ECC 203 : Electromagnetics and Radiating Systems

Antenna Parameters - 1

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    - Lobes
    - Isotropic, Directional, and Omnidirectional Patterns
    - Principal Patterns
    - Field Regions
    - Radian and Steradian
  - Radiation Power Density
  - Radiation Intensity
  - Beamwidth

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Coordinate System

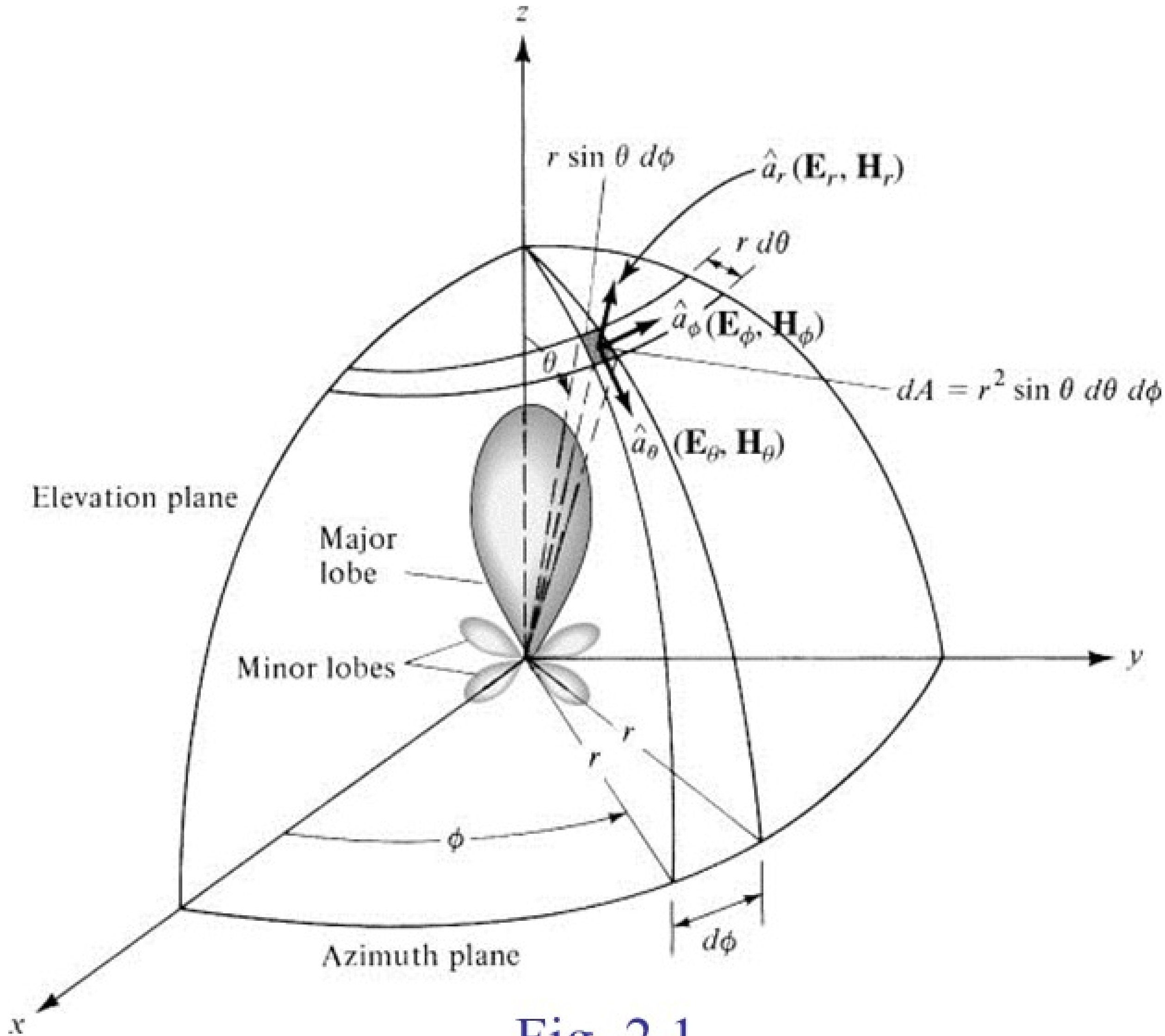


Fig. 2.1

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.

Radiation Pattern

Amplitude Radiation Pattern

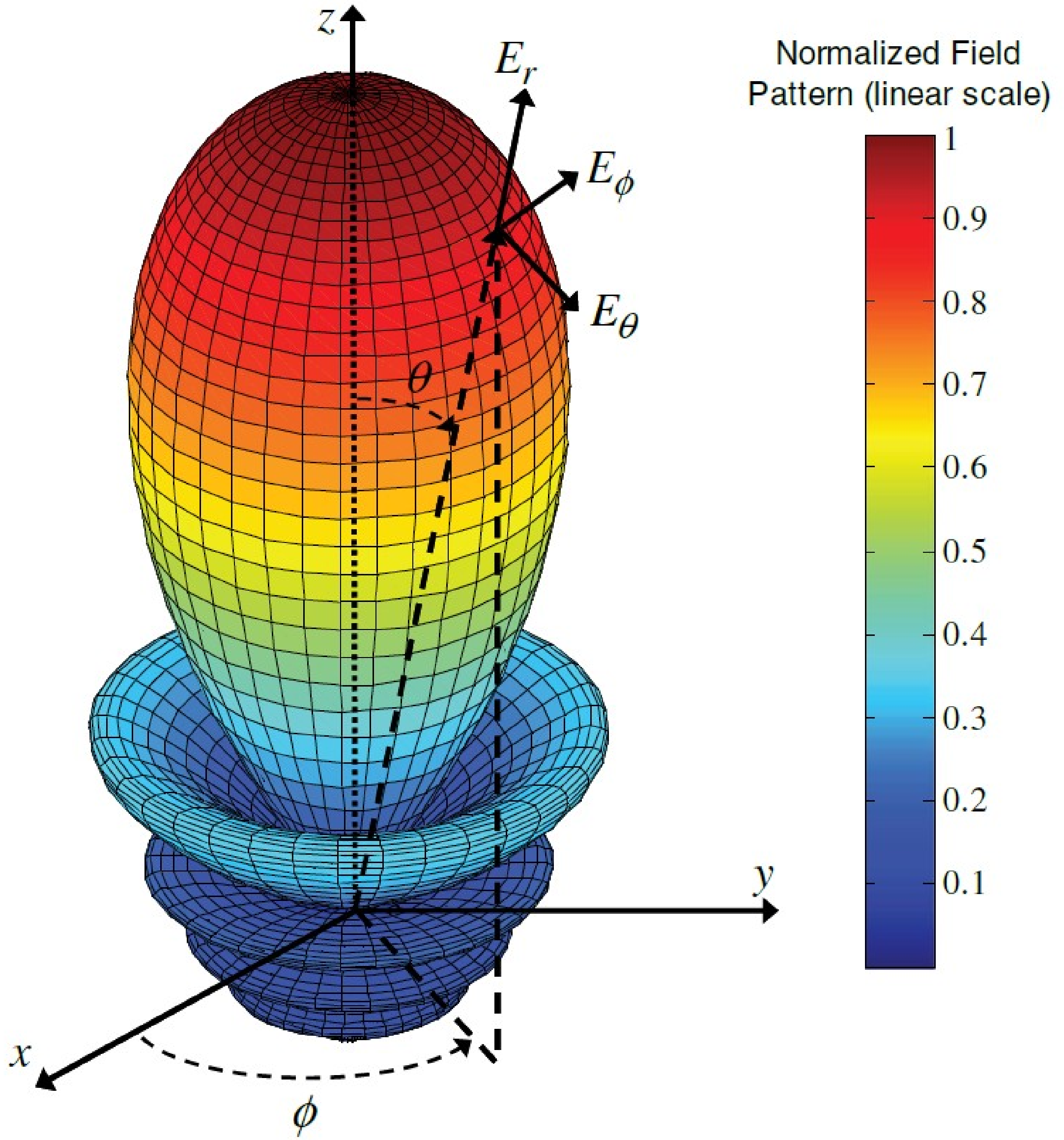
- Field Pattern:

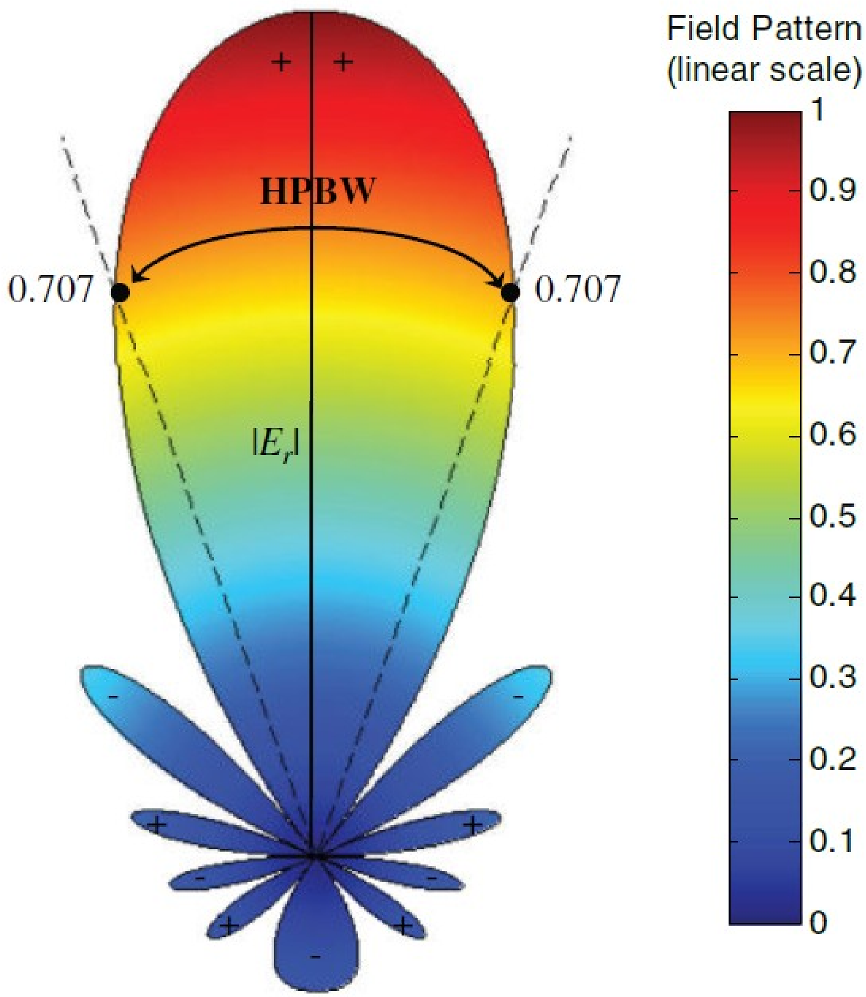
  A plot of the field (either electric $|\underline{E}|$ or magnetic $|\underline{H}|$) on a *linear* scale

- Power Pattern:

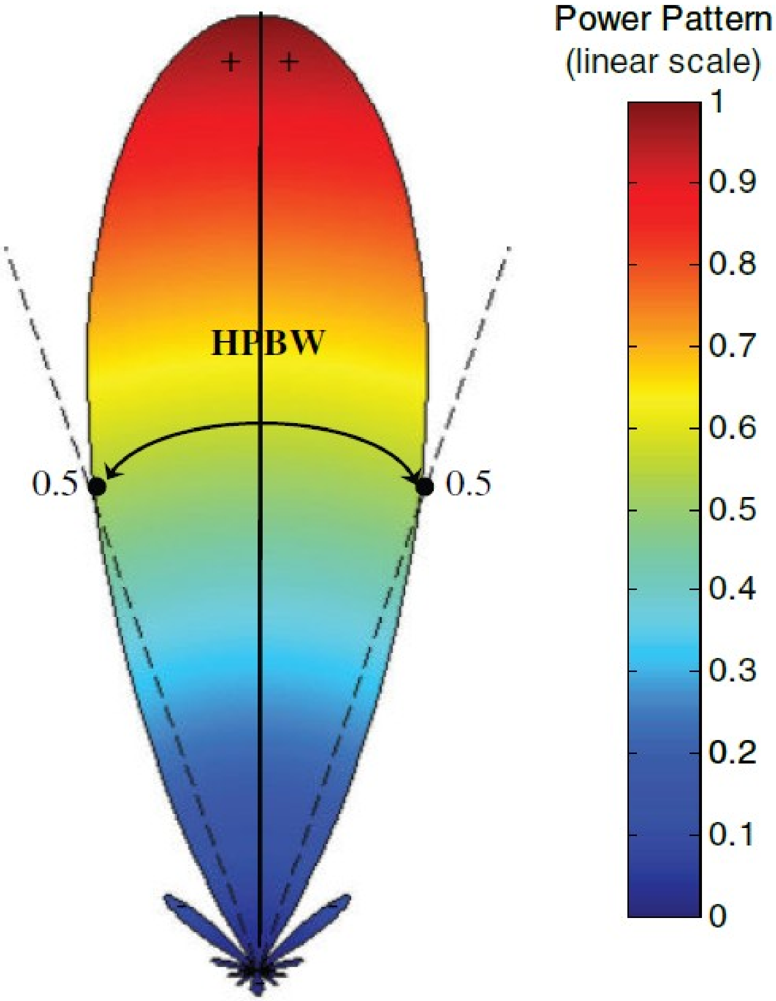
  A plot of the power (proportional to either the electric $|\underline{E}|^2$ or magnetic $|\underline{H}|^2$ fields) on a *linear* or *decibel* (dB) scale.

