity of isotropic source

P_{rad} = total radiated power

U_{max} = maximum radiation intensity

DIRECTIVITY

directivity of an isotropic source

$$D = D_0 = D_{max} = 1$$

For all other sources,

$$D_0 > 1$$

in general, directivity gain is between 0 and D_0

$$0 \leq D \leq D_0$$

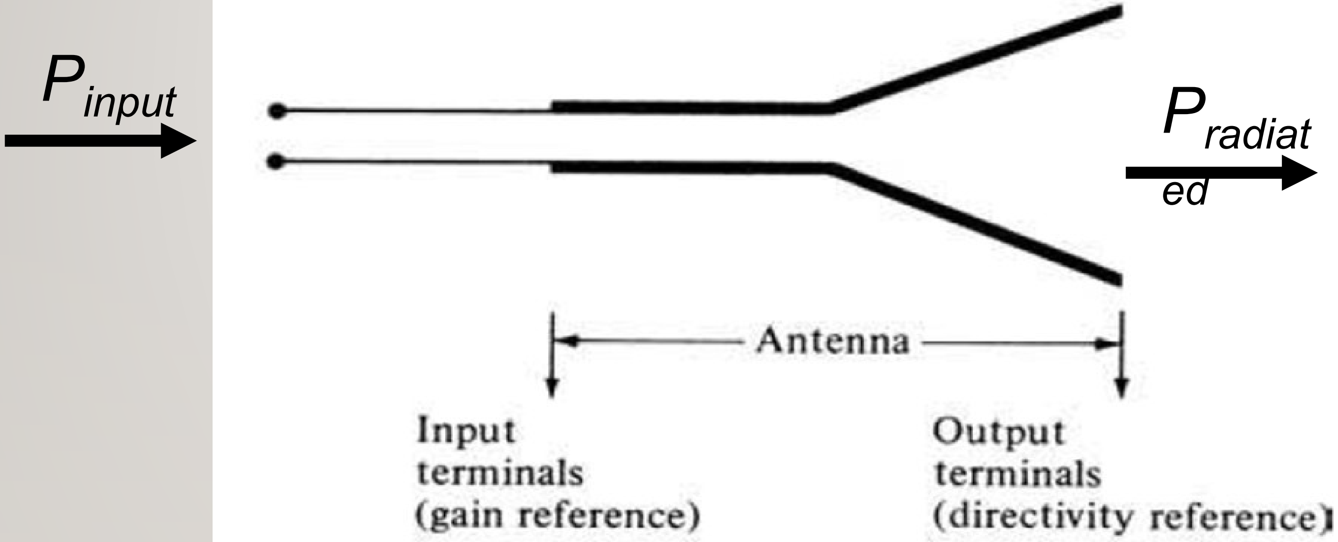
ANTENNA EFFICIENCY

The total antenna efficiency e_0

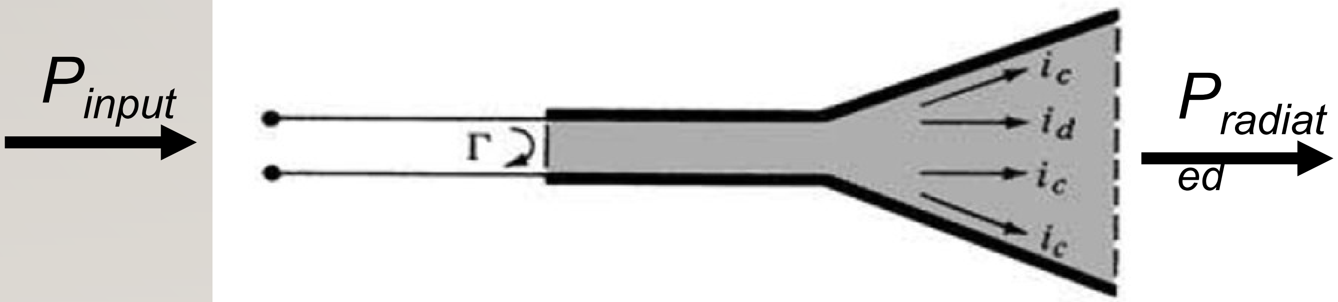
- ratio between radiated power and input power
- taking into account losses at the input terminals
- taking into account losses within the structure of the antenna (conduction and dielectric)

$$e_0 = \frac{P_{radiated}}{P_{input}}$$

ANTENNA EFFICIENCY



(a) Antenna reference terminals



(b) Reflection, conduction, and dielectric losses

ANTENNA EFFICIENCY

Total efficiency

$$e_0 = e_r e_c e_d$$

where

e_0 = total efficiency (dimensionless)
e_r = reflection (mismatch) efficiency $= (1 - |\Gamma|^2)$ (dimensionless)
e_c = conduction efficiency (dimensionless)
e_d = dielectric efficiency (dimensionless)

