Antennas

Lecture 2

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Antenna Parameters

Radiation Pattern

Antenna pattern refers to the *directional* (angular) dependence of the strength of the radio waves from the antenna or other source.

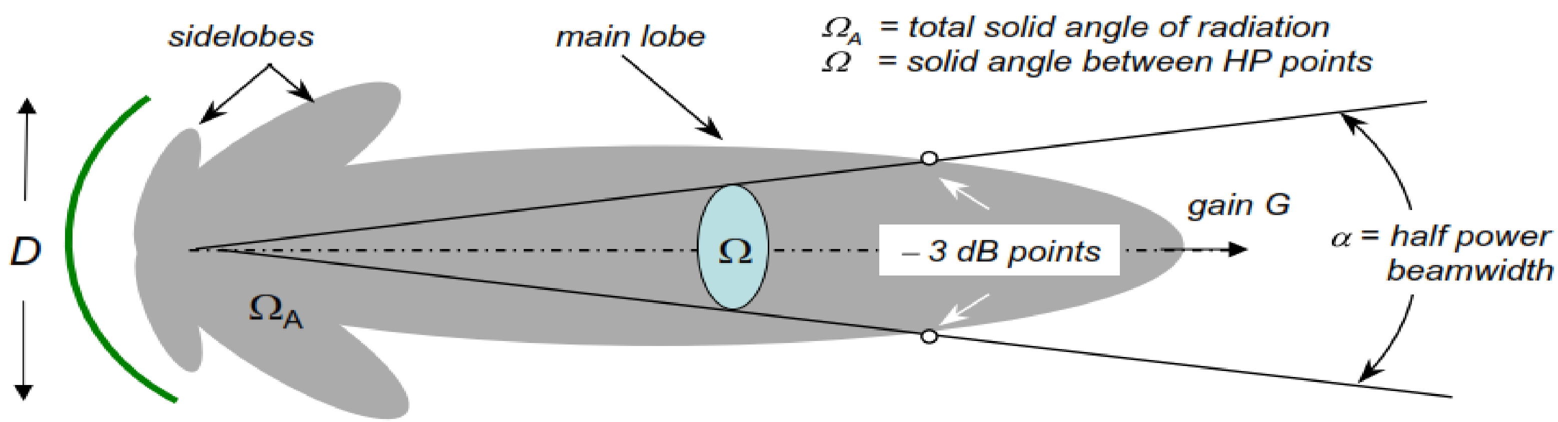
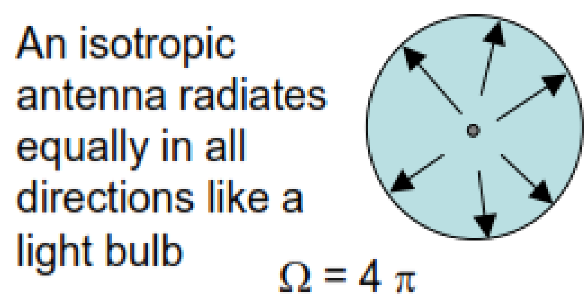


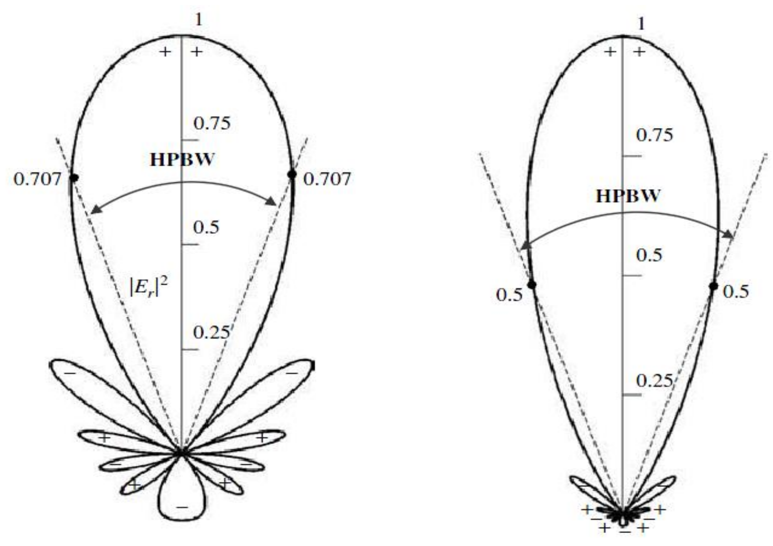
Figure-1 Antenna Pattern.



