Antennas and Transmission Lines

Electrical Department-3rd Stage

By

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Antennas

- "a usually metallic device (as a rod or wire) for radiating or receiving radio waves."
- In other words the antenna is the transitional structure between free-space and a guiding device, as shown in Figure 1
- A T-L Thevenin equivalent of the antenna system of Figure 1 in the transmitting mode is shown in Figure 2

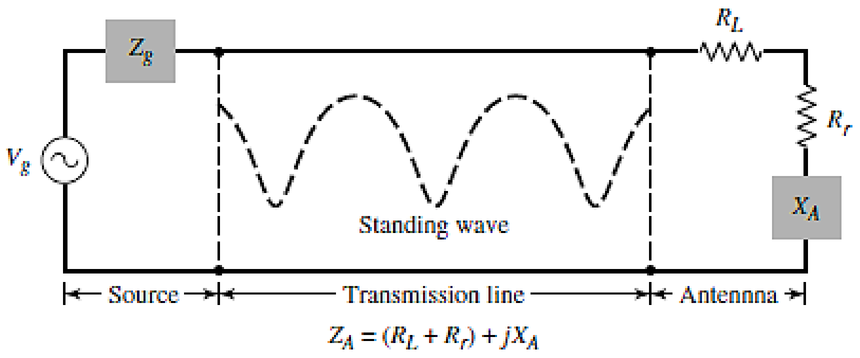


Figure 2 Transmission-line Thevenin equivalent of antenna in transmitting mode.

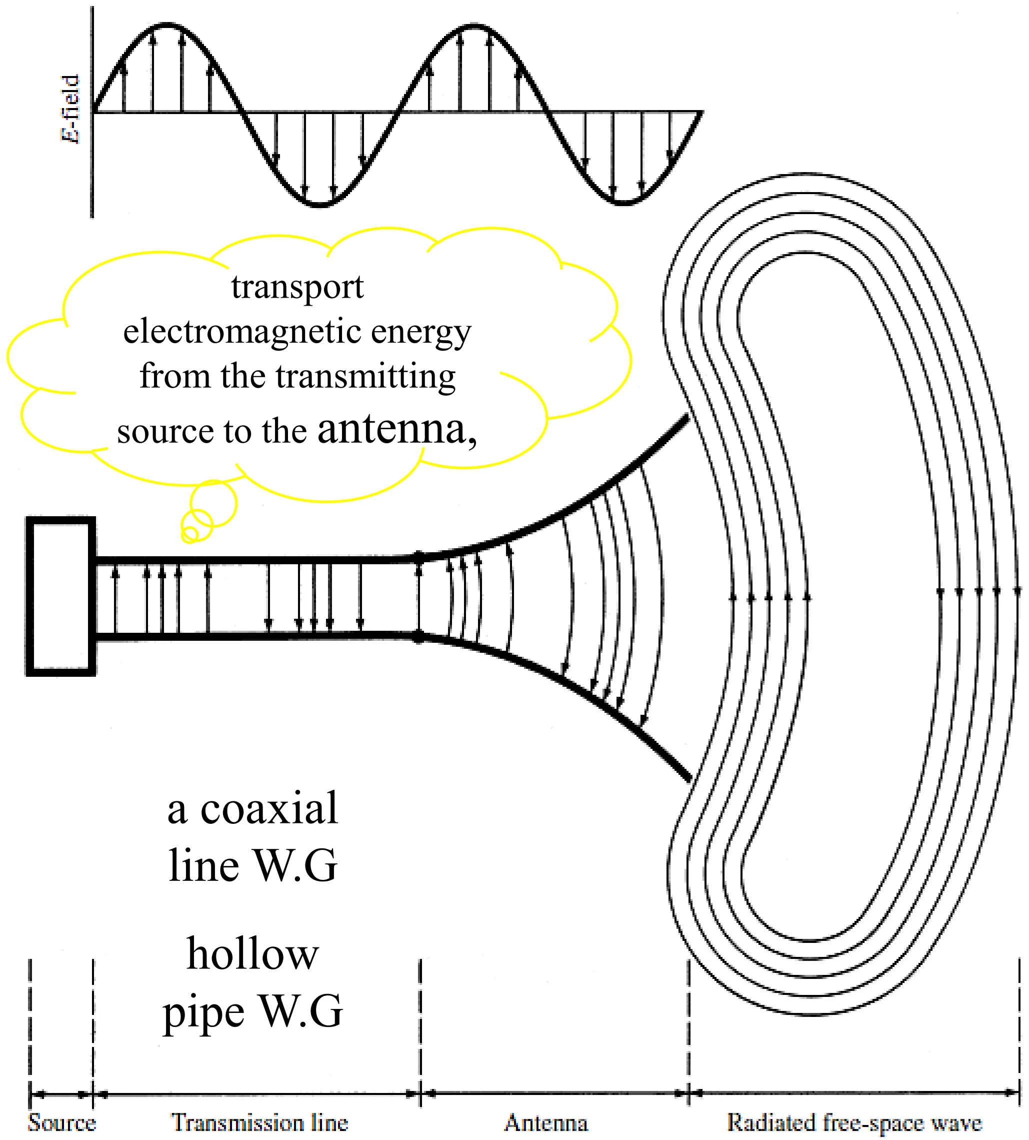


Figure 1. Antenna as a transition device.

- Where the source is represented by an ideal generator, the transmission line is represented by a line with characteristic impedance Z_c, and the antenna is represented by a load Z_A $[Z_A = (R_L + R_r) + jX_A]$ connected to the transmission line.
- The load resistance R_L …..the conduction and dielectric losses associated with the antenna structure R_r……..the *radiation resistance*, is used to represent radiation by the antenna.
- The reactance X_A is used to represent the imaginary part of the impedance associated with radiation by the antenna.

