Chapter 2

Fundamental Parameters of Antennas

Coordinate System

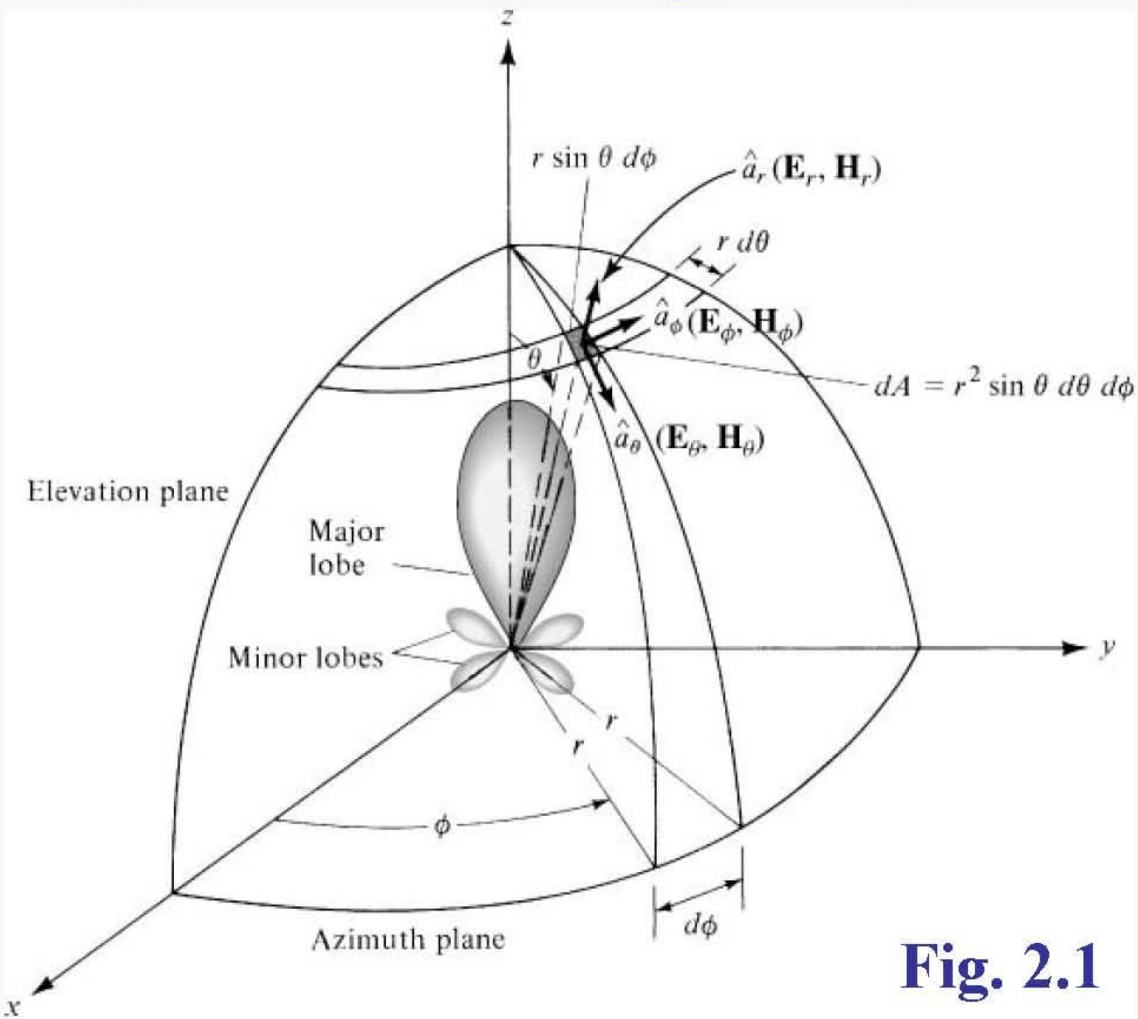


Fig. 2.1

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

$$0 \le \theta \le \pi$$

$$0 \le \phi \le 2\pi$$

✓

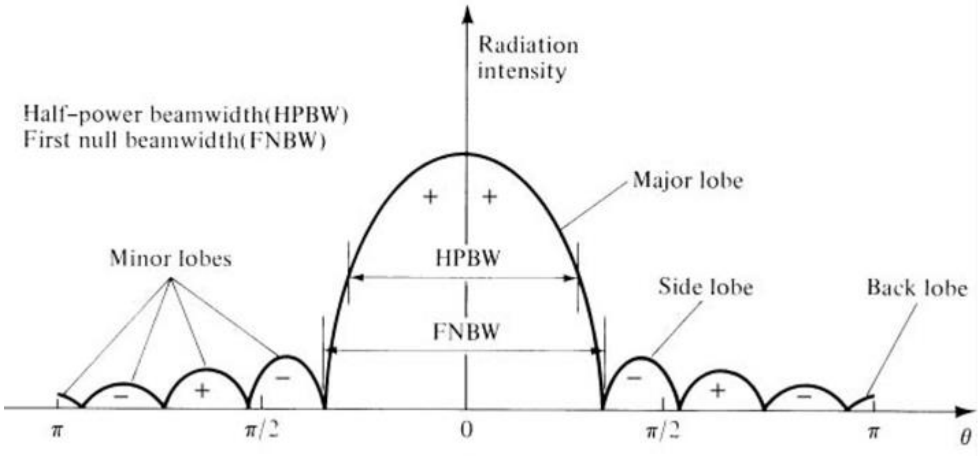
Radiation Pattern

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

