Communication Systems

Antenna and Propagation.

(Lecture 1 Basic Antenna parameters)

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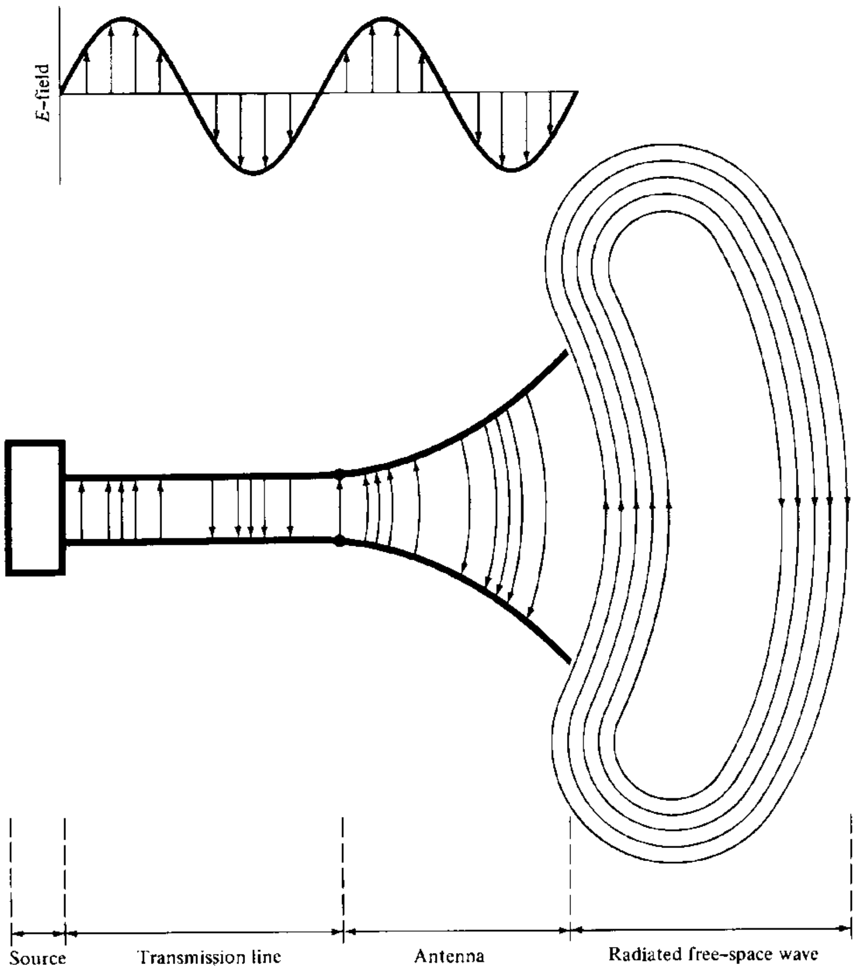
Overview

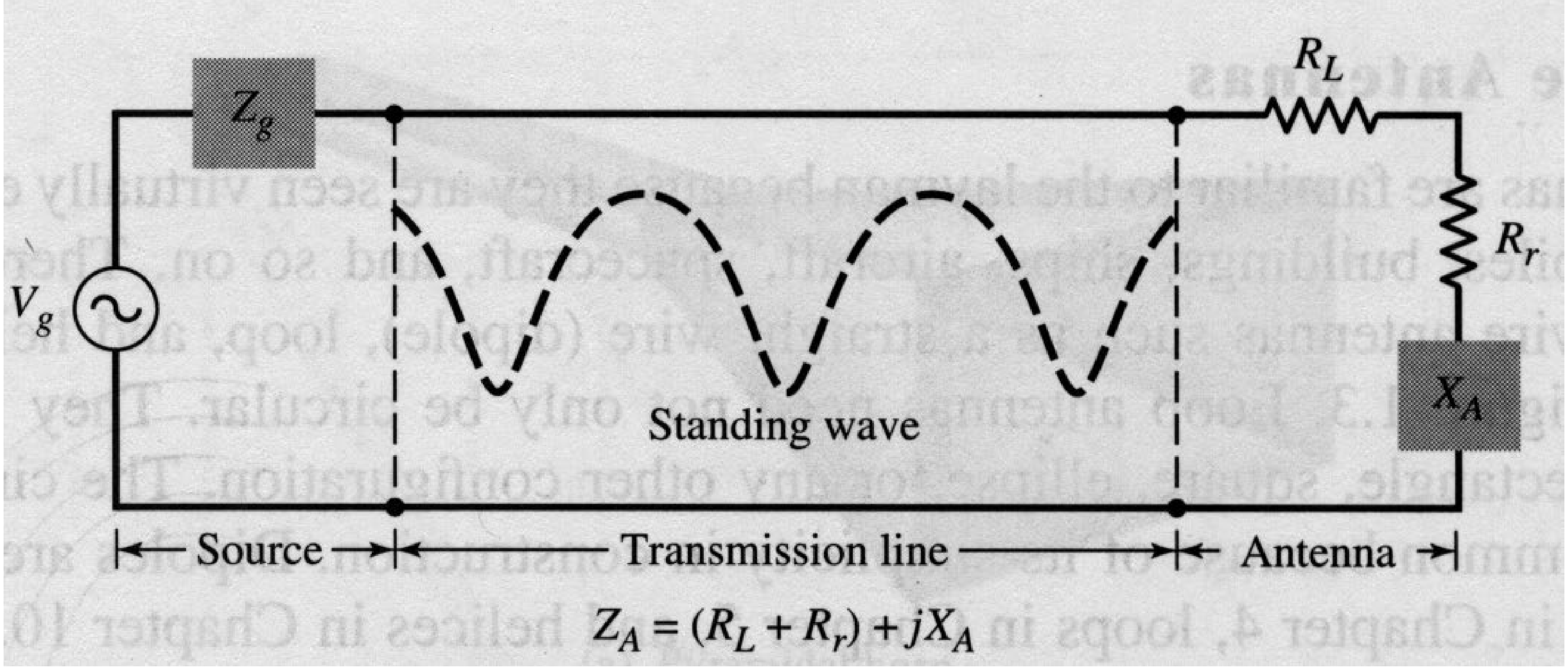
Function of antennas
How antennas work
Antenna types
Field regions
Directive properties, (Gain and Directivity)
Radiation from simple dipoles
Antenna Efficiency