TYPES OF ANTENNAS

1) Wire Antennas

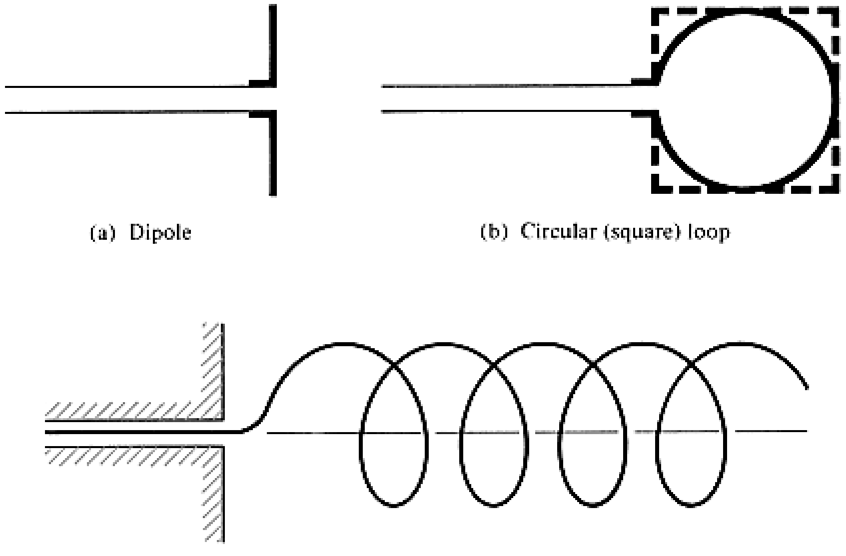
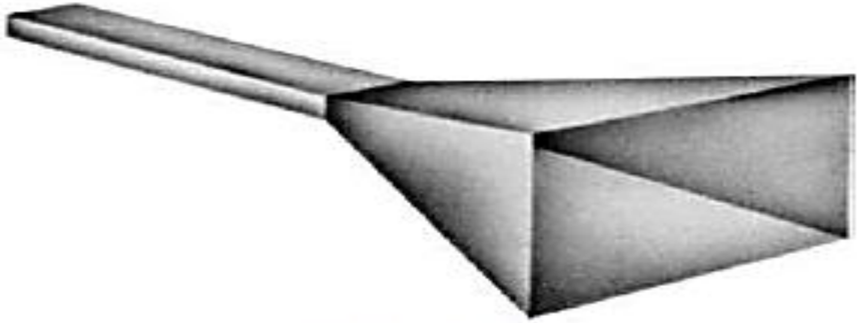


Figure .3 Wire antenna configurations.

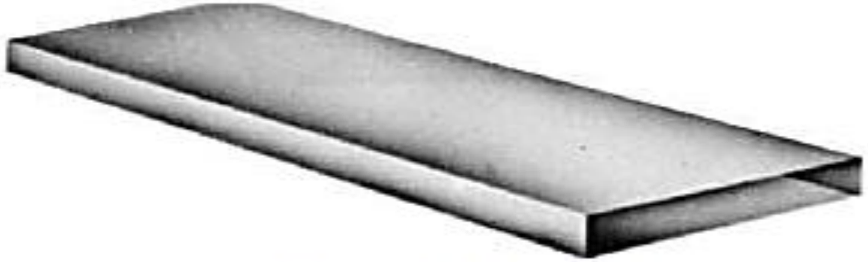
2) Aperture Antennas

- Used in higher frequencies.
- Antennas of this type are very useful for aircraft and spacecraft applications, because they can be very conveniently flush-mounted on the skin of the aircraft or spacecraft.
- Covered with a dielectric material to protect them from hazardous conditions of the environment.



(a) Pyramidal horn

(b) Conical horn

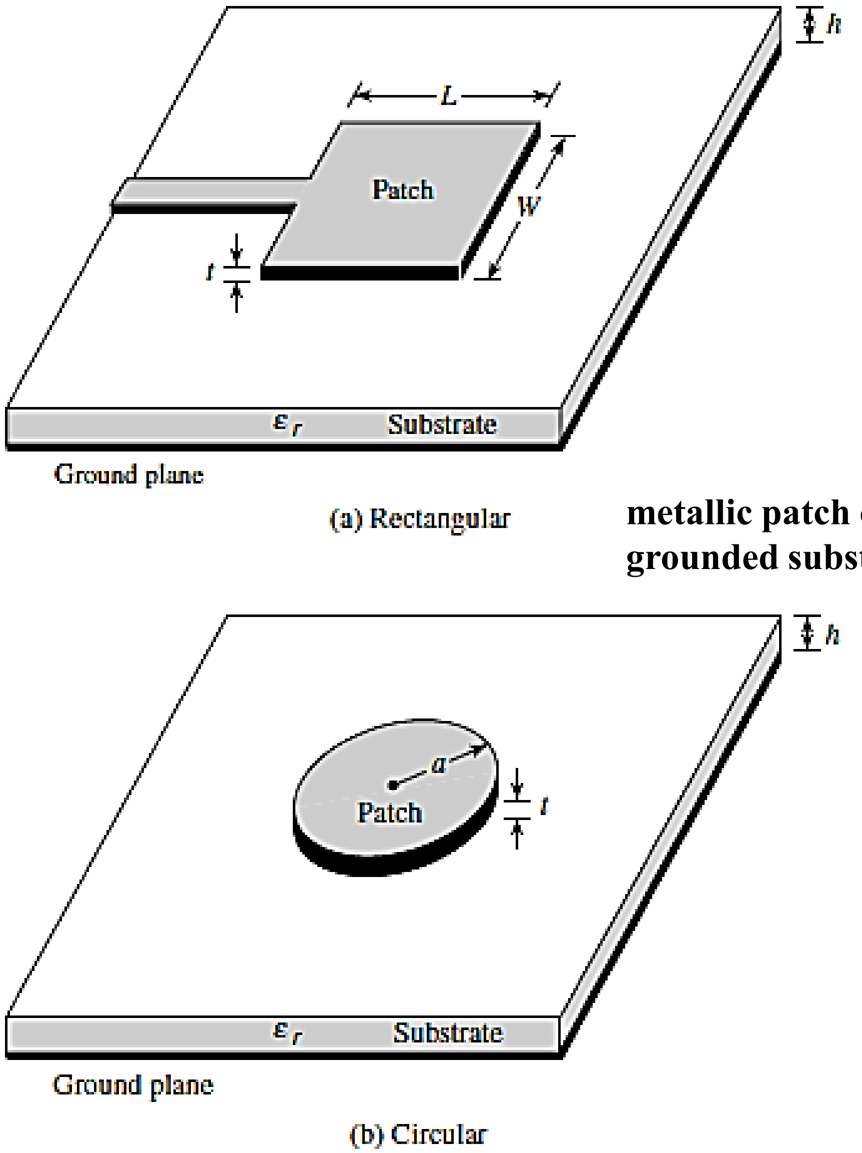


(c) Rectangular waveguide

Figure 4 Aperture antenna configurations.