- amplitude
- phase
- polarization, etc.

as a function of the angular space coordinates θ, ϕ.

Linear Pattern



Polar Pattern

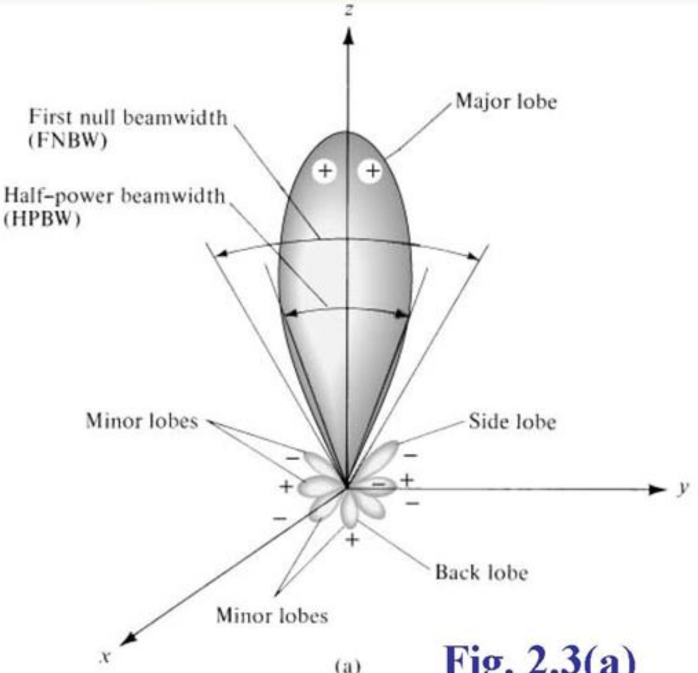


Fig. 2.3(a)

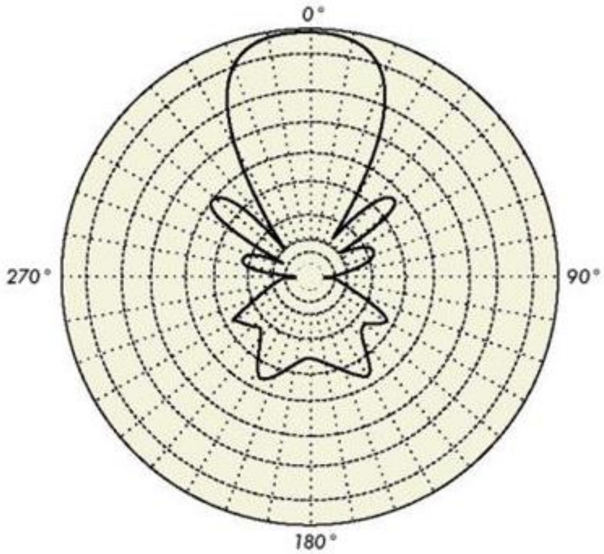
Amplitude Radiation Pattern

- 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.



