AVN INSTITUTE OF ENGINEERING & TECHNOLOGY
PATEL GUDA, IBRAHIMPATNAM (M), R.R.Dist, 501510, T.S
Ph.No. 08415-201345, www.avniet.ac.in, Email: avn.principal@gmail.com

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ANTENNA AND WAVE PROPAGATION

III B.TECH-II SEM

DEPT.OF.ECE

Prepared by
Mr.U.NARESH
Asst.Professor

ANTENNASS BASICS

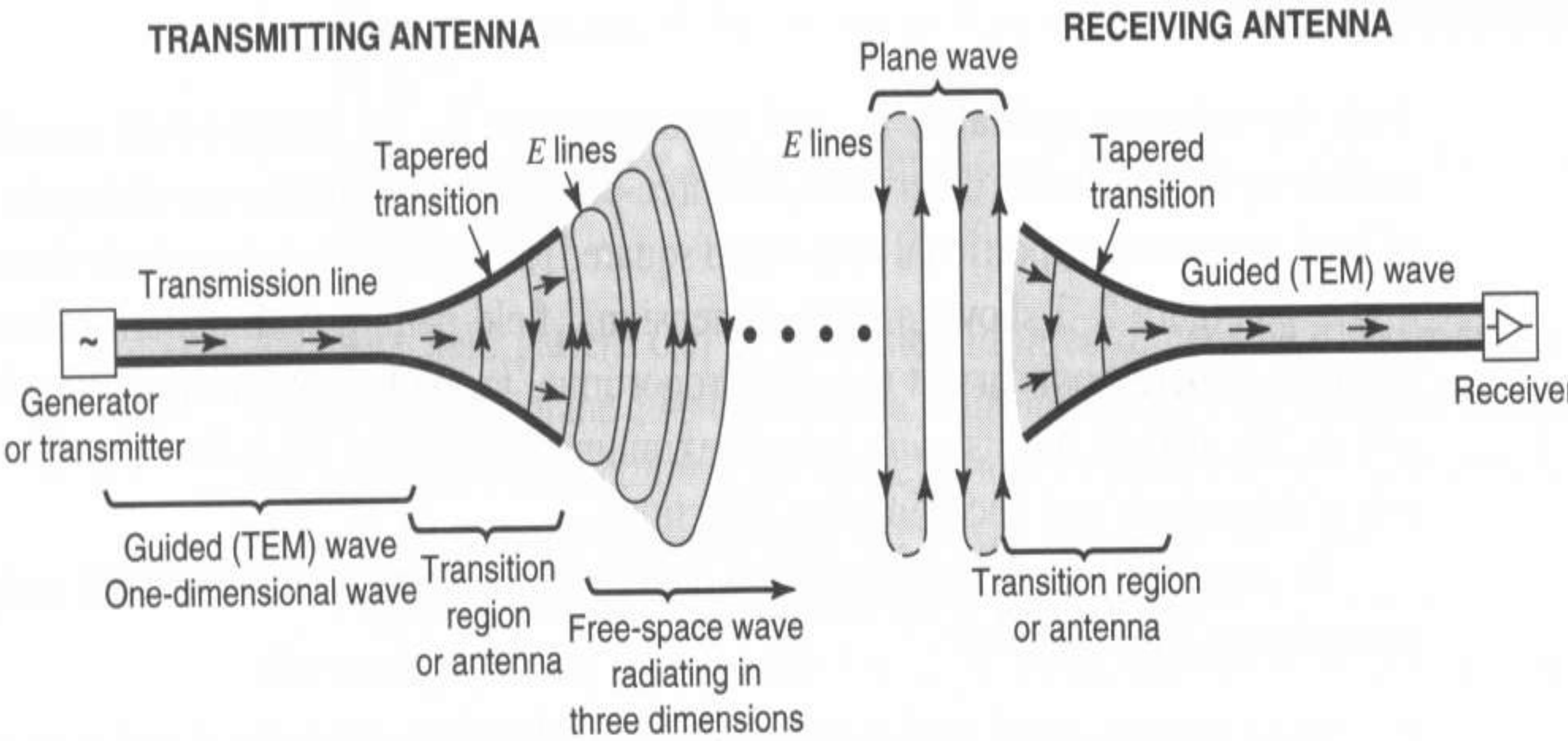
- Definition of antenna parameters :
  - Gain,
  - Directivity,
  - Effective aperture,
  - Radiation Resistance,
  - Band width,
  - Beam width,
  - Input Impedance.
    - Matching – Baluns,
    - Polarization mismatch,
    - Antenna noise temperature,
- Radiation from oscillating dipole, Half wave dipole. Folded dipole, Yagi array.

Antenna Background

- Maxwell (1831-79) Fundamental equations. (Scottish)
- Hertz (1857-94) First aerial propagation (German)
- Marconi (1874-1937) Transatlantic transmission (Italian)
- DeForest (Triode tube 1920) Signal generators (American)
- World War II (1939-45) Intense war-driven development

What is an Antenna?

- An antenna is a way of converting the guided waves present in a waveguide, feeder cable or transmission line into radiating waves travelling in free space, or vice versa.
- An antenna is a passive structure that serves as transition between a transmission line and air used to transmit and/or receive electromagnetic waves.
- Converts Electrons to Photons of EM energy
- It is a transducer which interfaces a circuit and freespace



Only accelerated (or decelerated) charges radiate EM waves.

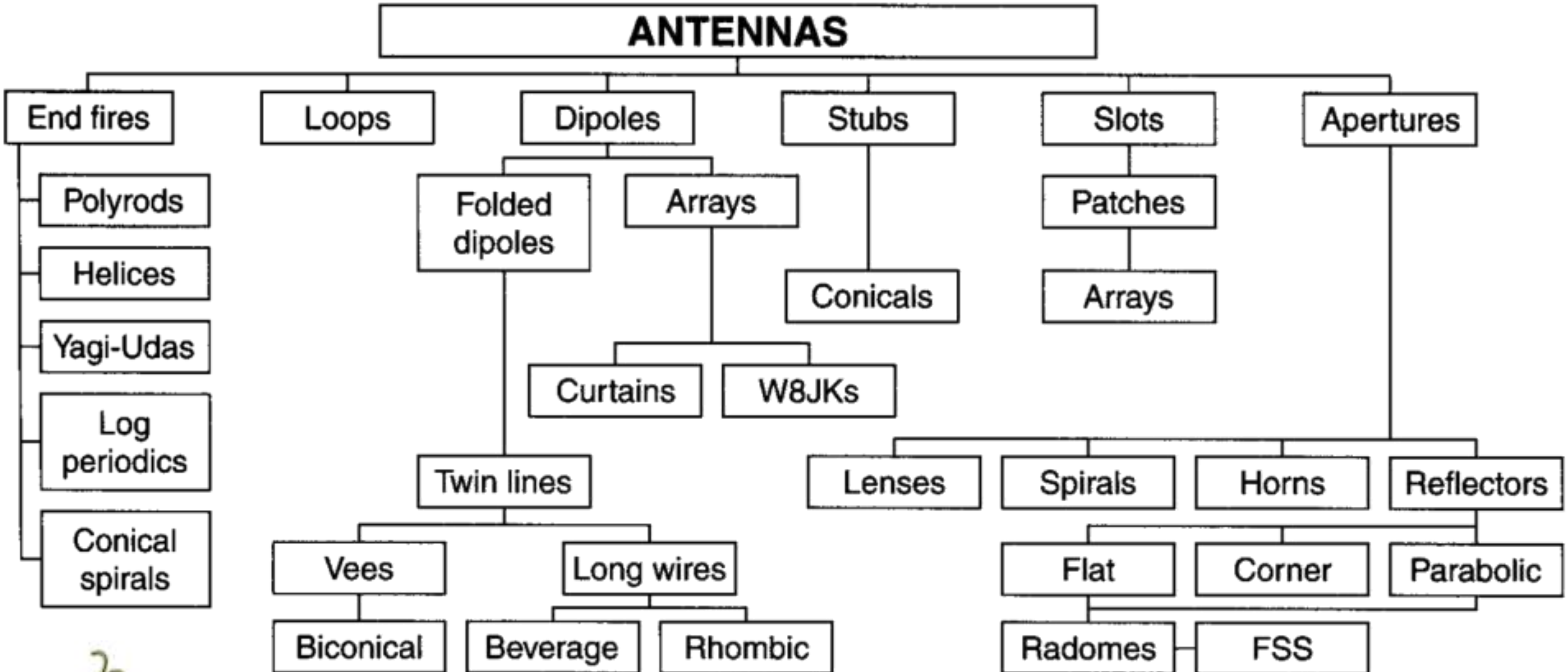
A current with a time-harmonic variation (AC current) satisfies this requirement.