Radiation Pattern

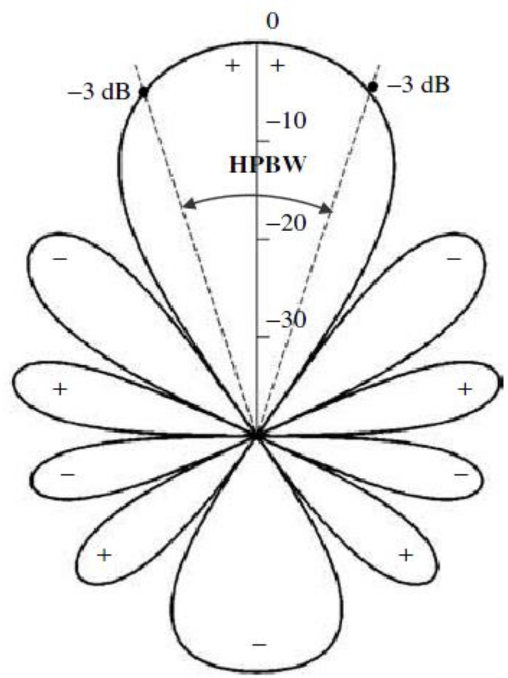
- In most cases, the radiation pattern is determined in the far field region and is represented as a function of the directional coordinates.
- Radiation properties include:
  - Power flux density,
  - radiation intensity,
  - field strength,
  - directivity,
  - Phase or polarization.
- A trace of the received electric (magnetic) field at a constant radius is called the amplitude field *pattern*.

- On the other hand, a graph of the spatial variation of the power density along a constant radius is called an amplitude *power pattern*.
- To find the points where the pattern achieves its half-power (−3 dB points), relative to the maximum value of the pattern, you set the value of the:
  - ***a.*** *field pattern at 0.707 value of its maximum, as shown in Figure-2(a)*



(a) Field pattern (in linear scale)　(b) Power pattern (in linear scale)

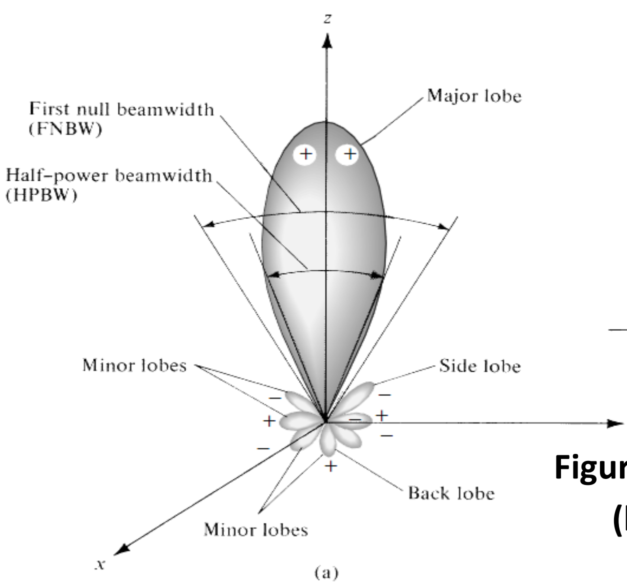
- ***b.*** *power pattern (in a linear scale) at its 0.5 value of its maximum, as shown in Figure-2(b)*
- ***c****. power pattern (in dB) at −3 dB value of its maximum, as shown in Figure-2(c)*.



(c) Power pattern (in dB)

Figure-2 Two-dimensional normalized *field* pattern (*linear scale*), *power* pattern(*linear scale*), and *power* pattern (*in dB*) of a 10-element linear array with a spacing of d = 0.25λ.

- <u>Various parts of a radiation pattern are referred to as *lobes*</u>, which may be sub <u>classified into *major* or *main, minor, side*, and *back* lobes</u>.
- A *radiation lobe* is a "portion of the radiation pattern bounded by regions of relatively weak radiation intensity." Figure-3(a) demonstrates a symmetrical three dimensional polar pattern with a number of radiation lobes.