Radiation Pattern

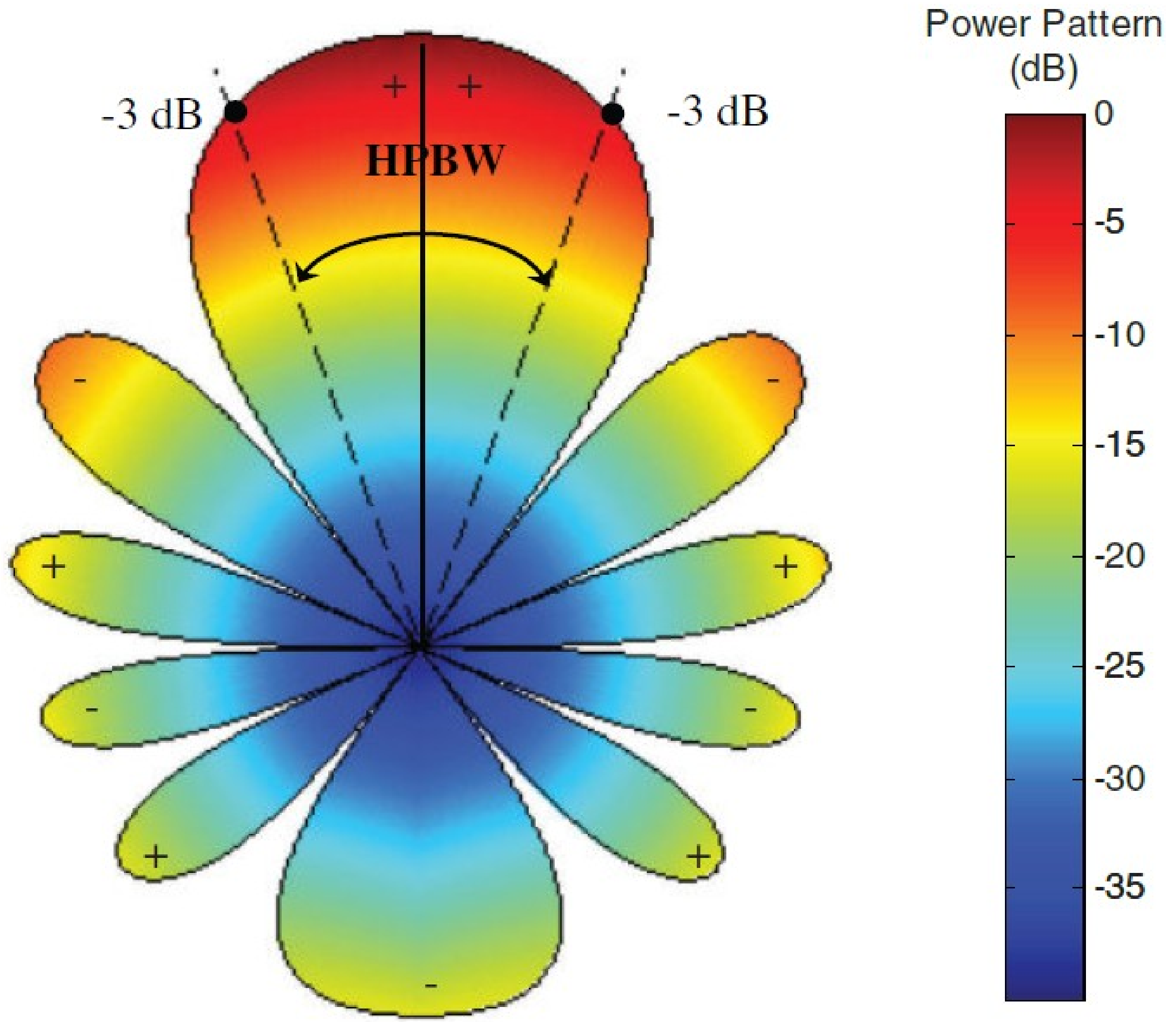




(a) Field pattern (in linear scale)



(b) Power pattern (in linear scale)



(c) Power pattern (in dB)

Radiation Pattern

A radiation pattern shows only the *relative* values but not the *absolute* values of the field or power quantity. Hence the values are usually normalized (i.e., divided) by the maximum value.

Radiation Pattern

- Radiation Pattern
- **Lobes**
- Isotropic, Directional, and Omnidirectional Patterns
- Principal Patterns
- Field Regions
- Radian and Steradian

- *Various parts of a radiation pattern are referred to as lobes - major or main, minor, side, and back lobes.*

- *A radiation lobe is a "portion of the radiation pattern bounded by regions of relatively weak radiation intensity."*

- *A major lobe (also called main beam) - "the radiation lobe containing the direction of maximum radiation."*

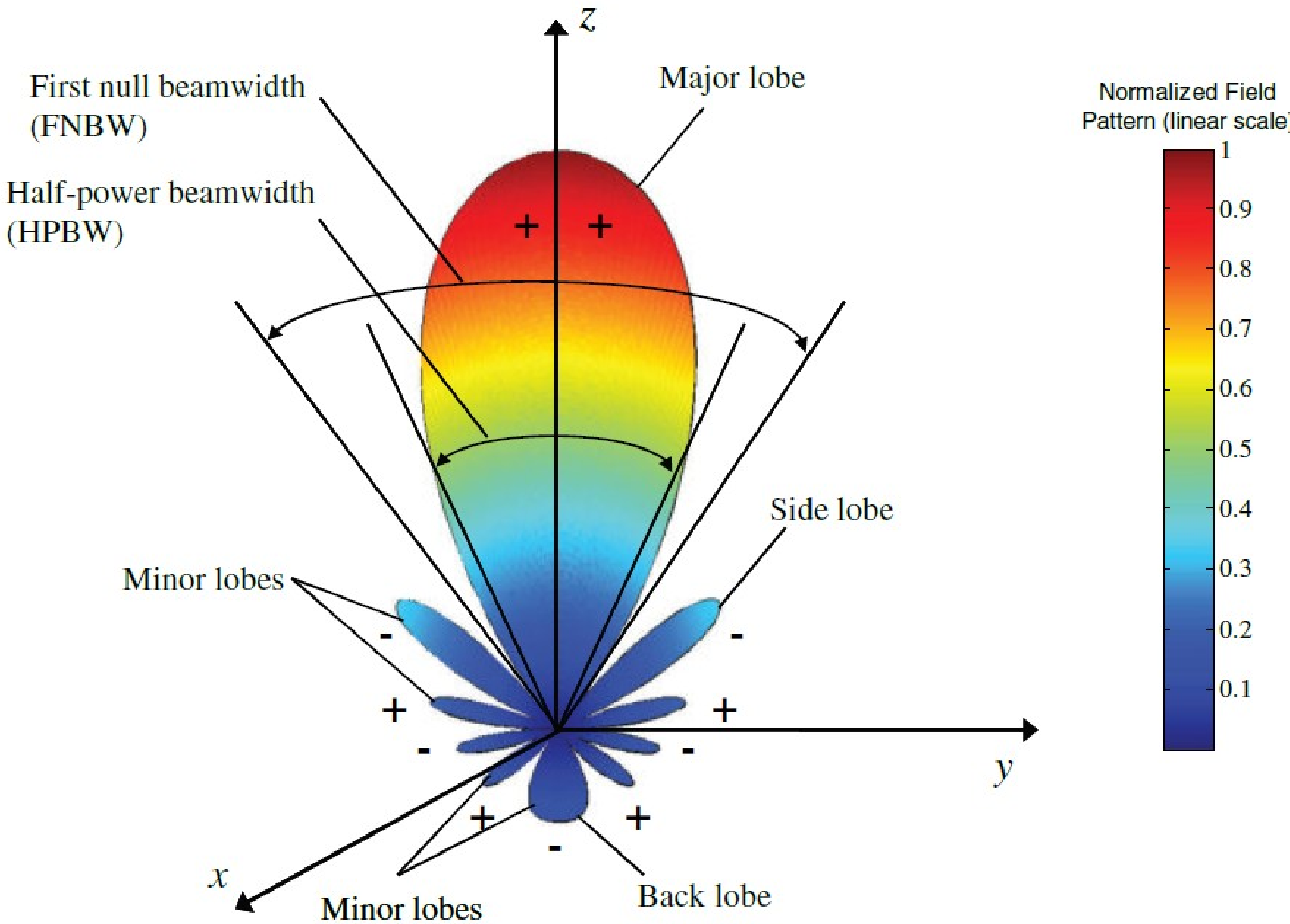
Radiation Pattern

- *A <u>minor lobe</u> is any lobe except a major lobe.*

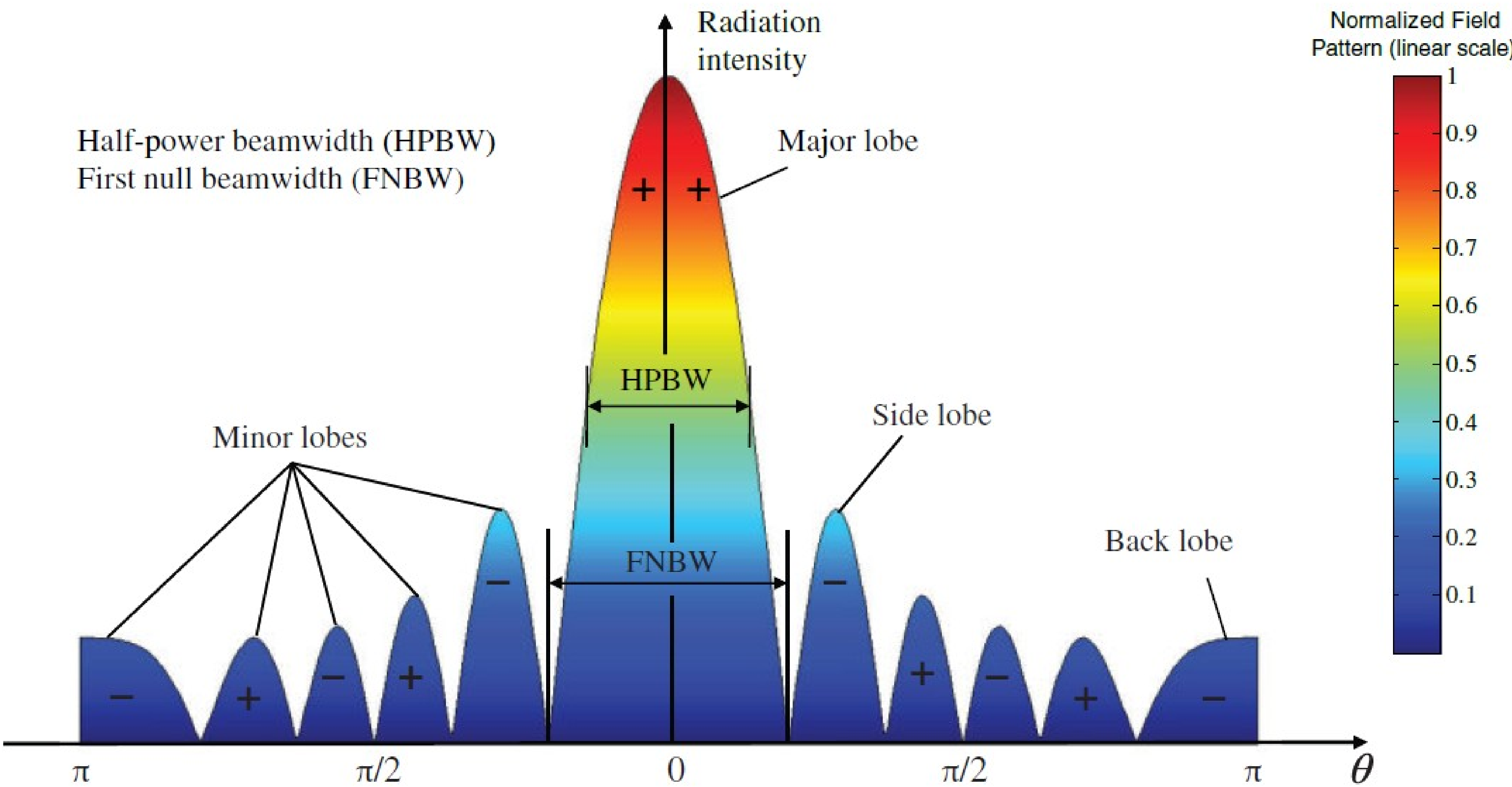
- *A <u>side lobe</u> is "a radiation lobe in any direction other than the intended lobe." (Usually a side lobe is adjacent to the main lobe and occupies the hemisphere in the direction of the main beam).*