The role of antennas

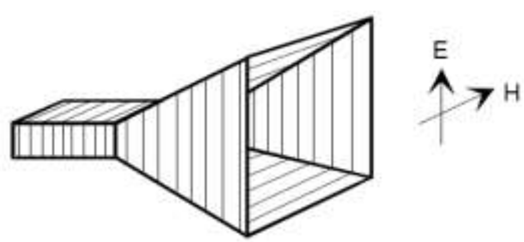
Antennas serve four primary functions:

- Spatial filter
  directionally-dependent sensitivity
- Polarization filter
  polarization-dependent sensitivity
- Impedance transformer (50 Ω to 377Ω)
  transition between free space and transmission line
- Propagation mode adapter
  from free-space fields to guided waves
  (e.g., transmission line, waveguide)

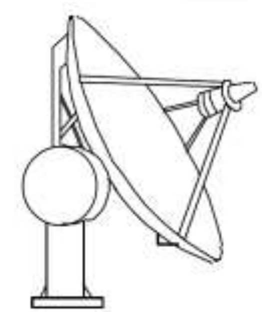
Antenna types



Helical antenna



Horn antenna



Parabolic reflector antenna

Antenna parameters

- Solid angle, W_A and Radiation intensity, U
- Radiation pattern, P_n, sidelobes, $HPBW$
- Far field zone, r_{ff}
- Directivity, D or Gain, G
- Antenna radiation impedance, R_{rad}
- Effective Area, A_e

All of these parameters are expressed in terms of a **transmission** antenna, but are identically applicable to a **receiving** antenna. We'll also study:

Isotropic antenna

- It's an hypothetic antenna, i.e., it does not exist in real life, yet it's used as a measuring bar for real antenna characteristics.

- It's a point source that occupies a negligible space. Has no directional preference.

- Its pattern is simply a sphere so it has ,

  beam area (W_A) = $W_{isotropic}$= 4p [steradians].

$$\Omega_{\text{isotropic}} = \iint_{4\pi} (1) d\Omega$$

$$\int_{\theta=0}^{\pi} \int_{\phi=0}^{2\pi} (1) \sin\theta \, d\theta \, d\phi = 4\pi$$

Isotropic Radiator:

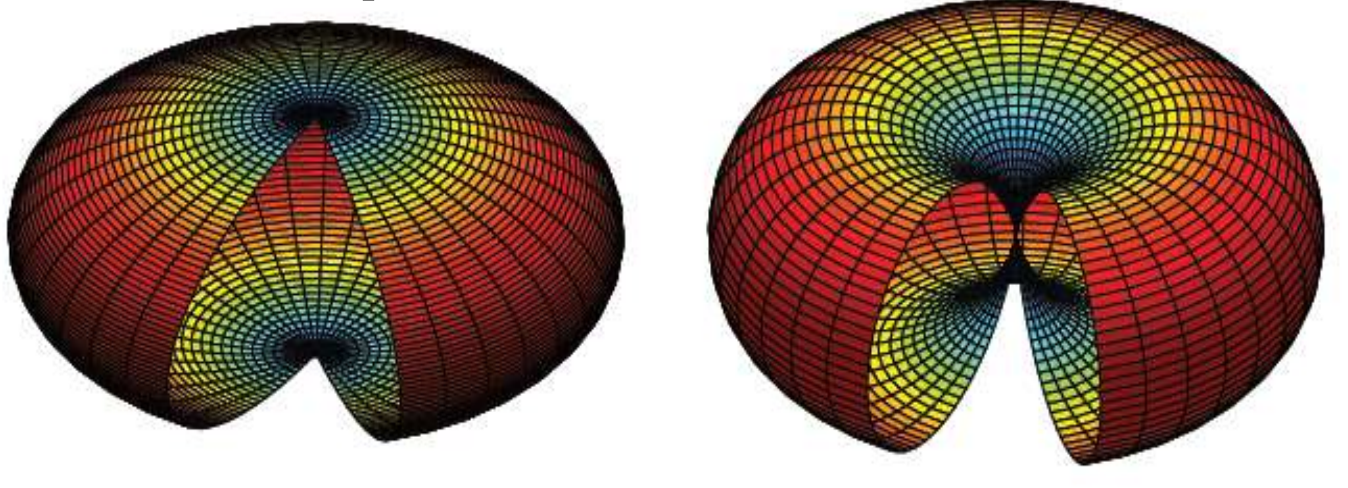
A hypothetical lossless antenna having equal radiation in all directions.

Omnidirectional Radiator:

An antenna having an essentially nondirectional pattern in a given plane (e.g., in azimuth) and a directional pattern in any orthogonal plane.

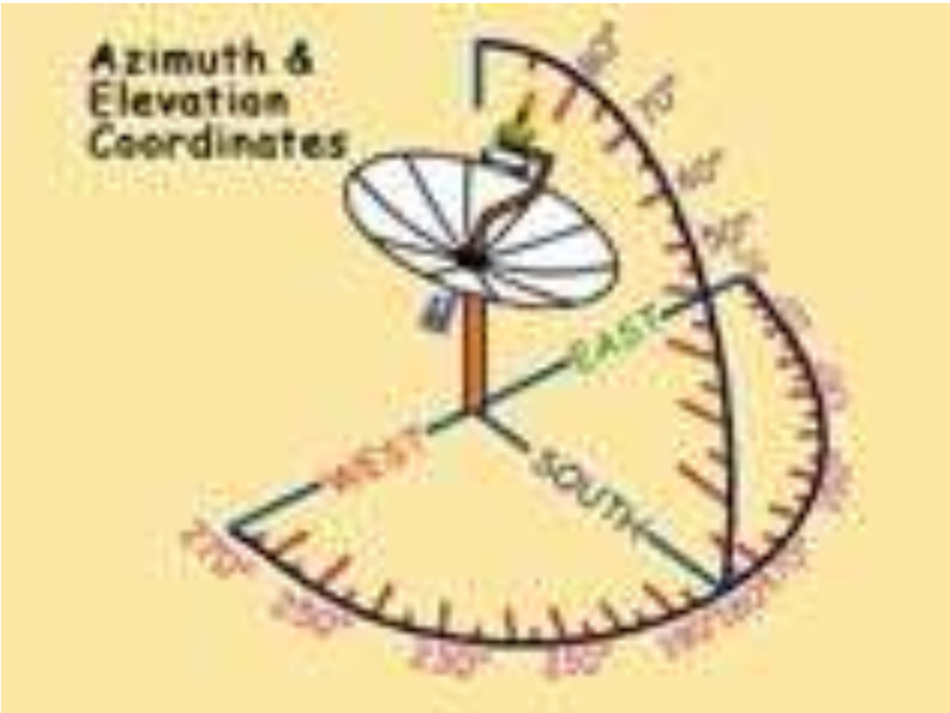
Directional Radiator:

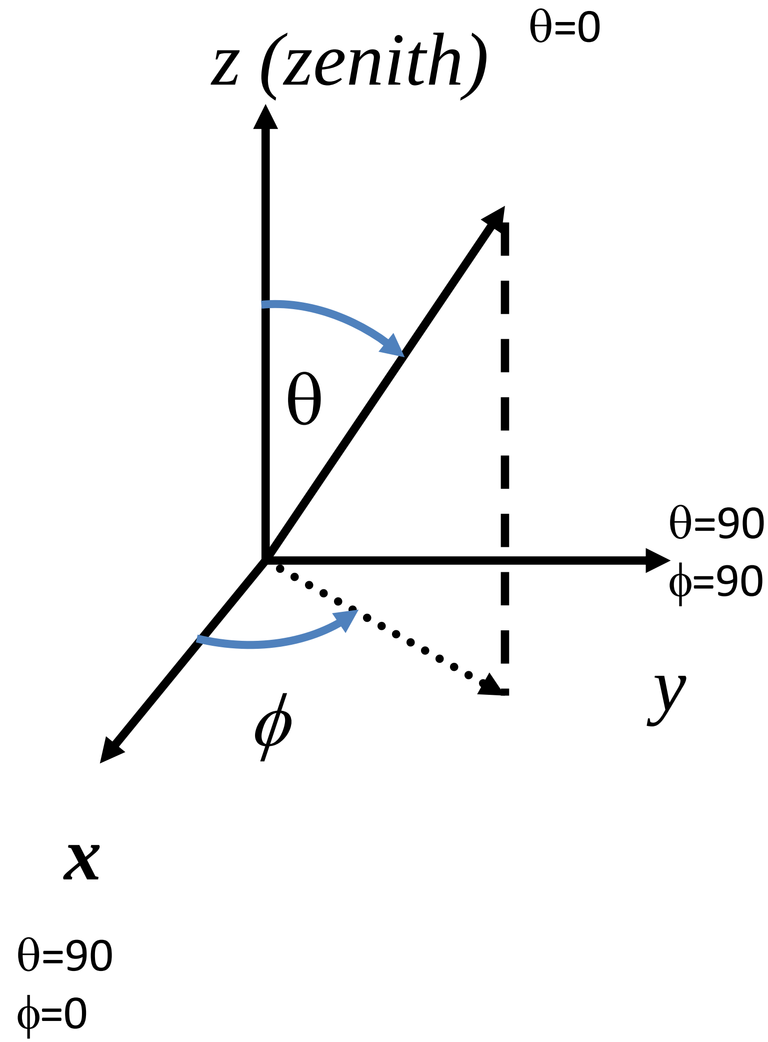
An antenna having the property of radiating or receiving more effectively in some directions than in others. Usually the maximum directivity is significantly greater than that of a half-wave dipole.



Isotropic   Omni-directional

Spherical coordinates

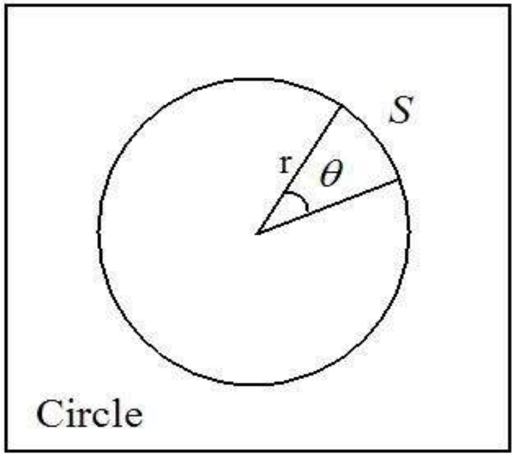


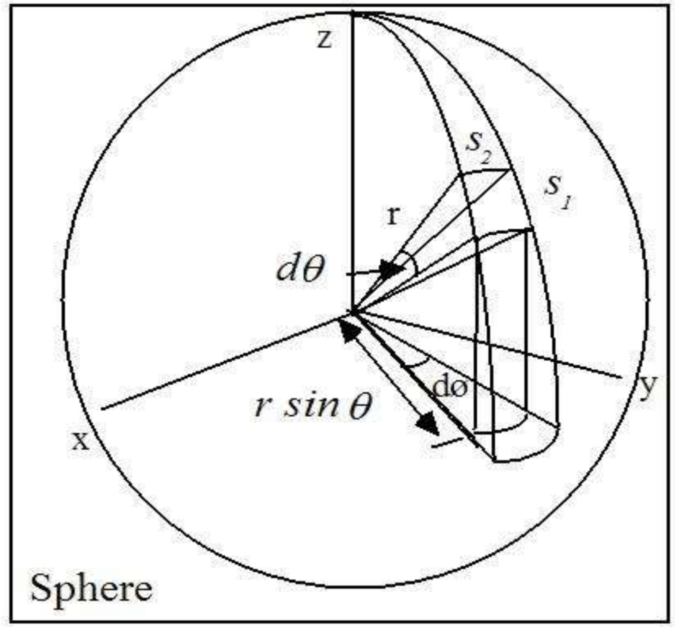


ϕ= azimuth

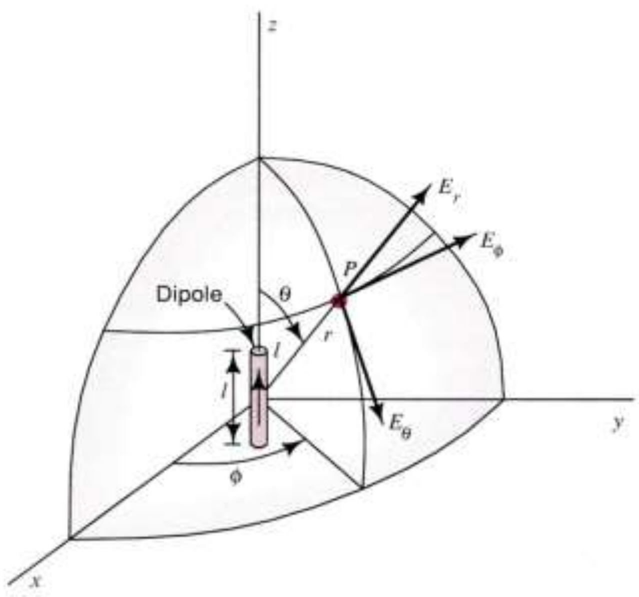
θ= elevation

Solid Angle





$s = \theta r$ = arco



$s_1 = r\,d\theta \quad s_2 = r \sin\theta\, d\phi$

$dA = s_1\, s_2$

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

$= r^2\, d\Omega$

Radiation Intensity

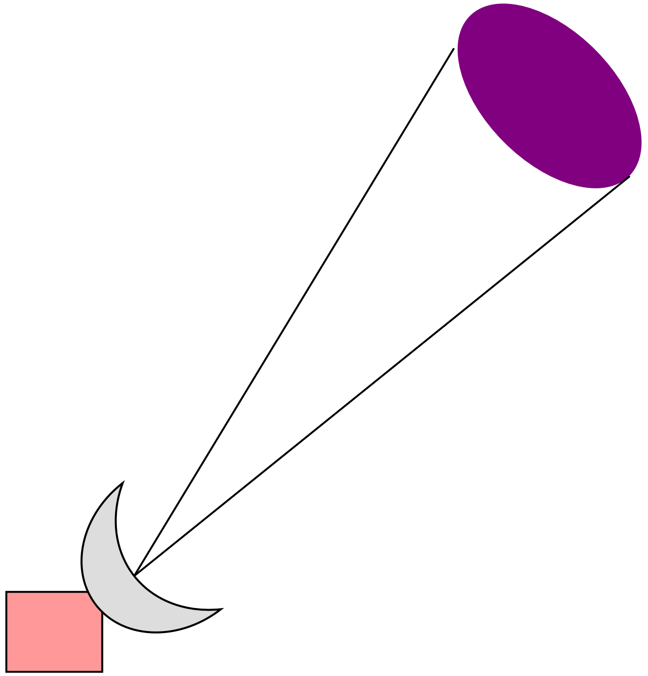
- Is the **power density per solid angle**:

$$U = r^2 \mathscr{P}_{\mathrm{r}} \qquad [\mathrm{W/sr}]$$

where

$$\mathscr{P}_r = ½\ \mathrm{Re}\{E \times H^*\}\hat{r}\ \ [\mathrm{W/m}^2]$$

is the power density also known as Poynting vector.