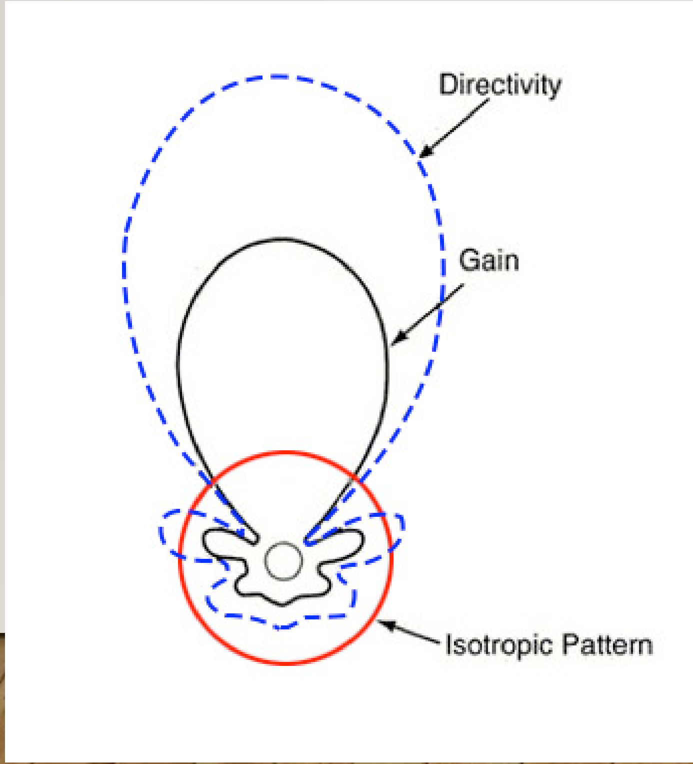
Or

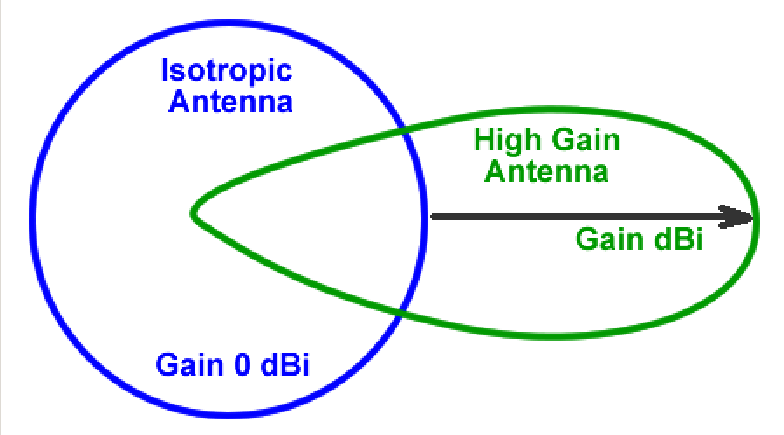
$$e_0 = e_r e_{cd} = e_{cd}(1 - |\Gamma|^2)$$

e_c and e_d difficult to compute, but determined experimentally.
e_c and e_d usually not separable
more convenient to write $e_{cd} = e_c e_d$ = antenna radiation efficiency
used to relate the gain and directivity (gain = directivity * efficiency)

ANTENNA GAIN

- the ability of the antenna to radiate more or less in any direction compared to a theoretical antenna.
- a measure that takes into account the **efficiency of the antenna** as well as **its directional capabilities**.
- directivity is a measure that describes only the directional properties of the antenna controlled only by the pattern.



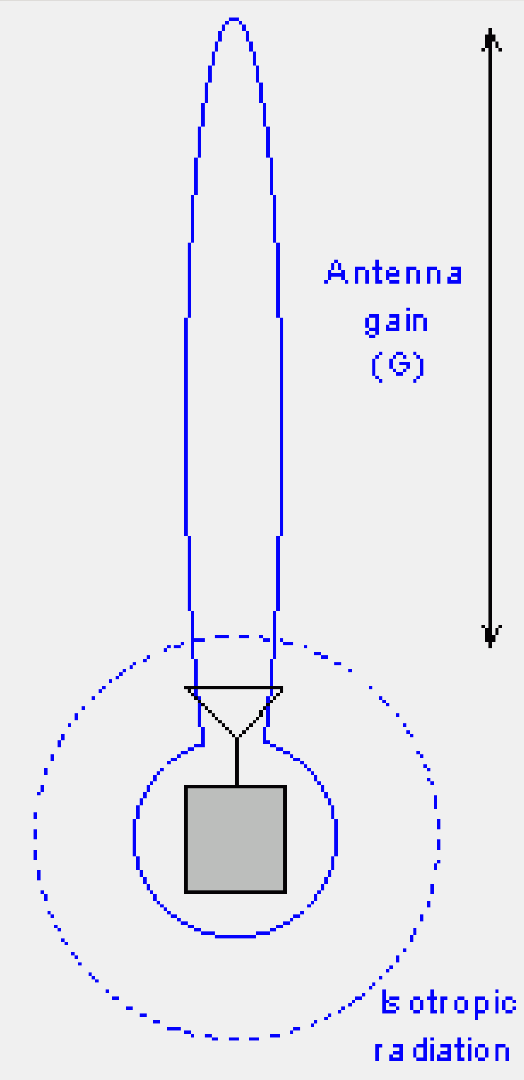


ANTENNA GAIN

- Gain of an antenna (in a given direction)
- 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) equal to the power accepted (input) by the antenna divided by 4π.

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

RELATIVE GAIN



- in most cases, relative gain is used
- defined as "the **ratio** of **the power gain in a given direction** to **the power gain of a reference antenna** in its referenced direction." The power input must be the same for both antennas.

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

GAIN

- When the direction is not stated, the power gain is usually taken in the direction of **maximum radiation**.
- The total input power by total radiated power (P_{rad}) related to the total input power (P_{in}) by

$$P_{rad} = e_{cd} P_{in}$$

- The relationship between gain and directivity:

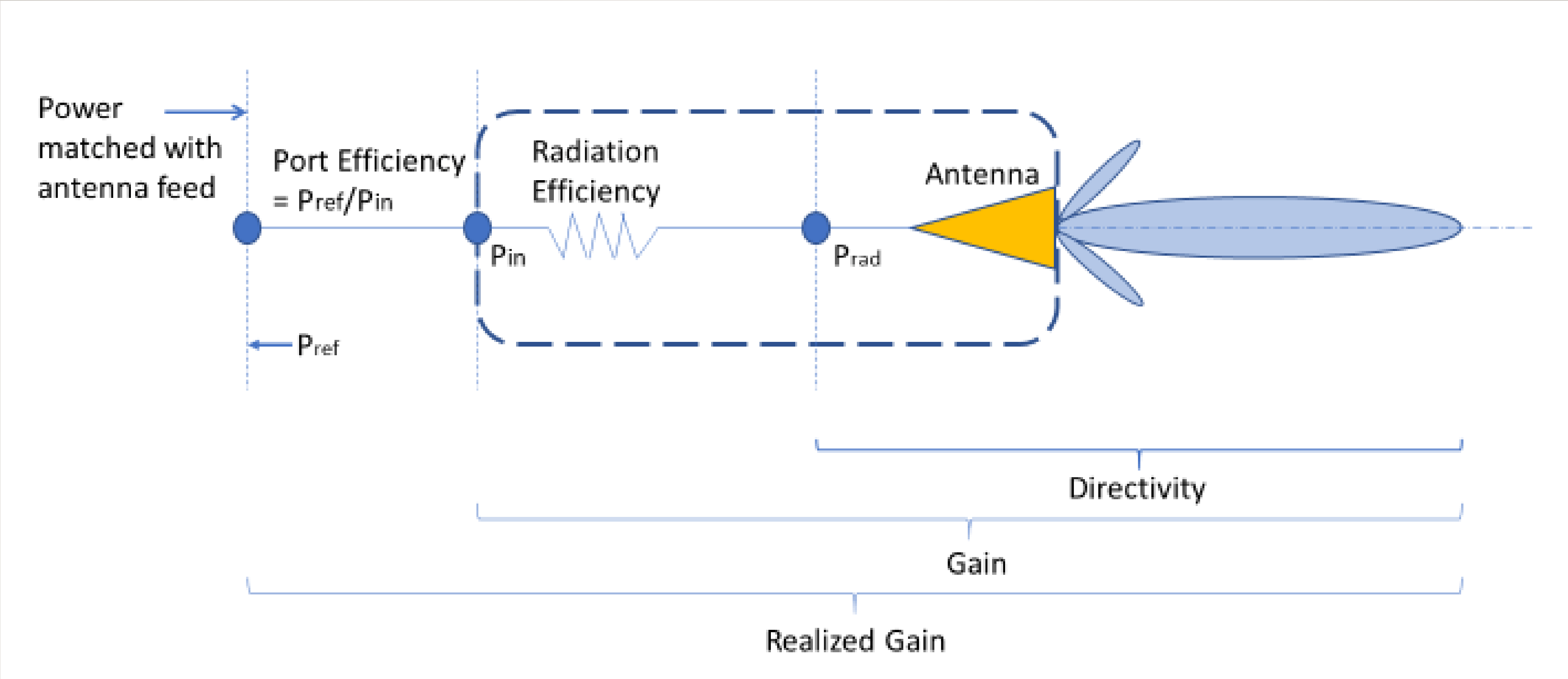
$$G(\theta,\phi) = e_{cd} D(\theta,\phi)$$

- absolute gain G_{abs} (realized gain) taking into account the reflection/mismatch losses (due to the connection of the antenna element to the transmission line)

$$G_{abs}(\theta,\phi) = e_r G(\theta,\phi) = (1 - |\Gamma|^2) G(\theta,\phi)$$
$$= e_r e_{cd} D(\theta,\phi) = e_0 D(\theta,\phi)$$

where e_0 is the overall efficiency

GAIN AND DIRECTIVITY (MATLAB)



GAIN IN DBI VS. DBD

$$0 \text{ dBd} = 2.15 \text{ dBi}$$

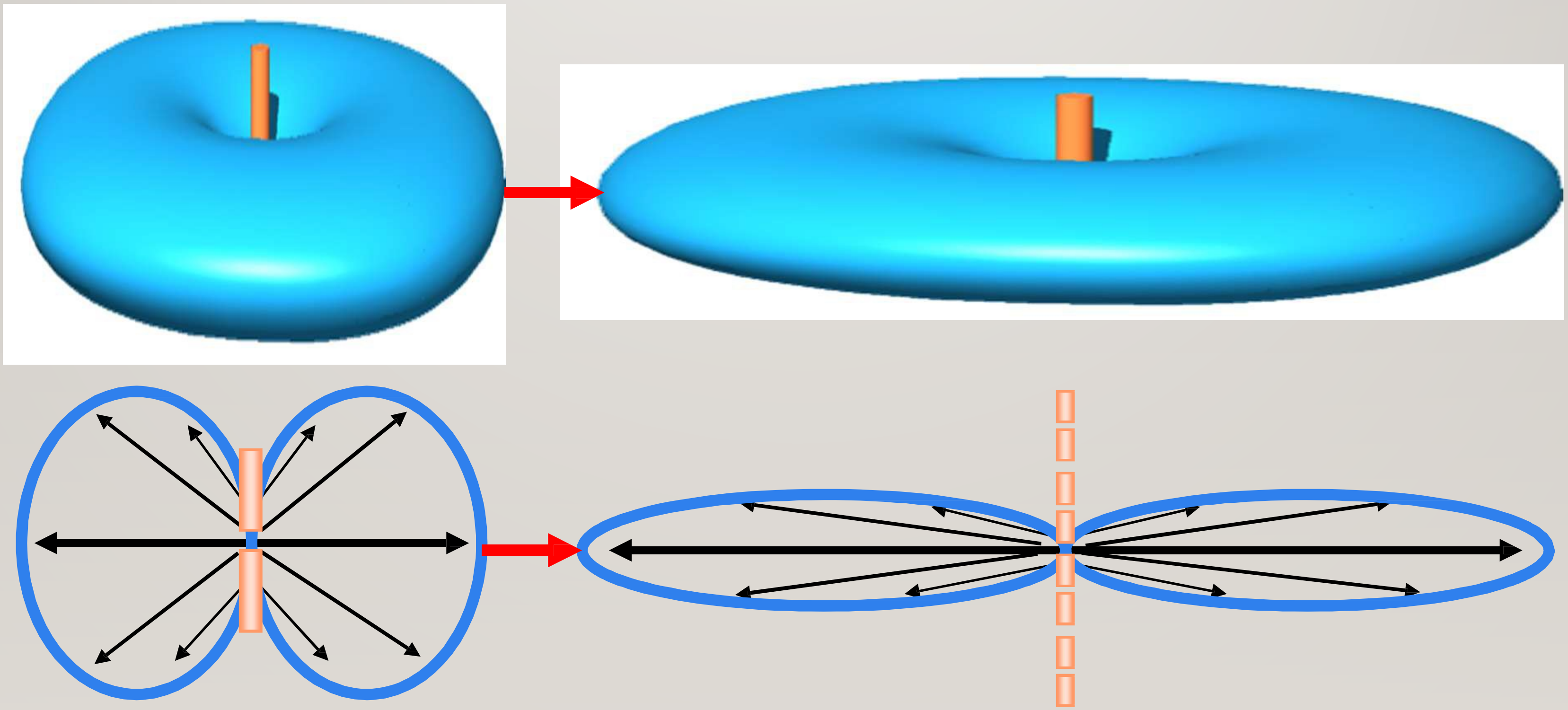
5’32’’

dBi is a measurement that compares the gain of an antenna with respect to an isotropic radiator (a theoretical antenna that disperses incoming energy evenly over the surface of an imaginary sphere.)