3) Microstrip Antennas

- The microstrip antennas are low profile, conformable to planar and nonplanar surfaces, simple and inexpensive to fabricate using modern printed-circuit technology,
- Mechanically robust when mounted on rigid surfaces, compatible with MMIC designs, and very versatile in terms of resonant frequency, polarization, pattern, and impedance.



metallic patch on a grounded substrate

Figure ˙.5 Rectangular and circular microstrip (patch) antennas.

4) Array Antennas

- Many applications require radiation characteristics that may not be achievable by a single element. It may, however, be possible that an aggregate of radiating elements in an electrical and geometrical arrangement (*an array*) will result in the desired radiation characteristics.

- The arrangement of the array may be such that the radiation from the elements adds up to give a radiation maximum in a particular direction or directions, minimum in others, or otherwise as desired.

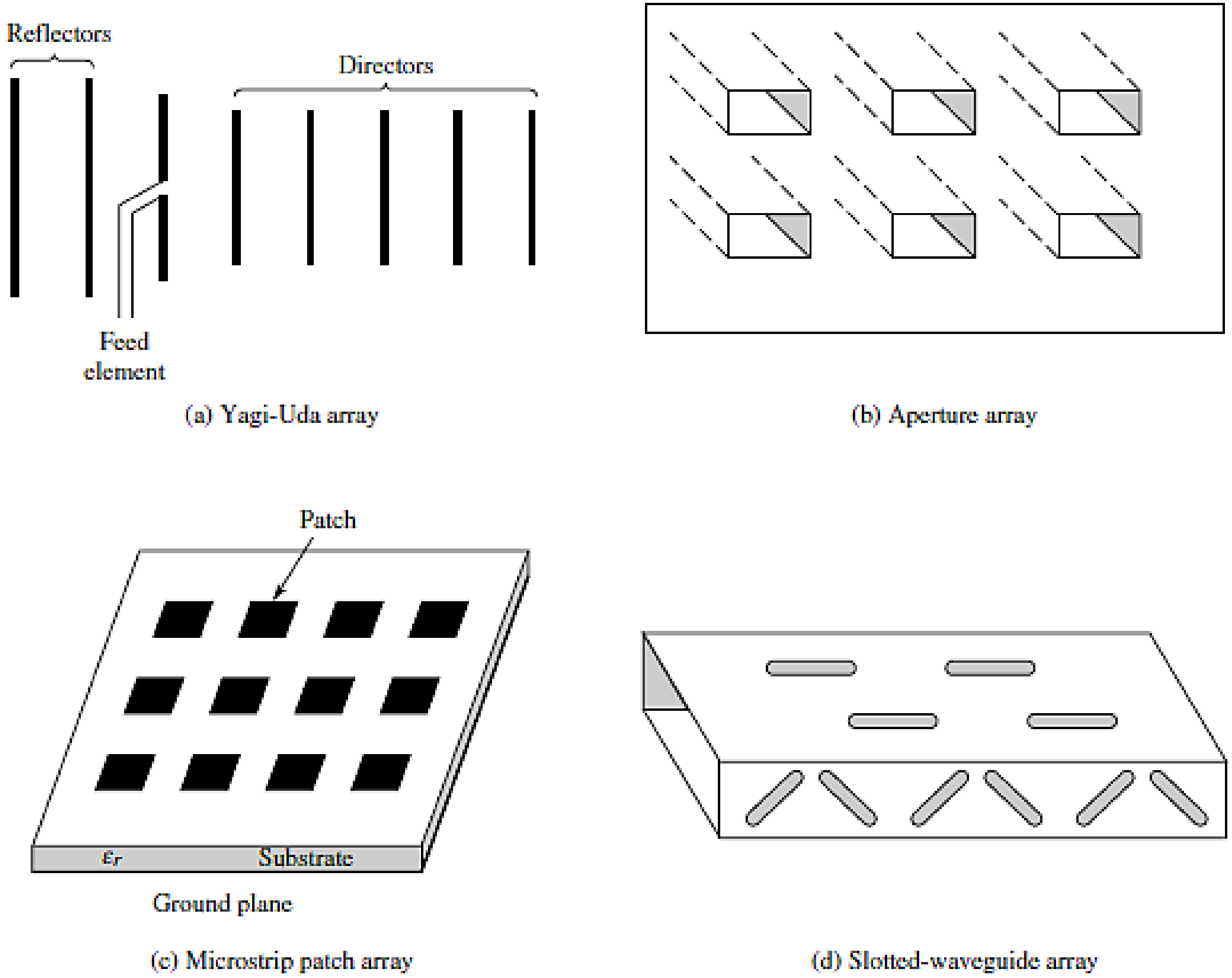


Figure 6 Typical wire, aperture, and microstrip array configurations.

5) Reflector Antennas

- Used in communicate over great distances, sophisticated forms of antennas had to be used in order to transmit and receive signals that had to travel millions of miles.
- Antennas of this type have been built with diameters as large as 305 m.
- Such large dimensions are needed to achieve the high gain required to transmit or receive signals after millions of miles of travel.