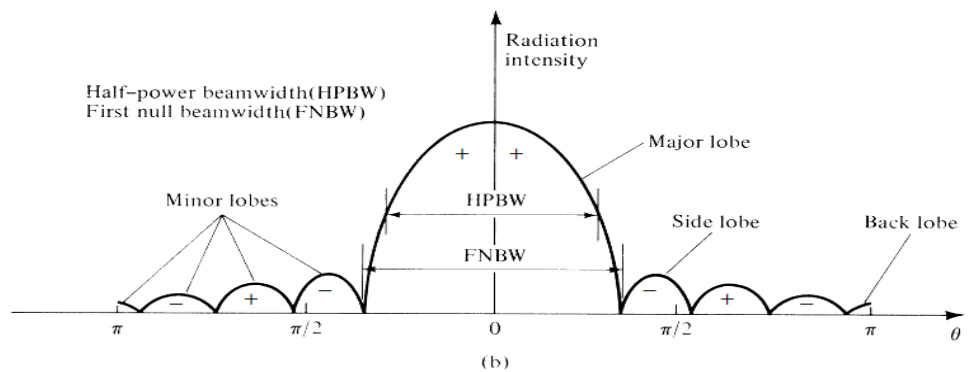


Figure-3 (a) Radiation lobes and beamwidths of an antenna pattern. (b) Linear plot of power pattern and its associated lobes and beamwidths.

Isotropic, Directional, and Omnidirectional Patterns

- An *isotropic* radiator is defined as "a hypothetical lossless antenna having equal radiation in all directions."
- Although it is ideal and not physically realizable.

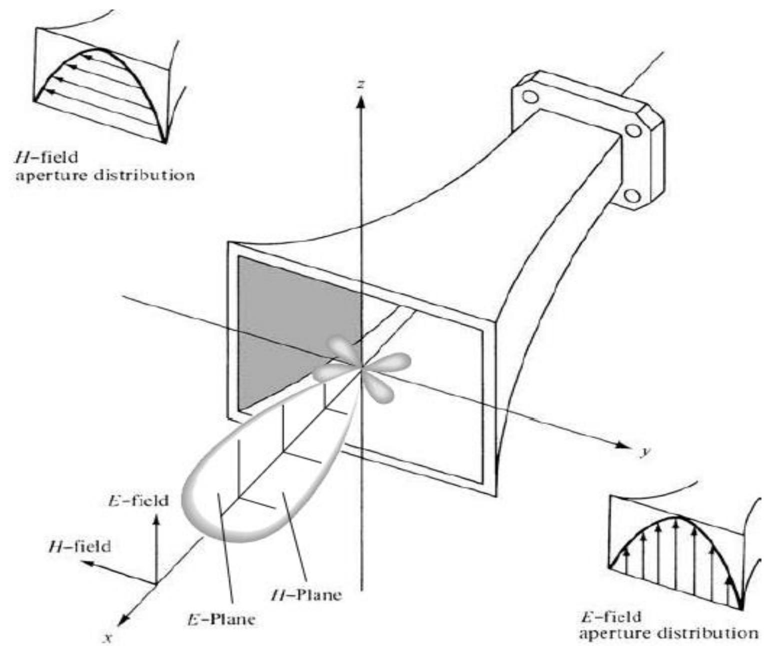


Figure-4 Principal *E*- and *H*-plane patterns for a pyramidal horn antenna.