Radiation Pattern

- A **radiation pattern** is a three-dimensional, graphical representation of the **far-field** radiation properties of an antenna as a function of space coordinates. The far-field region is a region far enough for the radiation pattern to be independent of the distance from the antenna. The radiation pattern of a particular antenna can be measured by experiment or can be calculated, if the current distribution is known.
- Typically measured in two planes:
  - E Plane
  - H Plane

Field pattern:

$$E_n(\theta,\phi) = \frac{E(\theta,\phi)}{E_{\max}(\theta,\phi)}$$

Power pattern:

$$F_n(\theta,\phi) = \frac{\mathcal{P}(\theta,\phi)}{\mathcal{P}_{\max}(\theta,\phi)} = \frac{U(\theta,\phi)}{U_{\max}(\theta,\phi)}$$

Radiation pattern – variation of the field intensity of an antenna as an angular function with respect to the axis

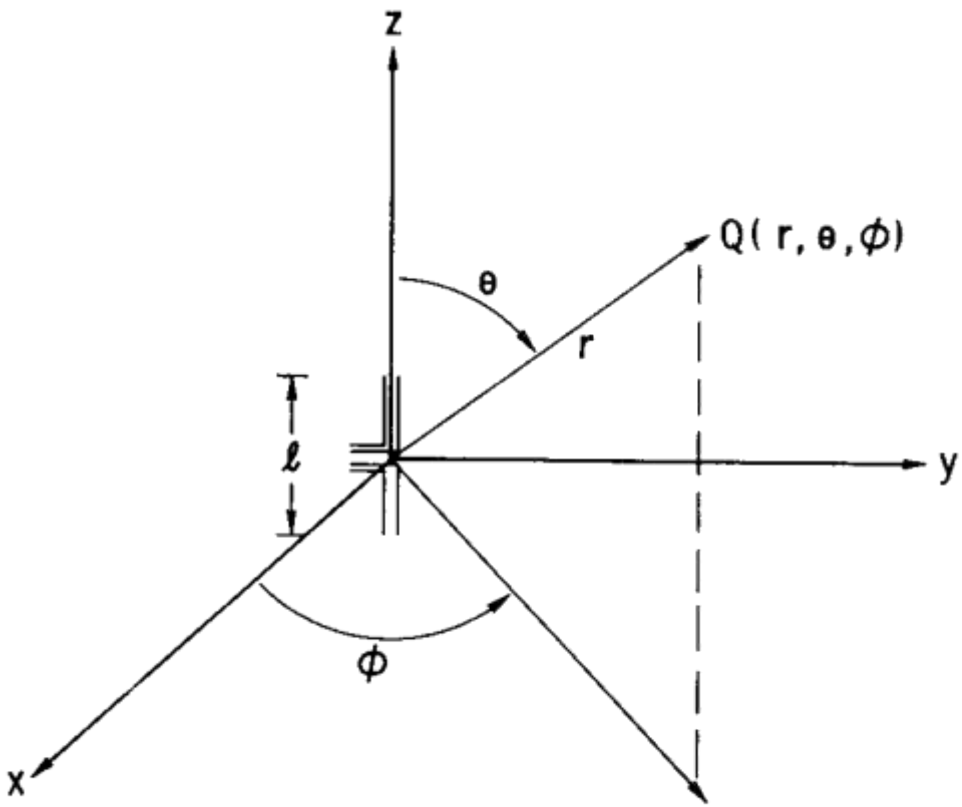
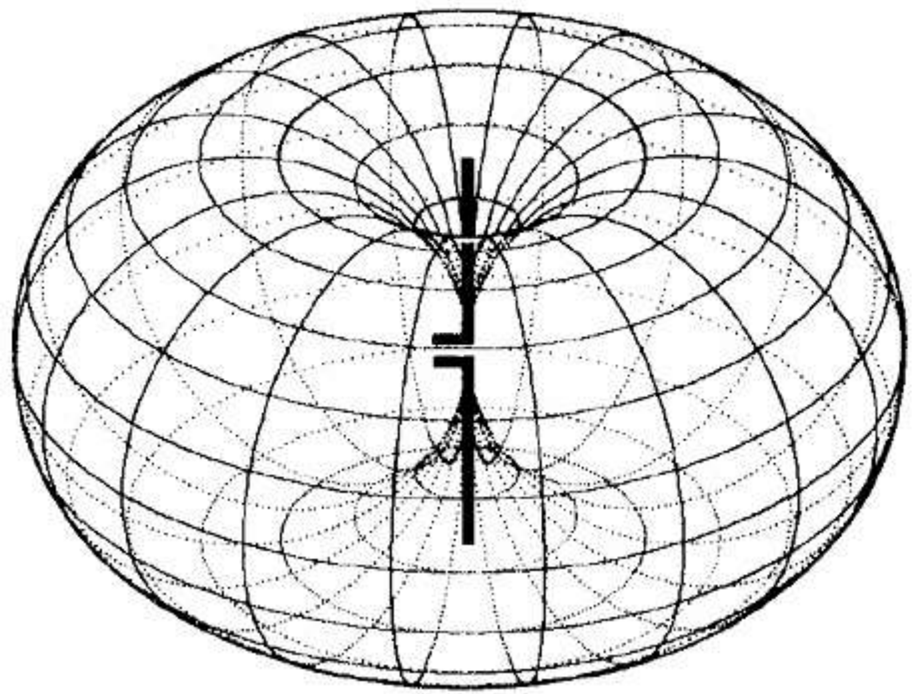


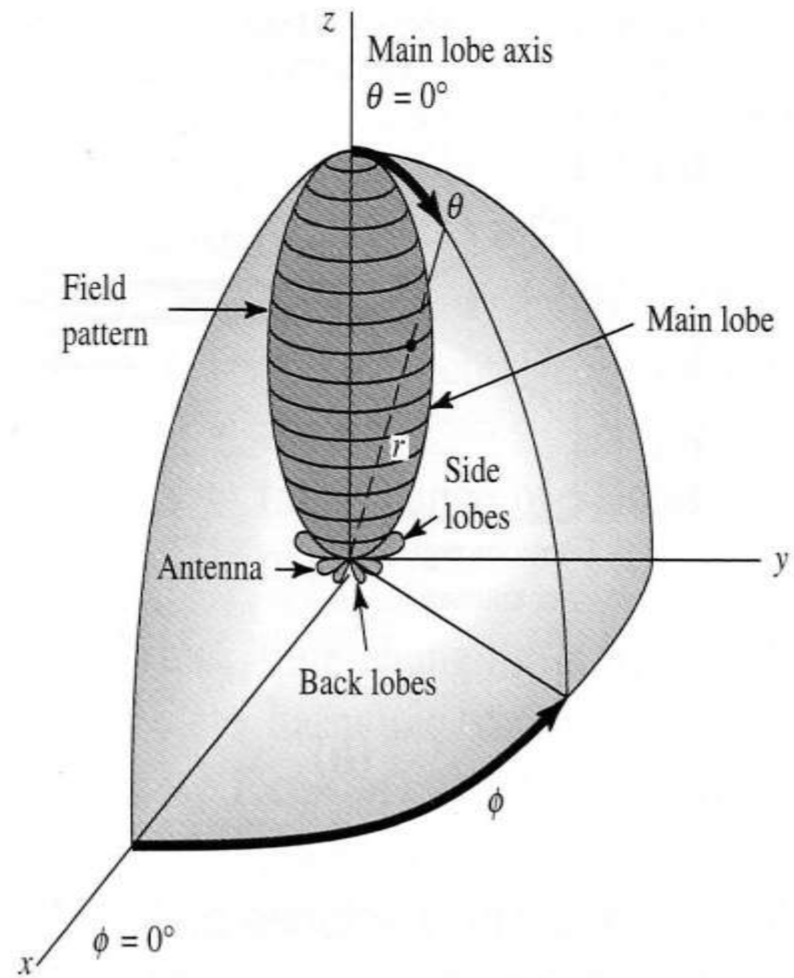
Fig. 3.7 Short dipole placed at the origin of a spherical coordinate system.