Amplitude Radiation Pattern

- Isotropic,
- Directional,
- Omnidirectional

Directional Pattern of a Horn

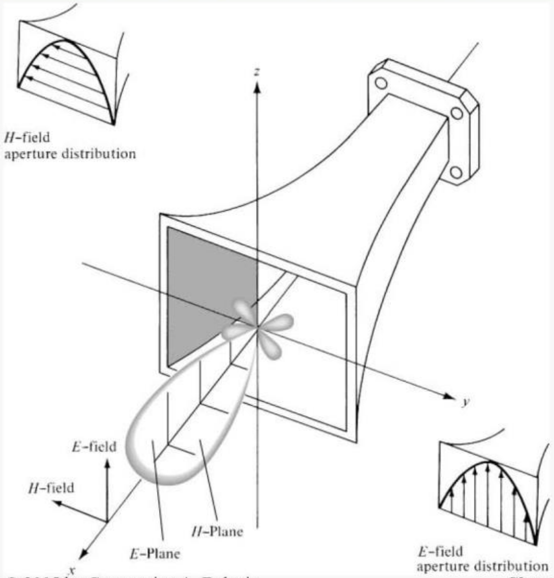
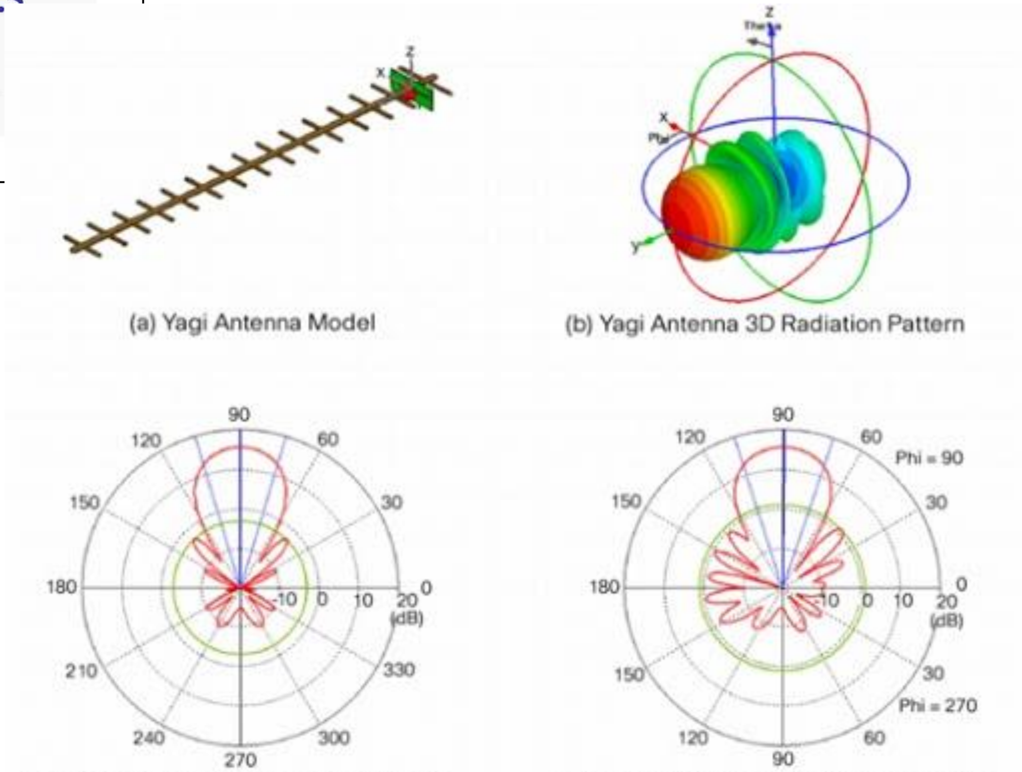