- *A <u>back lobe</u> is "a radiation lobe whose axis makes an angle of approximately 180◦ with respect to the beam of an antenna." Usually it refers to a minor lobe that occupies the hemisphere in a direction opposite to that of the major (main) lobe*

Radiation Pattern



Radiation Pattern



Radiation Pattern

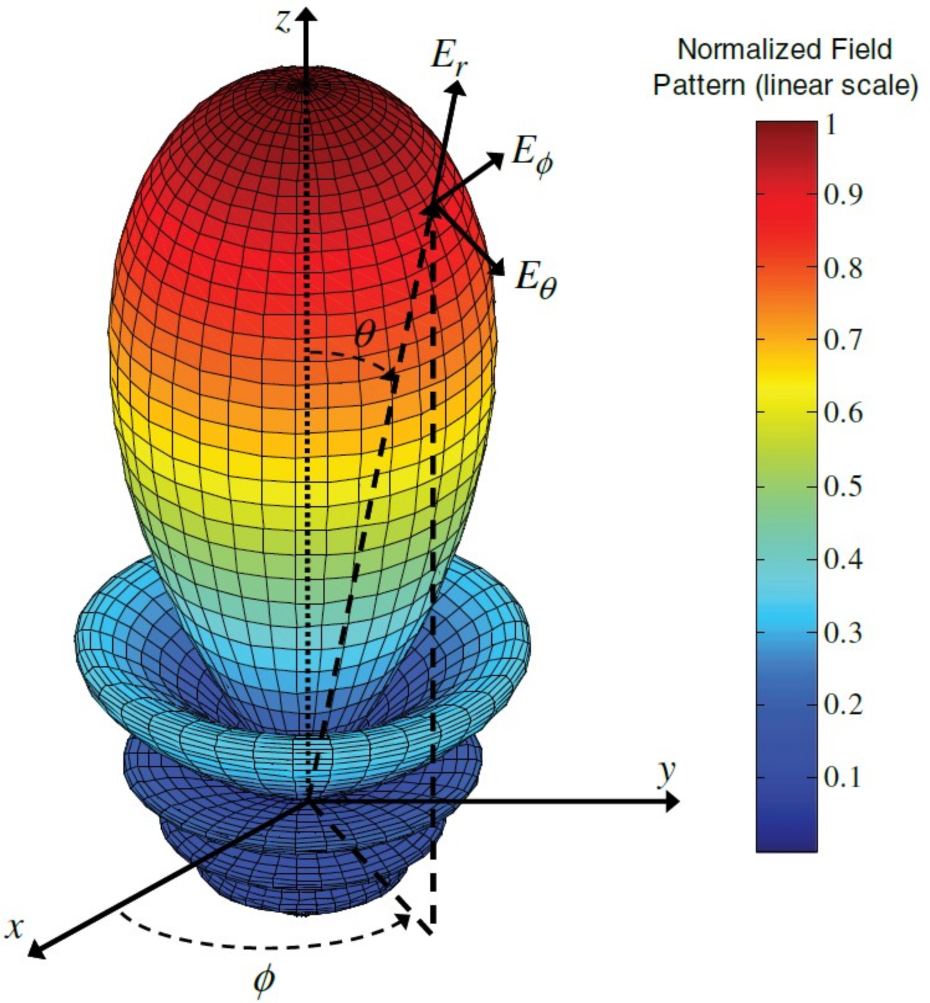
- Radiation Pattern
- Lobes
- **Isotropic, Directional, and Omnidirectional Patterns**
- Principal Patterns
- Field Regions
- Radian and Steradian

- *An isotropic radiator - “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.*

Radiation Pattern

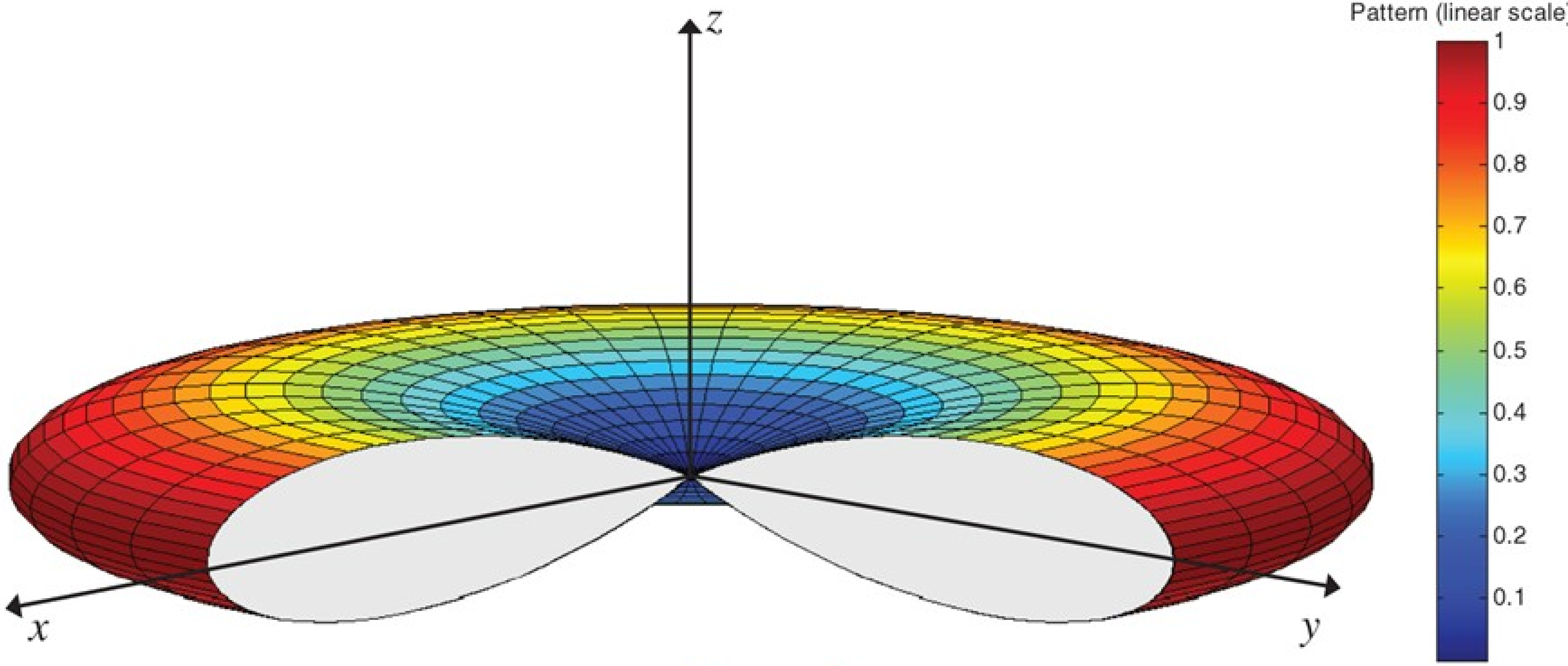
- *A <u>directional antenna</u> is one "having the property of radiating or receiving electromagnetic waves more effectively in some directions than in others".*



Radiation Pattern

- *Omnidirectional antenna - one "having an essentially nondirectional pattern in a given plane (say azimuth) and a directional pattern in any orthogonal plane (say elevation)." An omnidirectional pattern is then a special type of a directional pattern*

Omnidirectional Pattern Without Minor Lobes



$$U \approx \left|\sin^n(\theta)\right| \left\} \begin{matrix} 0 \le \theta \le \pi \\ 0 \le \phi \le 2\pi \end{matrix} \right.$$

Fig. 2.17(b)

Directional Patterns

$$U(\theta,\phi) = \begin{cases} B_o \cos^n(\theta) & \begin{cases} 0 \le \theta \le \pi/2 \\ 0 \le \phi \le 2\pi \end{cases} \\ 0 & \text{Elsewhere} \end{cases} \tag{2-31}$$

$$n = 1, 2, 3 \ldots 10, 15, 20$$

Non-Symmetrical Pattern

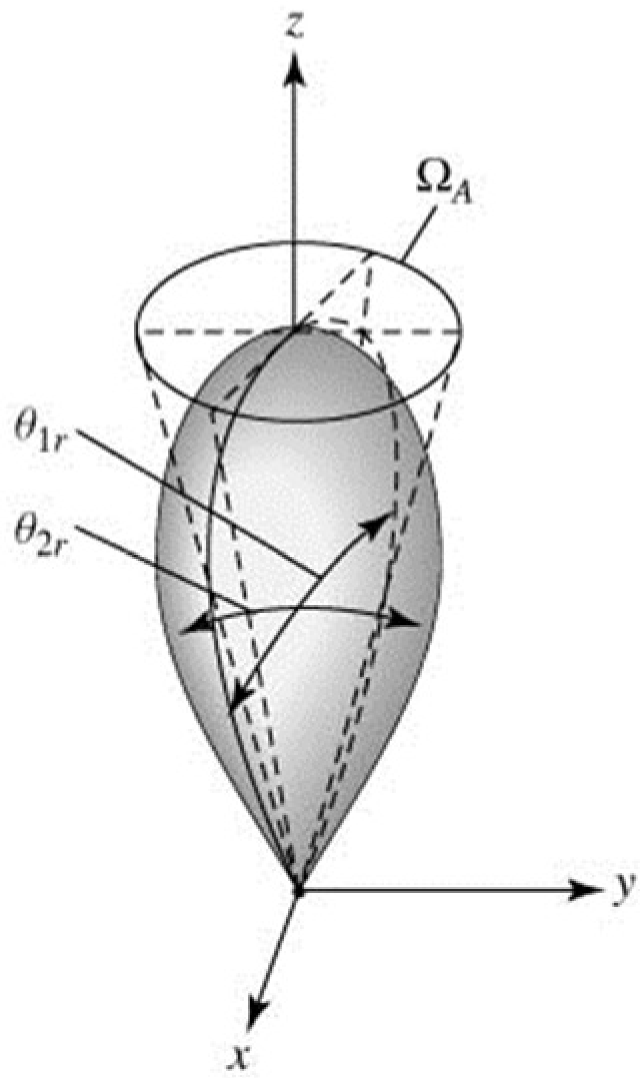


Fig. 2.14(a)