dBd compares the gain of an antenna to the gain of a reference dipole antenna (defined as 2.15 **dBi** gain).

GAIN IN DBI VS. DBD

- How to obtain higher gain?

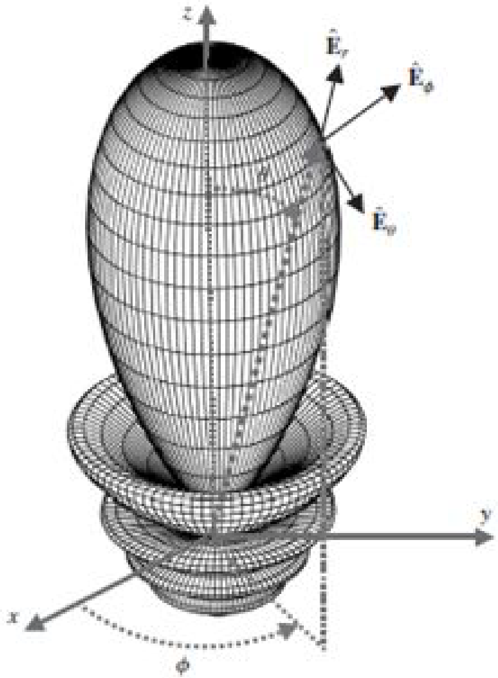


BEAM EFFICIENCY

– Another parameter that is frequently used to judge the quality of transmitting and receiving antennas.

$$\boxed{\mathrm{BE} = \frac{\text{power transmitted (received) within cone angle } \theta_1}{\text{power transmitted (received) by the antenna}}}$$

$$\boxed{\mathrm{BE} = \frac{\int_0^{2\pi}\int_0^{\theta_1} U(\theta,\phi)\sin\theta\, d\theta\, d\phi}{\int_0^{2\pi}\int_0^{\pi} U(\theta,\phi)\sin\theta\, d\theta\, d\phi}}$$



– Radiometry, astronomy, radar
  - High beam efficiency is necessary
  - Minor lobes must be minimized

θ_1 = half-angle of the cone

BANDWIDTH

- **frequency range** within which the performance of the antenna, with respect to **some characteristic**, conforms to a specified standard (**return loss**, axial ratio, etc.)
- **frequency range**, on **either side of a center frequency** (e.g. the resonance frequency for a dipole), where the antenna characteristics are within an acceptable value of those at the center frequency

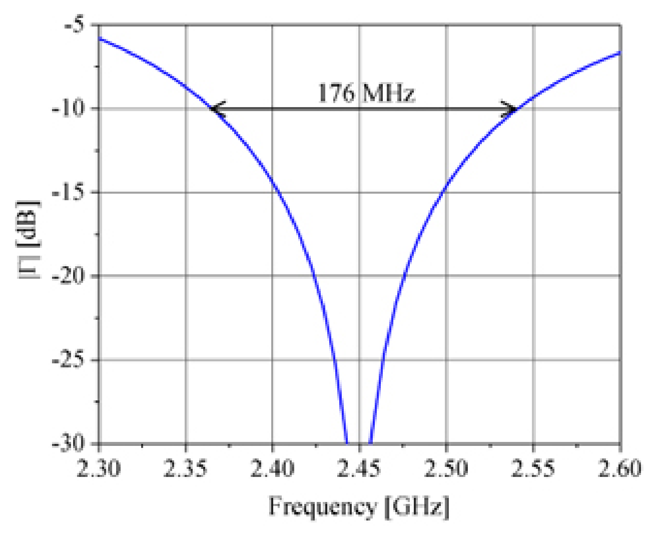


Fig. 3. Reflection coefficient magnitude.