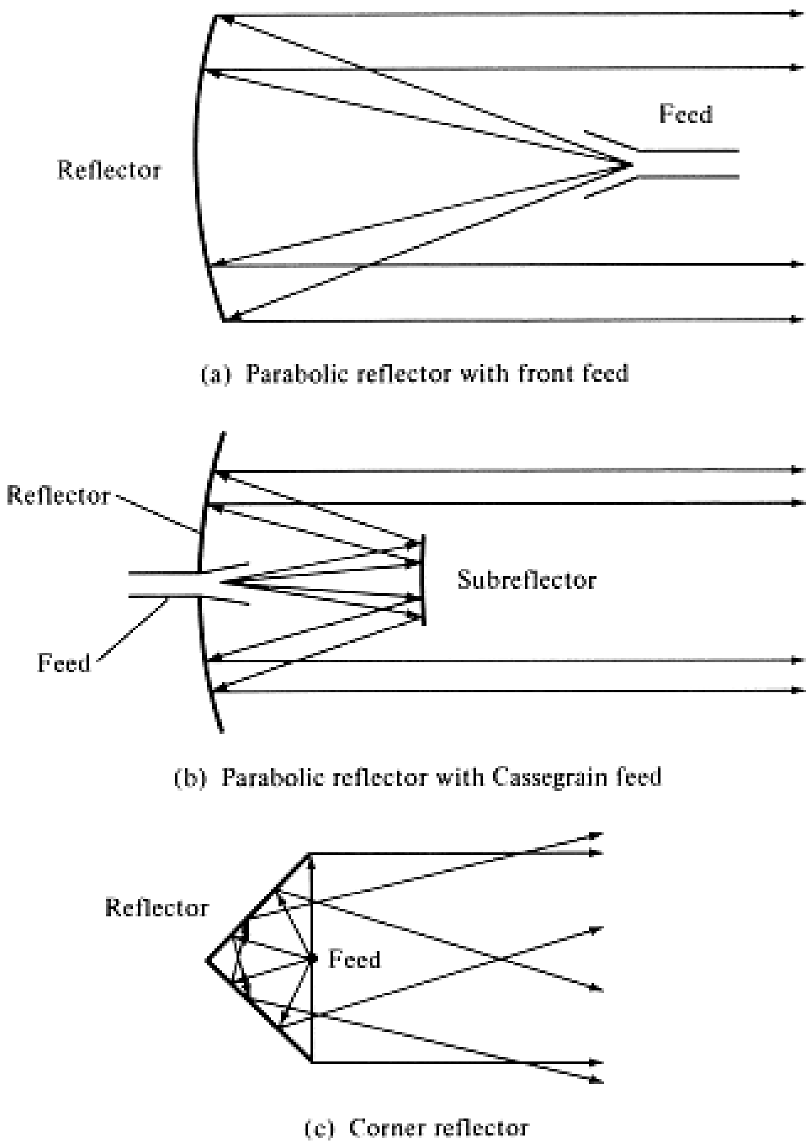


Figure 7 Typical reflector configurations.

6) Lens Antennas

- Lenses are primarily used to collimate incident divergent energy to prevent it from spreading in undesired directions.
- By properly shaping the geometrical configuration and choosing the appropriate material of the lenses, they can transform various forms of divergent energy into plane waves.
- They can be used in most of the same applications as are the parabolic reflectors, especially at higher frequencies.

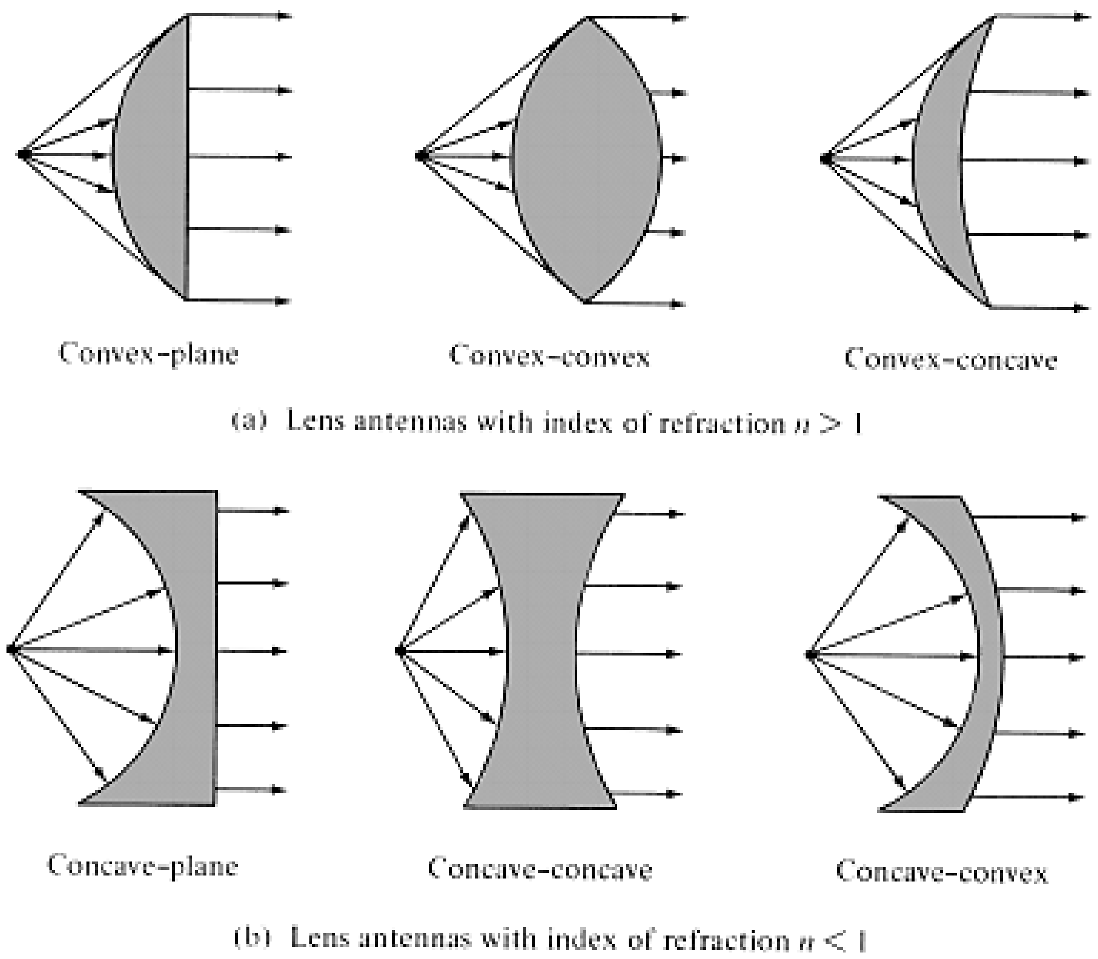


Figure 8 Typical lens antenna configurations. (SOURCE: L. V. Blake, *Antennas*, Wiley, New York, 1966).