- A *directional* antenna is one "having the property of radiating or receiving electromagnetic waves more effectively in some directions than in others.
- Examples of antennas with directional radiation patterns are shown in Figures-4 and 5.
- It is seen that the pattern in Figure-5 is non directional in the azimuth plane [$f(\varphi)$, $\vartheta = \pi/2$] and directional in the elevation plane [$g(\vartheta)$, φ = constant]. This type of a pattern is designated as *omnidirectional.*

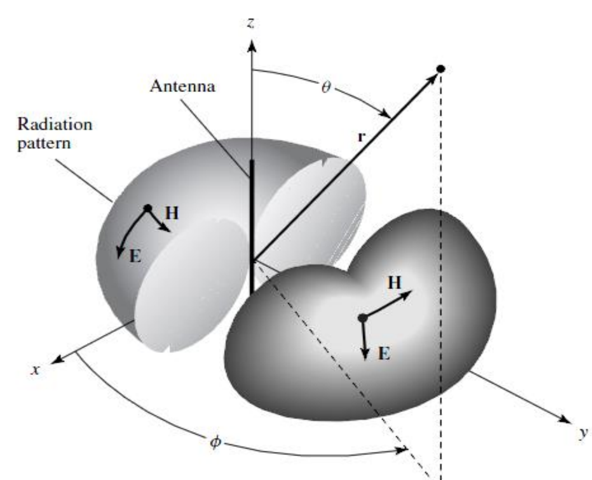


Figure-5 Omnidirectional antenna pattern.

- For a linearly polarized antenna, performance is often described in terms of its principal *E*- and *H*-plane patterns.
- The *E-plane* is defined as "the plane containing the electric field vector and the direction of maximum radiation," and the *H-plane* as "the plane containing the magnetic-field vector and the direction of maximum radiation.

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*.
- A graphical illustration is shown in Figure-6(a).

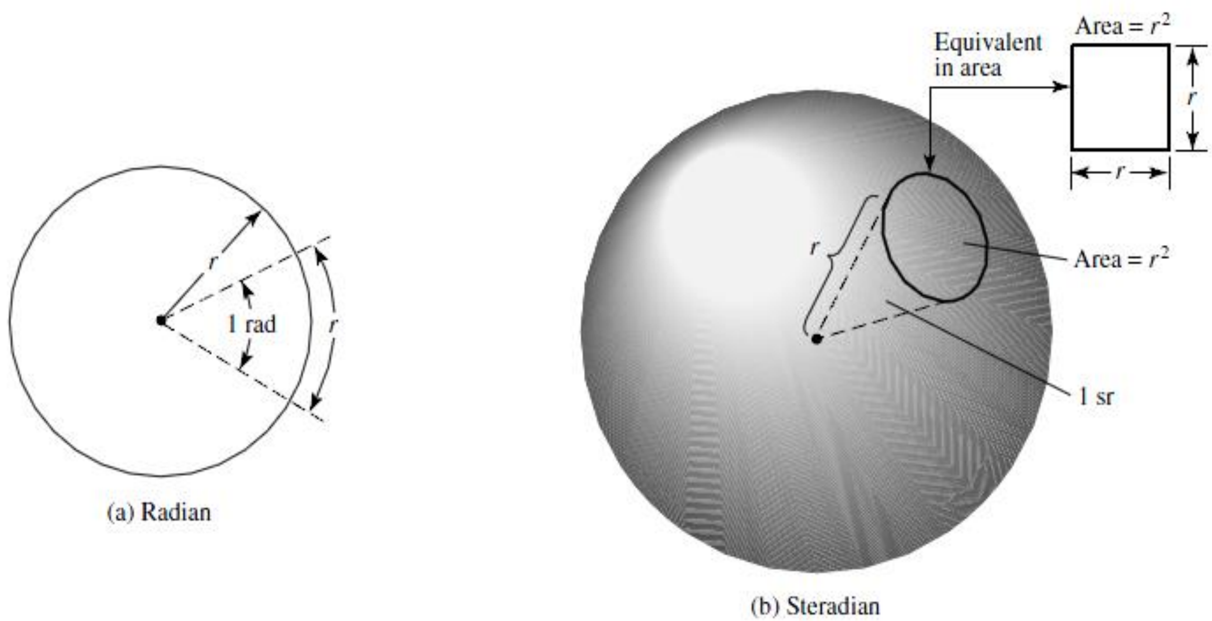


Figure 2.6 Geometrical arrangements for defining a radian and a steradian.

- Since the circumference of a circle of radius *r* is $C = 2\pi r$, there are 2π rad $(2\pi r/r)$ in a full circle.
- 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*.
- A graphical illustration is shown in Figure-6(b).
- Since the area of a sphere of radius *r* is $A = 4\pi r^2$, there are 4π sr $(4\pi r^2/r^2)$ in a closed sphere.