Directional Pattern of a Horn

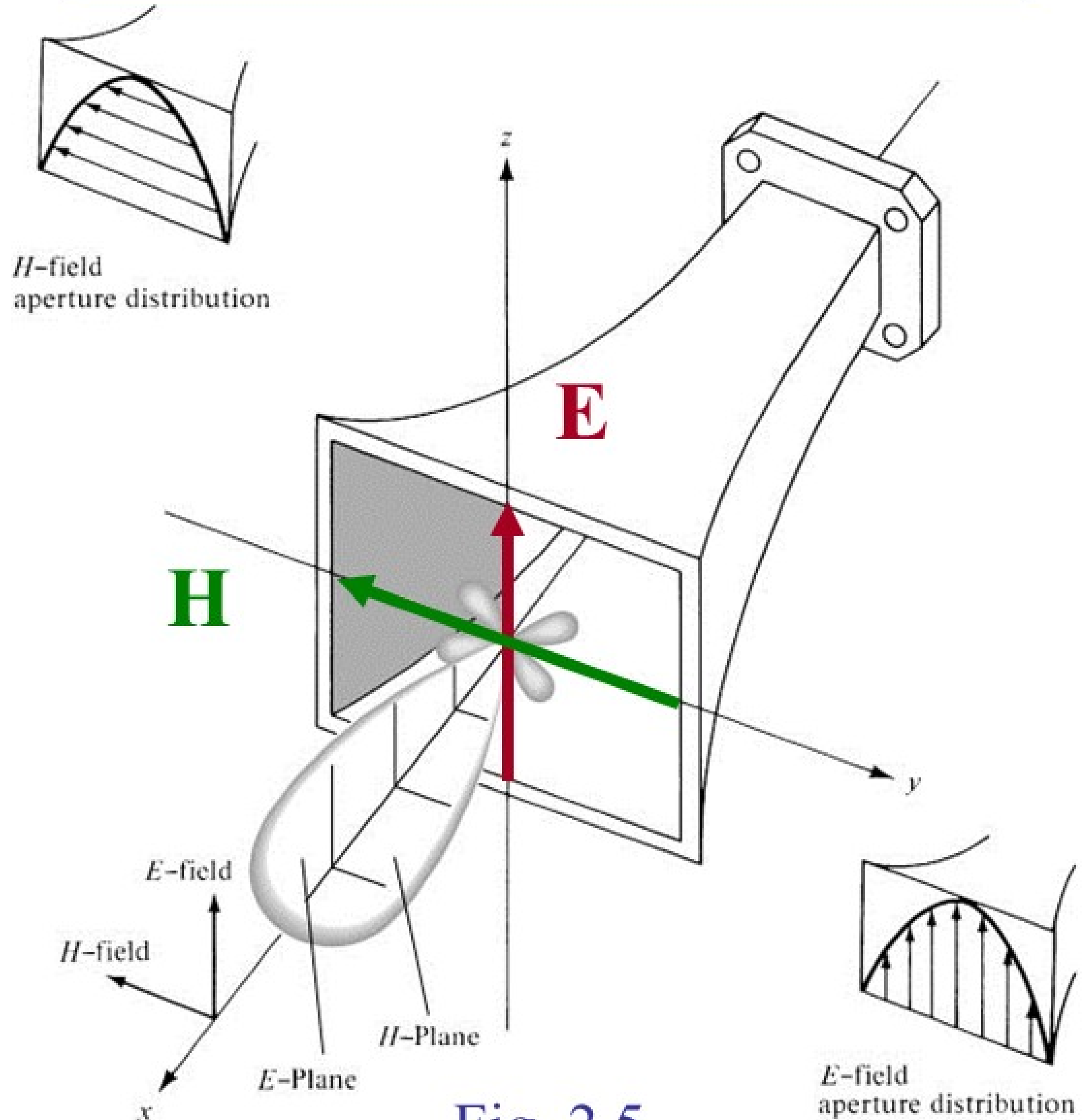
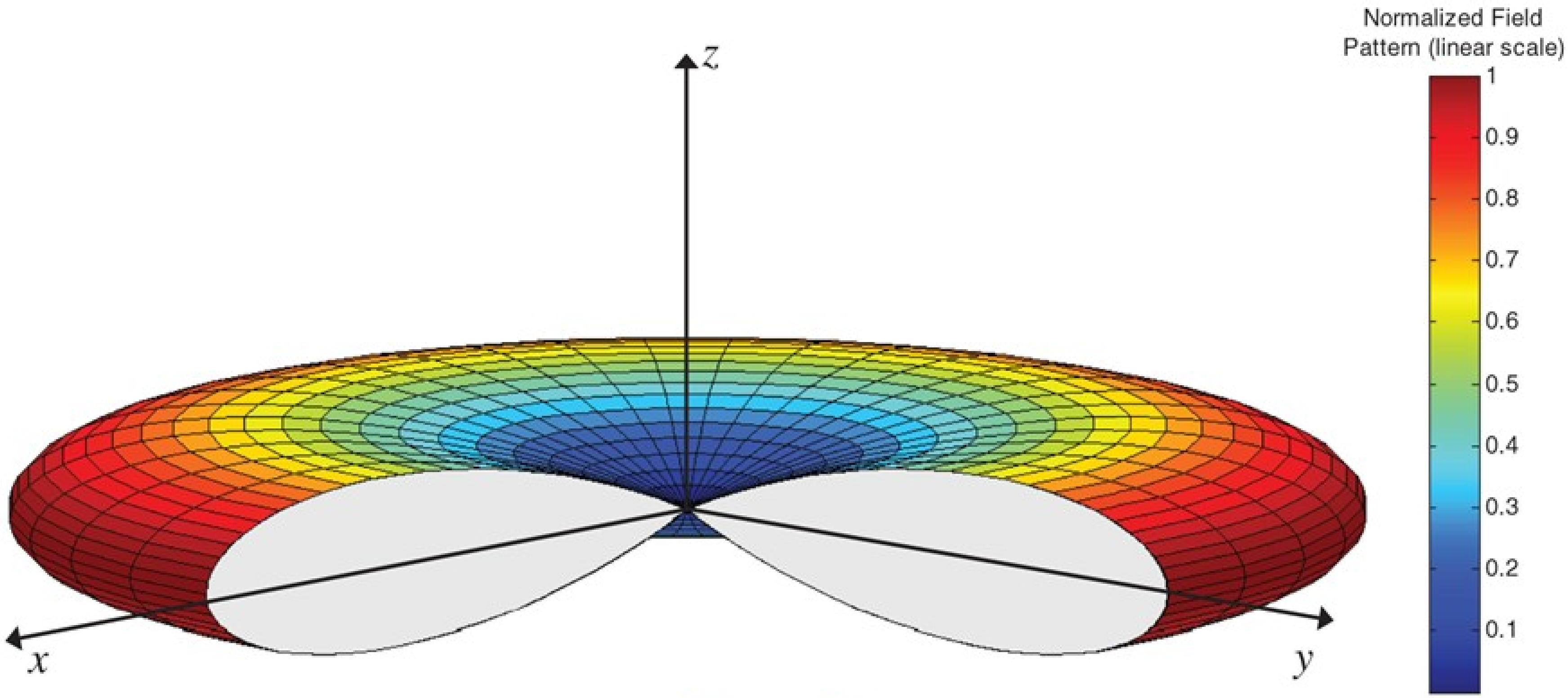


Fig. 2.5

Omindirectional Patterns

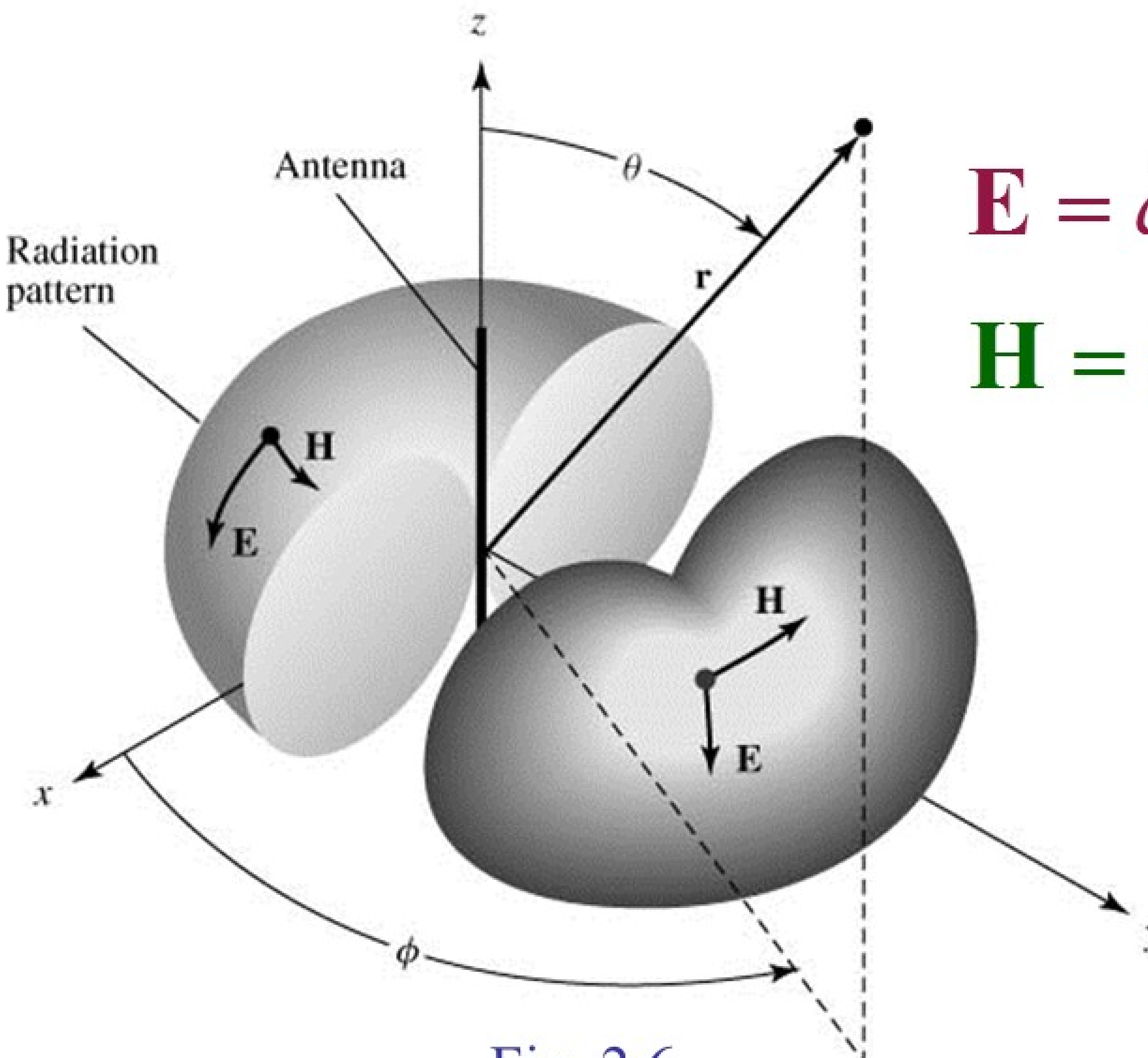
Omnidirectional Pattern Without Minor Lobes



$$U \approx \left|\sin^n(\theta)\right| \left\} \begin{matrix} 0 \leq \theta \leq \pi \\ 0 \leq \phi \leq 2\pi \end{matrix} \right.$$

Fig. 2.17(b)

Omnidirectional Pattern



$$\mathbf{E} = \hat{a}_\theta E_\theta$$

$$\mathbf{H} = \hat{a}_\phi H_\phi$$

Fig. 2.6

For example, the radiation pattern of the Hertzian dipole can be plotted using the following steps.