❖ **In summary, an ideal antenna is one that will radiate all the power delivered to it from the transmitter in a desired direction or directions.**

Fundamental Parameters of Antennas

Definitions

1-RADIATION PATTERN – نمط الاشعاع

An antenna *radiation pattern* or *antenna pattern* is defined as “a mathematical function or a graphical representation of the radiation properties of the antenna as a function of space coordinates.

ببساطة، هو تمثيل ثلاثي الأبعاد (أو ثنائي الأبعاد) لكيفية توزيع الإشعاع الكهرومغناطيسي الصادر من الهوائي في الفراغ المحيط به

$$P_t \propto |E|^2$$

$$P_t \propto |H|^2$$

2- Power pattern:- A graph of the received power of a constant radius.

$$P(\theta,\phi) \propto |F(\theta,\phi)|^2$$

3- Field pattern:- A graph of the received electric or magnetic field along a constant radius.

$$F(\theta,\phi)\ \text{normalized field pattern} = \frac{E(\theta,\phi)}{E(\theta,\phi)|_{max}}$$

- The radiation property of most concern is the two- or three dimensional spatial distribution of radiated energy as a function of the observer's position along a path or surface of constant radius. A convenient set of coordinates is shown in Figure 2.1.

- 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*.

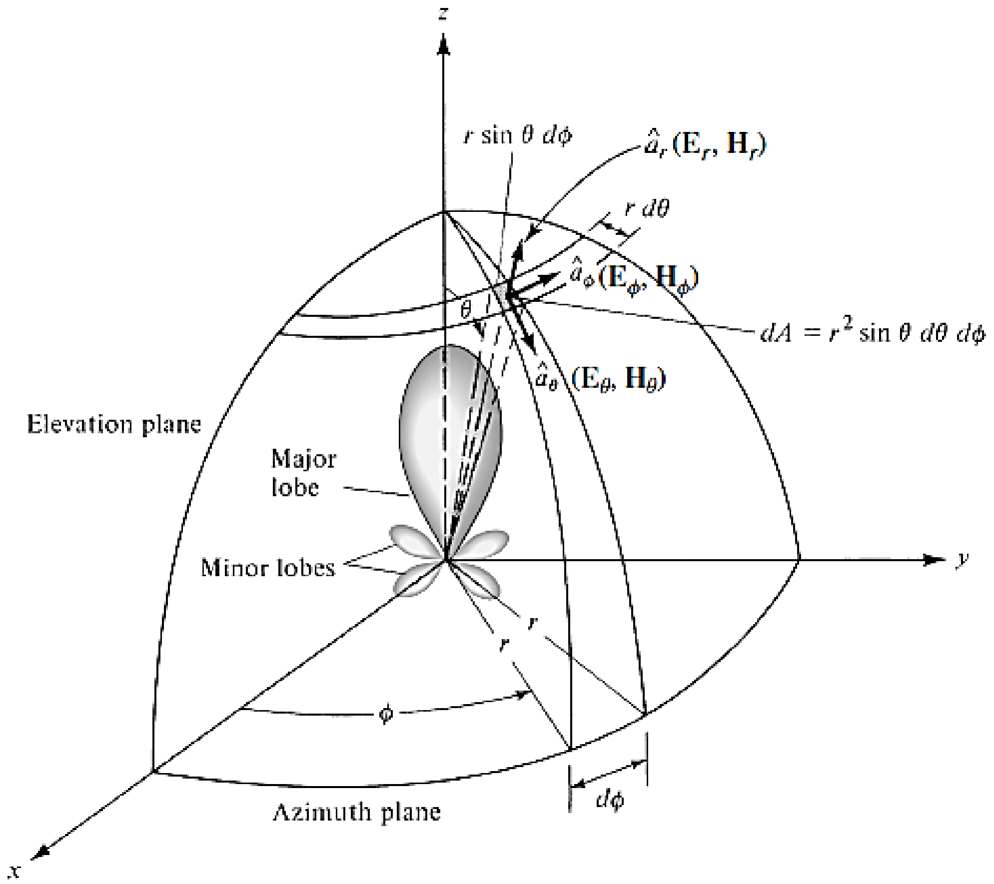


Figure 2.1 Coordinate system for antenna analysis.

4-Isotropic radiator :- A hypothetical antenna having equal radiation in all direction (point source).

5- Directional antenna :- An antenna having the property of radiating or receiving electromagnetic waves more effectively in some directions than others.

6-Omni directional antenna:- An antenna having a non directional pattern in azimuth and a directional in elevation.

$$\text{Azimuth plane } (\, F(\phi)\,,\, \theta = \text{constant}\,)$$
$$\text{elevation plane } (\, g(\theta)\,, \phi = \text{constant}\,)$$

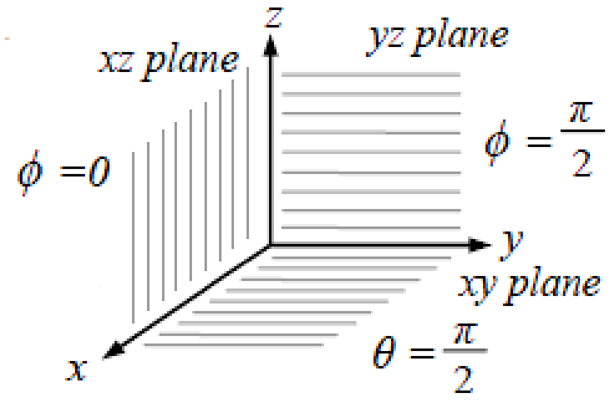


Figure 15 Coordinate system.

Radiation Pattern lobes

Radiating lobes:- A portion of the radiation pattern bounded by the regions of relatively weak direction intensity.

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

Side lobes:- A radiating lobe in any direction other than the intended lobe (usually side lobes is adjacent to the main lobe).
Back lobe:- A minor lobe that occupies the hemisphere in the direction apposite to that of the major lobe.