Based on **IEEE Standard Definitions** and C. A. Balanis *Antenna Theory*

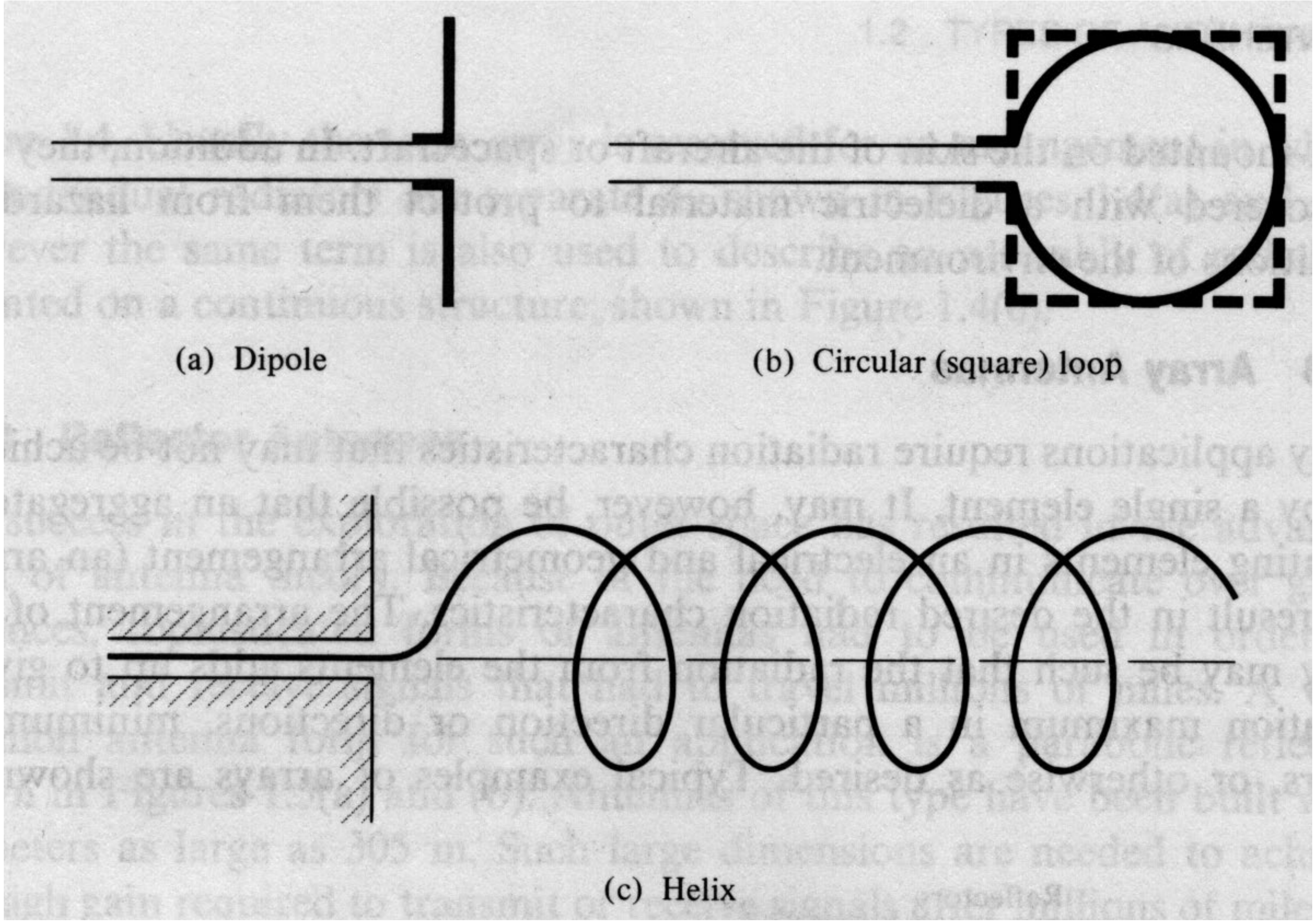
What is an Antenna



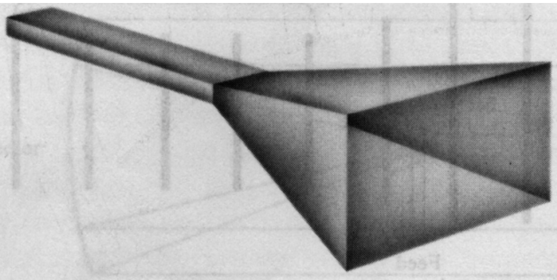
Transmission line equivalent of antenna



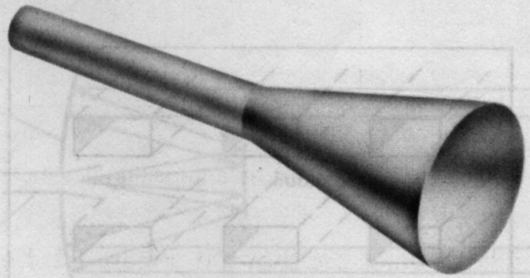
Wire Antennas



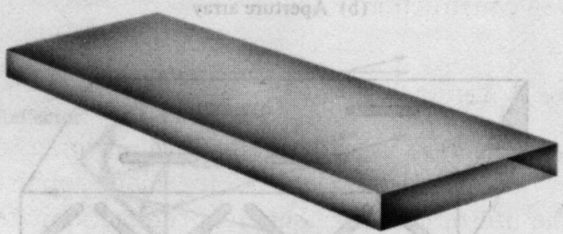
Aperture Antennas



(a) Pyramidal horn

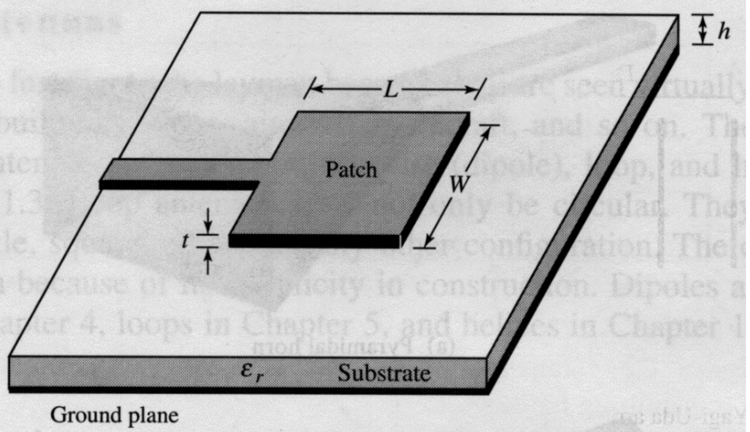


(b) Conical horn

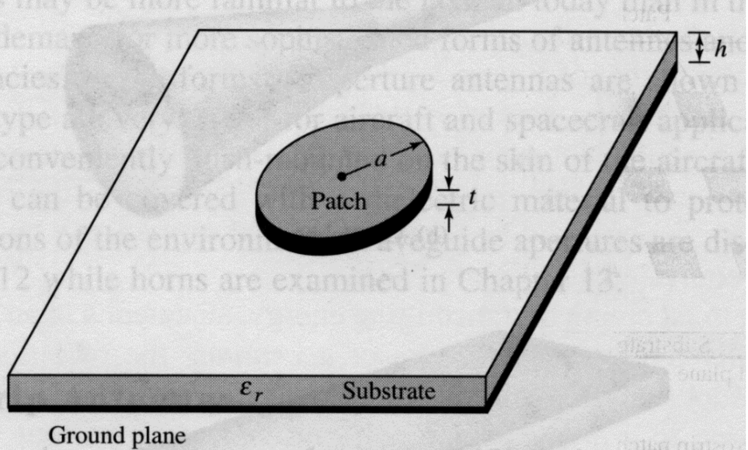


(c) Rectangular waveguide

Patch Antennas



(a) Rectangular



(b) Circular

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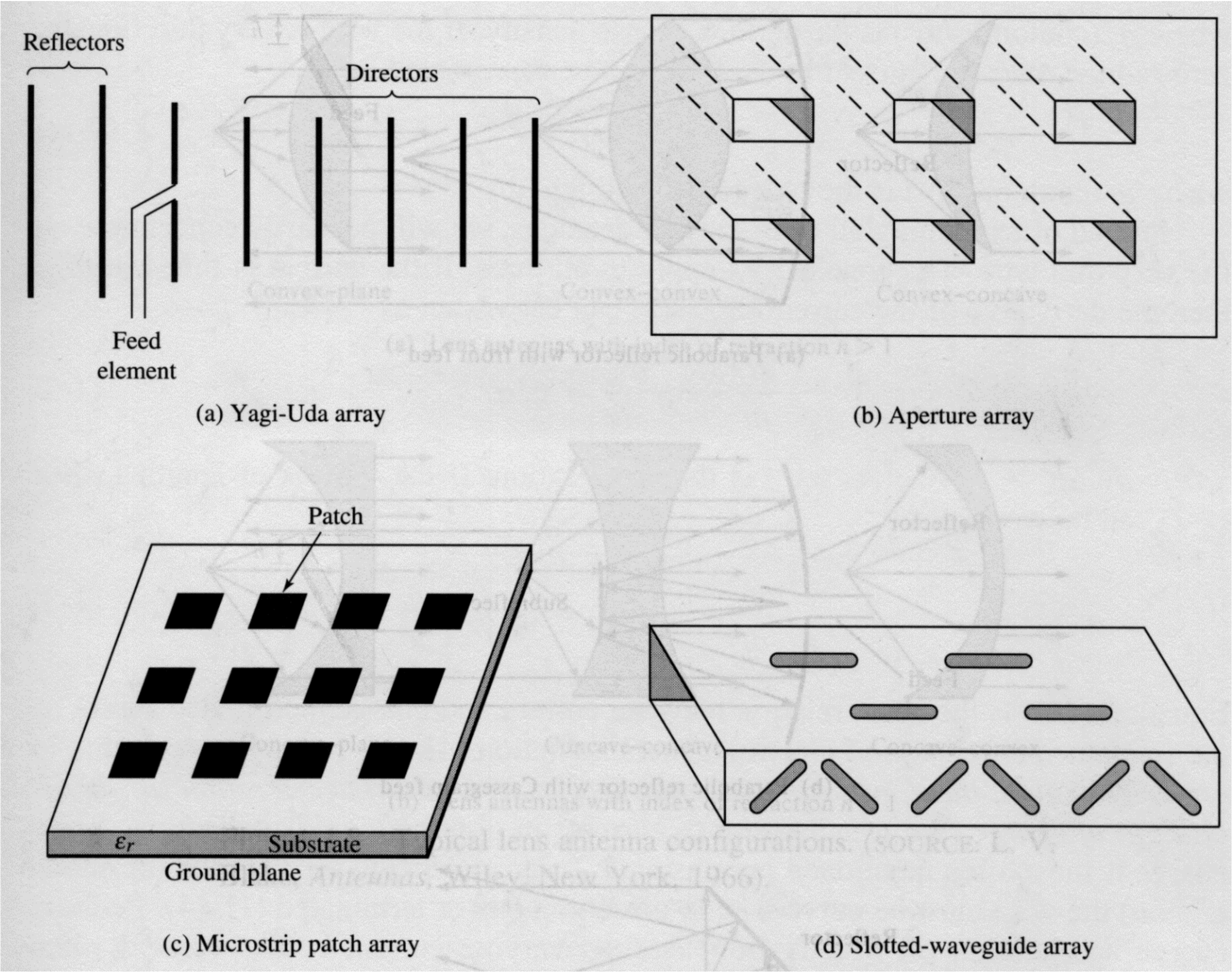
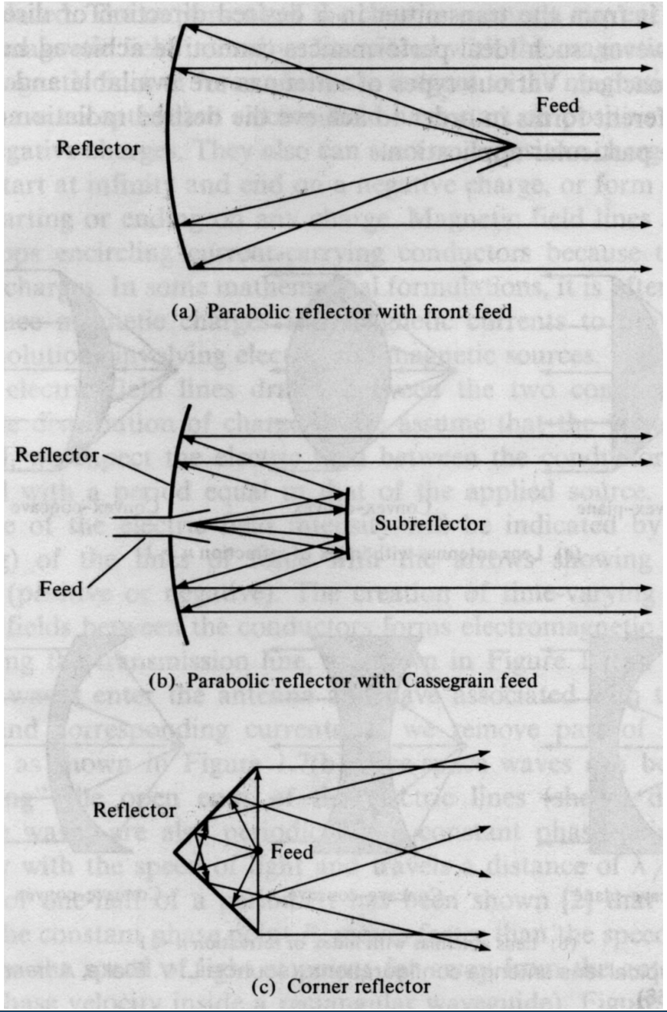
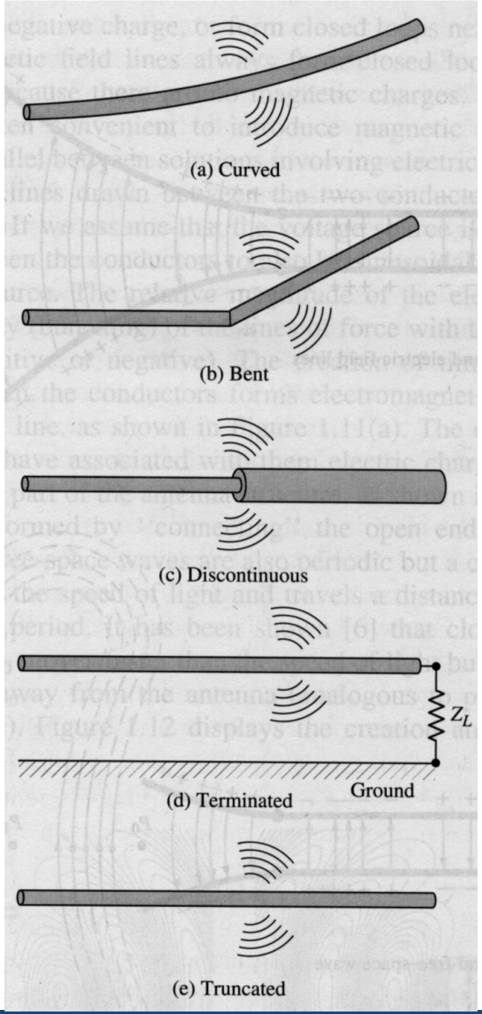
Array Antennas



Reflector Antennas



Radiation from Wires



1 No charge moving => no current created => No Radiation

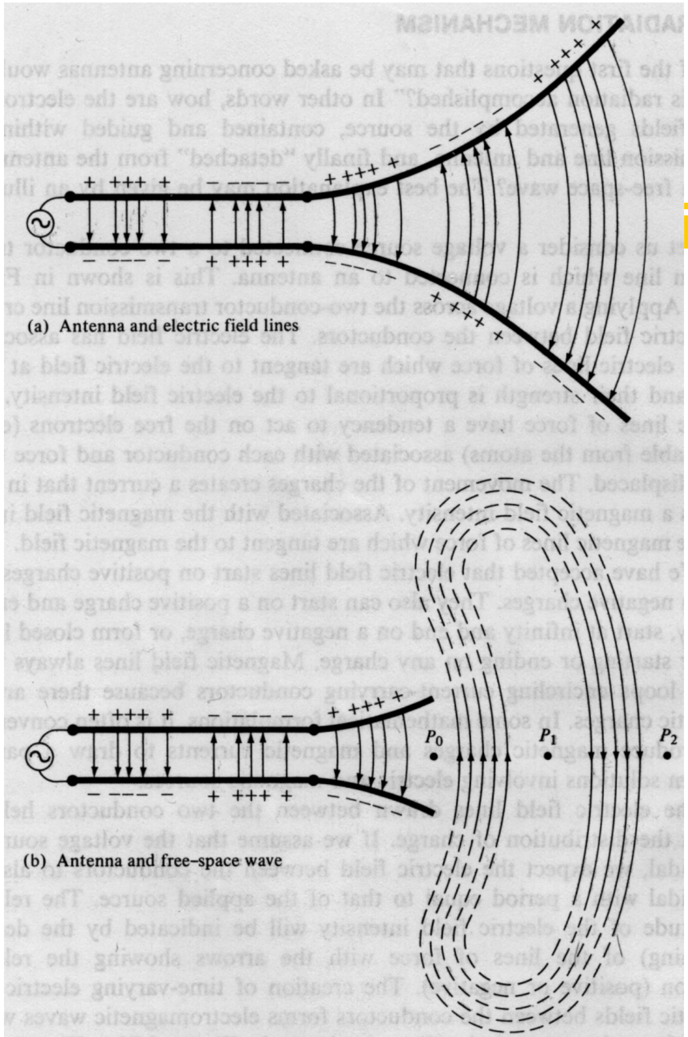
2 Charge moving @ uniform velocity:

A) Long straight wire => no radiation

B) Curved, Bent, Discontinuous, Terminated or Truncated => Radiation

3 Oscillating charge => Radiation

Two Wires



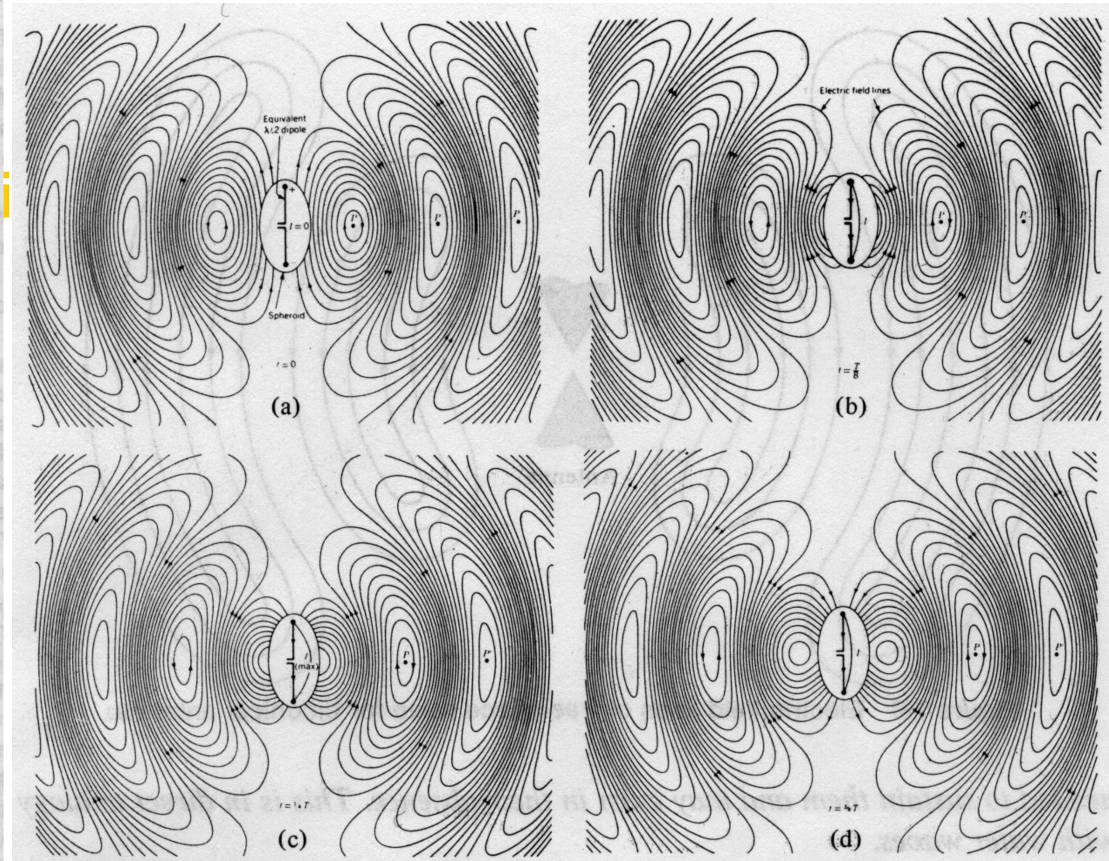
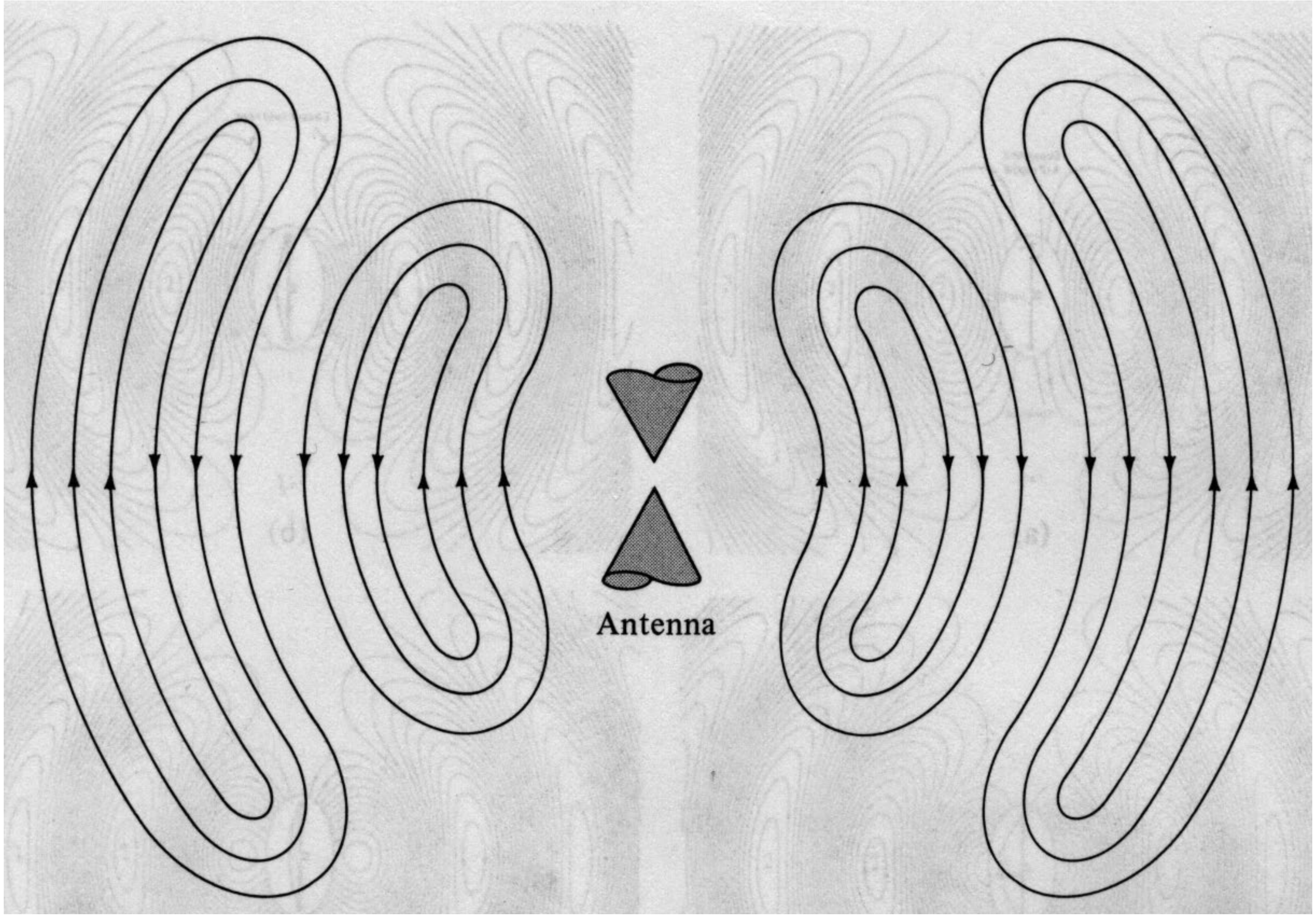
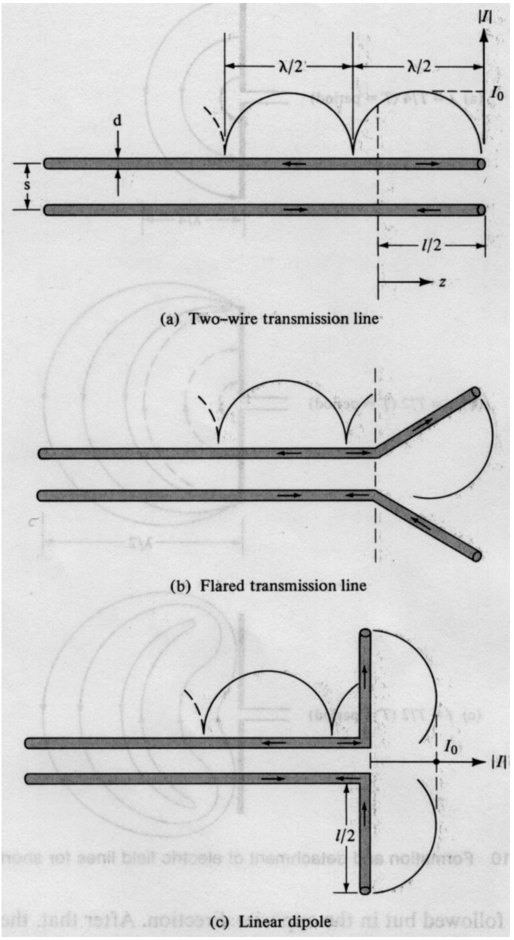


Figure 1.8 Electric field lines of free-space wave for a $\lambda/2$ antenna at $t=0$, $T/8$, $T/4$, and $3T/8$. (SOURCE: J. D. Kraus and K. R. Carver, *Electromagnetics*, 2nd ed., McGraw-Hill, New York, 1973. Reprinted with permission of J. D. Kraus and John D. Cowan, Jr.)

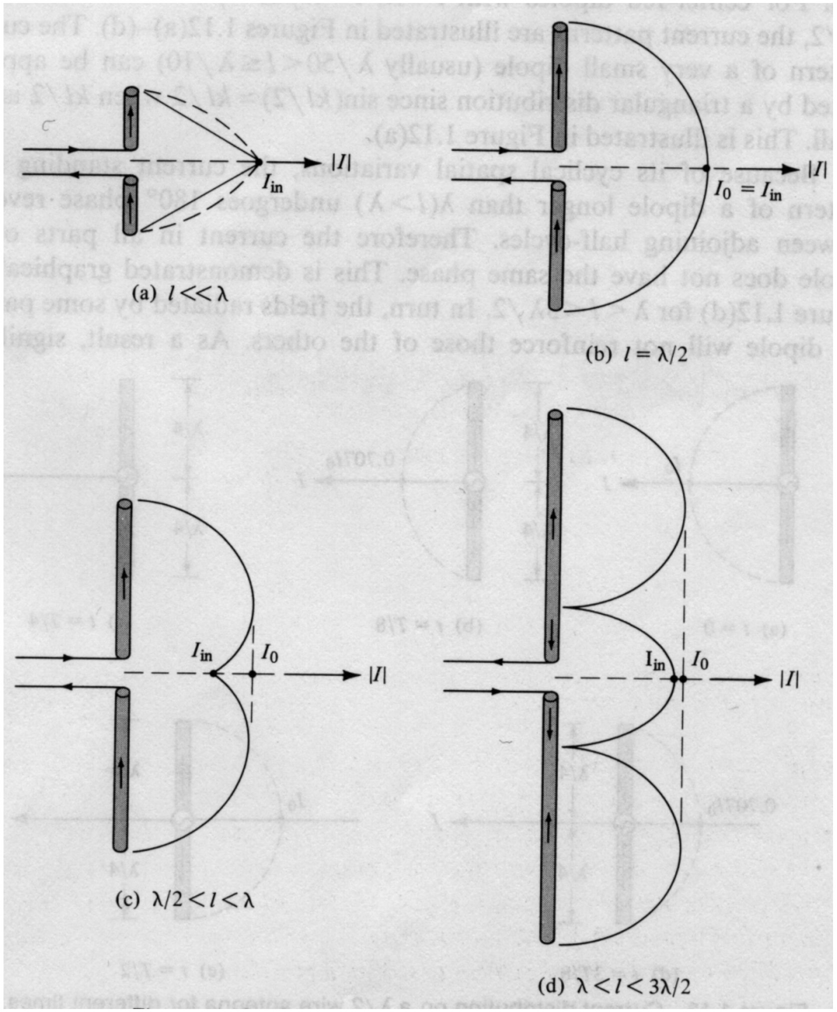
Dipole



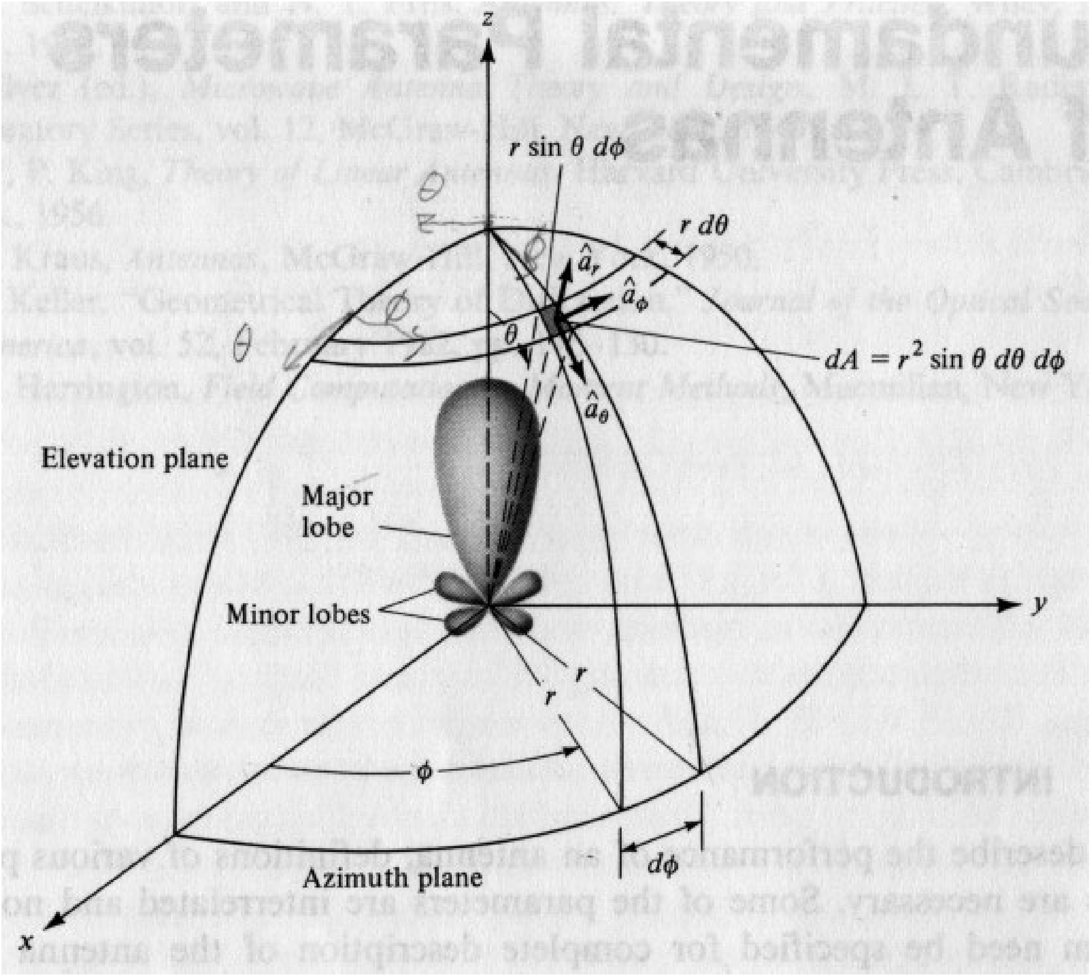
Current Distribution on two wire transmission line and Dipole



Current Distribution on Dipoles



Coordinate system for antenna analysis



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Coordinate system for antenna analysis

$$\int_0^{2\pi}\left[\int_0^{\pi} r^2 \sin(\theta)\, d\theta\right] d\phi = 4\pi r^2$$

$$\boxed{\begin{aligned} 0 \le \theta \le \pi \\ 0 \le \phi \le 2\pi \end{aligned}}$$

Radiation Pattern

A mathematical and/or graphical representation of the radiation properties of an antenna, such as The:

- Amplitude
- Phase
- Polarization

As a function of the ANGULAR space coordinates θ and φ

2-D Normalized *Field* $|\underline{E}_n|$ Pattern of a Linear Array

Linear Scale

$N = 10$ elements

$d = \lambda/4$ spacing

HPBW = 38.64°

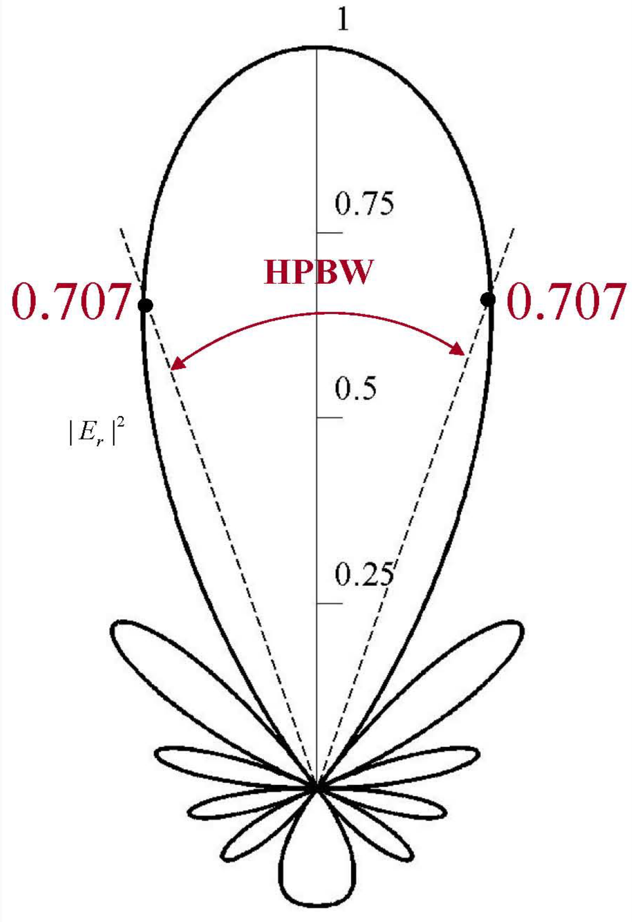


Fig. 2.2(a)