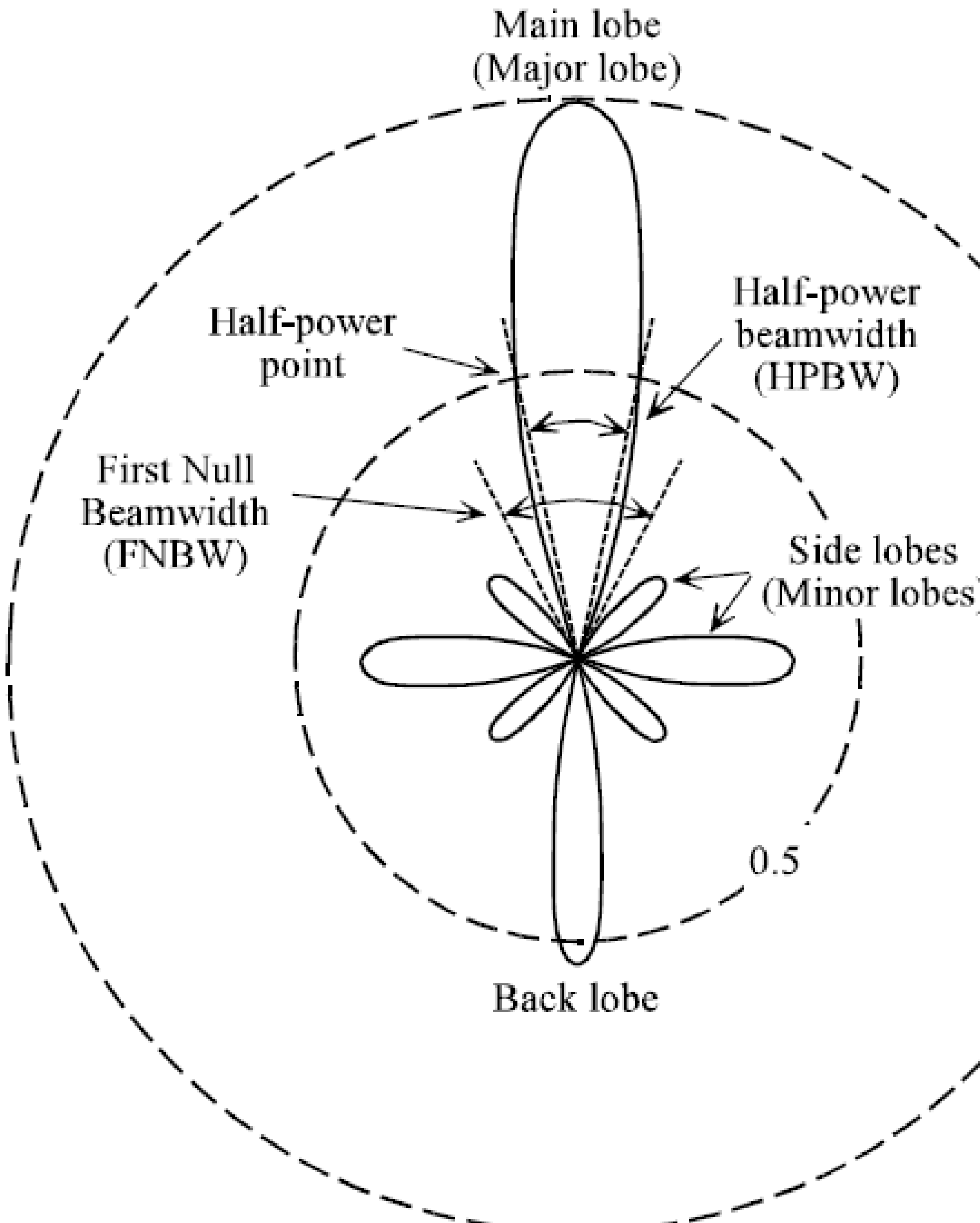
Three-dimensional representation of the radiation pattern of a dipole antenna