Beamwidth

- **Beamwidth** is the angular separation between two identical points on opposite site of the pattern maximum
- • **Half-power beamwidth (HPBW):** in a plane containing the direction of the maximum of a beam, <u>the angle between the two directions in which the radiation intensity is one-half value of the beam.</u>
- • **First-Null beamwidth (FNBW):** <u>angular separation between the first nulls of the pattern</u>

Beam width

Half-power beam width (HPBW):

- The angular width of the beam radiated by high-gain antennas is measured by the *half-power beam width* (HPBW), which is the angular separation between the points on the antenna radiation pattern at which the power drops to one-half (-3 dB) its maximum value.

Beamwidth shows size of beam.

$$\text{HPBW} = \alpha = k\frac{\lambda}{D} = 70^\circ \frac{\lambda}{D}$$ where k = antenna taper factor

First-Null Beam width **(*FNBW*):**

- Another important beam width is the angular separation between the first nulls of the pattern, and it is referred to as the *First-Null Beam width* (*FNBW*). Both the *HPBW* and *FNBW* are demonstrated for the pattern in Figure 2.7.

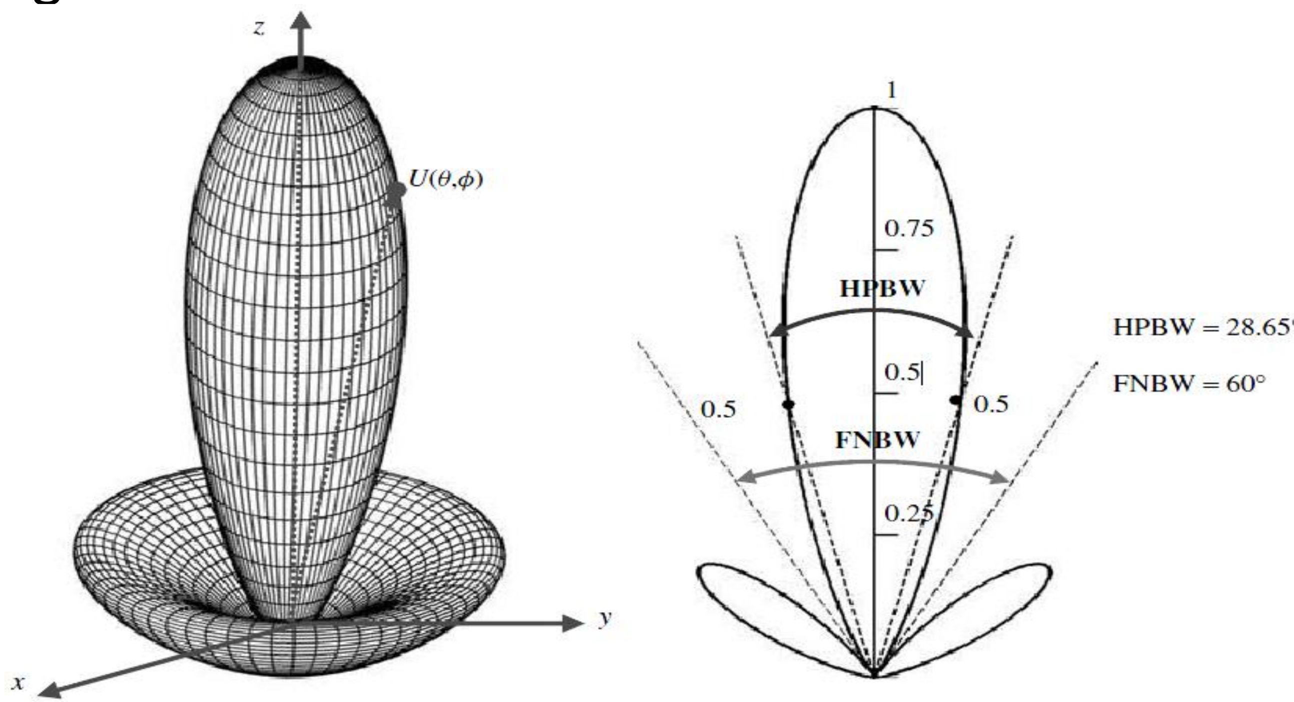


Figure 2.7 Three- and two-dimensional power patterns (in linear scale) of $U(\vartheta) = \cos^2(\vartheta)\cos^2(3\vartheta)$.