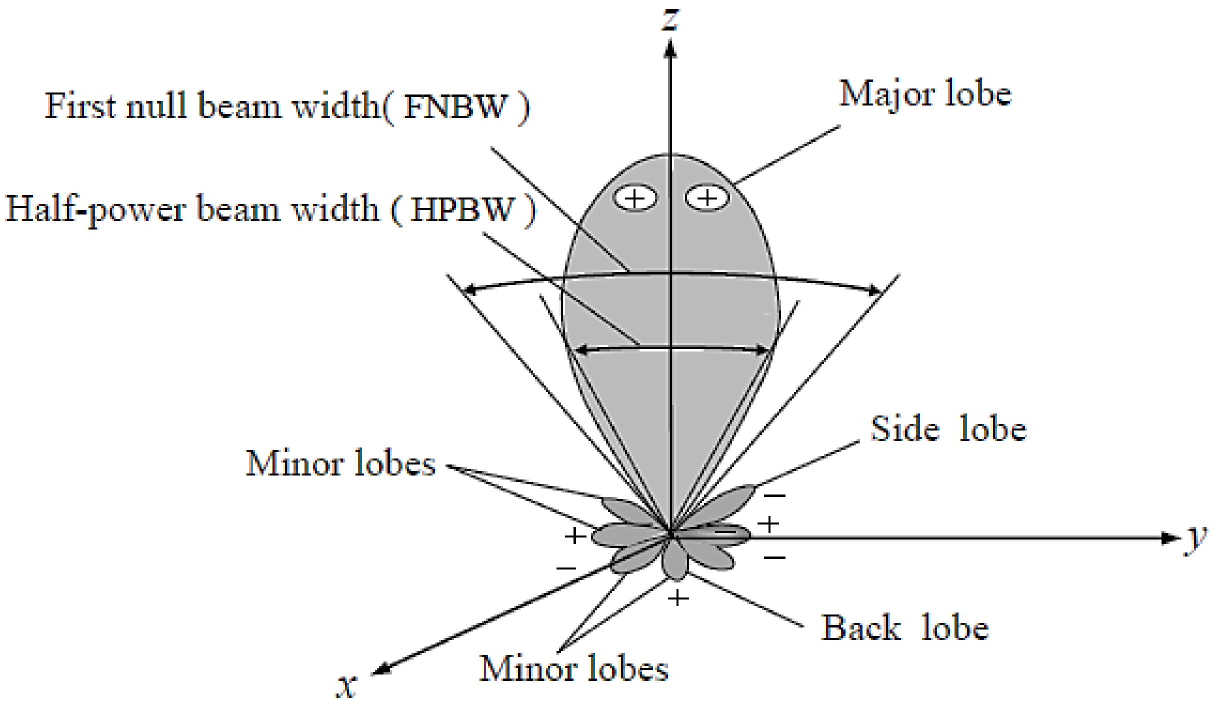


Figure 16 Radiation lobes and beam widths of an antenna pattern
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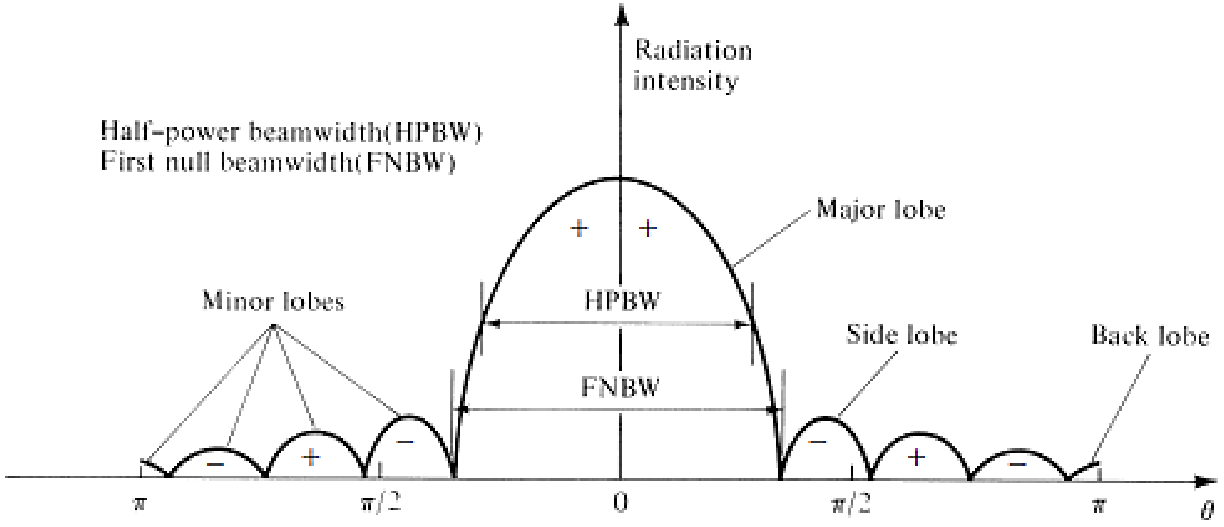

Figure 17 Linear plot of power pattern and its associated lobes and beamwidths.

Field Region

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 as shown in Figure 18.

$R < 0.62\sqrt{\frac{D^3}{\lambda}}$ reactive near field region .

$\frac{2D^2}{\lambda} > R \geq 0.62\sqrt{\frac{D^3}{\lambda}}$ radiating near field region .

$R > \frac{2D^2}{\lambda}$ far field region .

D: The largest dimension of the antenna .