(1) Far field:

$$E_\theta = j\frac{\eta k I d\ell}{4\pi}\left(\frac{e^{-jkr}}{r}\right)\sin\theta, \quad \begin{cases} 0 \le \theta \le \pi \\ 0 \le \phi \le 2\pi \\ r \text{ fixed} \end{cases}$$

(2) Far field magnitude:

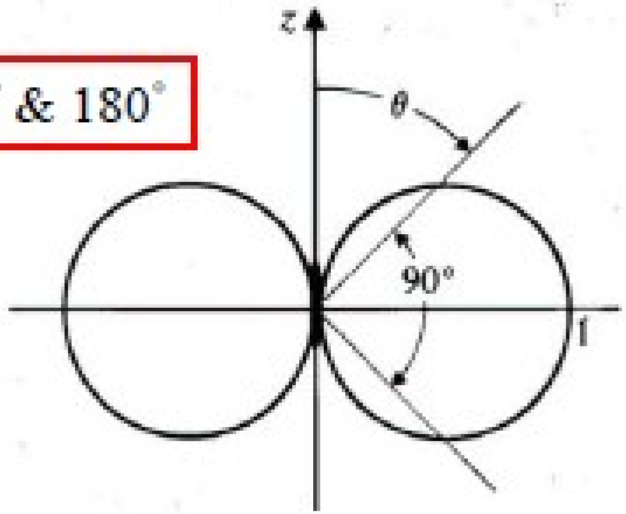
$$\left|E_\theta\right| = \frac{\eta k I d\ell}{4\pi r}\left|\sin\theta\right|, \quad \begin{cases} 0 \le \theta \le \pi \\ 0 \le \phi \le 2\pi \\ r \text{ fixed} \end{cases}$$

(3) Normalization:

$$\left|E_\theta\right|_n = \frac{\dfrac{\eta k I d\ell}{4\pi r}\left|\sin\theta\right|}{\dfrac{\eta k I d\ell}{4\pi r}} = \left|\sin\theta\right|, \quad \begin{cases} 0 \le \theta \le \pi \\ 0 \le \phi \le 2\pi \\ r \text{ fixed} \end{cases}$$

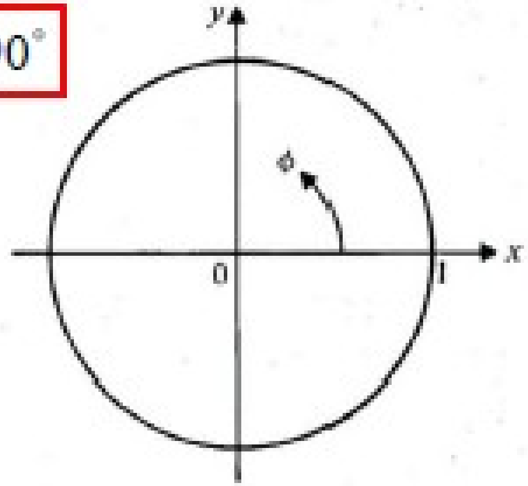
(4) Plot θ–plane pattern (fix ϕ at a chosen value, for example $\phi = 0^\circ$)

$\left|E_\theta\right|_n$ with θ at $\phi = 0^\circ$ & 180°



(5) Plot ϕ–plane pattern (fix θ at a chosen value, for example $\theta = 90^{\circ}$)

$\boxed{|E_{\theta}|_n \text{ with } \phi \text{ at } \theta = 90^{\circ}}$



Radiation Pattern

- Radiation Pattern
- Lobes
- Isotropic, Directional, and Omnidirectional Patterns
- **Principal Patterns**
- Field Regions
- Radian and Steradian

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

- *The E-plane - "the plane containing the electric-field vector and the direction of maximum radiation,"*

- *H-plane as "the plane containing the magnetic-field vector and the direction of maximum radiation."*

Directional Pattern of a Horn

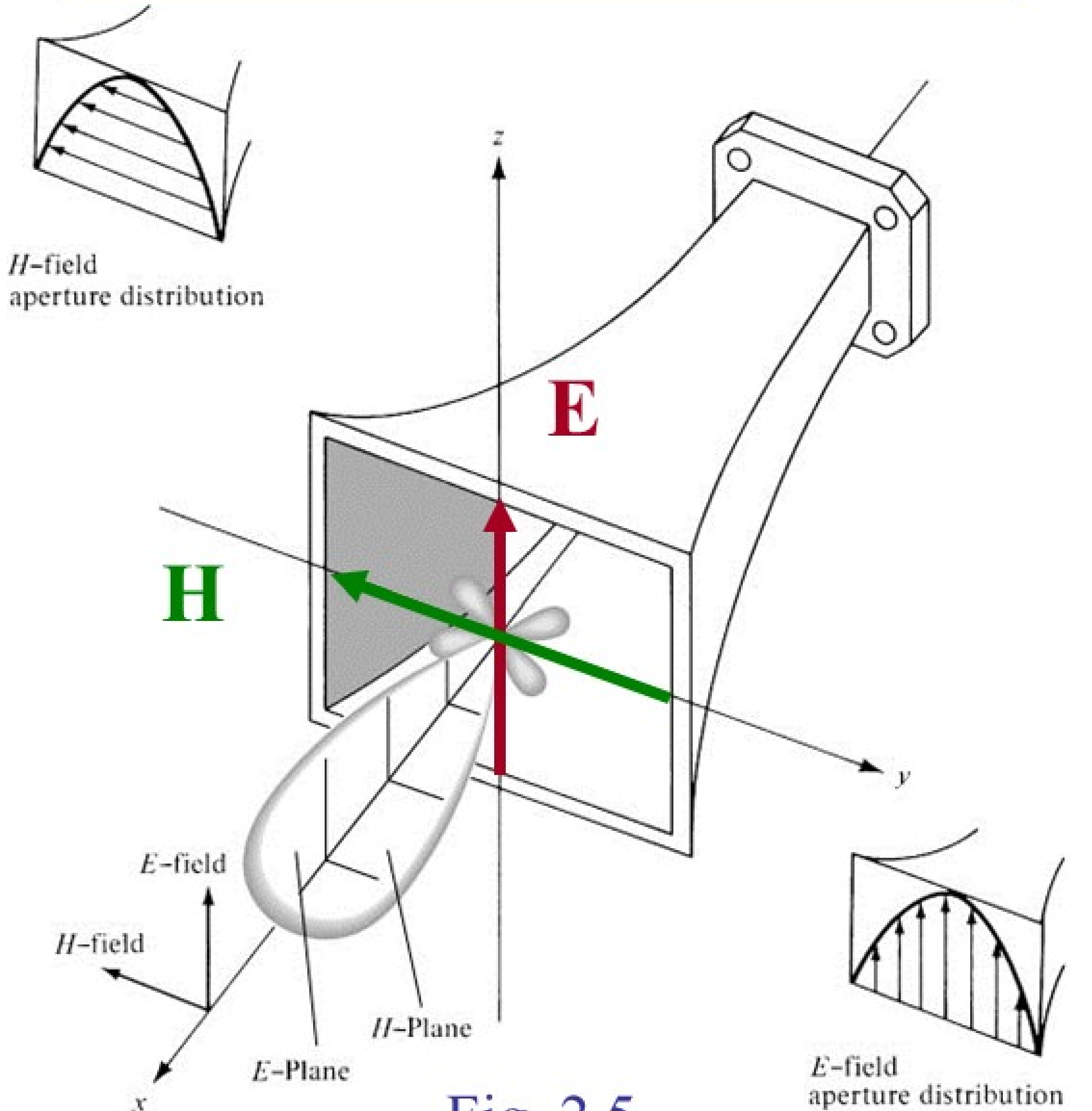


Fig. 2.5

Radiation Pattern

- Radiation Pattern
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- **Field Regions**
- Radian and Steradian

- *The space surrounding an antenna is usually subdivided into three regions: (a) reactive near-field, (b) radiating near-field (Fresnel) and (c) far-field (Fraunhofer) regions.*
- *no abrupt changes in the field configurations, there are distinct differences among them.*
- *The boundaries separating these regions are not unique, although various criteria have been established and are commonly used to identify the regions.*