Resolution Capability of the Antenna

- The most common resolution criterion states that *the resolution capability of an antenna to distinguish between two sources is equal to half the first-null beam width (FNBW/2), which is usually used to approximate the half power beam width (HPBW).*

Directivity

- *Directivity of an antenna* defined as "the ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions.
- The average radiation intensity is equal to the total power radiated by the antenna divided by 4*π.*
- In mathematical form

$$D = \frac{U}{U_0} = \frac{4\pi U}{P_{\text{rad}}}$$

- Maximum directivity expressed as:

$$D_{\max} = D_0 = \frac{U|_{\max}}{U_0} = \frac{U_{\max}}{U_0} = \frac{4\pi U_{\max}}{P_{\mathrm{rad}}}$$

D = directivity (dimensionless)

D_0 = maximum directivity (dimensionless)

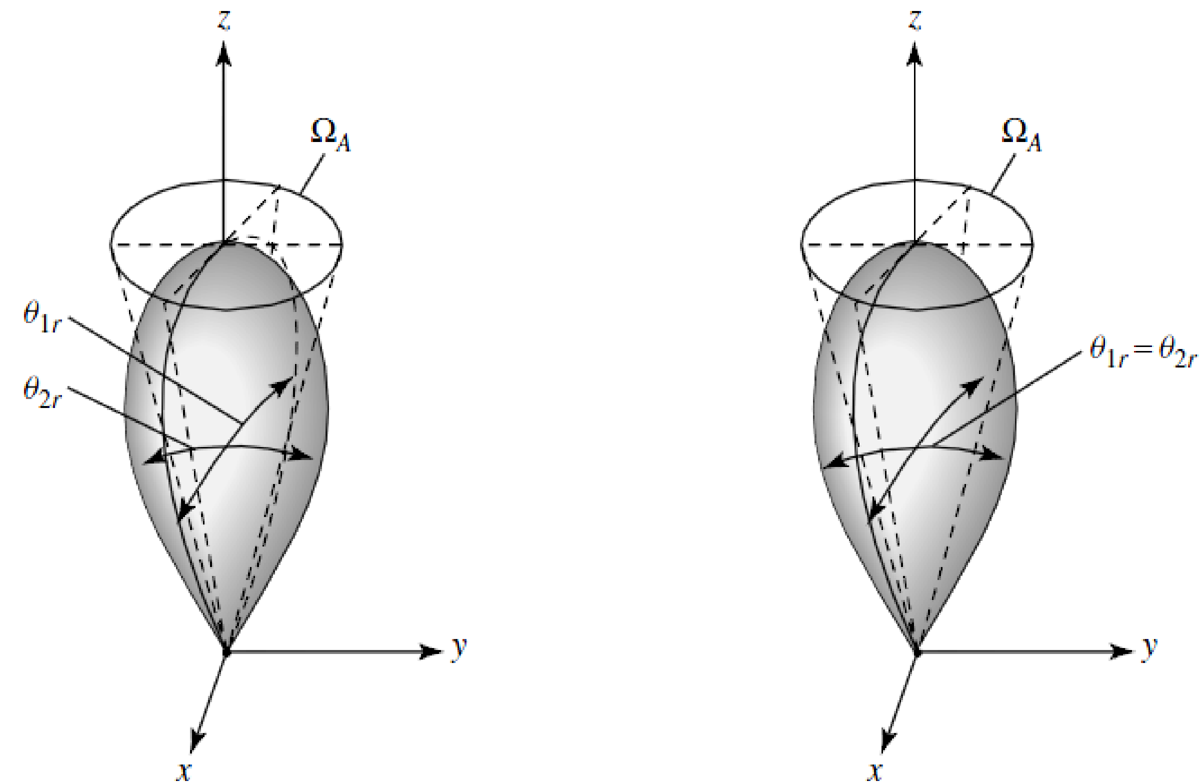
U = radiation intensity (W/unit solid angle)

U_{max} = maximum radiation intensity (W/unit solid angle)

U_0 = radiation intensity of isotropic source (W/unit solid angle)

P_{rad} = total radiated power (W)

- For antennas with one narrow major lobe and very negligible minor lobes, the beam solid angle is approximately equal to the product of the half-power beam widths in two perpendicular planes shown in Figure 8 (a).