Fig. 2.5

Chapter 2
Fundamental Parameters of Antennas



(a) Yagi Antenna Model

(b) Yagi Antenna 3D Radiation Pattern

(c) Yagi Antenna Azimuth Plane Pattern

(d) Yagi Antenna Elevation Plane Pattern

Omnidirectional Pattern

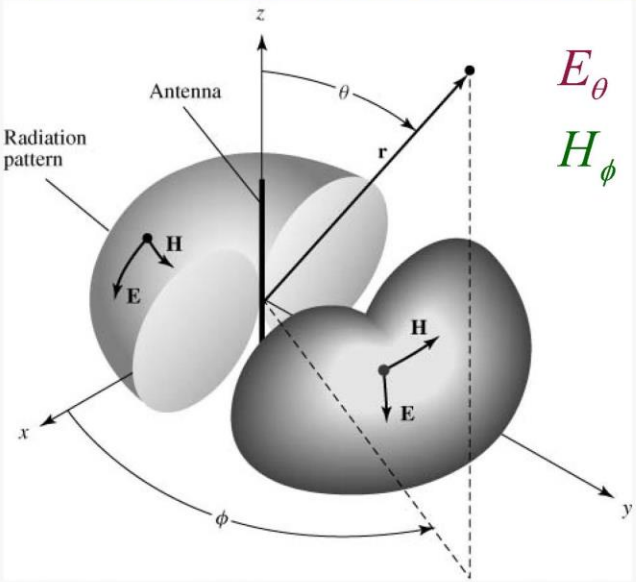
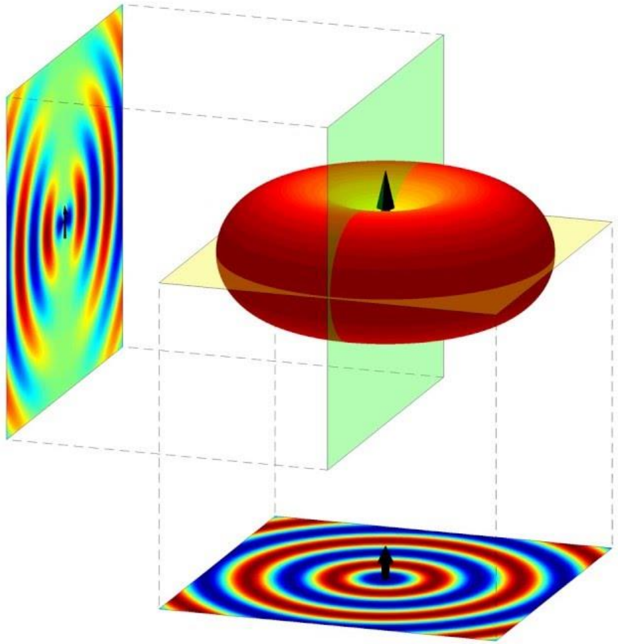