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

<u>*dB* Scale</u>

N = 10 element

$d = \lambda/4$ spacing

HPBW = 38.64°

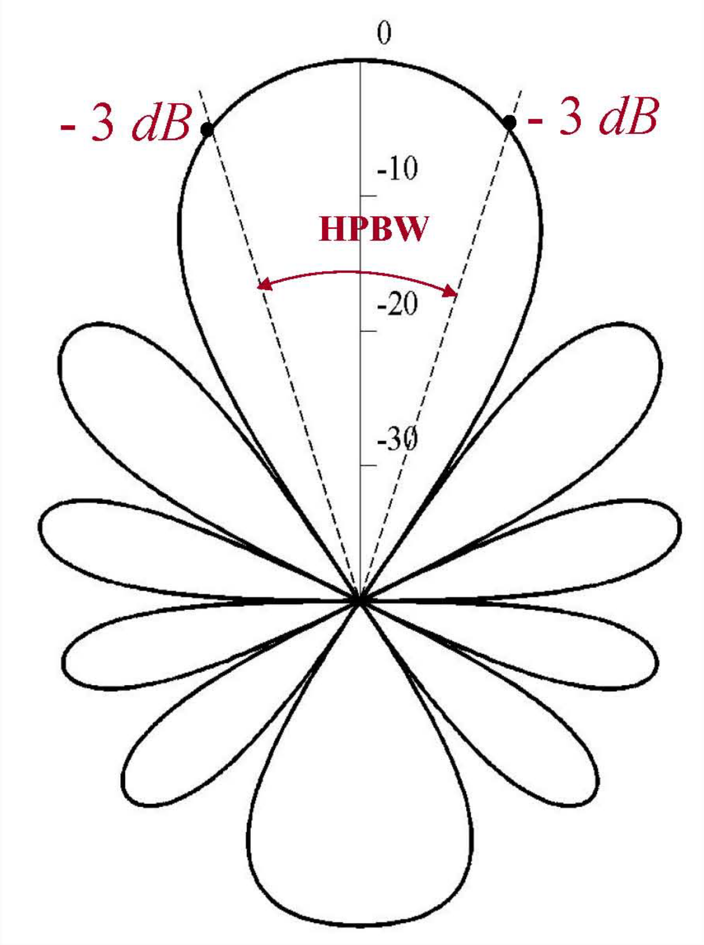
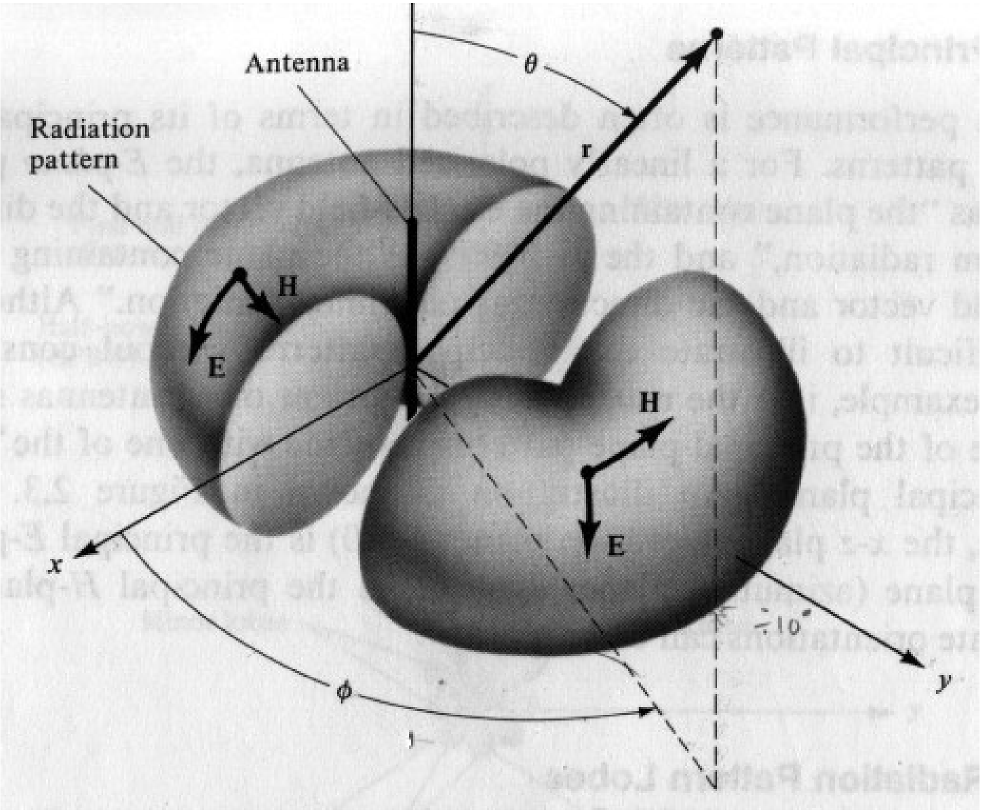


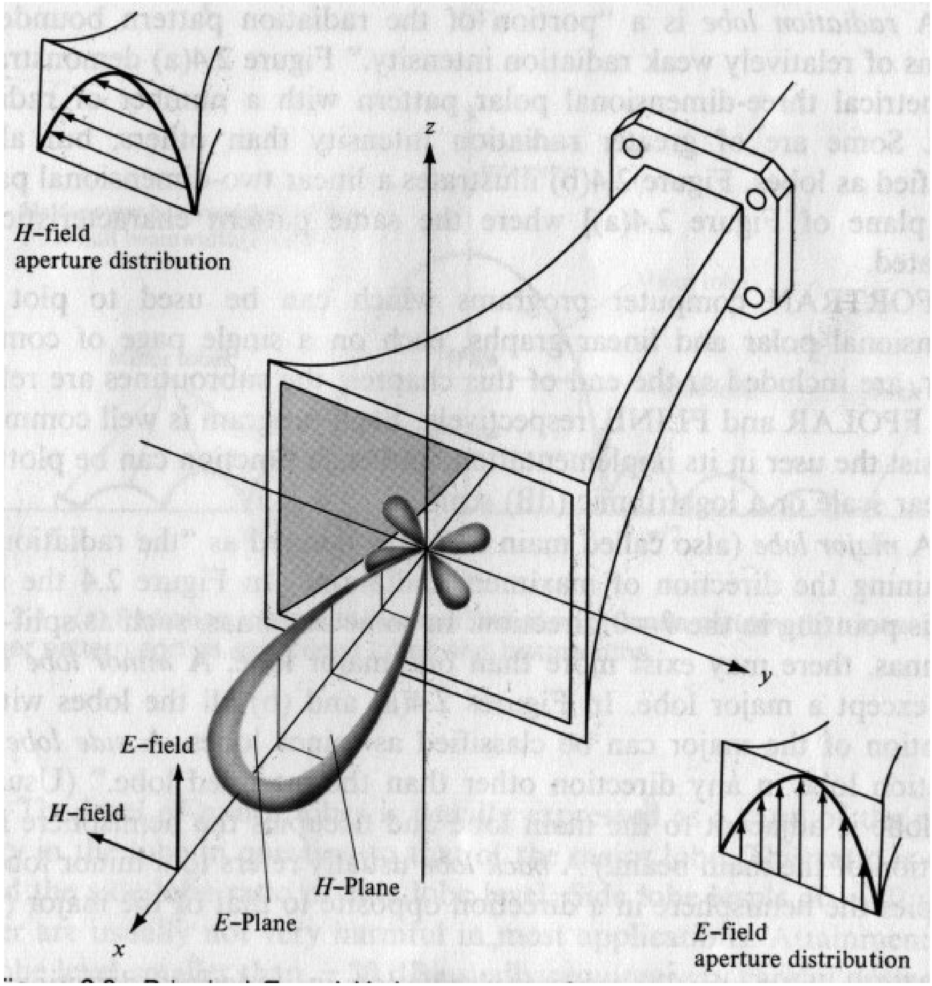
Fig. 2.2(c)

Directional Radiation pattern

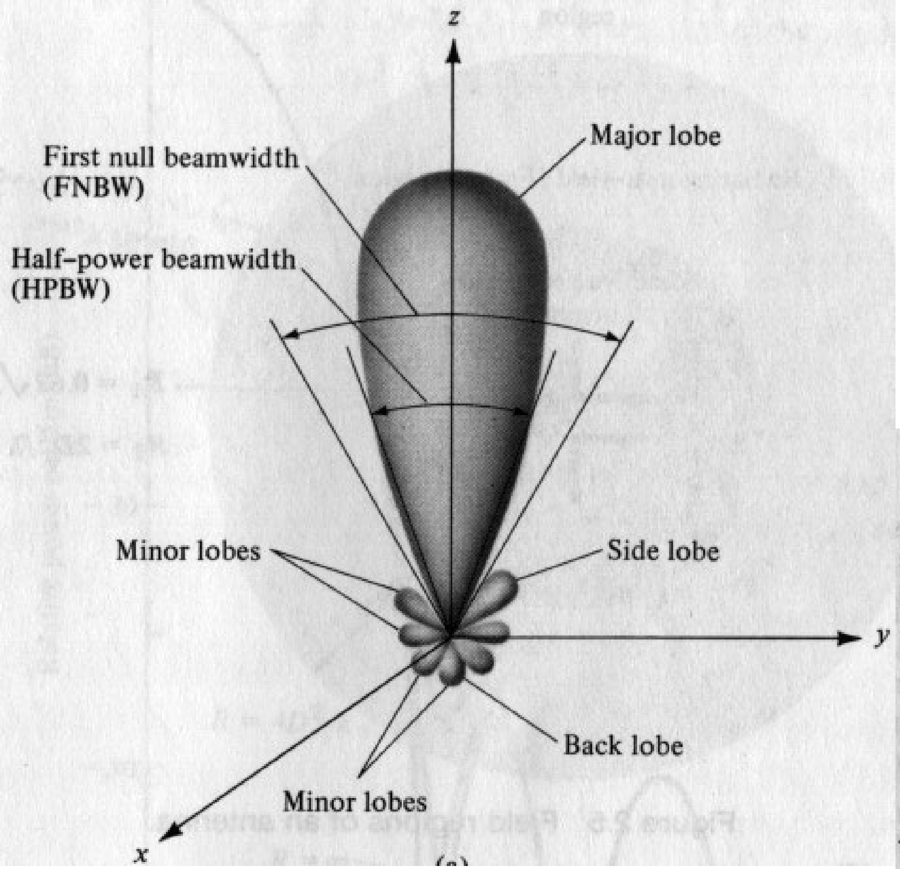
- Isotropic radiation
- Omnidirectional
- Directional