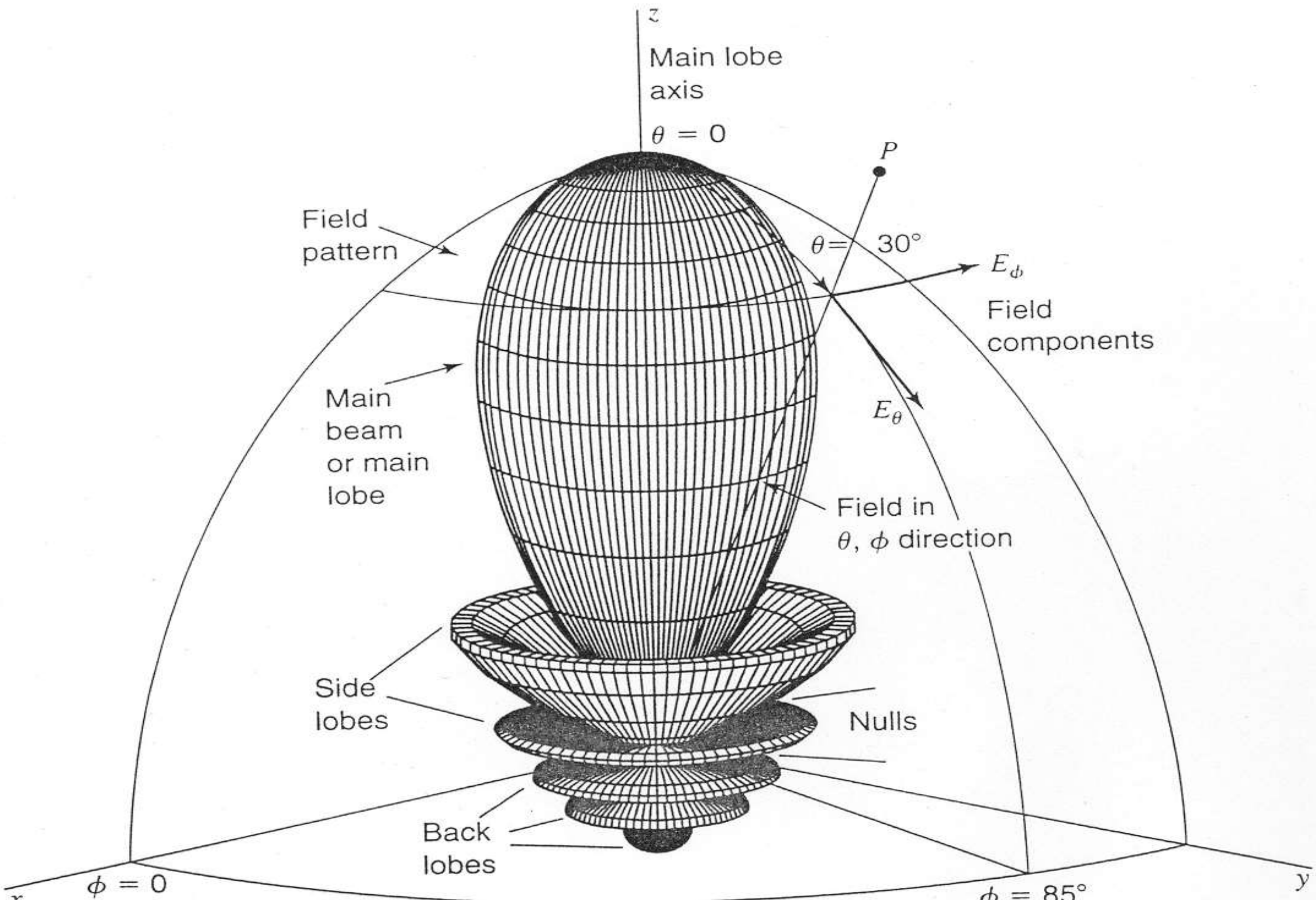
Radiation Pattern Characteristics

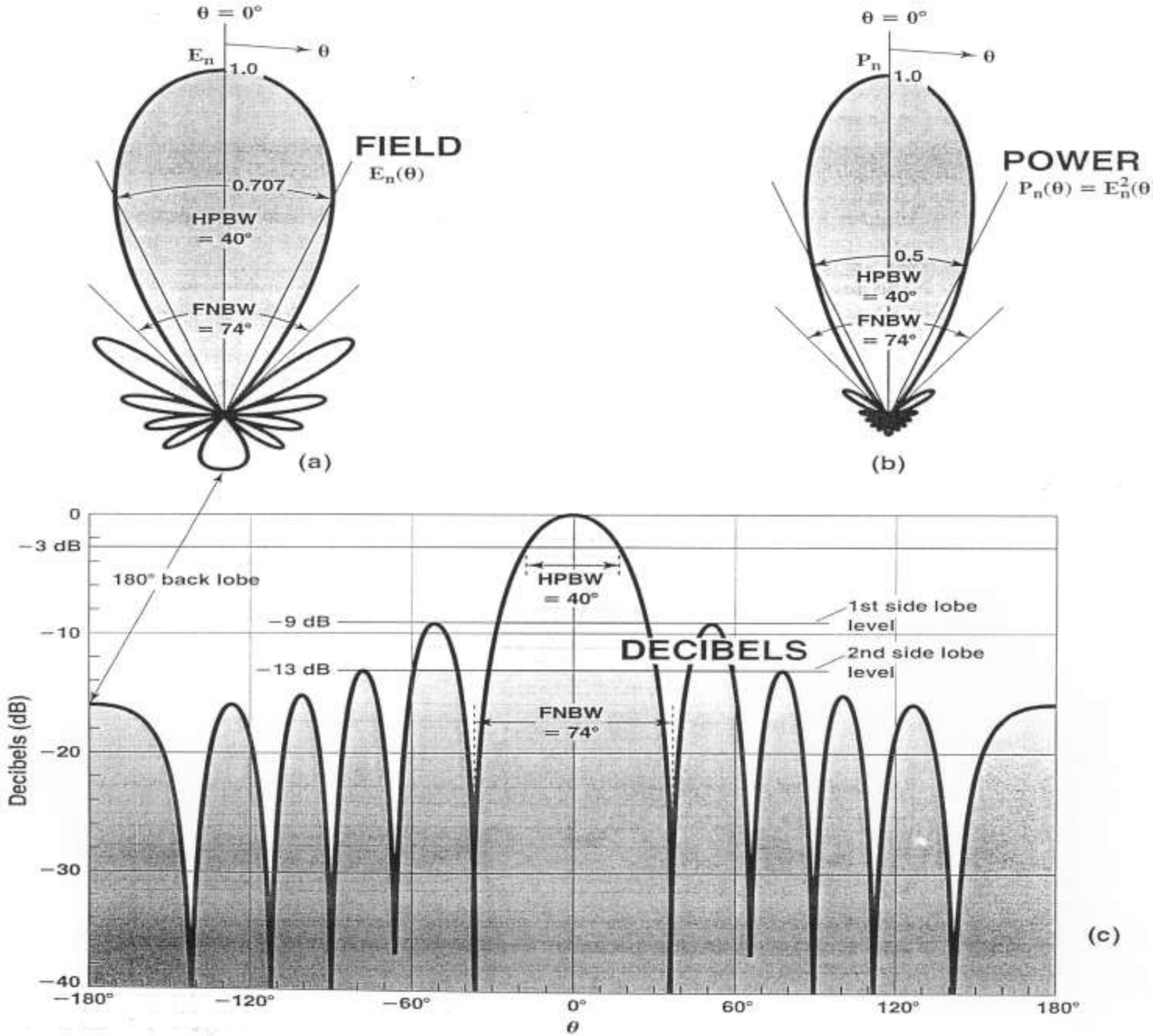
- 3 dB beamwidth (HPBW)
- Sidelobes
- Nulls
- Front-to-back ratio
- Gain (approximate)
- Maximum signal position



Antenna Pattern Parameters




z
Main lobe axis
θ = 0
P
Field pattern
θ = 30°
E_ϕ
Field components
Main beam or main lobe
E_θ
Field in θ, ϕ direction
Side lobes
Nulls
Back lobes
x
ϕ = 0
ϕ = 85°
y


θ = 0°
θ
E_n
1.0
FIELD
$E_n(\theta)$
0.707
HPBW
= 40°
FNBW
= 74°
(a)
θ = 0°
θ
P_n
1.0
POWER
$P_n(\theta) = E_n^2(\theta)$
0.5
HPBW
= 40°
FNBW
= 74°
(b)
0
−3 dB
180° back lobe
HPBW
= 40°
−9 dB
1st side lobe
level
−10
−13 dB
DECIBELS
2nd side lobe
level
FNBW
= 74°
Decibels (dB)
−20
−30
−40
(c)
−180°
−120°
−60°
0°
60°
120°
180°
θ

Directivity and GAIN

"The ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions."

Max Radiation intensity from subject or test antenna

Max Radiation Intensity from reference (Isotropic)antenna with same power input.

$G = \eta D$

Directivity and GAIN of an Antenna

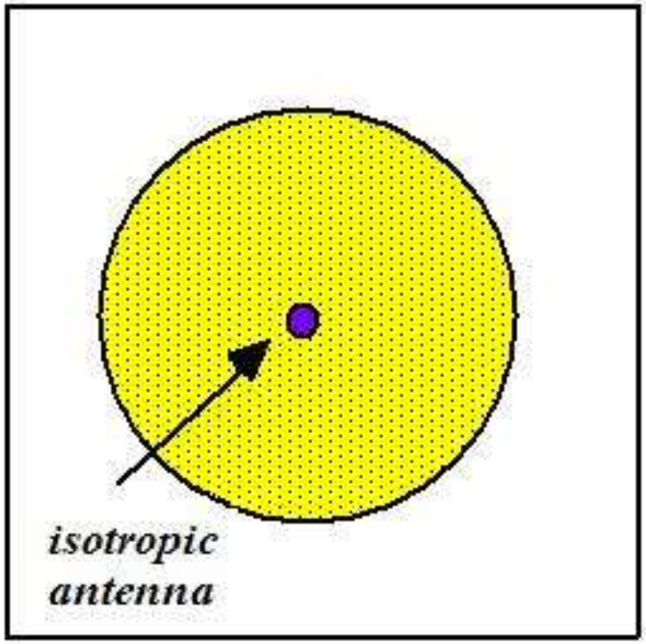
- The **D*irectivity*** or ***Gain*** of an antenna is defined as the ratio of the maximum value of the power radiated per unit solid angle to the average power radiated per unit solid angle

- **Directivity** is a fundamental antenna parameter. It is a measure of how '***directional***' an antenna's radiation pattern is. An antenna that radiates equally in all directions would have effectively zero directionality, and the directivity of this type of antenna would be 1 (or 0 dB).

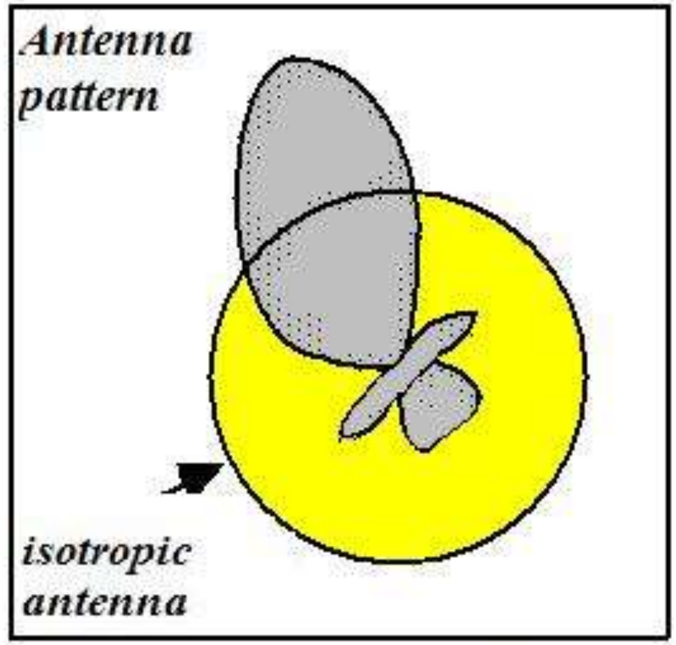
- It measures the power density of the antenna radiates in the direction of its strongest emission, versus the power density radiated by an ideal Isotropic Radiator (which emits uniformly in all directions) radiating the same total power.