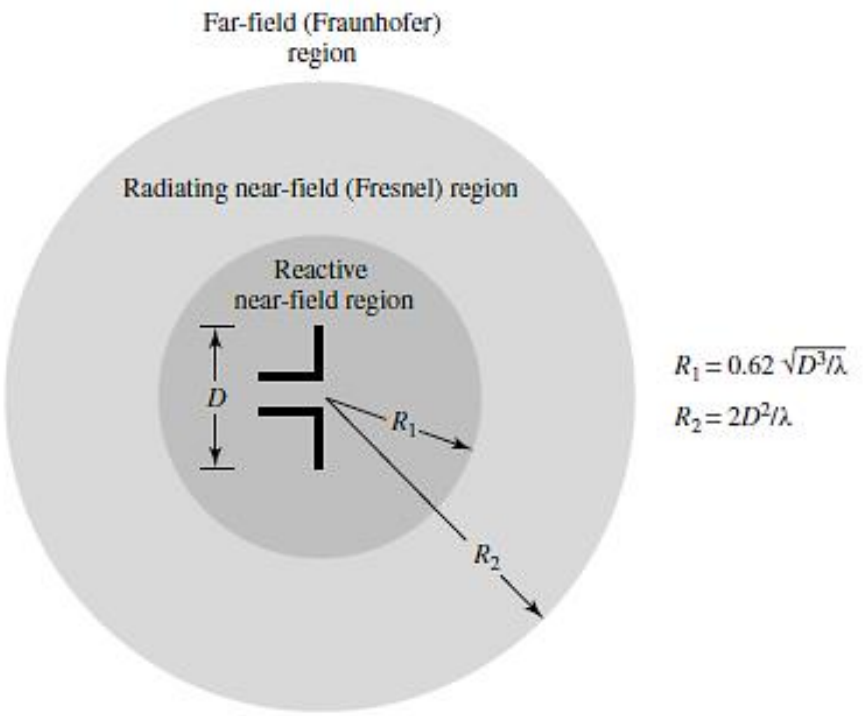

Figure 18 Field regions of an antenna.

Radiation Power Density كثافة القدرة الاشعاعية

$$\vec{W}_{av} = \frac{1}{2} R_e\left[\vec{E} \otimes \vec{H}^*\right]$$

$$P_{rad} = \int\int \vec{W}_{av} \,.\vec{ds}$$

$$P_{rad} = \int\int \frac{1}{2} R_e\left[\vec{E} \otimes \vec{H}^*\right] .\vec{ds} \quad \text{where } \vec{ds} = r^2 sin\theta\, d\theta d\phi \vec{a}_r$$

$\vec{W}_{av}$: The time average poynting vector $\frac{w}{m^2}$ or average power density.

P_{rad}:The radiated power (watt).

Radiation Intensity شدة الاشعاع

Radiation intensity is defined as the power radiated from an antenna per unit solid angle .

$U(\theta,\phi) = r^2 W_{rad}$ $\quad \dfrac{\text{watt}}{\text{Unit solid angle}}$

The radiation intensity is also related to the far-zone electric field of an antenna by $U \propto |E|^2$.

$$U(\theta,\phi) = r^2 W_{rad}$$

$$U(\theta,\phi) = r^2 \frac{1}{2} R_e\left[\vec{E} \otimes \vec{H}^*\right] \quad \text{where } \eta = \frac{E}{H} \Longrightarrow H = \frac{E}{\eta}$$

$$U(\theta,\phi) = r^2 \frac{1}{2} R_e\left[E\frac{E}{\eta}\right]$$

$$U(\theta,\phi) = \frac{r^2}{2\eta}|E(\theta,\phi)|^2 \qquad \text{where } \eta = 120\pi$$

$$P_{rad} = \int\int U(\theta,\phi)\ d\Omega \qquad \text{where } d\Omega = sin\theta\ d\theta d\phi$$

$$P_{rad} = \int\int U(\theta,\phi)\ sin\theta\ d\theta d\phi$$

η = intrinsic impedance of the medium

where $d\Omega$ = element of solid angle = $\sin\theta\, d\theta\, d\phi$.

Directivity التوجيهية -

Directive gain in a given direction is the ratio of the radiation intensity in that direction to the radiation intensity of a reference antenna (isotropic antenna).

$$D_g(\theta,\phi) = 4\pi \frac{U(\theta,\phi)}{P_{rad}}$$

$$D_o = D_g(\theta,\phi)\big|_{max} = 4\pi \frac{U(\theta,\phi)|_{max}}{P_{rad}}$$

$$D_g(\theta,\phi) = 4\pi \frac{U(\theta,\phi)}{\int\int U(\theta,\phi)\ d\Omega} = 4\pi \frac{\frac{r^2}{2\eta}|E_\theta|^2}{\int_0^{2\pi}\int_0^{\pi} \frac{r^2}{2\eta}|E_\theta|^2\ sin\theta\ d\theta d\phi}$$

$$D_g(\theta,\phi) = 4\pi \frac{|E_{\theta max}|^2}{2\pi \int_0^{\pi} |E_\theta|^2\ sin\theta\ d\theta} = 2\frac{|E_{\theta max}|^2}{\int_0^{\pi} |E_\theta|^2\ sin\theta\ d\theta} = \frac{2|E_{\theta max}|^2}{\int F(\theta)\ d\theta}$$

$$U_o = \frac{P_{rad}}{4\pi}$$

$D_g(\theta,\phi)$: directive gain in a given direction.
$U(\theta,\phi)$: radiation intensity in a given direction.
$U(\theta,\phi)|_{max}$: maximum radiation intensity.
U_o: radiation intensity of isotropic antenna.
P_{rad}: radiated power.

Power Gain

power gain of an antenna in a given direction is defined as 4π times the ratio of radiation intensity in that direction to the net power accepted by the antenna from a connected transmitter.

$$G_g(\theta,\phi) = 4\pi \frac{U(\theta,\phi)}{P_{in}}$$

$$\text{Efficiency } \eta = \frac{P_{rad}}{P_{in}} \%$$

$$G_g(\theta,\phi) = 4\pi \frac{U(\theta,\phi)}{P_{rad}} \eta$$

$$G_g(\theta,\phi) = D_g(\theta,\phi)\,\eta$$

$$G_o(\theta,\phi) = G_g(\theta,\phi)\big|_{max} = D_o\eta$$

Half Power Beam Width(HPBW)

Is the angular separation of the points where the main beam of the power pattern equals one half the maximum value. on the field pattern these points corresponding to the value $\frac{1}{\sqrt{2}}$ =0.707