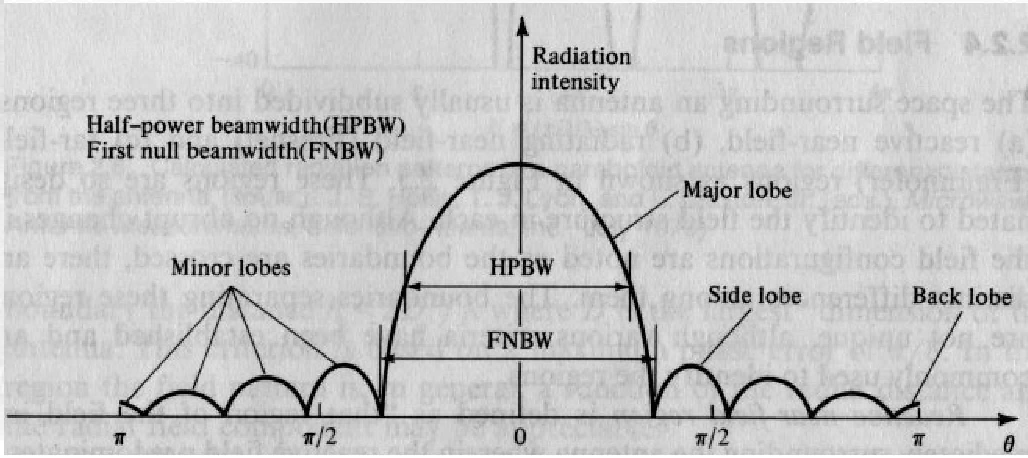


Principal E- and H-Plane patterns

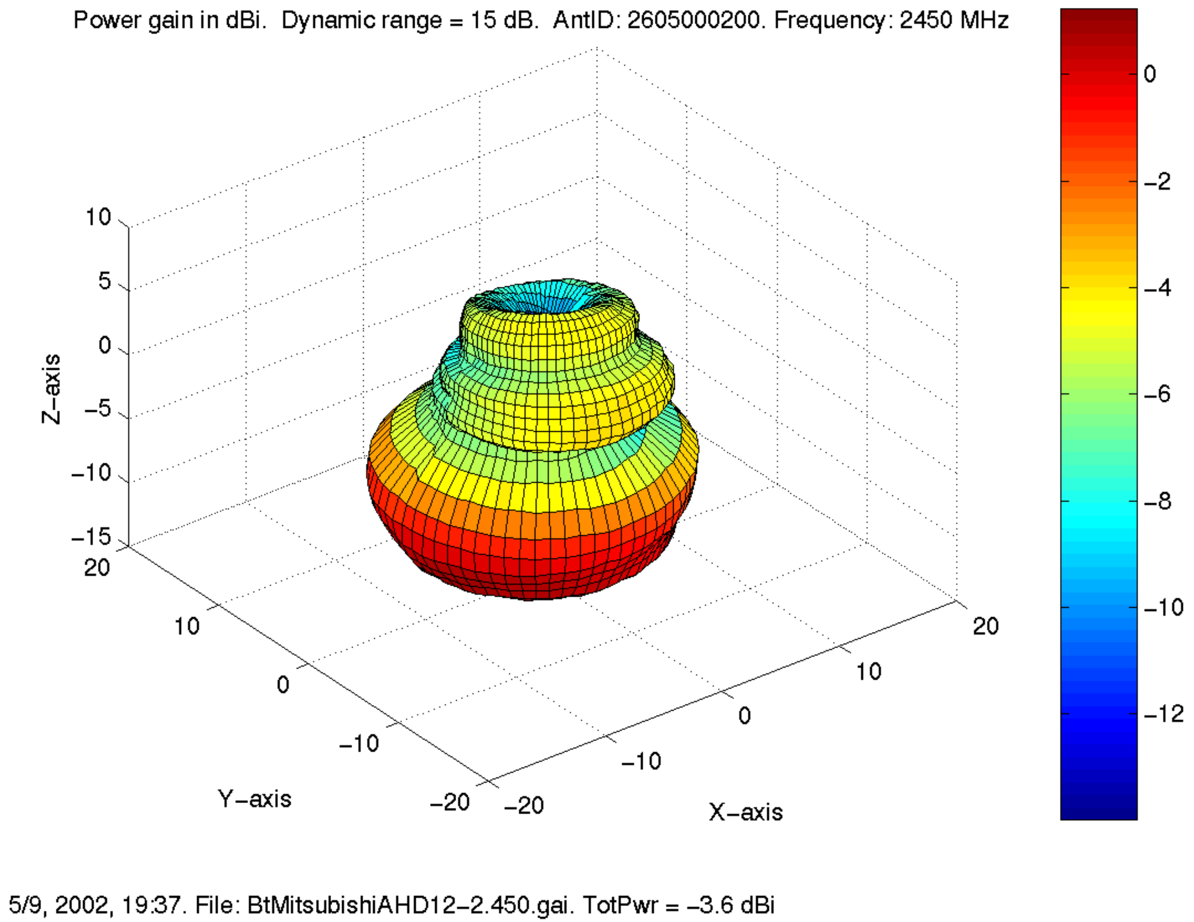


Directional Radiation pattern

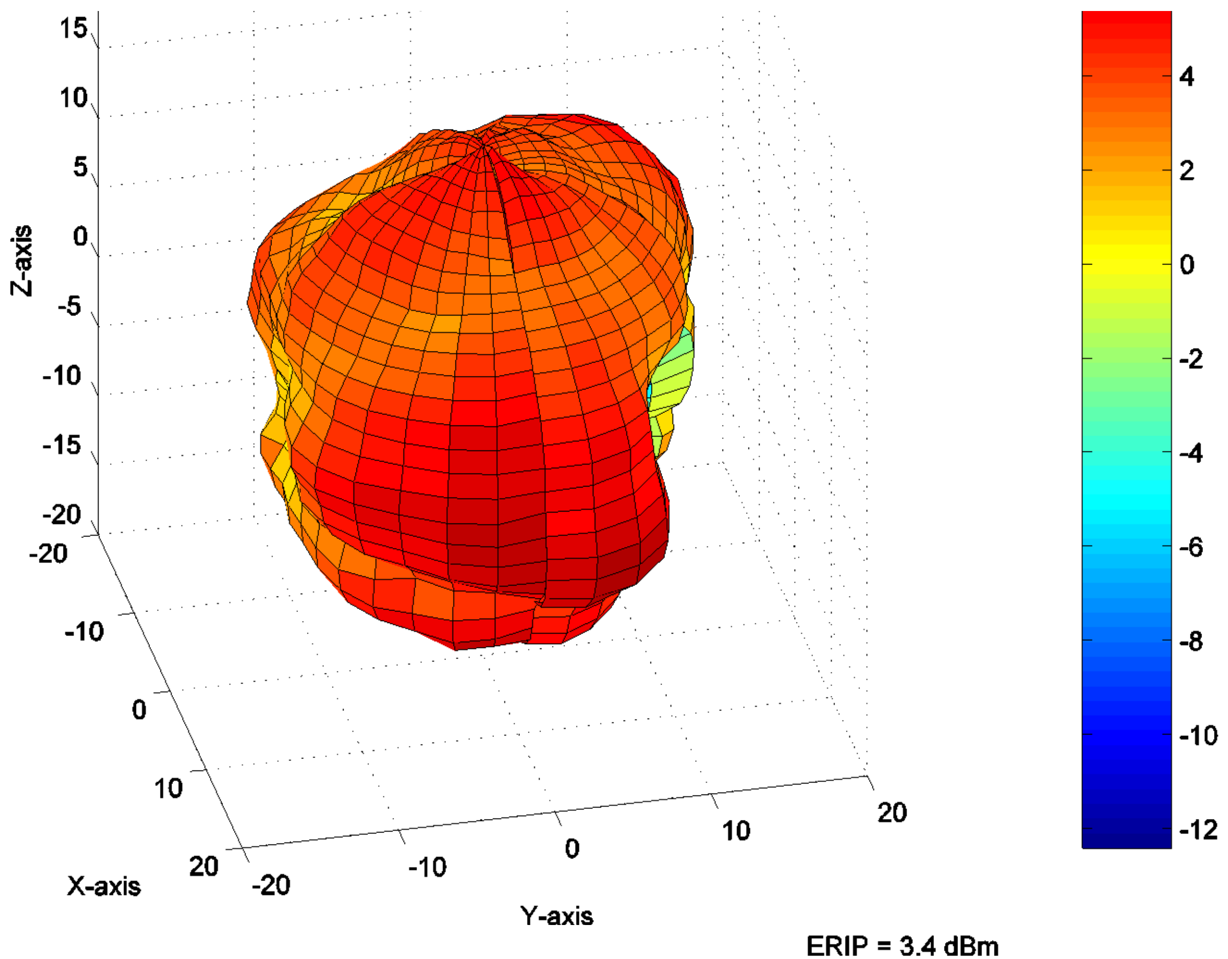




Directional Radiation pattern?



Directional Radiation pattern?



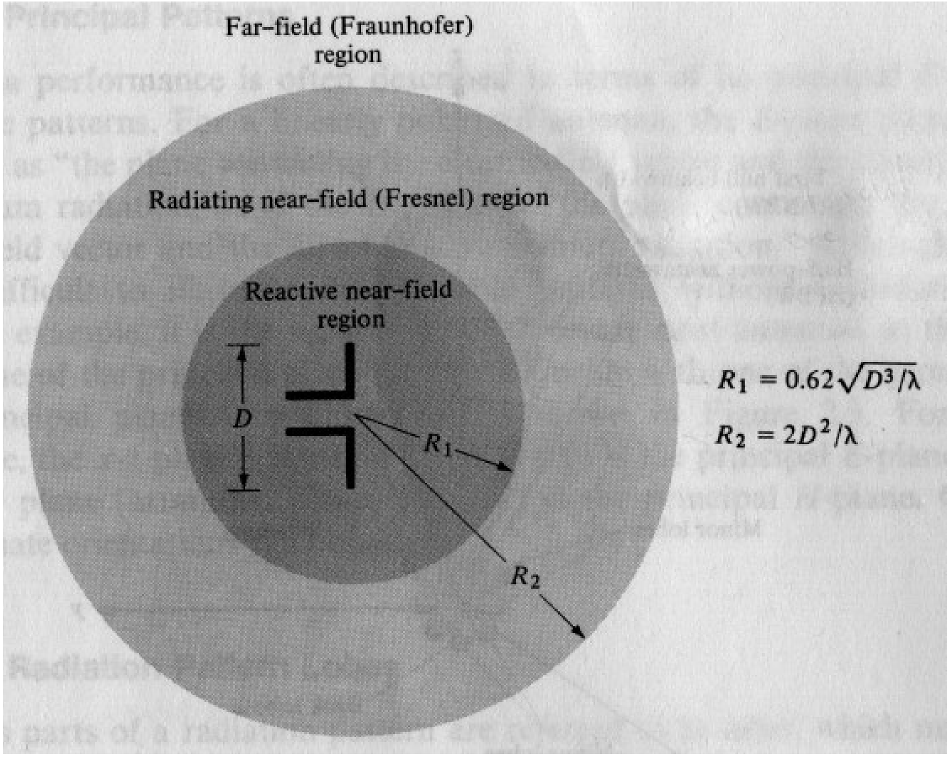
Field Regions around an Antenna

- Reactive Near field

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

- Radiating Near field
- Farfield

$$R > \frac{2D^2}{\lambda}$$



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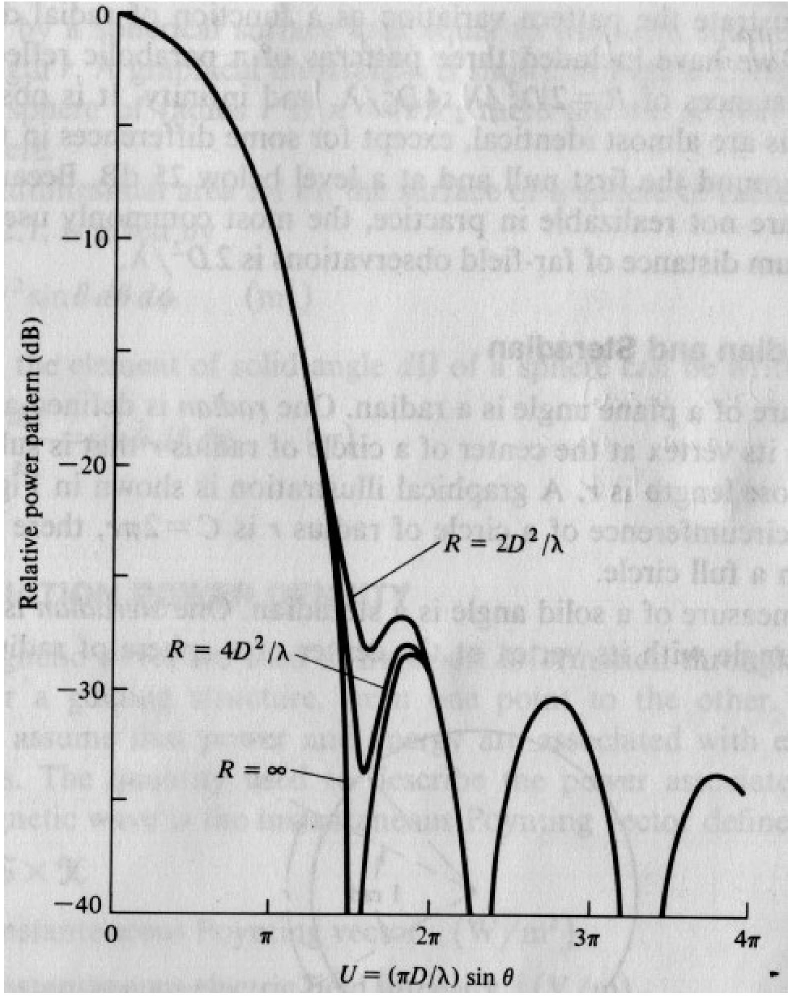
Farfield Criterion

Farfield

$$R > \frac{2D^2}{\lambda}$$

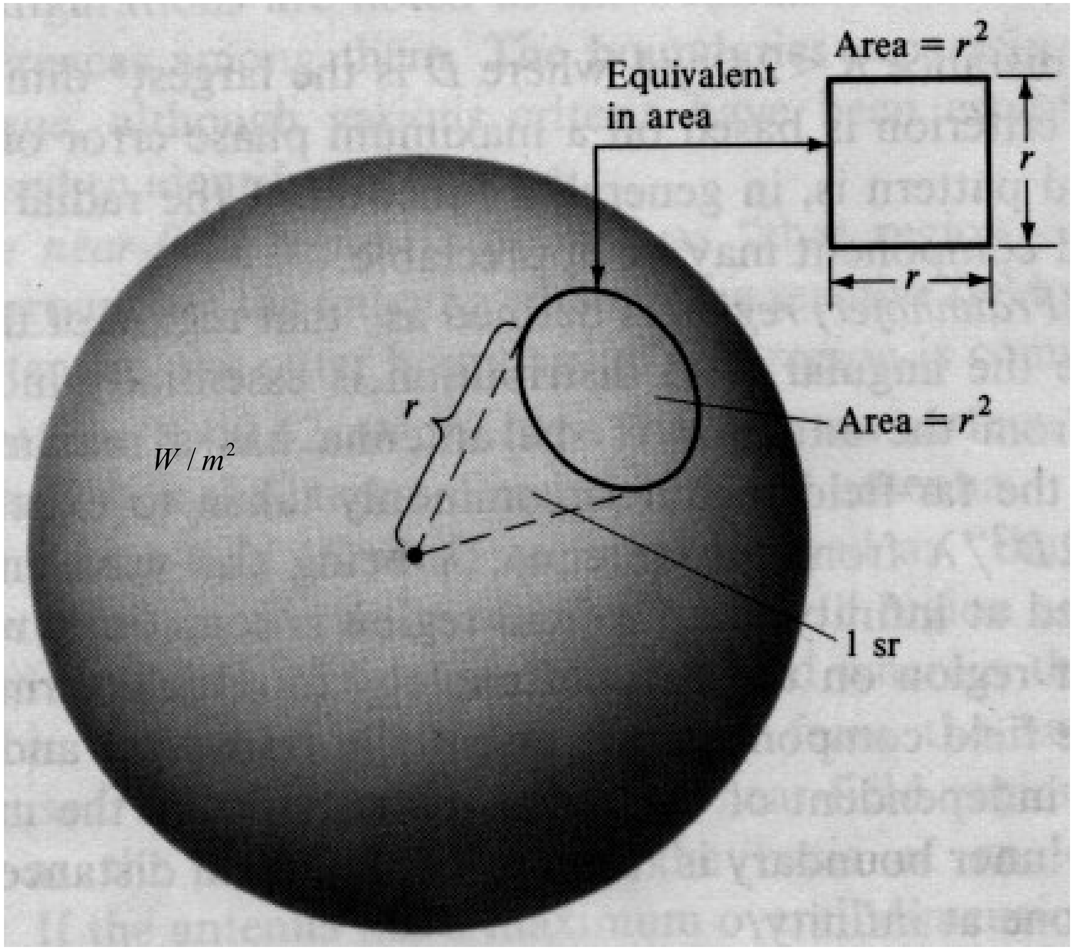


Radiation Power Density [W/m^2]

$$P_{RAD} = P_{AV} =$$

$$\oiint_S \mathbf{W}_{RAD} d\mathbf{S} =$$

$$\frac{1}{2} \oiint_S \mathrm{Re}(\mathbf{E} \times \mathbf{H}^*) d\mathbf{S}$$



Radiation Intensity

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

U = Radiation intensity (W/unit Solid Angle)