Fig. 2.6

Chapter 2
Fundamental Parameters of Antennas



Field Regions

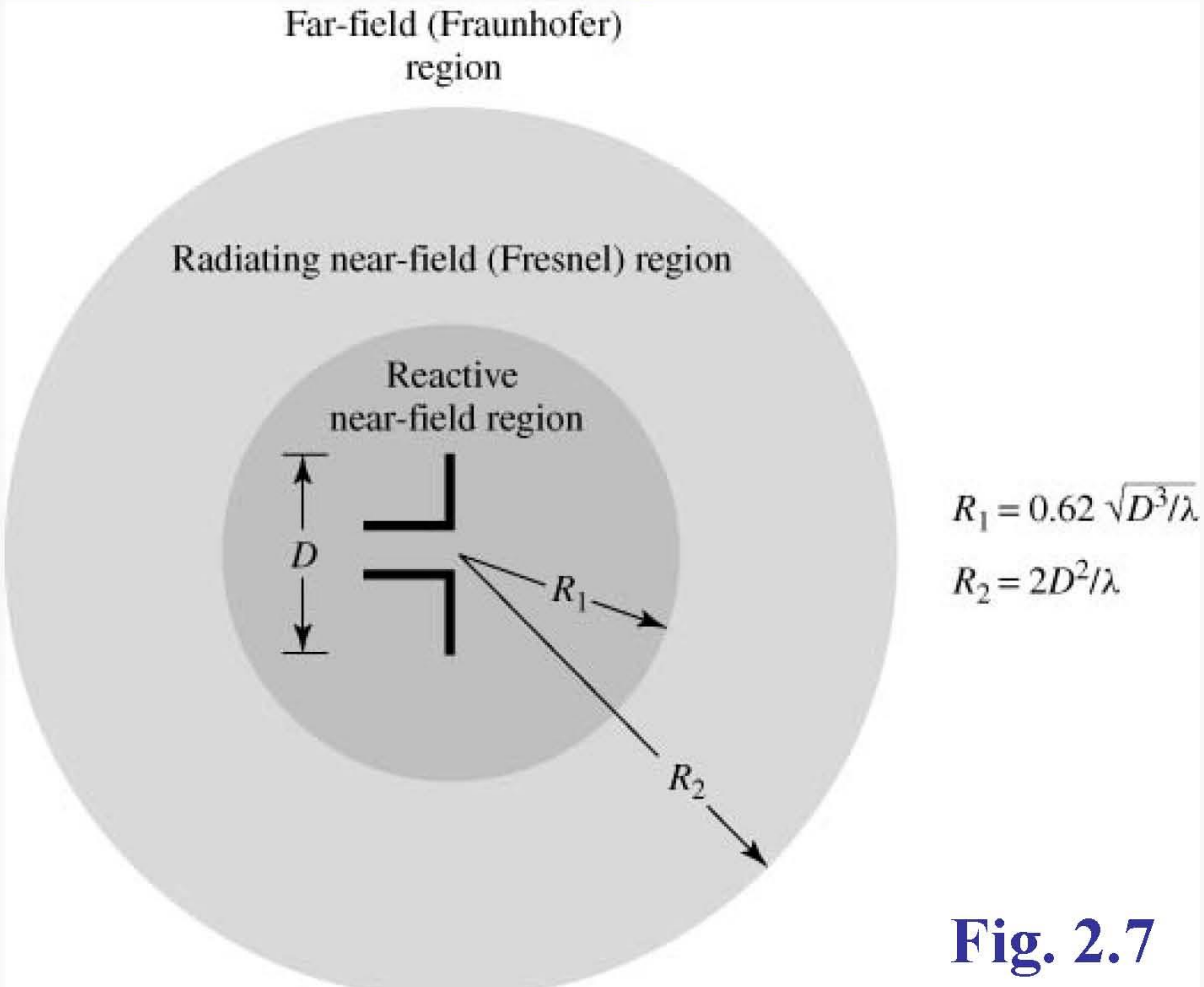


Fig. 2.7

Field Regions

1. Reactive Near-field
2. Radiating Near-field: Fresnel
3. Far-field: Fraunhofer

I. Reactive Near-Field

1. Highly reactive wave impedance
2. High content of non-propagating stored energy near the antenna

II. Radiating Near-Field

Region where near-field measurements are made

III. Far-Field

A. Electric & magnetic fields are in-phase
B. Wave impedance is, ideally, real
C. Power predominantly real; propagating energy

1. Radiation Power
   Density
2. Radiation
   Intensity

$$\underline{W}\Big|_{ave} = \frac{1}{2}\mathrm{Re}\left[\underline{E} \times \underline{H}^{*}\right] \qquad (2\text{-}8)$$

It is assumed that both $\underline{E}$ and $\underline{H}$ represent peak amplitude values (not RMS: Root Mean Square). If $\underline{E}$ and $\underline{H}$ were to represent RMS values, then the one-half (1/2) must be omitted. Measuring instruments typically measure RMS values.

$$P = \oiint_S \underline{W}_{ave} \cdot d\underline{s} = \int_0^{2\pi}\int_0^{\pi} \underline{W}_{ave} \cdot \hat{a}_r r^2 \sin\theta d\theta d\phi$$

$$P_{rad} = P_{ave} = \int_0^{2\pi}\int_0^{\pi} \left(\frac{1}{2}\mathrm{Re}\left[\underline{E} \times \underline{\mathrm{H}}^{*}\right] \right) \cdot \hat{a}_r r^2 \sin\theta d\theta d\phi \qquad (2\text{-}9)$$