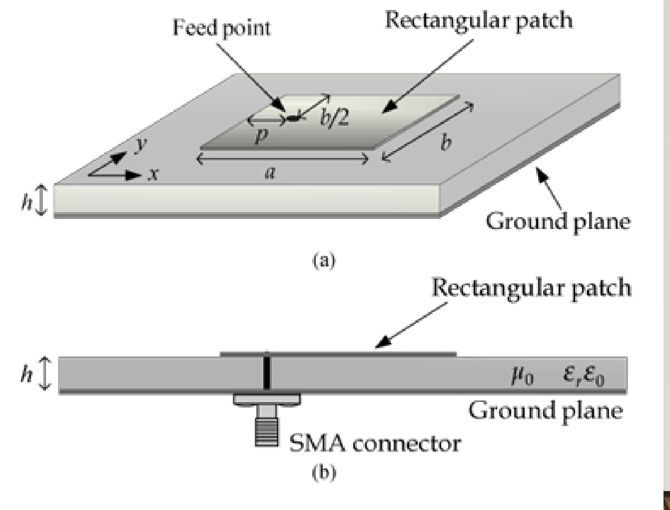
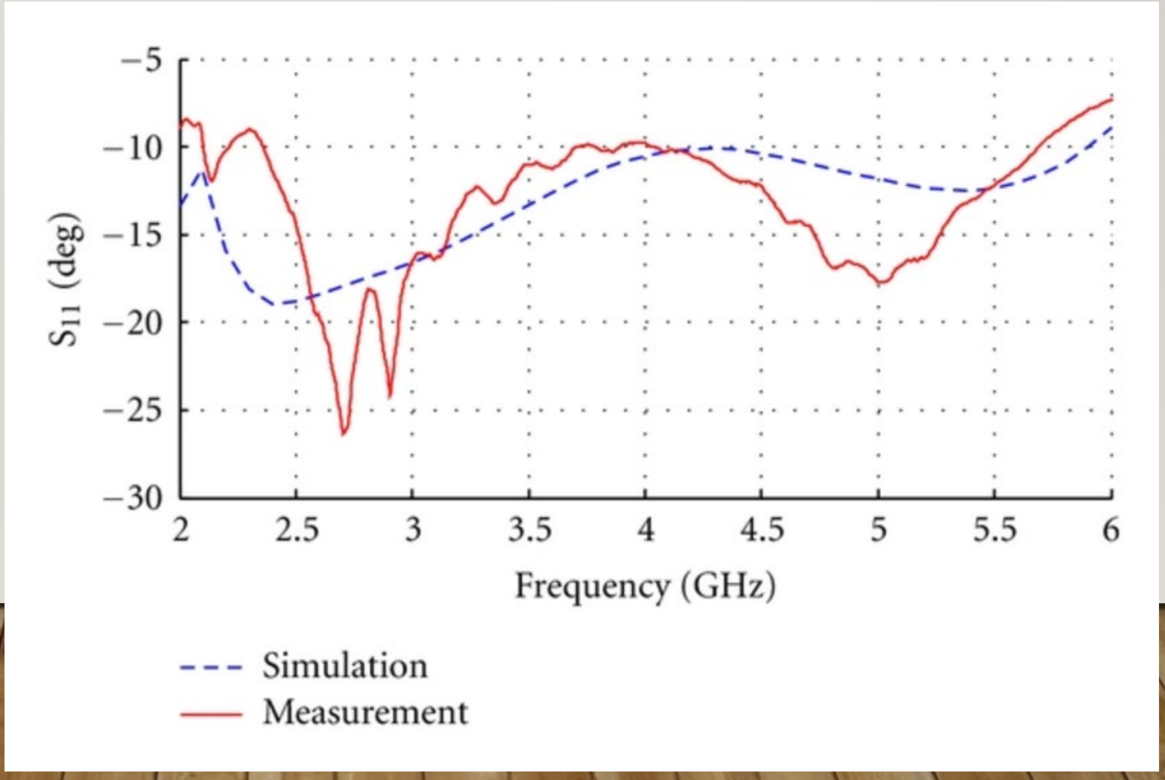


Fig. 1. Probe-fed rectangular-patch LP antenna: (a) top view - (b) side view.

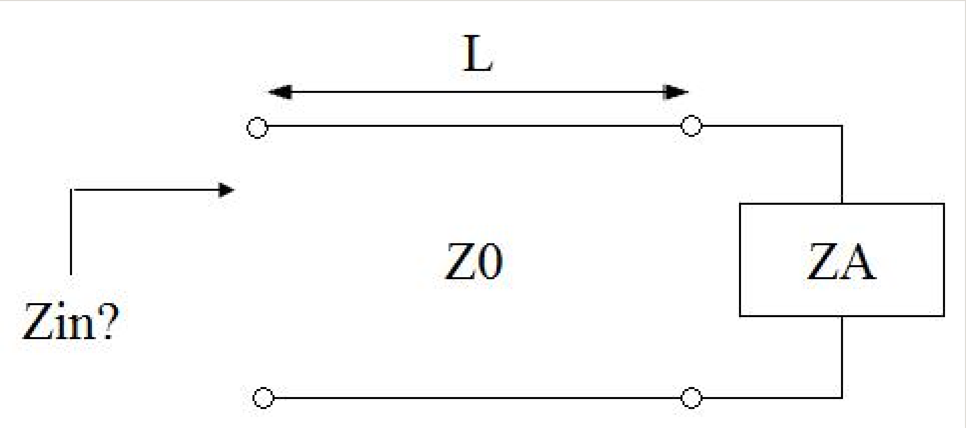
BANDWIDTH (BROADBAND ANTENNAS)

- **frequency ratio**: ratio of the upper-to-lower frequencies of acceptable operation. (e.g., a 10:1 bandwidth indicates that the upper frequency is 10 times greater than the lower)
- **fractional bandwidth**: a percentage of the frequency difference over the center frequency of the bandwidth. (e.g., the figure below shows a 100% bandwidth)