- Directivity is a component of its Gain, If lossless antenna, $G=D$

Gain or Directivity



Isotropic Pattern



Comparison of regular antenna pattern with isotripic

An isotropic antenna and a practical antenna fed with the same power. Their patterns would compare as in the figure on the right.

Directivity and Gain

- All practical antennas radiate more than the isotropic antenna in some directions and less in others.
- Gain is inherently directional; the gain of an antenna is **usually measured in the direction which it radiates best**.

"The directivity of an antenna is equal to the ratio of the maximum power density P_{max} to its average value over a sphere as observed in the far field of an antenna"

$$D = D_{\max}(\theta,\phi) = \mathcal{P}_{\max} / \mathcal{P}_{ave} = U_{\max} / U_{ave}$$

Gain or Directivity

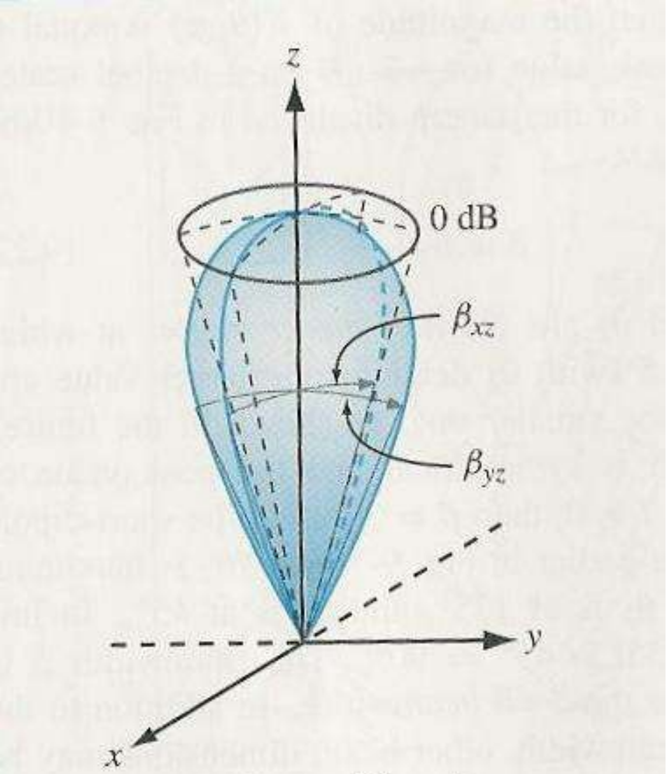
- Gain is measured by comparing an antenna to a model antenna, typically the isotropic antenna which radiates equally in all directions.

$$D(\theta,\phi) = \mathcal{P} / \mathcal{P}_{AVE} = \frac{\mathcal{P}(\theta,\phi)}{\frac{1}{A}\iint \mathcal{P}\, dA} = \frac{4\pi r^2 \mathcal{P}(\theta,\phi)}{P_{rad}}$$

$$D_o = \frac{4\pi U_{\max}}{P_{rad}} = 4\pi/\Omega_{\mathrm{A}} = \Omega_{\mathrm{isotropic}}/\Omega_{\mathrm{A}}$$

Relation b/w Directivity, HPBW, Ω_A

- For an antenna with a single main lobe pointing in the z-direction , Beam area(W_A) can be approximated to the product of the HPBW



Beam solid angle

$$\Omega_A \cong \beta_{xz}\beta_{yz}$$

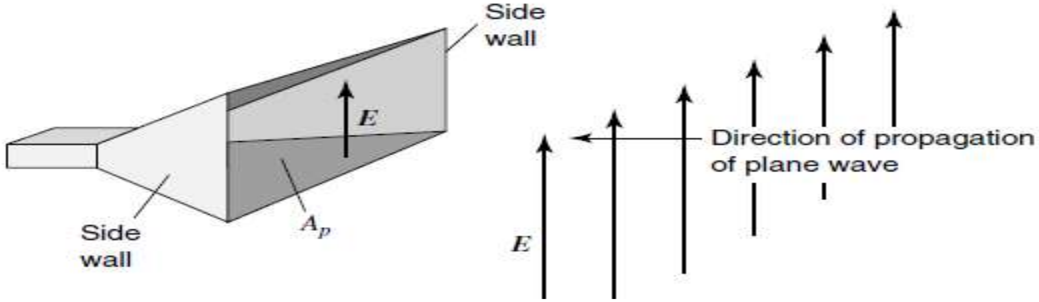
then

The Directivity:

$$D = 4\pi/\Omega_A \cong \frac{4\pi}{\beta_{xz}\beta_{yz}}$$

Effective Aperture

"A useful parameter in calculating the received power of an antenna is the ***effective area*** or ***effective aperture***"



Effective area or Effective aperture (square meters)

The effective area corresponds to the effective absorbance area presented by an antenna to an incident plane wave. For an aperture antenna, it is equal to or smaller than the physical aperture. The relationship between the gain and the wavelength is