Intensity U (Far-field)

$$U = r^2\, W_{rad} = r^2 W_{ave}$$ (2-12)

$$d\Omega = \frac{dA}{r^2} = \frac{r^2 \sin\theta \, d\theta \, d\phi}{r^2}$$

$$d\Omega = \sin\theta \, d\theta \, d\phi$$

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

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

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

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

Isotropic Source

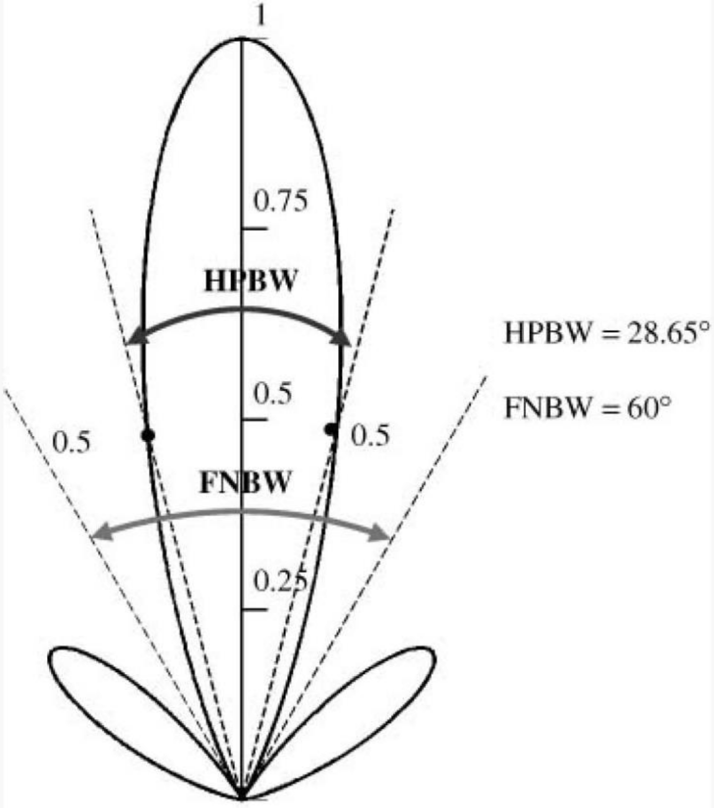
$$W_o = \frac{P}{4\pi r^2}\left(W/m^2\right)$$

$$U_o = \frac{P}{4\pi}\left(W/Sr\right)$$

Beamwidths

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

HPBW and FNBW of Radiation Intensity U



(b) Two-dimensional

Linear Scale

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

Fig. 2.11(b)

Directivity *D*

$$D = \frac{U(\theta,\phi)}{U_o} = \frac{4\pi U(\theta,\phi)}{P_{rad}} \quad (2\text{-}16)$$

$$D_{\max} = D_o = \frac{U_{\max}}{U_o} = \frac{4\pi U_{\max}}{P_{rad}} \quad (2\text{-}16a)$$

$$D(dB) = 10\log_{10}\left[D(\text{dimensionless})\right]$$

Summary

1. $D = \dfrac{4\pi U}{P_{rad}} = 1 = D_o$ (isotropic)

2. $D = \dfrac{4}{\pi} \sin\theta = 1.27\ \sin\theta = D_o \sin\theta$ (no specific one)

3. $D = \dfrac{3}{2}\ \sin^2\theta = 1.5\ \sin^2\theta = D_o \sin^2\theta$ (infinitesimal dipole)

4. $D = 1.67\ \sin^3\ \theta = D_o \sin^3\theta$ ($\lambda/2$ dipole)

General Formulation of Directivity

$$P_{rad} = \oiint_S U(\theta,\phi)\, d\Omega = B_0 \int_0^{2\pi}\int_0^{\pi} F(\theta,\phi)\sin\theta\, d\theta\, d\phi$$

(2-20)

$$D_0 = 4\pi \frac{B_0 F_{\max}(\theta_{\mathrm{m}},\phi_{\mathrm{m}})}{B_0 \int_0^{2\pi}\int_0^{\pi} F(\theta,\phi)\sin\theta\, d\theta\, d\phi}$$

$$D_0 = \frac{4\pi F_{\max}(\theta_{\mathrm{m}},\phi_{\mathrm{m}})}{\int_0^{2\pi}\int_0^{\pi} F(\theta,\phi)\sin\theta\, d\theta\, d\phi}$$