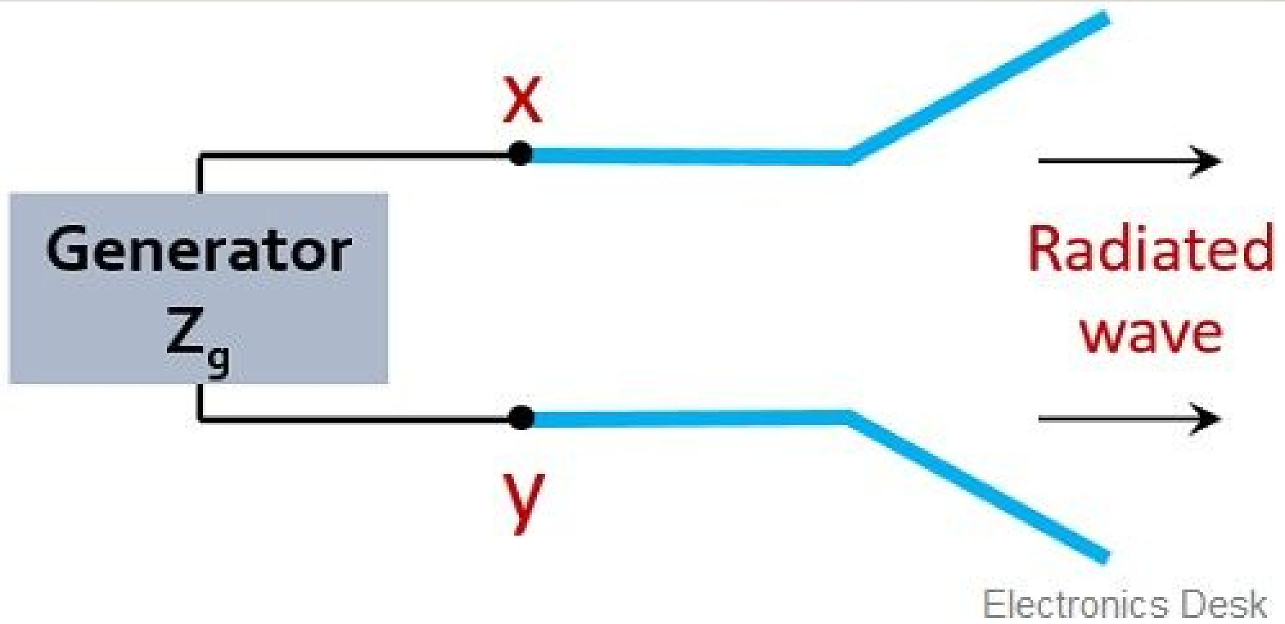
INPUT IMPEDANCE

- the impedance presented by an antenna at its terminals
- the ratio of the voltage to current at a pair of terminals
- the ratio of the appropriate components of the electric to magnetic fields at a point
- generally a function of frequency
- matched to the interconnecting transmission line and other associated equipment only within a bandwidth.



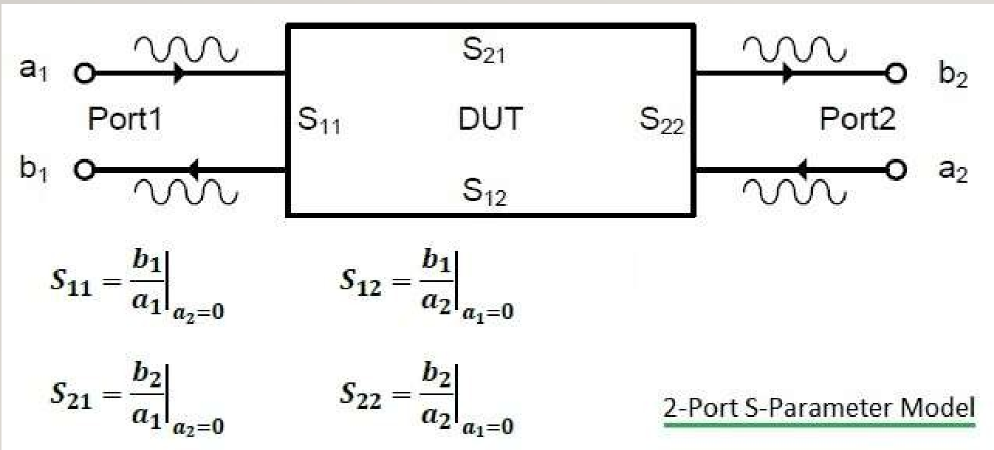
INPUT IMPEDANCE

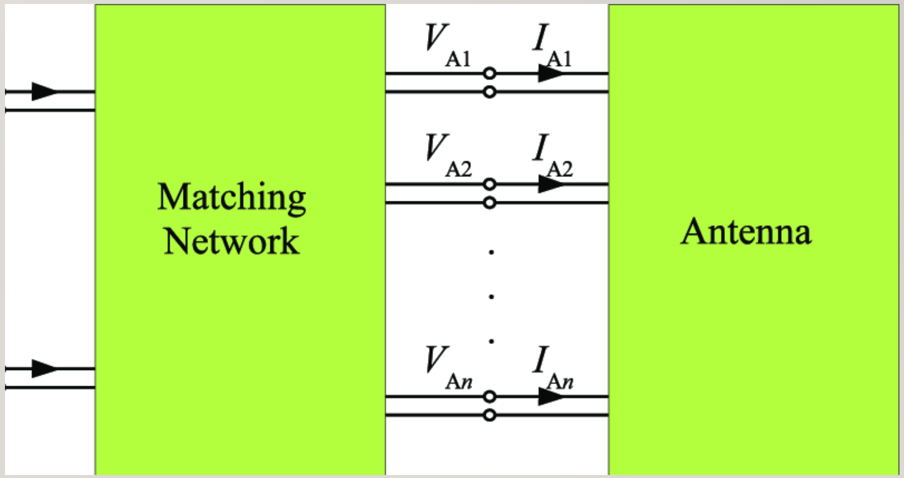
- depends on many factors
- its geometry, its method of excitation, and its proximity to surrounding objects.
- due to their complex geometries, only a limited number of practical antennas investigated analytically.
- for many others, determined experimentally or through EM simulation



S-PARAMETER

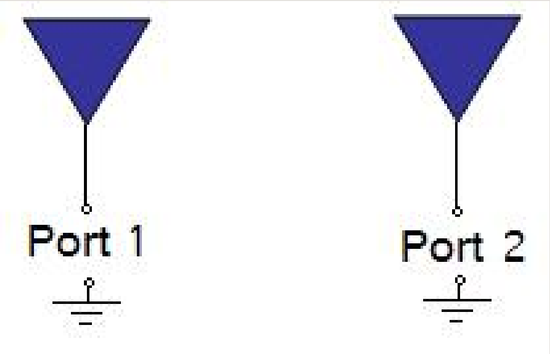
Scattering parameters or S-parameters (the elements of a scattering matrix or S-matrix) describe the electrical behavior of linear electrical networks when undergoing various steady state stimuli by electrical signals.





ANTENNA S-PARAMETER

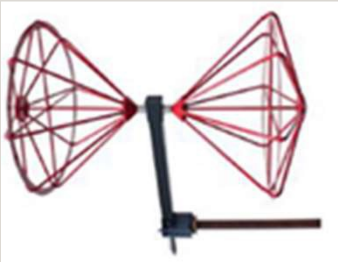
describe the input-output relationship between ports (or terminals) in an electrical system. S_{NM} represents the power transferred from Port M to Port N in a multi-port network.