W_{RAD} = Radiation density $\quad (W/m^2)$

$$U(\theta,\varphi) = \frac{r^2}{2\eta}\left|\mathbf{E}(r,\theta,\varphi)\right|^2 \approx \frac{1}{2\eta}\left[\left|E_\theta(\theta,\varphi)\right|^2 + \left|E_\varphi(\theta,\varphi)\right|^2\right]$$

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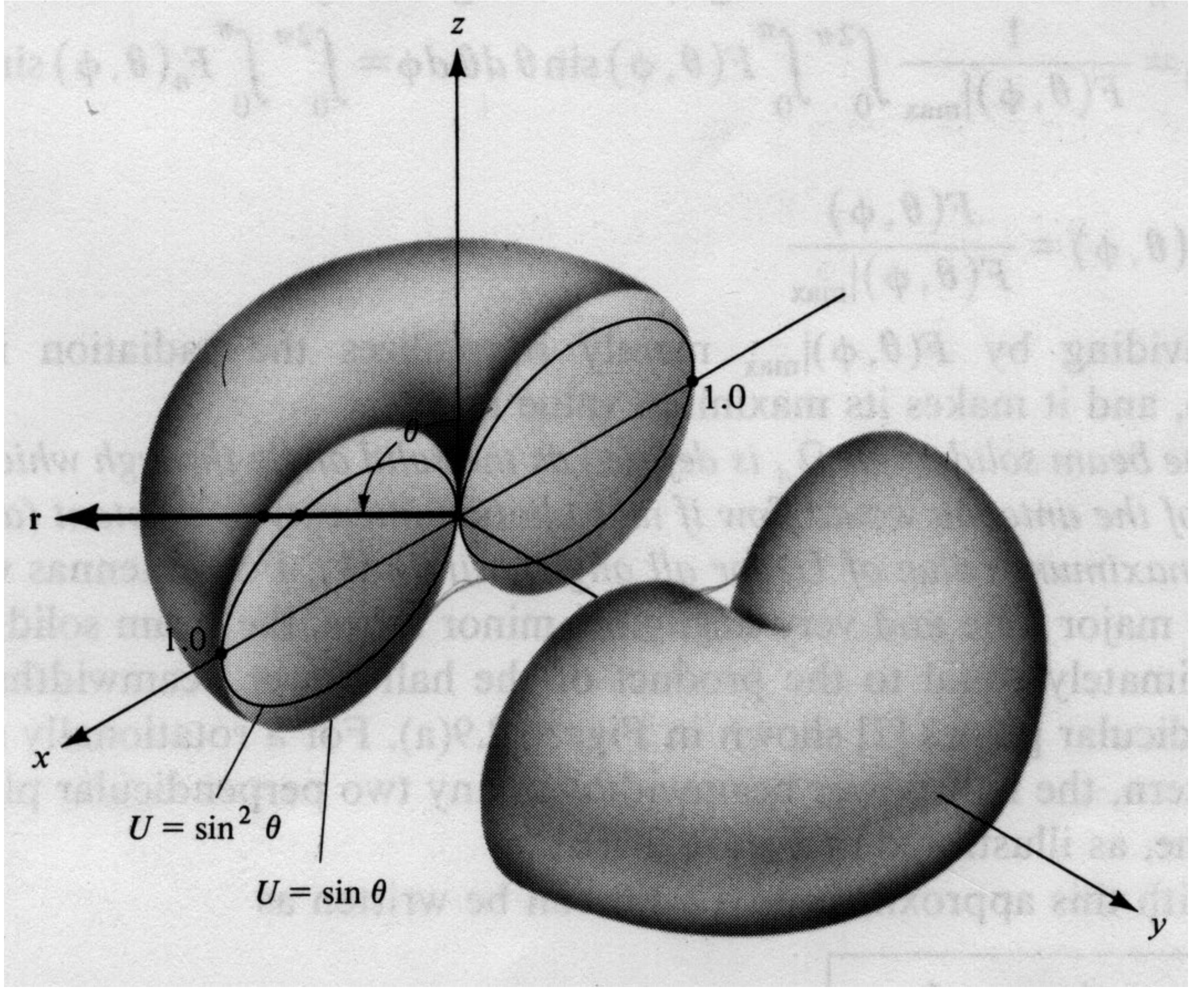
Radiation Intensity Patterns



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Directivity

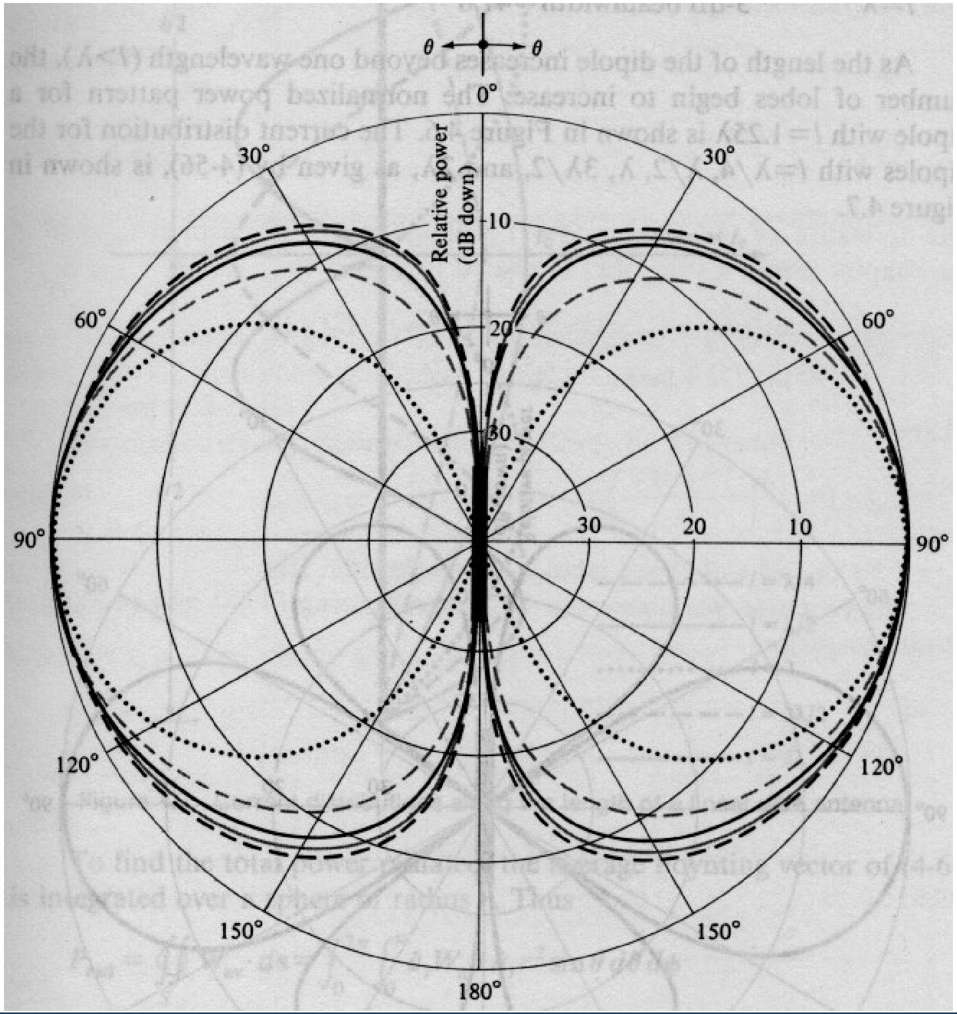
Directive gain

$$D_g(\theta,\varphi) = \frac{U(\theta,\varphi)}{U_0} = \frac{U(\theta,\varphi)}{P_{RAD}/4\pi}$$

Directivity

$$D_0 = \frac{U_{\max}}{U_0} = \frac{U_{\max}}{P_{RAD}/4\pi}$$

2D Directivity Patterns

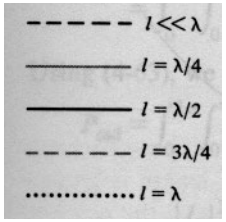


$$E_r \cong H_r = H_\theta = E_\varphi = 0$$

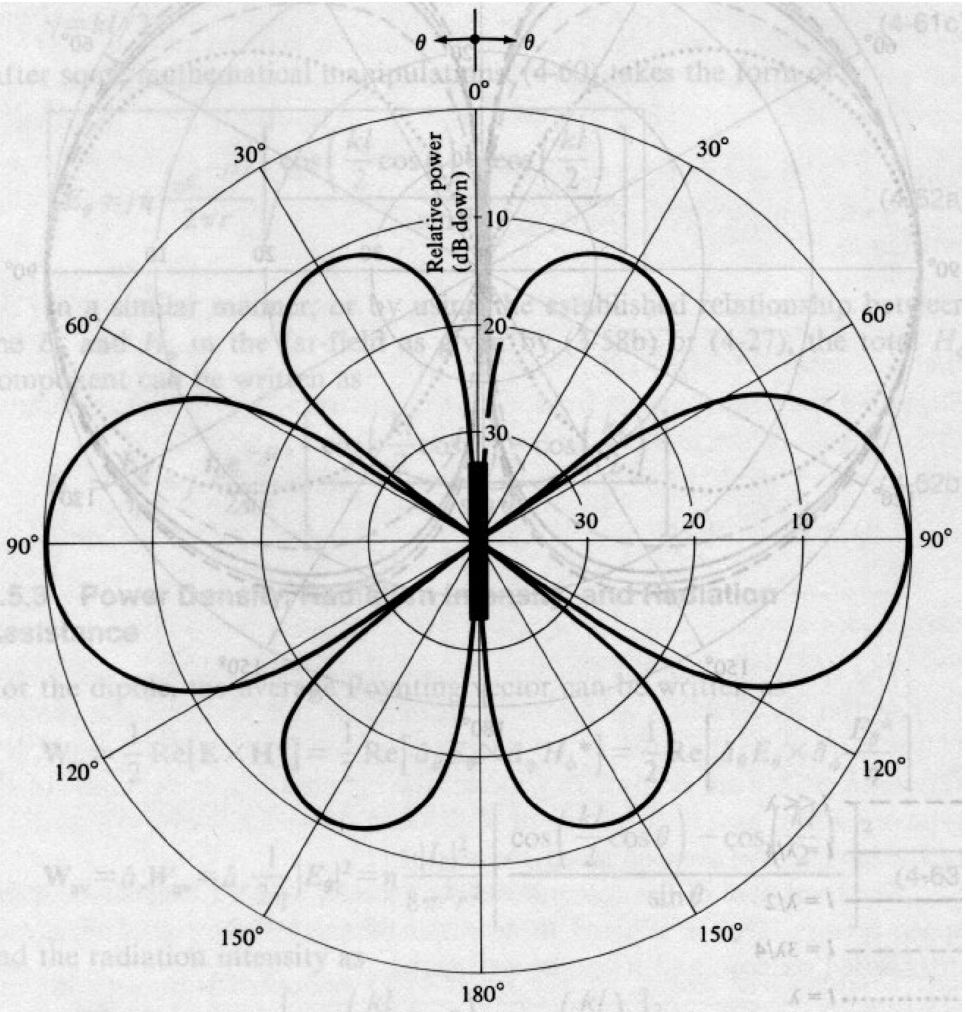
$$H_\varphi \cong j\frac{kI_0 l \sin(\theta)}{4\pi r}e^{-jkr}$$

$$E_\theta \cong j\eta\frac{kI_0 l \sin(\theta)}{4\pi r}e^{-jkr}$$

$$\Rightarrow Z = \frac{E_\theta}{H_\varphi} \cong \eta$$



Farfield for a Dipole larger than one wavelength



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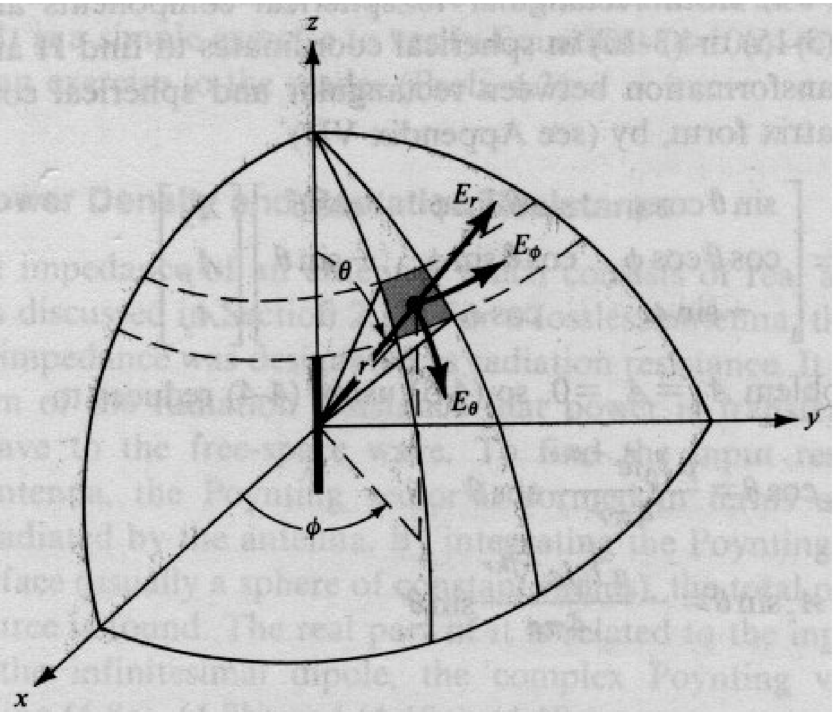
Field Radiated from a small Dipole Antenna