(2-22)

$$D_0 = \frac{4\pi}{\int_0^{2\pi}\int_0^{\pi} \underbrace{\frac{F(\theta,\phi)}{F_{\max}(\theta_m,\phi_m)}}_{F_n(\theta,\phi)} \sin\theta \, d\theta \, d\phi}$$

$$D_0 = \frac{4\pi}{\int_0^{2\pi}\int_0^{\pi} F_n(\theta,\phi) \sin\theta \, d\theta \, d\phi} = \frac{4\pi}{\Omega_A} \qquad (2\text{-}23)$$

$$\Omega_A = \int_0^{2\pi}\int_0^{\pi} F_n(\theta,\phi) \sin\theta \, d\theta \, d\phi = \text{Beam solid angle} \qquad (2\text{-}24)$$

Kraus

$$\Omega_A = \int_0^{2\pi}\int_0^{\pi} F_n(\theta,\phi)\sin\theta\, d\theta\, d\phi \simeq \Theta_{1r}\Theta_{2r}$$

$$D_0 = \frac{4\pi}{\Omega_A} \simeq \frac{4\pi}{\Theta_{1r}\Theta_{2r}} = \frac{41,253}{\Theta_{1d}\Theta_{2d}} \quad (2\text{-}26)$$

$$D_0 \simeq \frac{4\pi}{\Theta_{1r}\Theta_{2r}} = \frac{4\pi(180/\pi)^2}{\Theta_{1d}\Theta_{2d}} = \frac{41,253}{\Theta_{1d}\Theta_{2d}} \quad (2\text{-}27)$$

Antenna Efficiency e_o

$$e_o = e_r e_c e_d = e_r e_{cd} \qquad (2\text{-}44)$$

$$e_o = (1 - |\Gamma_{in}|^2) e_{cd} \qquad (2\text{-}45)$$

$$e_o = Total\ efficiency$$

$$e_r = Reflection\ efficiency$$

$$e_{cd} = Radiation\ efficiency$$

$$e_{cd} = \text{Radiation Efficiency}$$

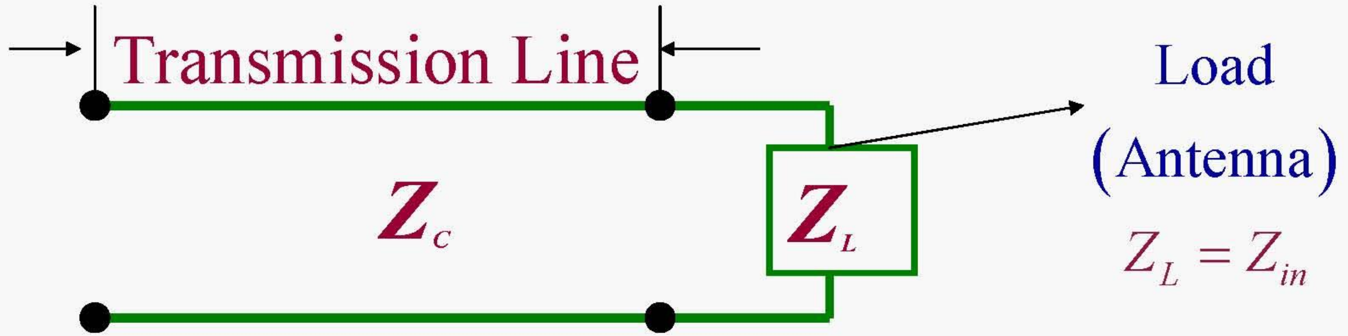
$$e_{cd} = \frac{\text{Power Radiated by Antenna } (P_r)}{\text{Power Delivered to Antenna } (P_r + P_L)}$$

$$e_{cd} = \frac{R_r}{R_r + R_L}$$

Transmission Line and Load

Z_c = Characteristic Impedance of Line

Z_L = Load Impedance



$$\Gamma_{in} = \frac{Z_L - Z_c}{Z_L + Z_c} = \frac{Z_{in} - Z_c}{Z_{in} + Z_c}$$