$$G = \frac{4\pi}{\lambda^2} A_e$$

THANK YOU

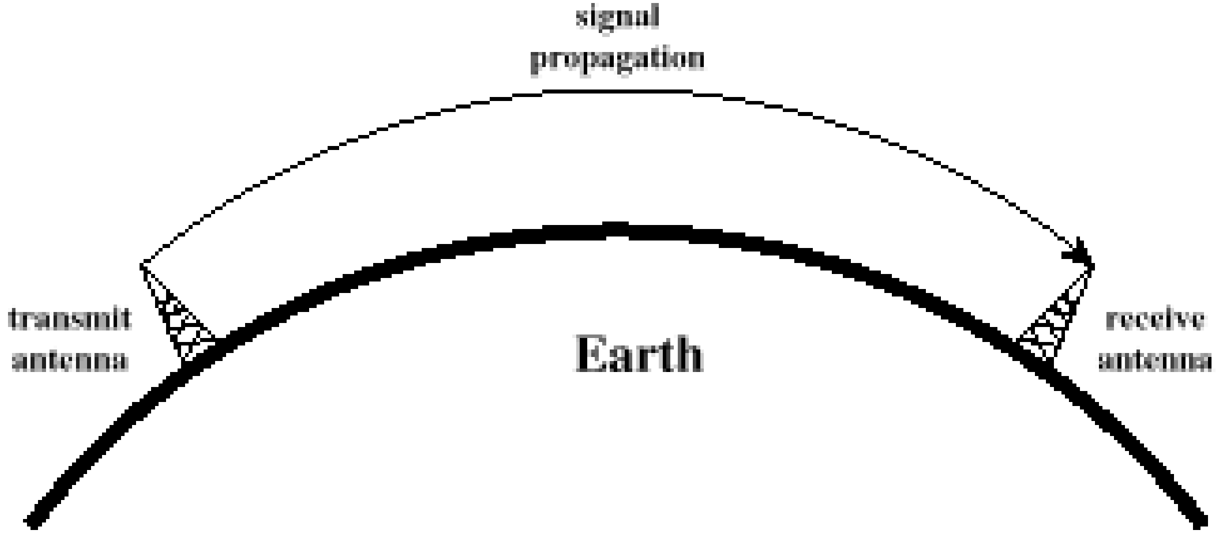
Antennas Wave and Propagation

Prepared by
Mr.U.Naresh
Asst.Professor

Wave Propagation

- Ground-wave propagation
- Sky-wave propagation
- Line-of-sight propagation

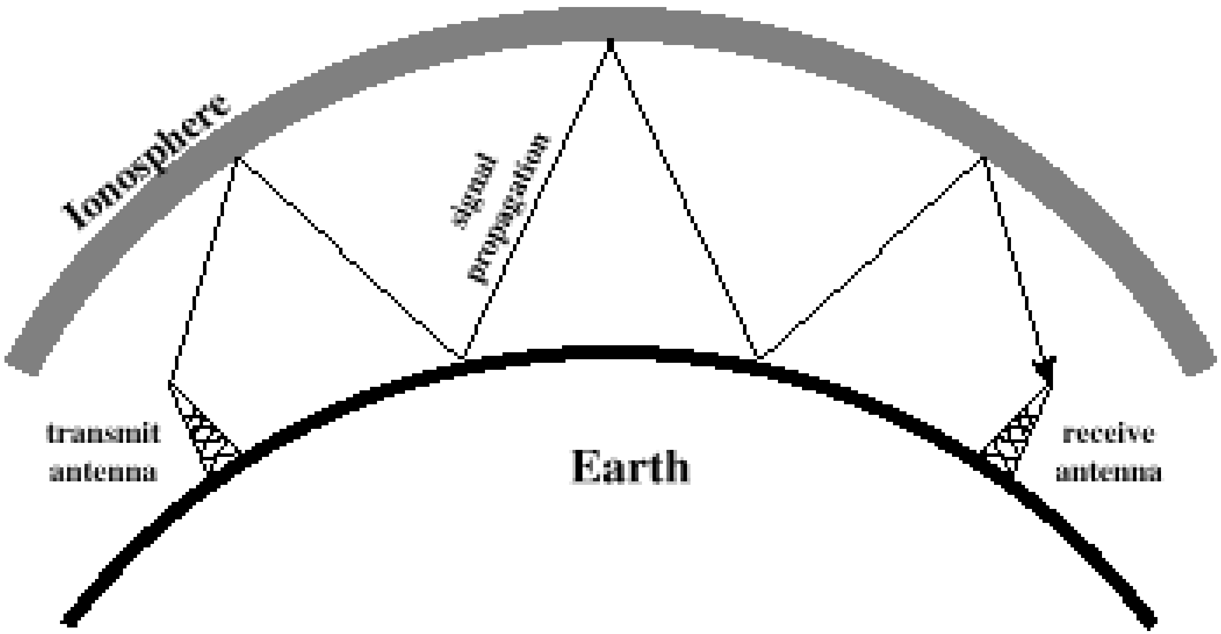
Ground Wave Propagation



Ground Wave Propagation

- Follows contour of the earth
- Can Propagate considerable distances
- Frequencies up to 2 MHz
- Example
  - AM radio

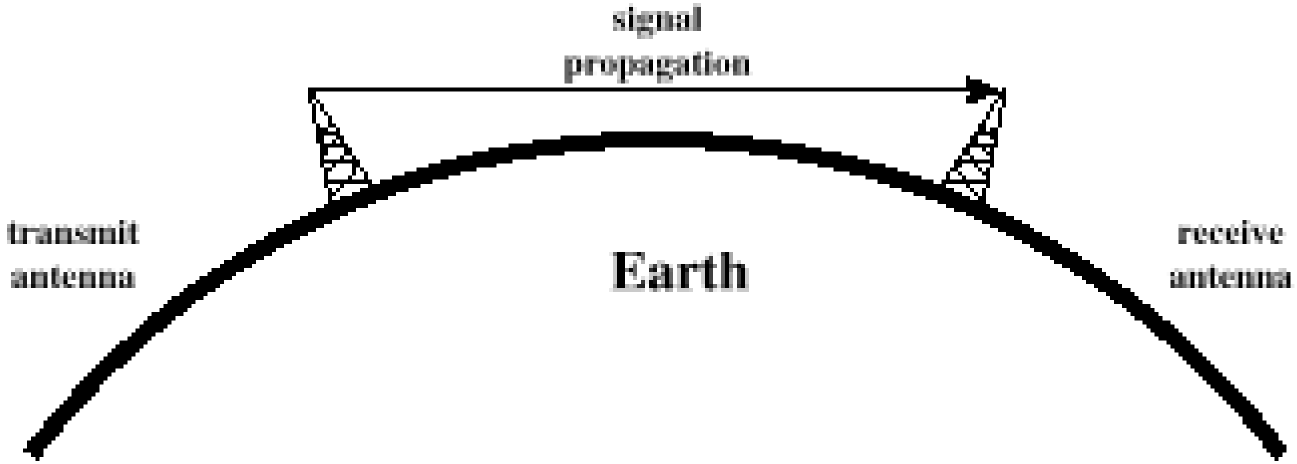
Sky Wave Propagation



Sky Wave Propagation

- Signal reflected from ionized layer of atmosphere back down to earth
- Signal can travel a number of hops, back and forth between ionosphere and earth's surface
- Reflection effect caused by refraction
- Examples
  - Amateur radio
  - CB radio

Line-of-Sight Propagation



Line-of-Sight Propagation

- Transmitting and receiving antennas must be within line of sight
  - Satellite communication – signal above 30 MHz not reflected by ionosphere
  - Ground communication – antennas within *effective* line of site due to refraction
- Refraction – bending of microwaves by the atmosphere
  - Velocity of electromagnetic wave is a function of the density of the medium
  - When wave changes medium, speed changes
  - Wave bends at the boundary between mediums

Line-of-Sight Equations

- Optical line of sight

$$d = 3.57\sqrt{h}$$

- Effective, or radio, line of sight

$$d = 3.57\sqrt{\mathrm{K}h}$$

  - d = distance between antenna and horizon (km)
  - h = antenna height (m)
  - K = adjustment factor to account for refraction, rule of thumb K = 4/3

Line-of-Sight Equations

- Maximum distance between two antennas for LOS propagation:

$$3.57\left(\sqrt{Kh_1} + \sqrt{Kh_2}\right)$$

  - h_1 = height of antenna one
  - h_2 = height of antenna two

Attenuation

- Strength of signal falls off with distance over transmission medium
- Attenuation factors for unguided media:
  - Received signal must have sufficient strength so that circuitry in the receiver can interpret the signal
  - Signal must maintain a level sufficiently higher than noise to be received without error
  - Attenuation is greater at higher frequencies, causing distortion

Free Space Loss

- Free space loss, ideal isotropic antenna

$$\frac{P_t}{P_r} = \frac{(4\pi d)^2}{\lambda^2} = \frac{(4\pi f d)^2}{c^2}$$

  - P_t = signal power at transmitting antenna
  - P_r = signal power at receiving antenna
  - λ = carrier wavelength
  - *d* = propagation distance between antennas
  - *c* = speed of light (» 3 ´ 10 8 m/s)

where *d* and λ are in the same units (e.g., meters)

Free Space Loss

- Free space loss equation can be recast:

$$L_{dB} = 10\log\frac{P_t}{P_r} = 20\log\left(\frac{4\pi d}{\lambda}\right)$$

$$= -20\log(\lambda) + 20\log(d) + 21.98\ \text{dB}$$

$$= 20\log\left(\frac{4\pi f d}{c}\right) = 20\log(f) + 20\log(d) - 147.56\ \text{dB}$$

Free Space Loss

- Free space loss accounting for gain of other antennas

$$\frac{P_t}{P_r} = \frac{(4\pi)^2 (d)^2}{G_r G_t \lambda^2} = \frac{(\lambda d)^2}{A_r A_t} = \frac{(cd)^2}{f^2 A_r A_t}$$

- G_t = gain of transmitting antenna
- G_r = gain of receiving antenna
- A_t = effective area of transmitting antenna
- A_r = effective area of receiving antenna

Free Space Loss

- Free space loss accounting for gain of other antennas can be recast as

$$L_{dB} = 20\log(\lambda) + 20\log(d) - 10\log(A_t A_r)$$

$$= -20\log(f) + 20\log(d) - 10\log(A_t A_r) + 169.54\text{dB}$$

Types of Fading

- Fast fading
- Slow fading
- Flat fading
- Selective fading
- Rayleigh fading
- Rician fading