(b) Electric field orientation

$$H_r = H_\theta = 0$$

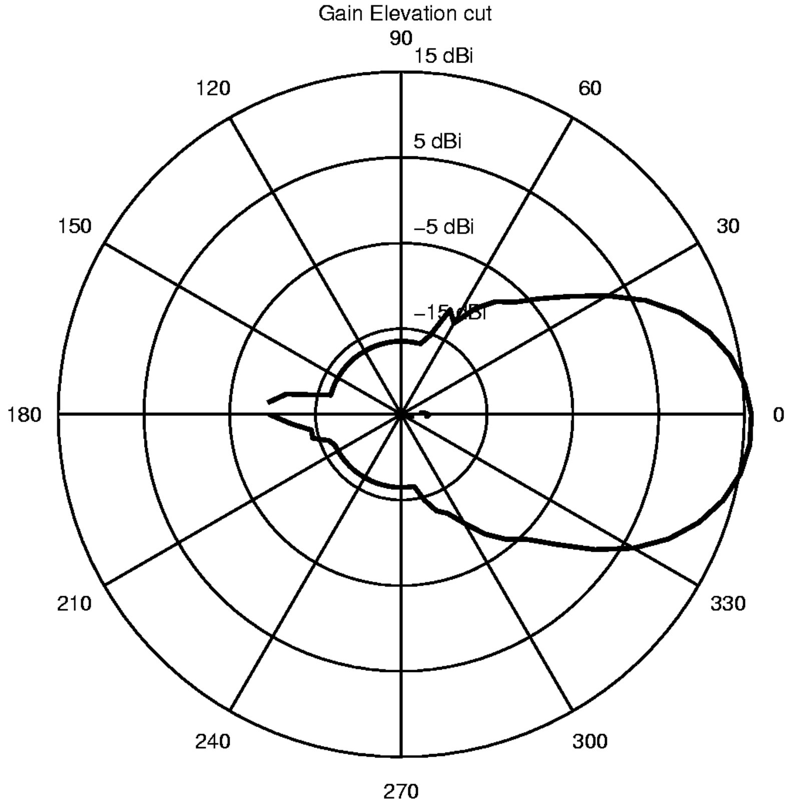
$$H_\varphi = j\frac{kI_0 l\sin(\theta)}{4\pi r}\left[1+\frac{1}{jkr}\right]e^{-jkr}$$

$$E_r = \eta\frac{I_0 l\cos(\theta)}{2\pi r^2}\left[1+\frac{1}{jkr}\right]e^{-jkr}$$

$$E_\theta = j\eta\frac{kI_0 l\sin(\theta)}{4\pi r}\left[1+\frac{1}{jkr}-\frac{1}{(kr)^2}\right]e^{-jkr}$$

$$E\varphi = 0$$

Antenna Gain

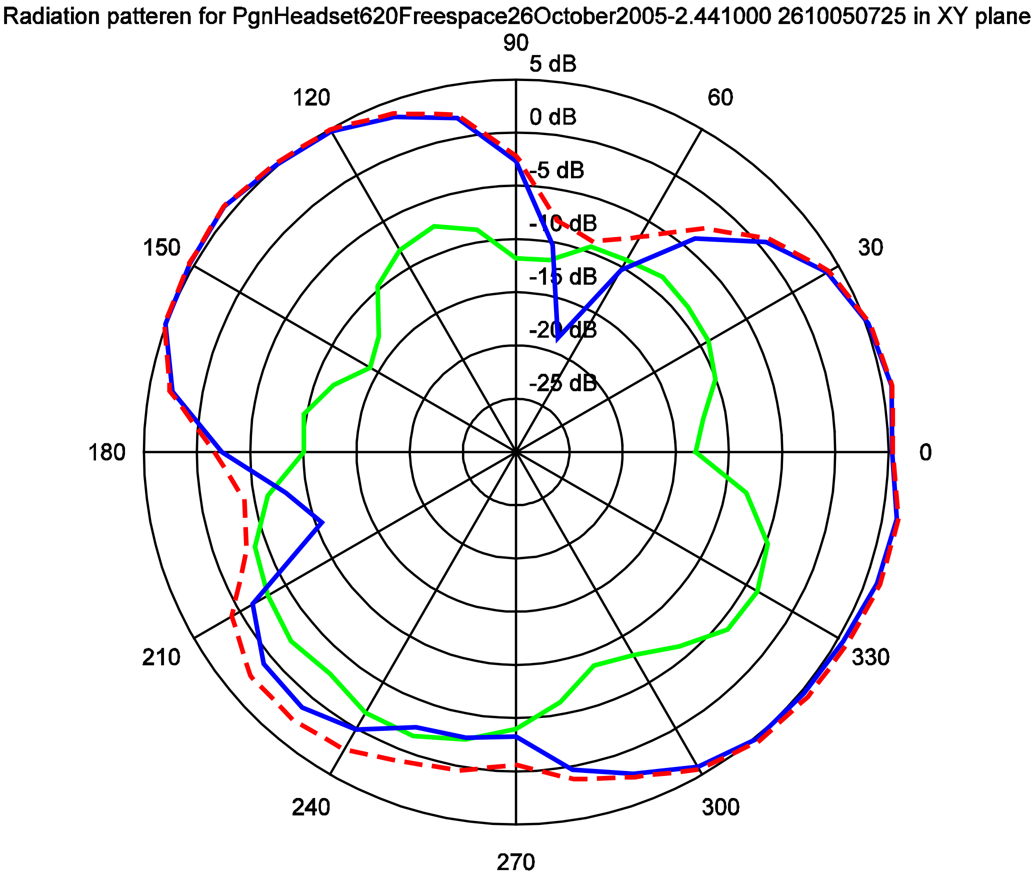


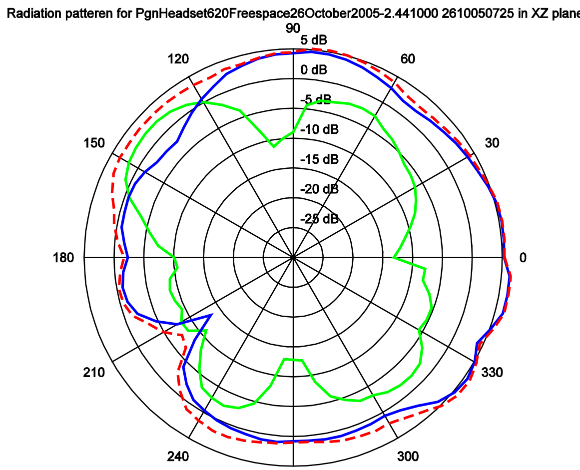
$$G_g(\theta,\varphi)=\frac{U(\theta,\varphi)}{P_{IN}/4\pi}$$

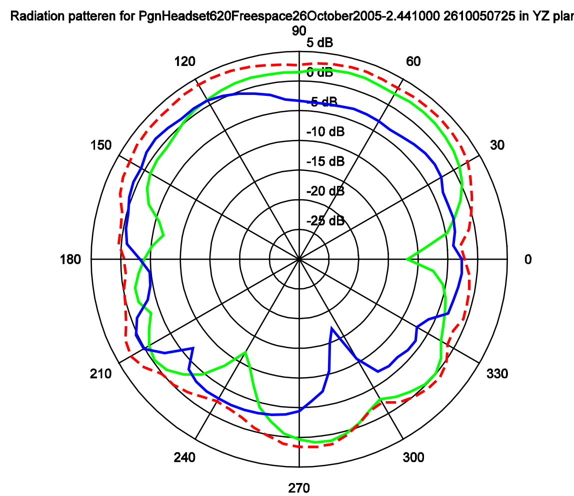
$$G_g(\theta,\varphi)=e_t D_g(\theta,\varphi)$$

$$G_0=e_t D_0$$

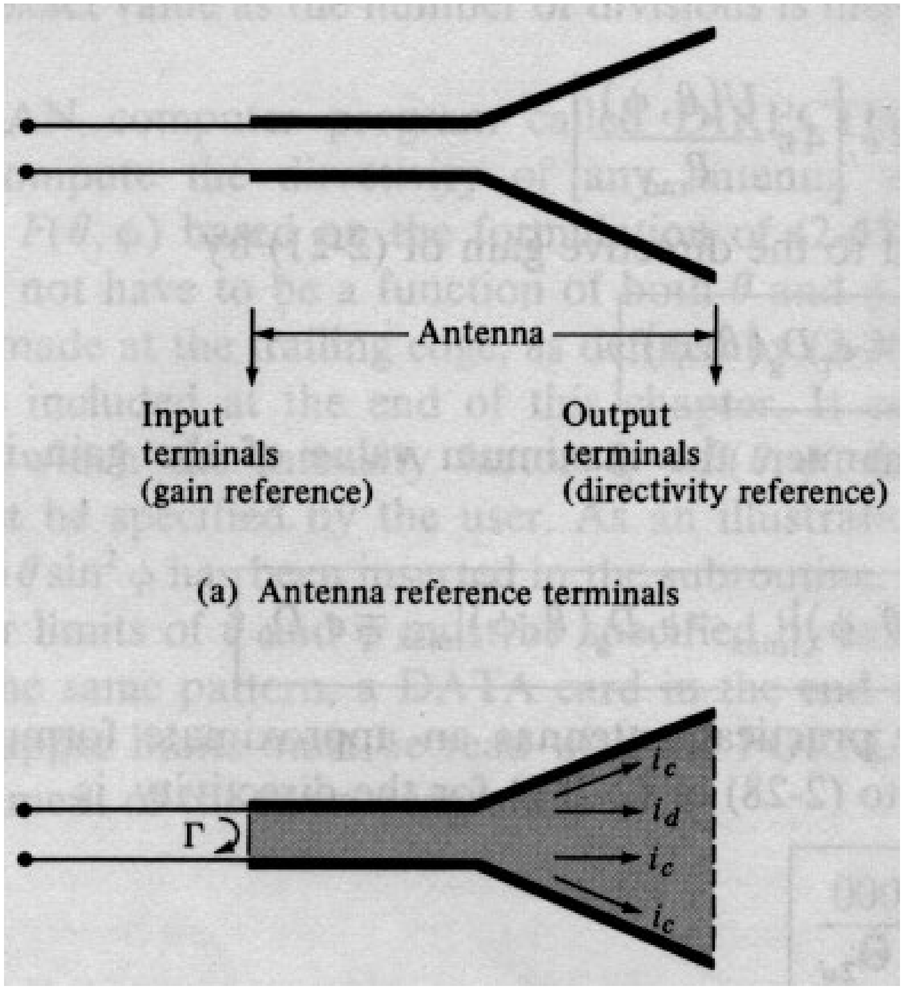
Directional Radiation pattern?