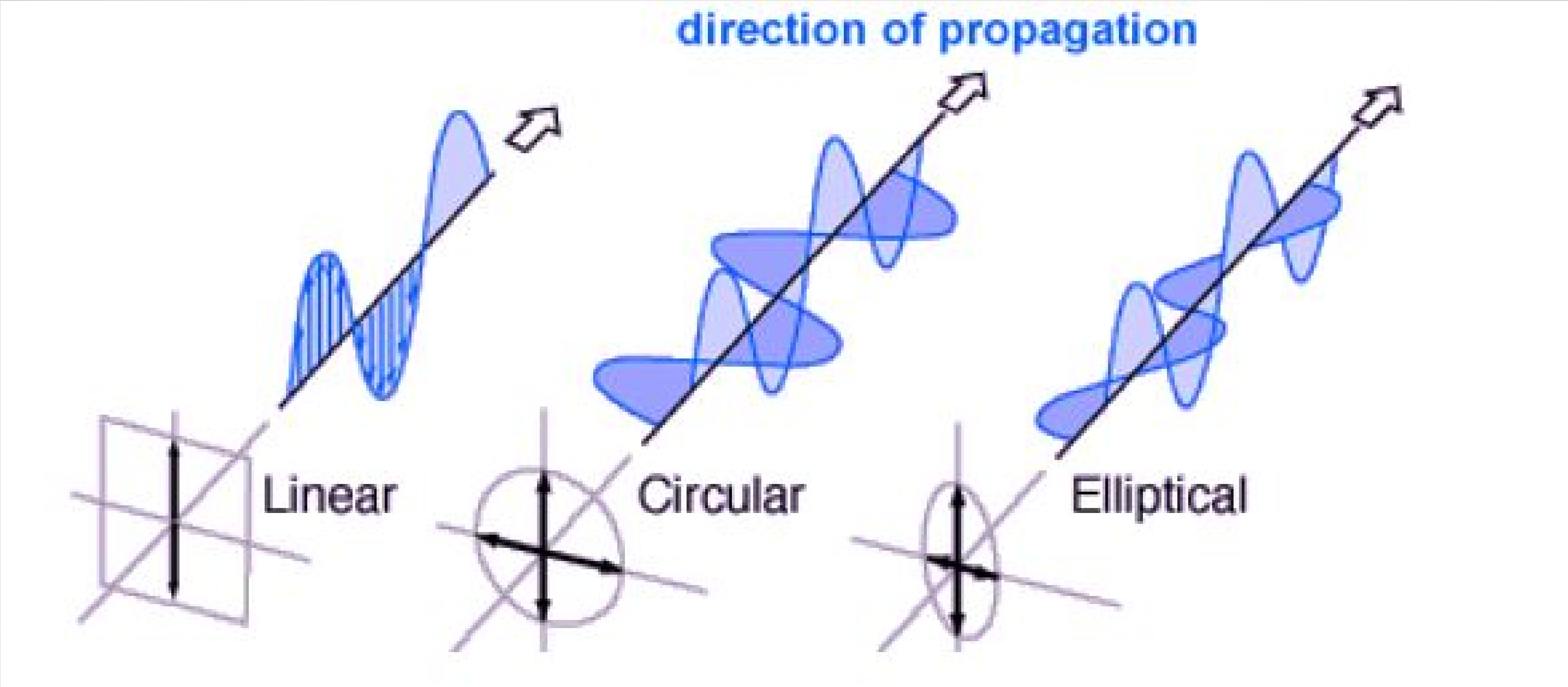
S_{21} represents the power received at antenna 2 relative to the power input to antenna 1.
S_{11} represents how much power is reflected from the antenna at Port 1.

POLARIZATION OF ANTENNA

- in a given direction defined as "the polarization of the wave transmitted (radiated) by the antenna. Note: When the direction is not stated, the polarization is taken to be the polarization in **the direction of maximum gain**."
- In practice, polarization of the radiated energy varies with the direction from the center of the antenna, so **that different parts of the pattern may have different polarizations**.