Field Regions

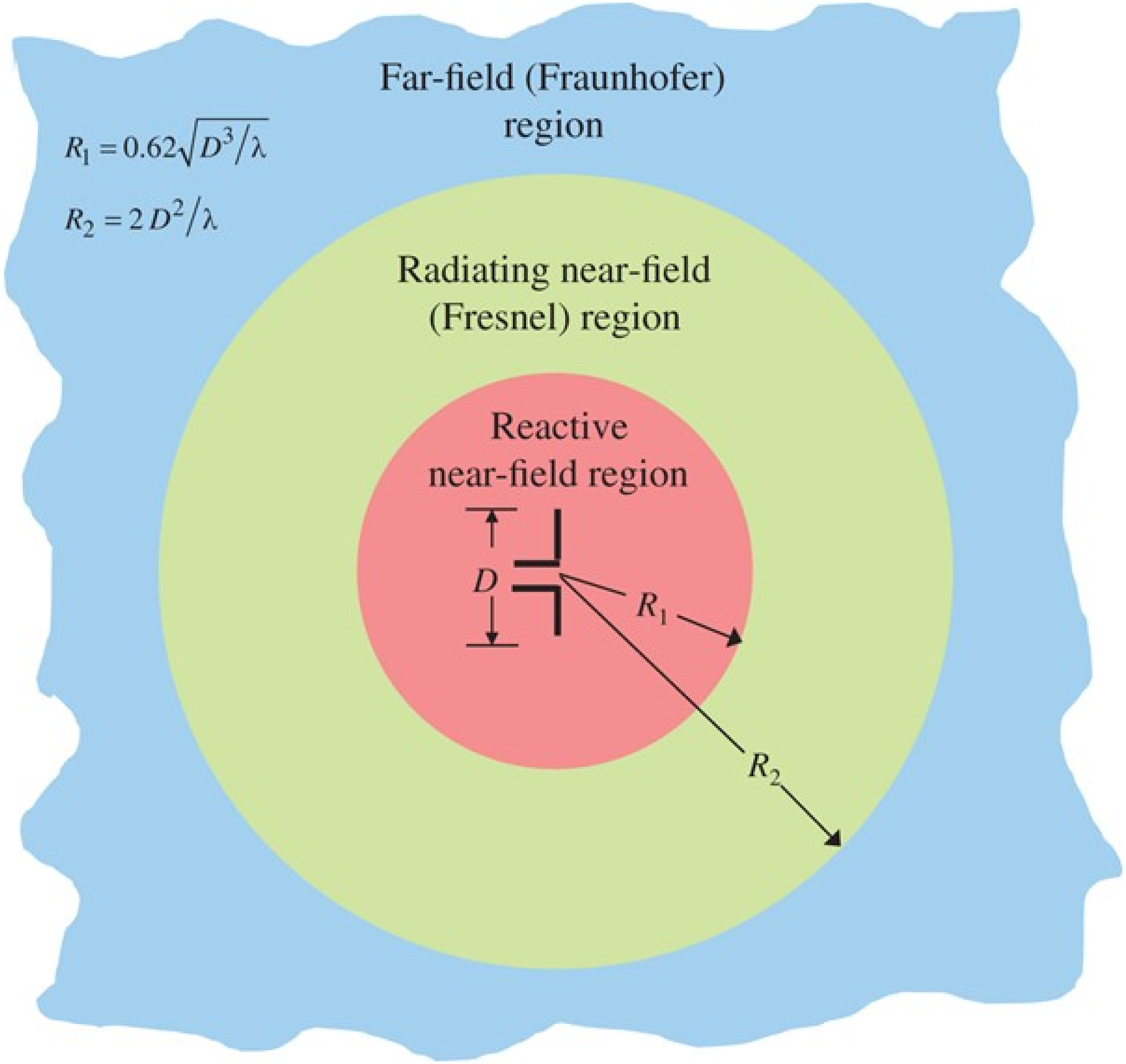


Fig. 2.7

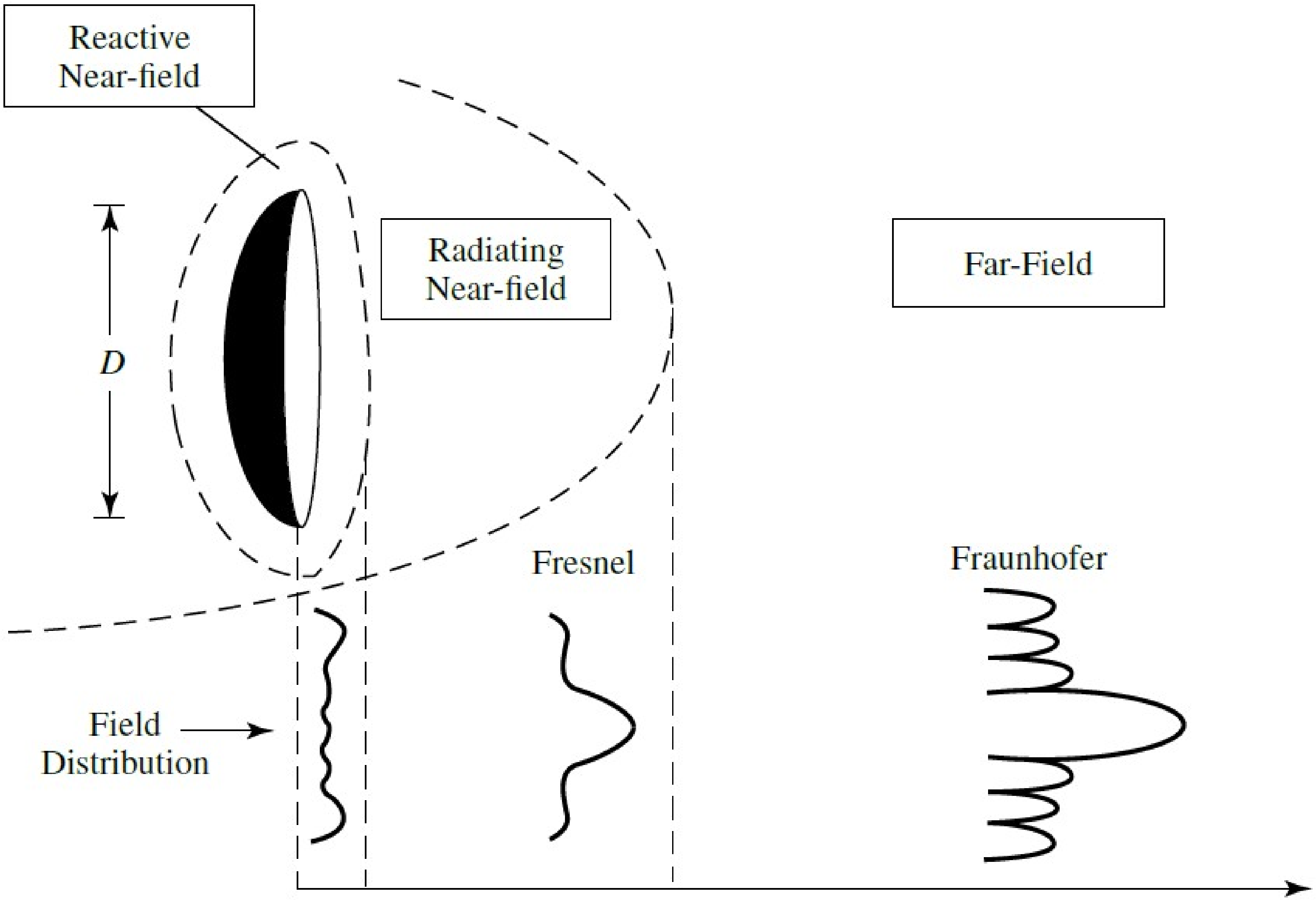
Radiation Pattern

- *Reactive near-field region - "that portion of the near-field region immediately surrounding the antenna wherein the reactive field predominates."*

- *Radiating near-field (Fresnel) region -"that region of the field of an antenna between the reactive near-field region and the far-field region wherein radiation fields predominate and wherein the angular field distribution is dependent upon the distance from the antenna".*

- *Far-field (Fraunhofer) region - "that region of the field of an antenna where the angular field distribution is essentially independent of the distance from the antenna.*

Radiation Pattern



Radiation Pattern

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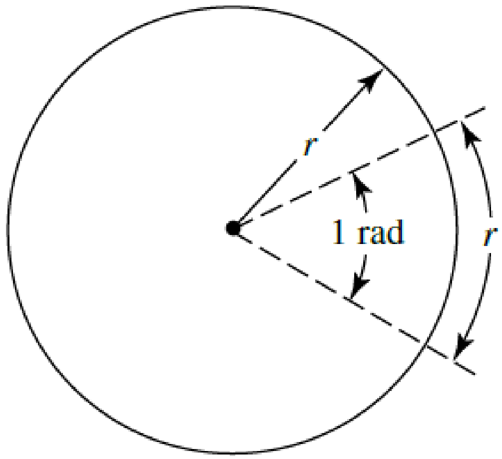
- **Radian and Steradian**

- *The measure of a plane angle is a radian. One radian is defined as the plane angle with its vertex at the center of a circle of radius r that is subtended by an arc whose length is r.*

- *Since the circumference of a circle of radius r*

*is C = 2π*r, there are 2π rad (2π*r/r) in a full circle*



Radiation Pattern

- *The measure of a solid angle is a steradian. One steradian is defined as the solid angle with its vertex at the center of a sphere of radius r that is subtended by a spherical surface area equal to that of a square with each side of length r.*
- *Since the area of a sphere of radius r is A = 4πr², there are 4π sr (4π r²/ r²) in a closed sphere.*

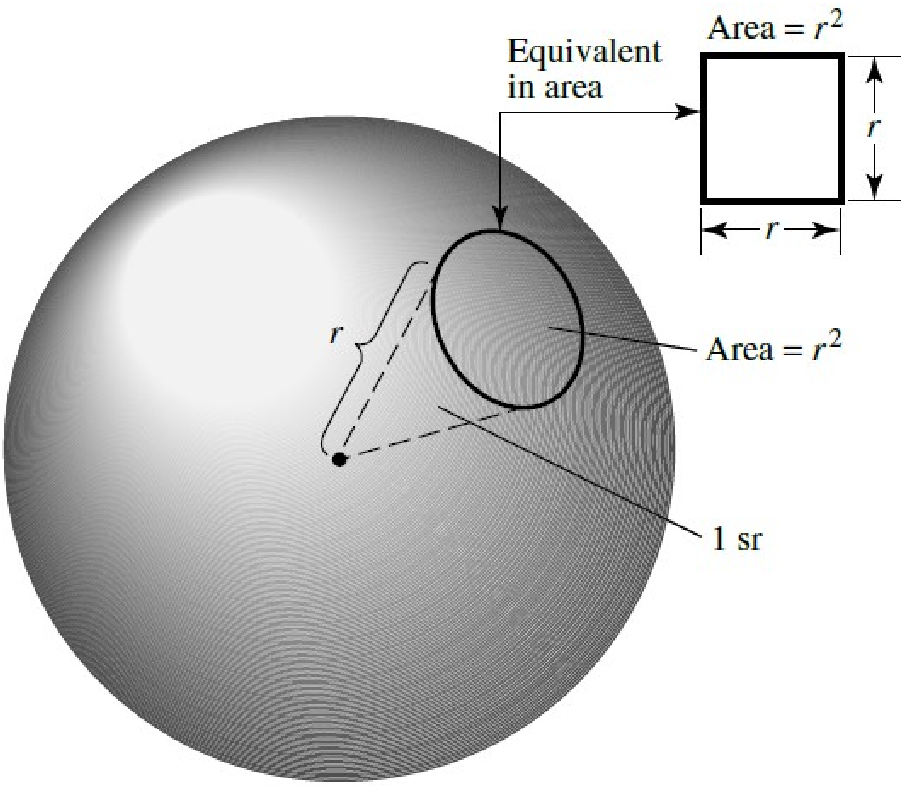
$$dA = r^2 \sin\theta d\theta d\phi \quad (2\text{-}1)$$

$$d\Omega = \frac{dA}{r^2}$$

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

$$d\Omega = \sin\theta d\theta d\phi \quad (2\text{-}2)$$

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



Coordinate System

$$dA = r^2 \sin\theta d\theta d\phi \quad (2\text{-}1)$$

$$d\Omega = \frac{dA}{r^2}$$

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

$$d\Omega = \sin\theta d\theta d\phi \quad (2\text{-}2)$$

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

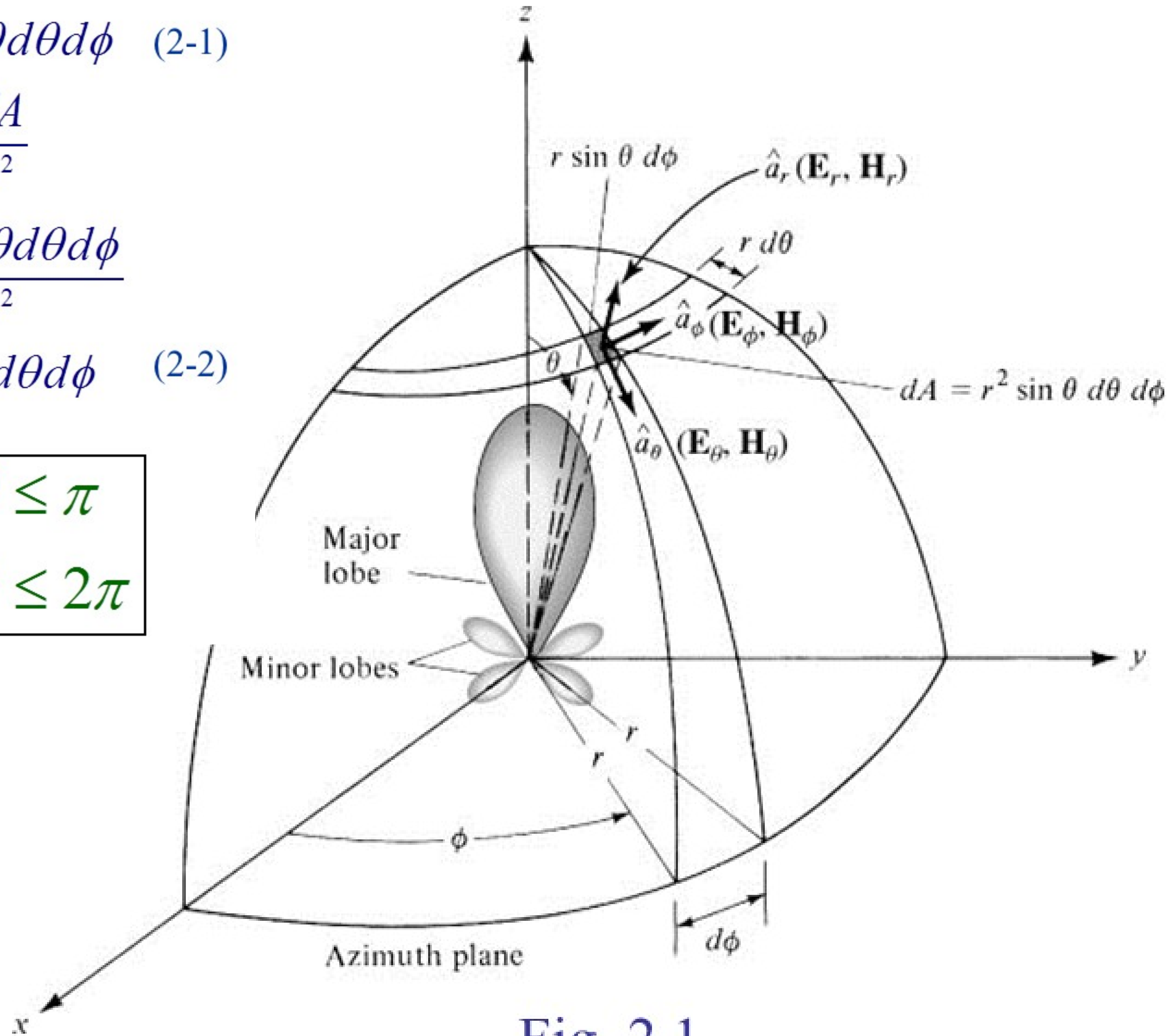


Fig. 2.1

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  - Radiation Intensity
  - Beamwidth

Radiation Power Density

- *power associated with an electromagnetic wave - instantaneous Poynting vector:*

$$\mathscr{W} = \mathscr{E} \times \mathscr{H} \tag{2-3}$$

$\mathscr{W}$ = instantaneous Poynting vector (W/m^2)

$\mathscr{E}$ = instantaneous electric-field intensity (V/m)

$\mathscr{H}$ = instantaneous magnetic-field intensity (A/m)

- *Since the Poynting vector is a power density, the total power crossing a closed surface can be obtained by integrating the normal component of the Poynting vector over the entire surface.*

$$\mathscr{P} = \oiint_S \mathscr{W} \cdot d\mathbf{s} = \oiint_S \mathscr{W} \cdot \hat{\mathbf{n}}\, da \tag{2-4}$$

Radiation Power Density

- *For applications of time-varying fields, it is often more desirable to find the average power density which is obtained by integrating the instantaneous Poynting vector over one period and dividing by the period.*

$$\mathscr{E}(x, y, z; t) = \mathrm{Re}[\mathbf{E}(x, y, z)e^{j\omega t}] \qquad (2\text{-}5)$$

$$\mathscr{H}(x, y, z; t) = \mathrm{Re}[\mathbf{H}(x, y, z)e^{j\omega t}] \qquad (2\text{-}6)$$

$$\mathrm{Re}[\mathbf{E}e^{j\omega t}] = \frac{1}{2}[\mathbf{E}e^{j\omega t} + \mathbf{E}^* e^{-j\omega t}]$$

$$\mathscr{W} = \mathscr{E} \times \mathscr{H} = \frac{1}{2}\mathrm{Re}[\mathbf{E} \times \mathbf{H}^*] + \frac{1}{2}\mathrm{Re}[\mathbf{E} \times \mathbf{H}e^{j2\omega t}] \qquad (2\text{-}7)$$