Antenna Efficiency



$$e_t = e_r e_c e_d$$

- Total efficiency
- Reflection efficiency $(1-|\Gamma|^2)$
- Conduction effeciency
- Dielectric efficiency

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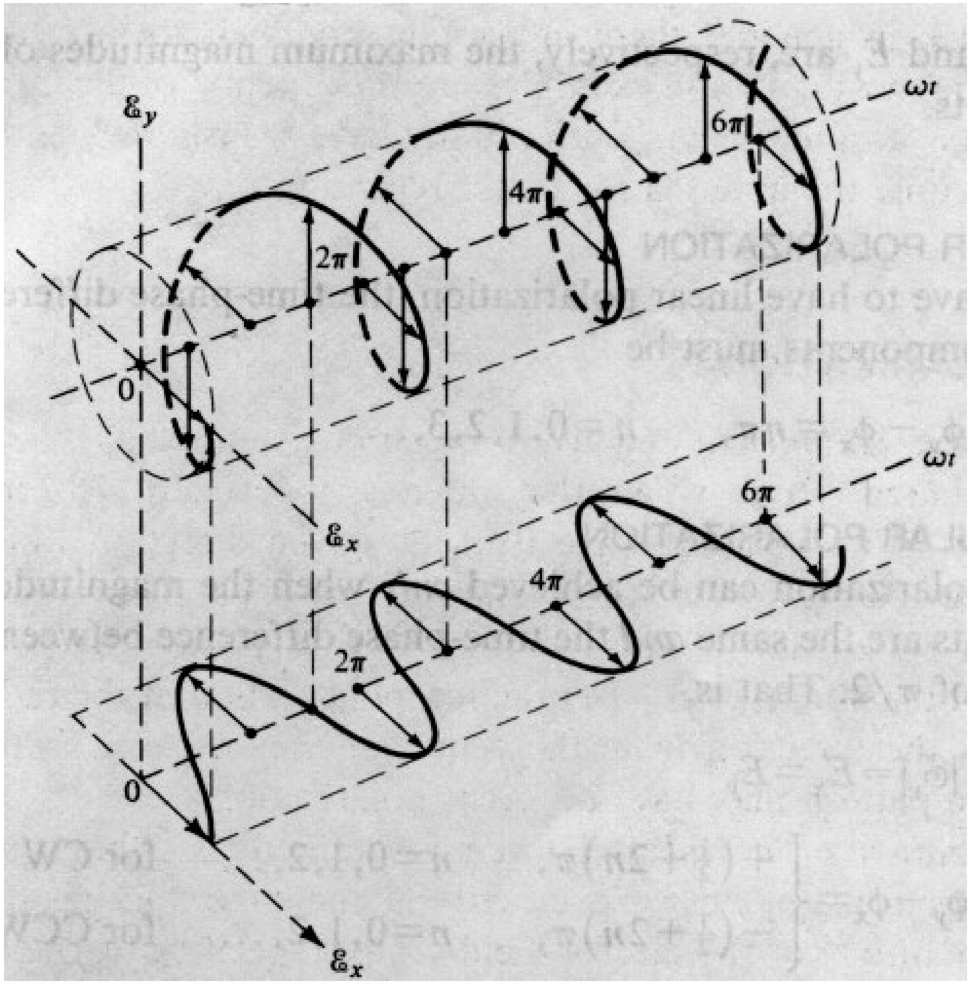
Polarization

- Linear
- Circular
  - Clock Wise (CW) or Right Hand (RH)
  - Counter Clockwise (CCW) or LH
- Elliptical (Axial Ratio)
  - CW) or RH
  - CCW or LH

Polarization



Rotation of plane EM Wave propagation in the Positive Z direction

Polarization

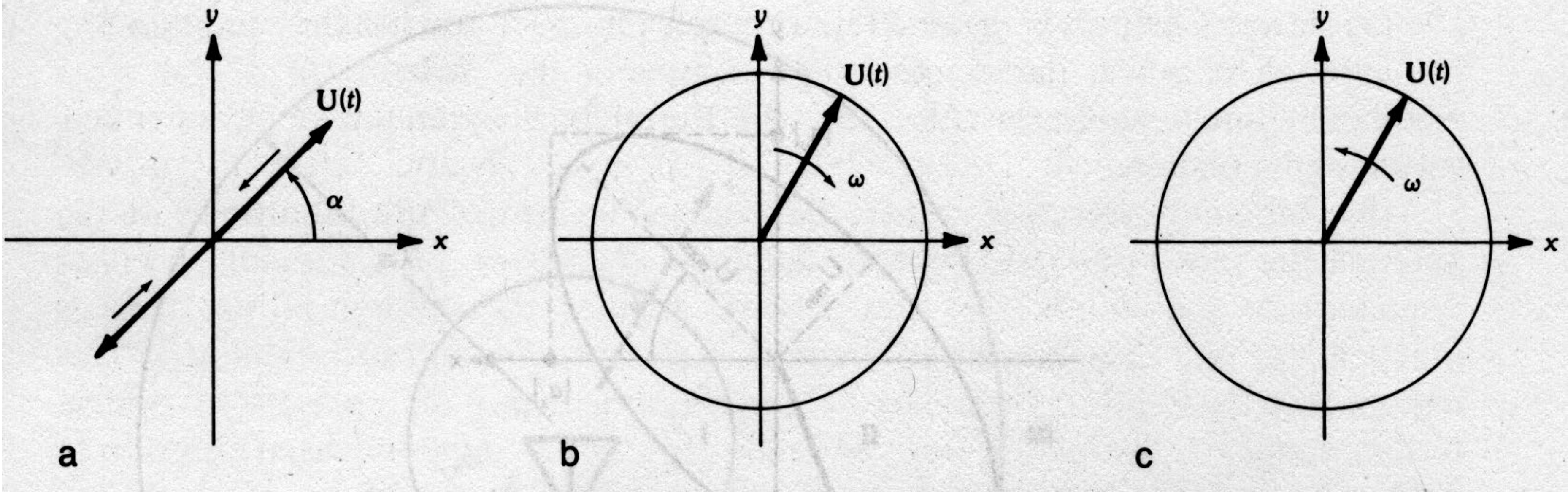


Fig. 7. Rotating vector **U**(t) for linear and circular polarizations. (a) Linear. (b) Left-hand circular. (c) Right-hand circular.

Polarization

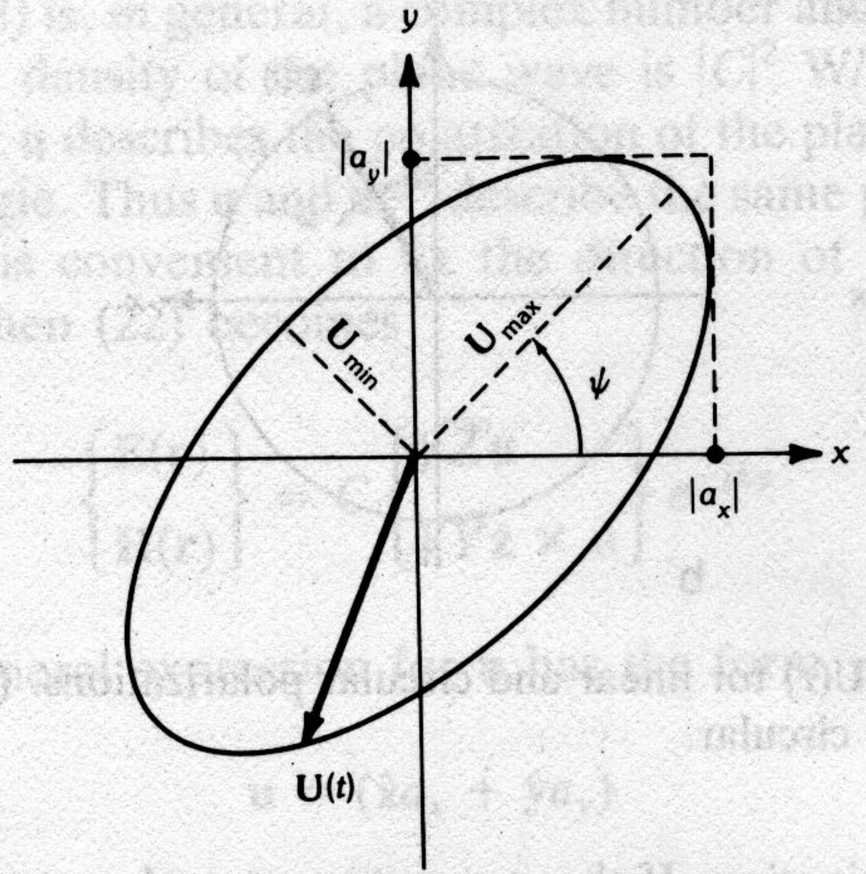
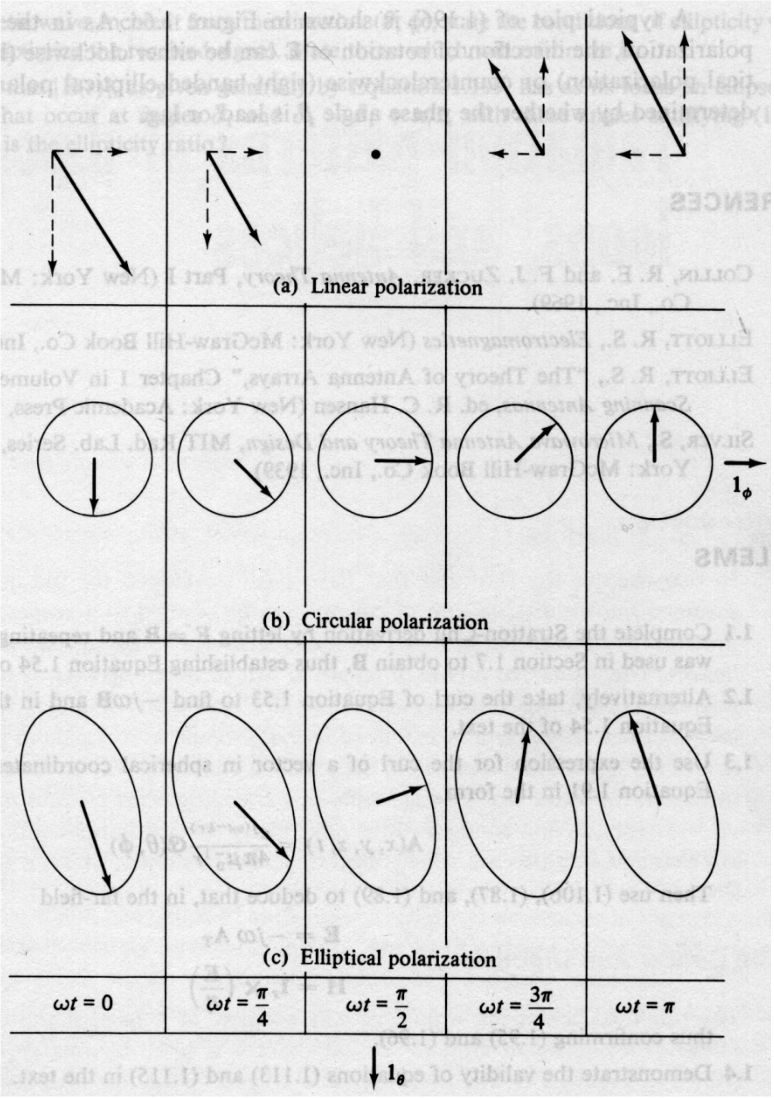
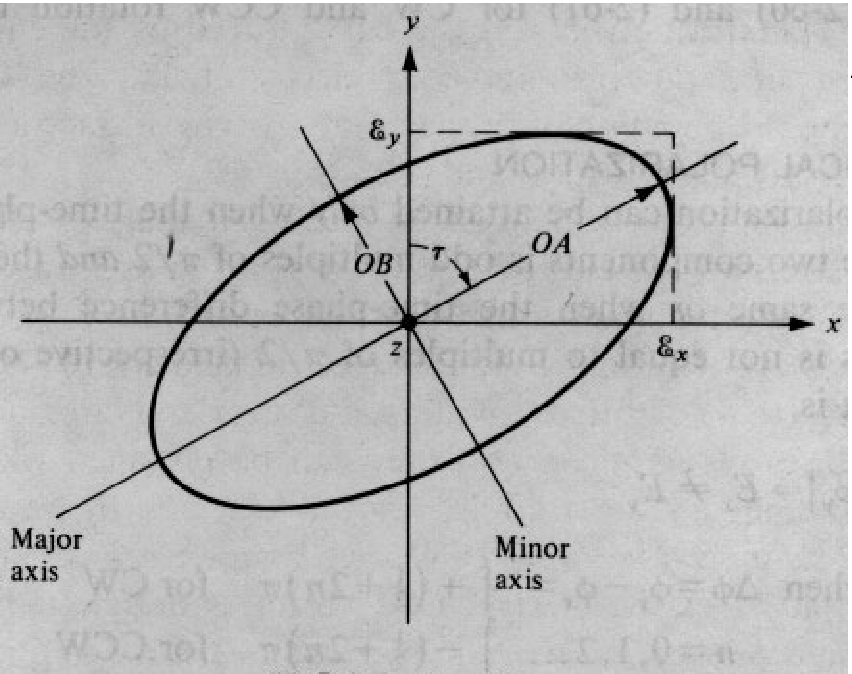


Fig. 8. Elliptical polarization: the tip of the rotating vector **U**(t) traces out an ellipse.

Polarization



Polarization



(b) Polarization ellipse

A Linear

$$\Delta\varphi = \varphi_Y - \varphi_X = n\pi$$

B Circular

$$E_X = E_Y \wedge$$

$$\Delta\varphi = \varphi_Y - \varphi_X = \begin{cases} (\frac{1}{2}+2n)\pi \\ -(\frac{1}{2}+2n)\pi \end{cases}$$

C Elliptical

Problems

Problem 1.1.

A hypothetical isotropic antenna is radiating in freespace. At a distance of 100 meters from the antenna the total electrical field (E_Θ) is measured to be 5 V/m. Find the

a) Power density (W_{rad})
b) Power radiated (P_{rad})

Problems

Problem 1.2

The maximum radiation intensity of a 90% efficient antenna is 200 mW/unit solid angle.
Find the directivity and gain (dimensionless and in dB) when the:

a) Input power is 125.66 mW
b) Radiated power is 125.66 mW

Problems

Problem 1.3

In target-search ground-mapping radars it is desirable to have ecco power received from target, of constant cross section, to be independent of its range. For one such application, the desireble radiation intensity of the antenna is given by

$U(\Theta,\Phi) = 1$ for $0^\circ \leq \Theta < 20^\circ$

$U(\Theta,\Phi) = 0{,}342 \csc(\Theta)$ for $20^\circ \leq \Theta < 60^\circ$

$U(\Theta,\Phi) = 0$ for $60^\circ \leq \Theta \leq 180^\circ$

Find the directivity in dB using the exact formula.

Problems

Problem 1.4

The radiation intensity of an antenna is given by

$U(\Theta,\Phi)= \cos^4(\Theta)\sin^2(\Phi)$,
for $0 \leq \Theta \leq \pi/2$ and $0 \leq \Phi \leq 2\pi$ (i.e. In the upper half-space)
It is 0 in the lower half-space.

Find the:

a) Exact directivity (dimensionless and in dB).
b) Elevation plane half-power beamwidth in degrees.