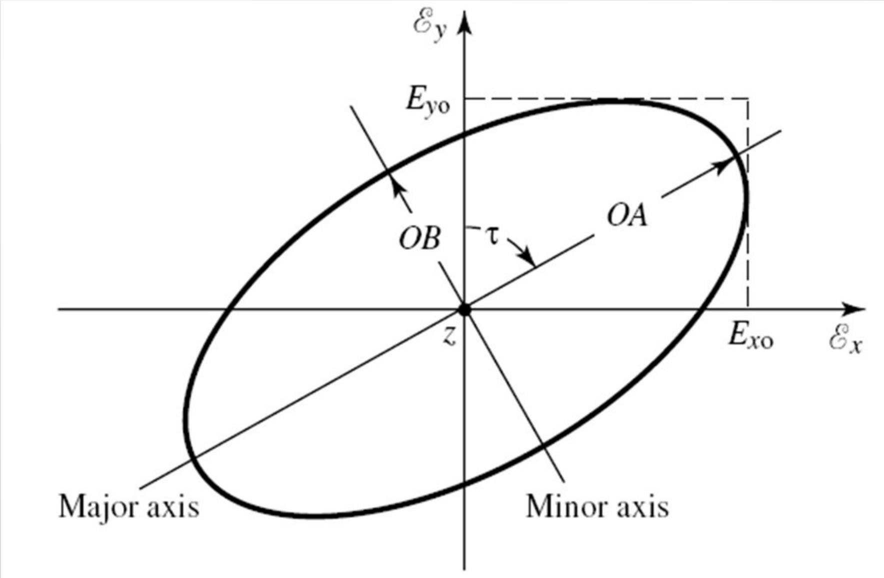


POLARIZATION OF ANTENNA



AXIAL RATIO

elliptical/circular polarization

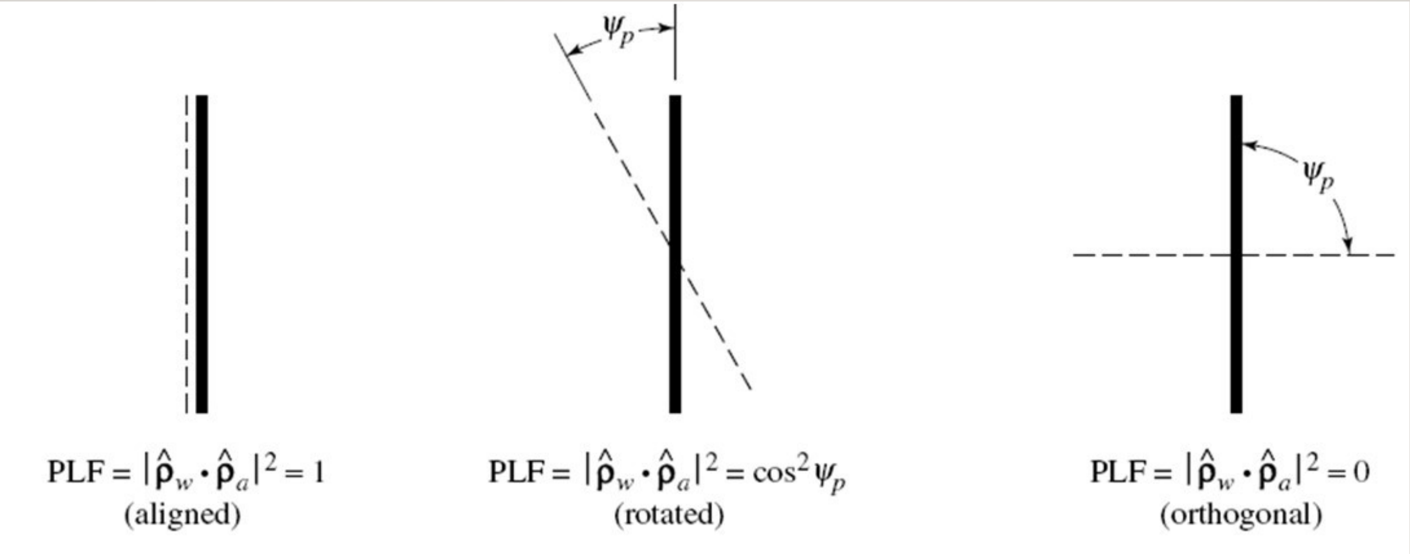


$$AR = \frac{major\ axis}{minor\ axis} = \frac{OA}{OB}, \qquad 1 \leq AR \leq \infty$$

POLARIZATION LOSS FACTOR

the polarization of the receiving antenna not the same as the polarization of the incoming (incident) wave

$$\text{PLF}=|\hat{\rho}_w \cdot \hat{\rho}_a|^2 = \left|cos\psi_p\right|^2 \ (dimensionless)$$



PLF for transmitting and receiving linear wire antennas

HOMEWORK

1. Write Matlab code to plot radiation pattern in 2D polar coordinates. Calculate
   - exact maximum directivity
   - HPBW and FNBW in azmuth plane
   - HPBW and FNBW in elevation plane

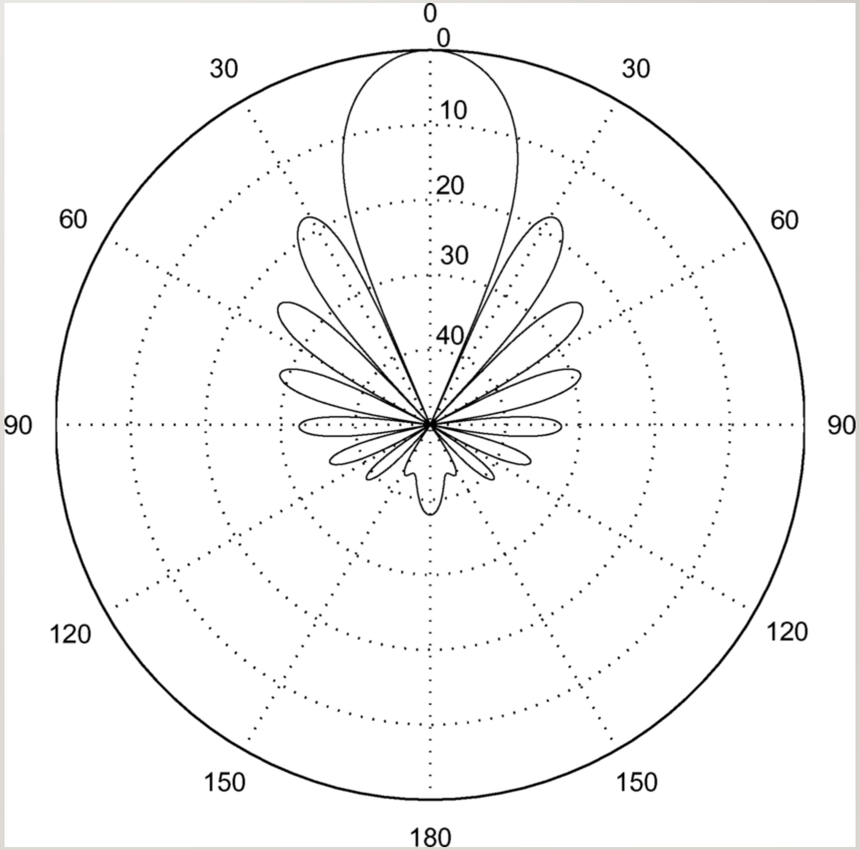
Plot 3D radiation pattern using Matlab

Test your program using normalized radiation intensity

$$U=\sin^2\theta \cos^2\varphi$$

for $0 \le \theta \le 180^\circ$ $0 \le \varphi \le 360^\circ$

2. What is HPBW and FNBW of the antenna pattern plot on the right? Please estimated maximum directivity (explain).



E-plane Directivity in dBi