- *The first term of (2-7) is not a function of time, and the time variations of the second are twice the given frequency. The time average Poynting vector (average power density) can be written as:*

$$\boxed{\mathbf{W}_{\mathrm{av}}(x, y, z) = [\mathscr{W}(x, y, z; t)]_{\mathrm{av}} = \frac{1}{2}\mathrm{Re}[\mathbf{E} \times \mathbf{H}^*]} \qquad (\mathrm{W/m^2}) \qquad (2\text{-}8)$$

Radiation Power Density

- *The average power radiated by an antenna (radiated power) can be written as:*

$$P_{\text{rad}} = P_{\text{av}} = \oiint_S \mathbf{W}_{\text{rad}} \cdot d\mathbf{s} = \oiint_S \mathbf{W}_{\text{av}} \cdot \hat{\mathbf{n}}\, da = \frac{1}{2} \oiint_S \text{Re}(\mathbf{E} \times \mathbf{H}^*) \cdot d\mathbf{s} \tag{2-9}$$

E and H are the peak values

Radiation Power Density

- *An isotropic radiator is an ideal source that radiates equally in all directions.*
- *Because of its symmetric radiation, its Poynting vector will not be a function of the spherical coordinate angles θ and ϕ.*
- *It will have only a radial component.*
- *Thus the total power radiated by it is given by*

$$P_{\text{rad}} = \oiint_S \mathbf{W}_0 \cdot d\mathbf{s} = \int_0^{2\pi} \int_0^{\pi} [\hat{\mathbf{a}}_r W_0(r)] \cdot [\hat{\mathbf{a}}_r r^2 \sin\theta \, d\theta \, d\phi] = 4\pi r^2 W_0 \tag{2-10}$$

and the power density by

$$\mathbf{W}_0 = \hat{\mathbf{a}}_r W_0 = \hat{\mathbf{a}}_r \left(\frac{P_{\text{rad}}}{4\pi r^2} \right) \quad (\text{W/m}^2) \tag{2-11}$$

which is uniformly distributed over the surface of a sphere of radius r.

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Radiation Intensity

- *Radiation intensity in a given direction - "the power radiated from an antenna per unit solid angle."*

$$U = \frac{\text{Power}}{\text{Unit Solid Angle}} = \frac{\text{Power}}{\text{Unit Area}/r^2}$$

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

$$U = r^2 \frac{\text{Power}}{\text{Unit Area}} = r^2 W_{av} = r^2 W_{rad}$$

$$\boxed{U = r^2 W_{rad} \quad \Rightarrow \quad W_{rad} = \frac{U}{r^2}} \qquad (2.12)$$

Radiation Intensity

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

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

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

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

Radiation Intensity

$$P_{rad} = \int_0^{2\pi}\int_0^{\pi} \hat{a}_r W_{rad} \cdot \hat{a}_r r^2 \sin\theta d\theta d\phi$$

$$= \int_0^{2\pi}\int_0^{\pi} W_{rad} r^2 \sin\theta d\theta d\phi$$

<u>Since</u> $W_{rad} = \dfrac{U}{r^2}$

$$\boxed{P_{rad} = P_{av} = \int_0^{2\pi}\int_0^{\pi} U \underbrace{\sin\theta d\theta d\phi}_{d\Omega}}$$

(2.13)

Radiation Intensity

- *For an isotropic source U will be independent of the angles θ and ϕ,*

$$P_{\text{rad}} = \oiint_{\Omega} U_0 \, d\Omega = U_0 \oiint_{\Omega} d\Omega = 4\pi U_0 \tag{2-14}$$

or the radiation intensity of an isotropic source as

$$U_0 = \frac{P_{\text{rad}}}{4\pi} \tag{2-15}$$

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Beamwidth

- *The beamwidth of a pattern - the angular separation between two identical points on opposite side of the pattern maximum.*

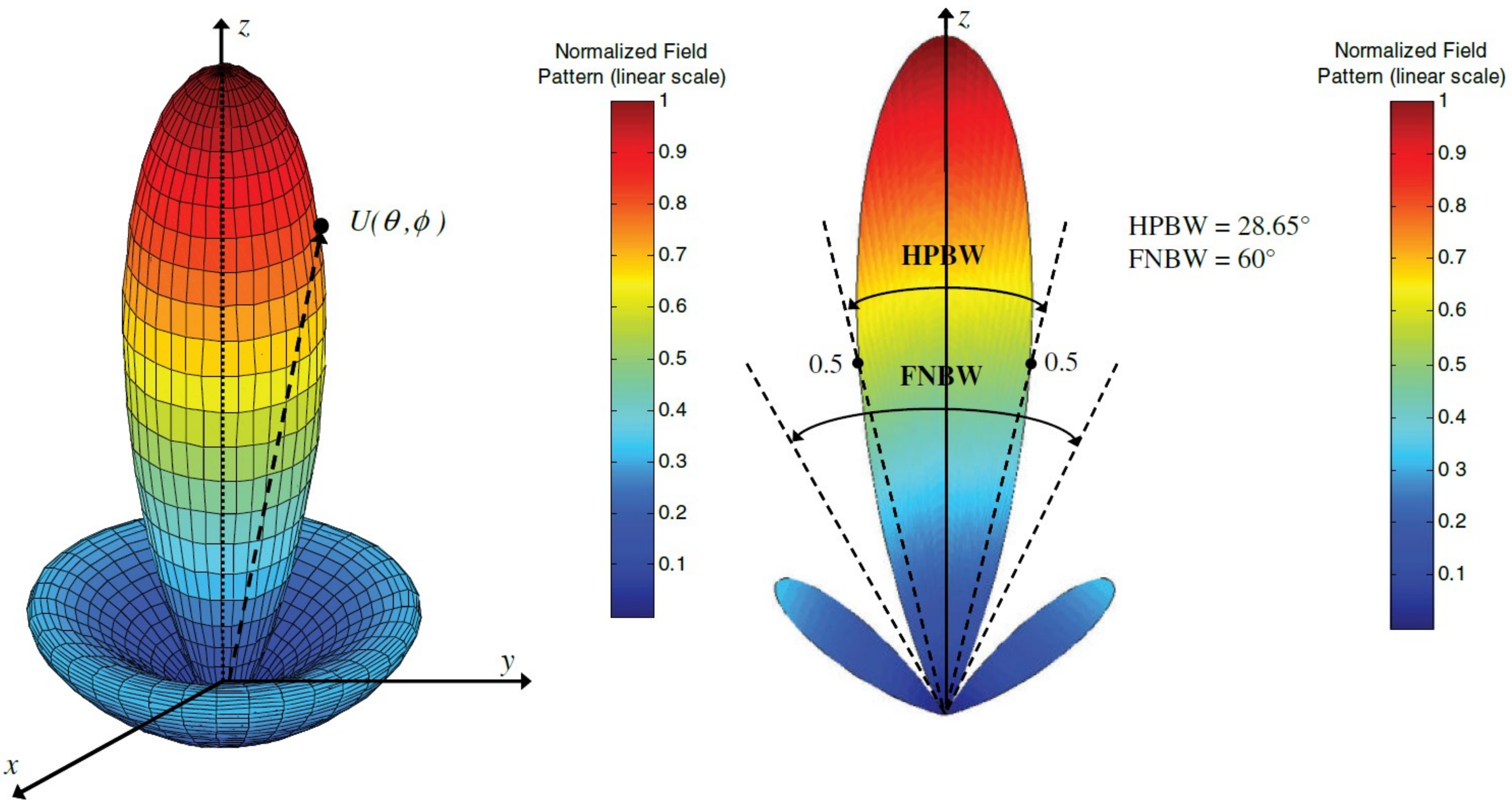
- *Half-Power Beamwidth (HPBW) : In a plane containing the direction of the maximum of a beam, the angle between the two directions in which the radiation intensity is one-half value of the beam.*

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

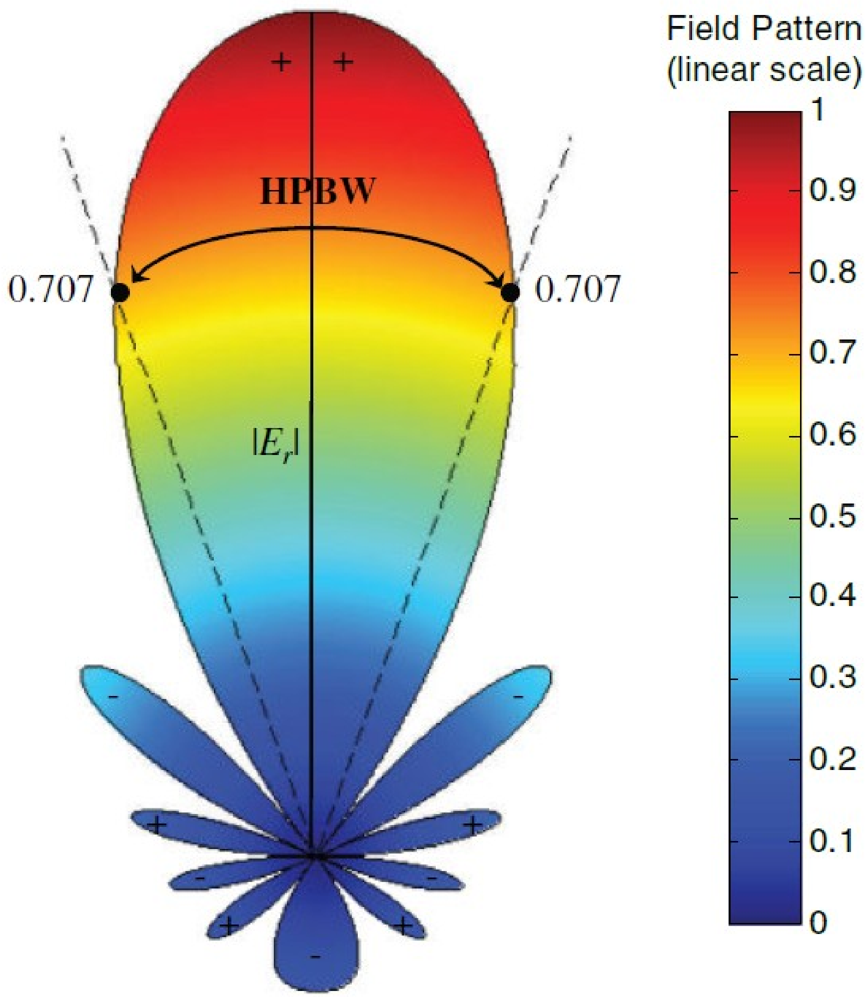
- *The beamwidth of an antenna is a very important figure of merit and often is used as a trade-off between it and the side lobe level; that is, as the beamwidth decreases, the side lobe increases and vice versa.*

- *In addition, the beamwidth of the antenna is also used to describe the resolution capabilities of the antenna to distinguish between two adjacent radiating sources or radar targets.*