(a) Nonsymmetrical pattern (b) Symmetrical pattern

Figure-8 Beam solid angles for nonsymmetrical and symmetrical radiation patterns

- With this approximation, directivity can be approximated by:

$$D_0 = \frac{4\pi}{\Omega_A} \simeq \frac{4\pi}{\Theta_{1r}\Theta_{2r}}$$

- The beam solid angle Ω_A has been approximated by

$$\Omega_A \simeq \Theta_{1r}\Theta_{2r}$$

where:

θ_{1r} = half-power beamwidth in one plane (rad)

θ_{2r} = half-power beamwidth in a plane at a right angle to the other (rad)

- If the beamwidths are known in degrees, directivity can be written as:

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

where

θ_{1d} = half-power beamwidth in one plane (degrees)

θ_{2d} = half-power beamwidth in a plane at a right angle to the other (degrees)

Antenna Efficiency

- The total antenna efficiency e_0 is used to take into account losses at the input terminals and within the structure of the antenna. Such losses are:
  - 1. Reflections because of the mismatch between the transmission line and the antenna.
  - 2. I^2R losses (conduction and dielectric).
- In general, the overall efficiency can be written as

$$e_0 = e_r e_c e_d$$

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)

Γ = voltage reflection coefficient at the input terminals of the antenna

$$\Gamma = (Z_{in} - Z_0)/(Z_{in} + Z_0)$$

Where:

Z_{in} = antenna input impedance,

Z_0 = characteristic impedance of the transmission line

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

Where:

$e_{cd} = e_c e_d$ = antenna radiation efficiency, which is used to relate the gain and directivity.

Gain

- The gain of the antenna is closely related to the directivity.
- *Gain* of an antenna (in a given direction) is defined as "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 is equal to the power accepted (input) by the antenna divided by 4π."
- In equation form this can be expressed as

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

- In most cases we deal with *relative gain*, which is 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. In most cases, however, the reference antenna is a *lossless isotropic source*. Thus

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

- *When the direction is not stated, the power gain is usually taken in the direction of maximum radiation*.

- We can write that the total radiated power (P_{rad}) is related to the total input power (P_{in}) by

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

$$G(\theta, \phi) = e_{cd} \left[4\pi \frac{U(\theta, \phi)}{P_{\text{rad}}} \right]$$

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

$$\boxed{G_0 = G(\theta, \phi)|_{\max} = e_{cd} D(\theta, \phi)|_{\max} = e_{cd} D_0}$$

Gain as a function of λ:

- The gain as a function of wavelength and antenna physical aperture area is given by:

$$G = 4\pi / (\theta_{AZ} \text{ x } \theta_{EL}),$$

$$\theta_{AZ} \text{ (in degree)} = 70\ \lambda/L_{AZe} \approx \lambda/\ L_{AZe} \text{ in radian}$$

$$\theta_{EL} \text{ (in degree)} = 70\ \lambda/L_{ELe} \approx \lambda/\ L_{ELe} \text{ in radian}$$

$$G = 4\pi\ L_{AZe}\ L_{ELe} / \lambda^2 = 4\pi\ A_e / \lambda^2$$

Where: L_{AZe} = effective azimuth antenna length

L_{ELe} = effective elevation antenna length

A_e = effective antenna aperture area

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

$$G = \frac{4\pi\eta A}{\lambda^2} \quad \text{Where} \quad \begin{aligned} \eta &= \text{Efficiency} = e_{cd} \\ A &= \text{Physical aperture area} \\ \lambda &= \text{wavelength} \end{aligned}$$

- The gain of parabolic antennas that are often used in satellite communications is:

$$G = \eta\left(\frac{\pi D}{\lambda}\right)^2$$

where η is aperture efficiency (50-70%),D is antenna diameter, λ is wavelength.