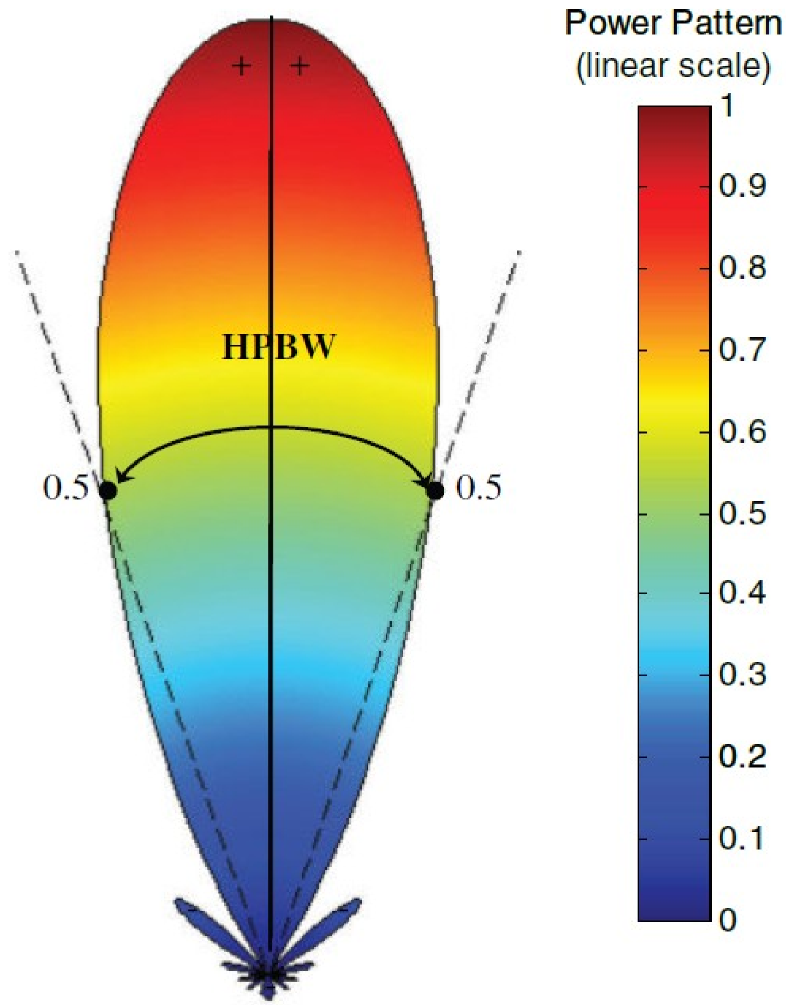
Beamwidth



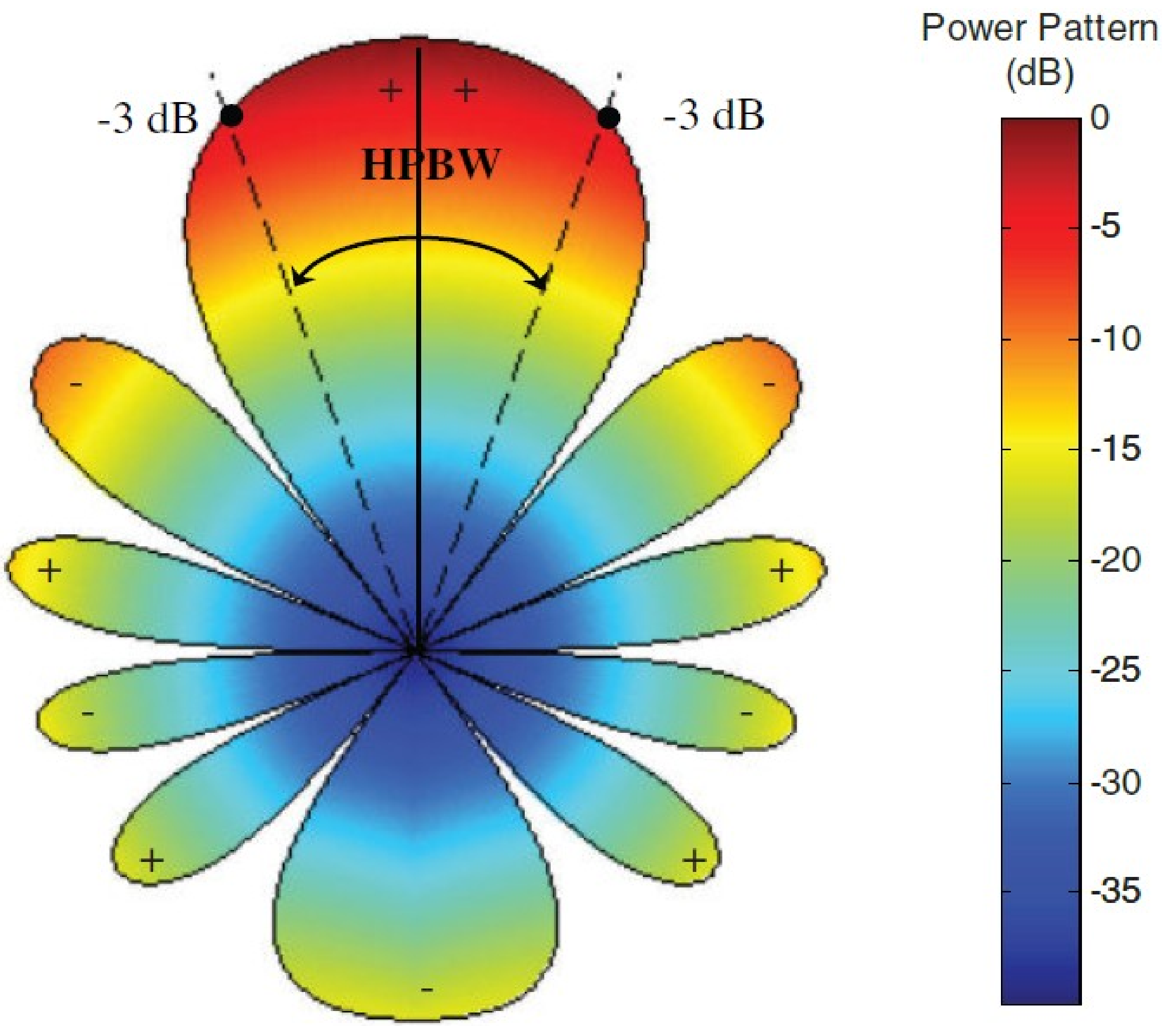
z
U(θ,φ)
y
x
Normalized Field
Pattern (linear scale)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
z
HPBW
0.5
FNBW
0.5
HPBW = 28.65°
FNBW = 60°
Normalized Field
Pattern (linear scale)
1
0.9
0.8
0.7
0.6
0.5
0.4
0 3
0.2
0.1



(a) Field pattern (in linear scale)



(b) Power pattern (in linear scale)



(c) Power pattern (in dB)

The normalized radiation intensity of an antenna is represented by

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

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

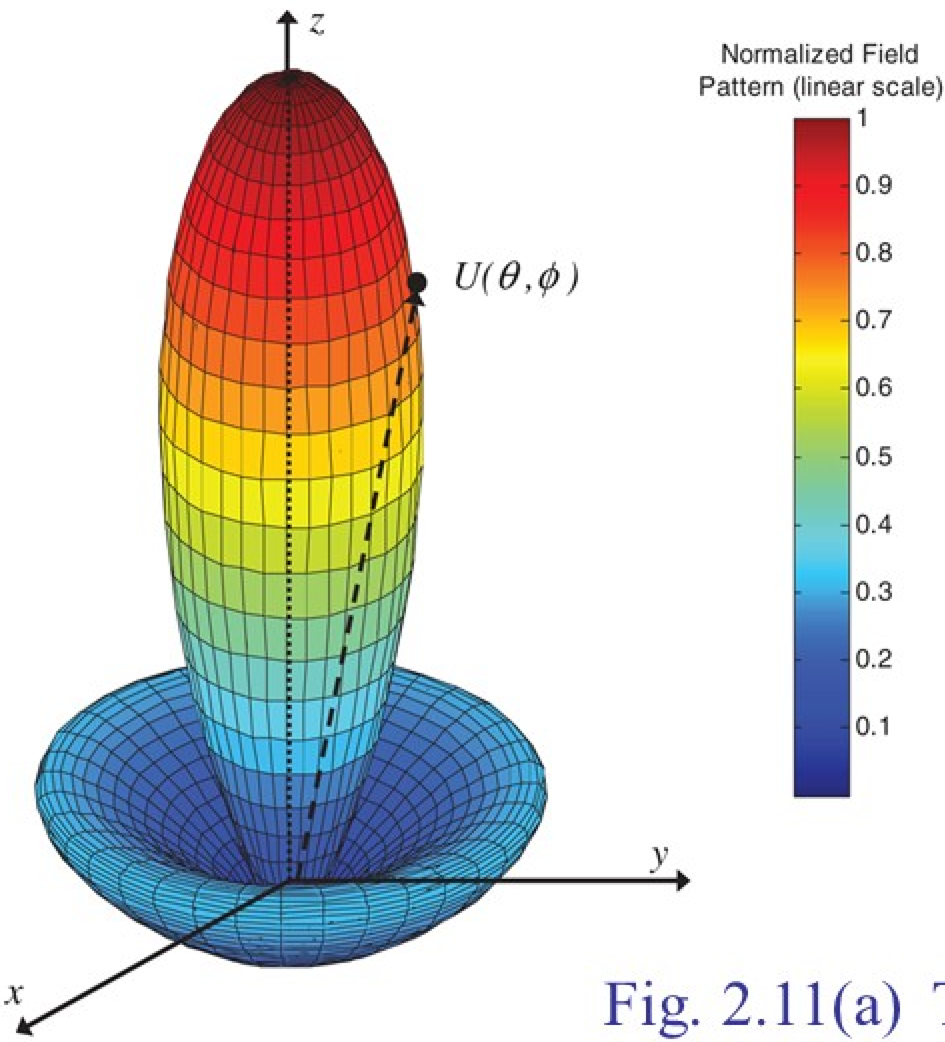
The three- and two-dimensional plots of this plotted in a linear scale, are shown in the figure.

Find the:

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

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

HPBW and FNBW of Radiation Intensity U

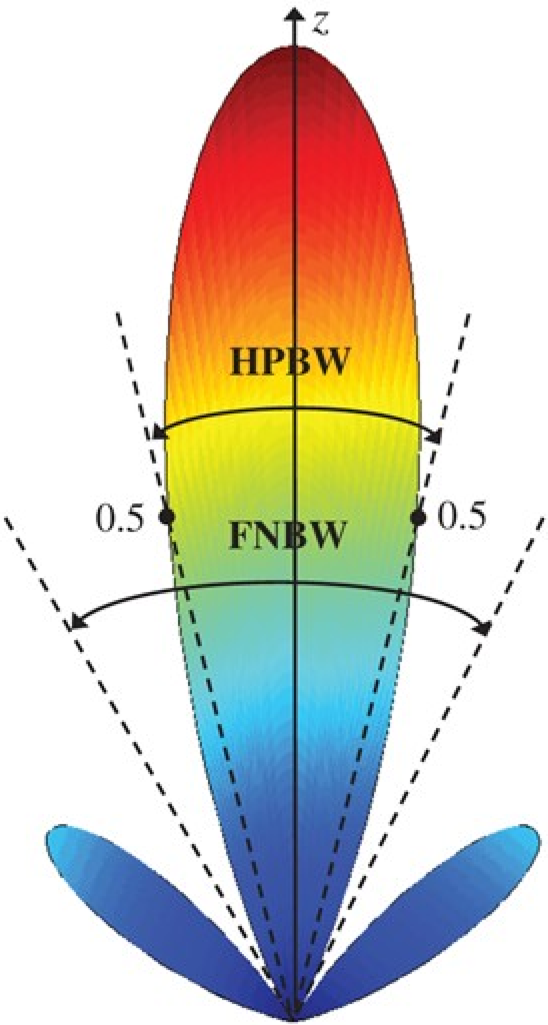


Linear Scale

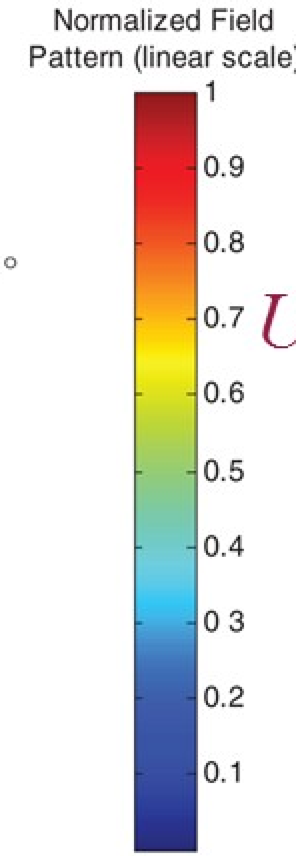
$$(\theta,\phi) = \cos^2\theta \cos^2 3\theta$$

Fig. 2.11(a) Three-dimensional

HPBW and FNBW of Radiation Intensity U



HPBW = 28.65°
FNBW = 60°



Linear Scale

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

Fig. 2.11(b) Two-dimensional

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

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

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

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 θ=0, then the HPBW is

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

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

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

Thank You

Questions?