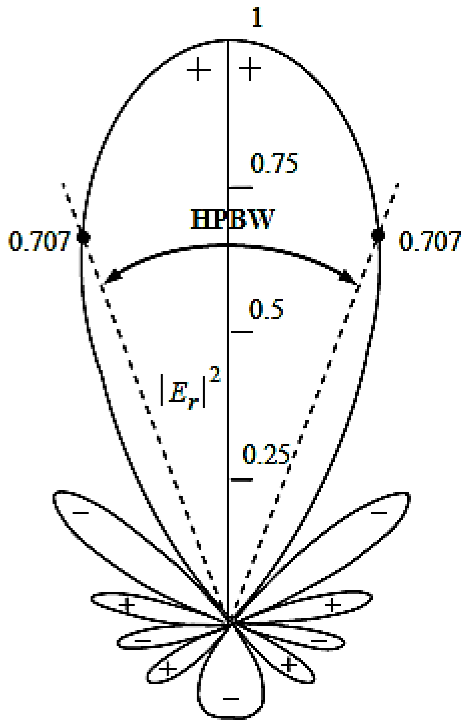

Figure 19 Field pattern (in linear scale).

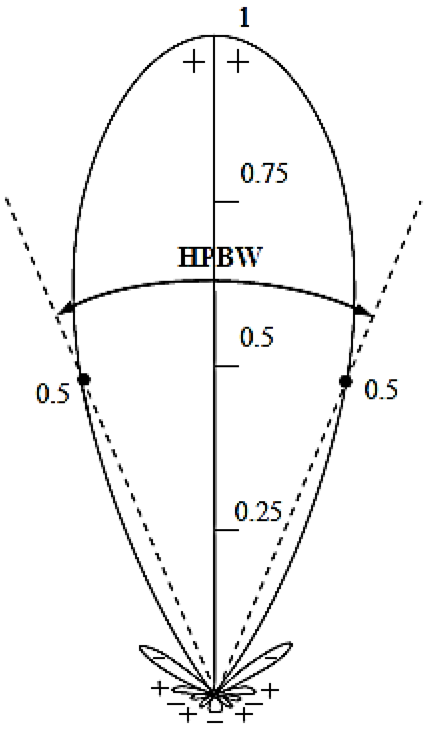

Figure 2.0Power pattern (in linear scale) .

$E(\theta,\phi) = 10 sin\theta$

$0.707(max) = E(\theta,\phi)$

$0.707(10) = 10 sin\theta_h$

$sin\theta_h = 0.707$

$\theta_h = sin^{-1} 0.707 = 45^o$

$\text{HPBW} = 2(90 - \theta_h)$

$\text{HPBW} = 2(90^o - 45^o)$

$\text{HPBW} = 90^o$

or normalization

$E(\theta,\phi)_n = sin\theta$

$0.707(max) = E(\theta,\phi)$

$0.707(1) = sin\theta_h$

$sin\theta_h = 0.707$

$\theta_h = sin^{-1} 0.707 = 45^o$

$\text{HPBW} = 2(90 - \theta_h)$

$\text{HPBW} = 2(90^o - 45^o)$

$\text{HPBW} = 90^o$

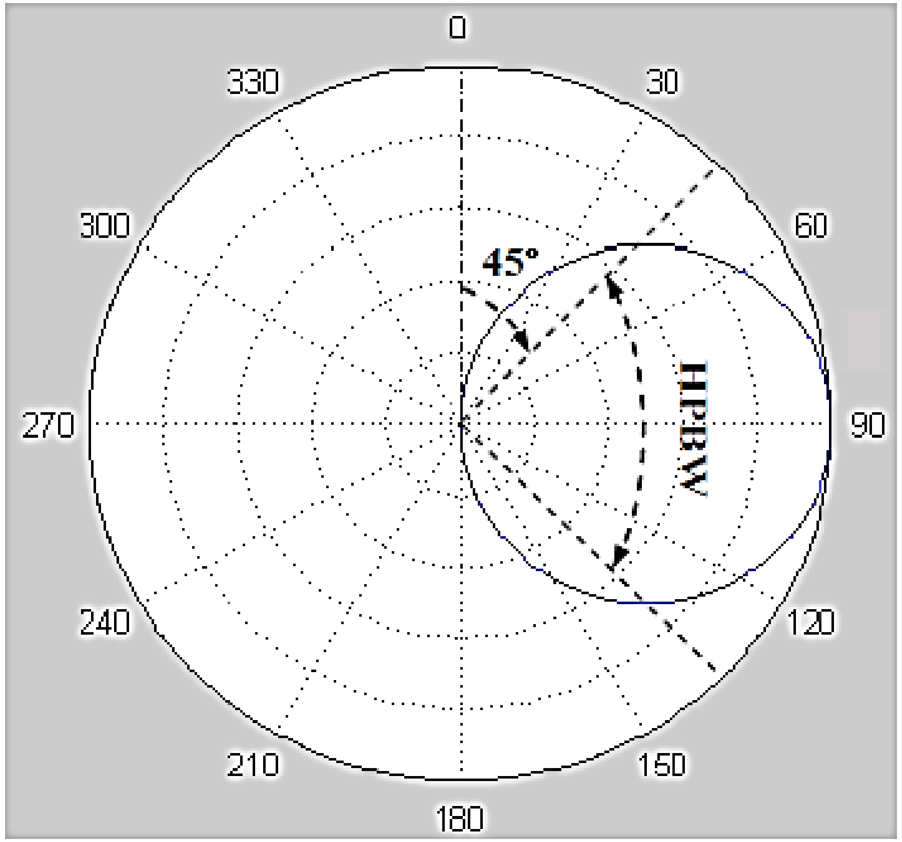

Figure 2 Radiation pattern of the antenna .

note: Field ⟶ 0.5

power ⟶ 0.707

$$E(\theta,\phi) = 10cos\theta$$
$$0.707(max) = E(\theta,\phi)$$
$$0.707(1) = cos\theta_h$$
$$cos\theta_h = 0.707$$
$$\theta_h = cos^{-1}0.707 = 45^o$$
$$\text{HPBW} = 2|0 - \theta_h|$$
$$\text{HPBW} = 2|0 - 45^o|$$
$$\text{HPBW} = 90^o$$

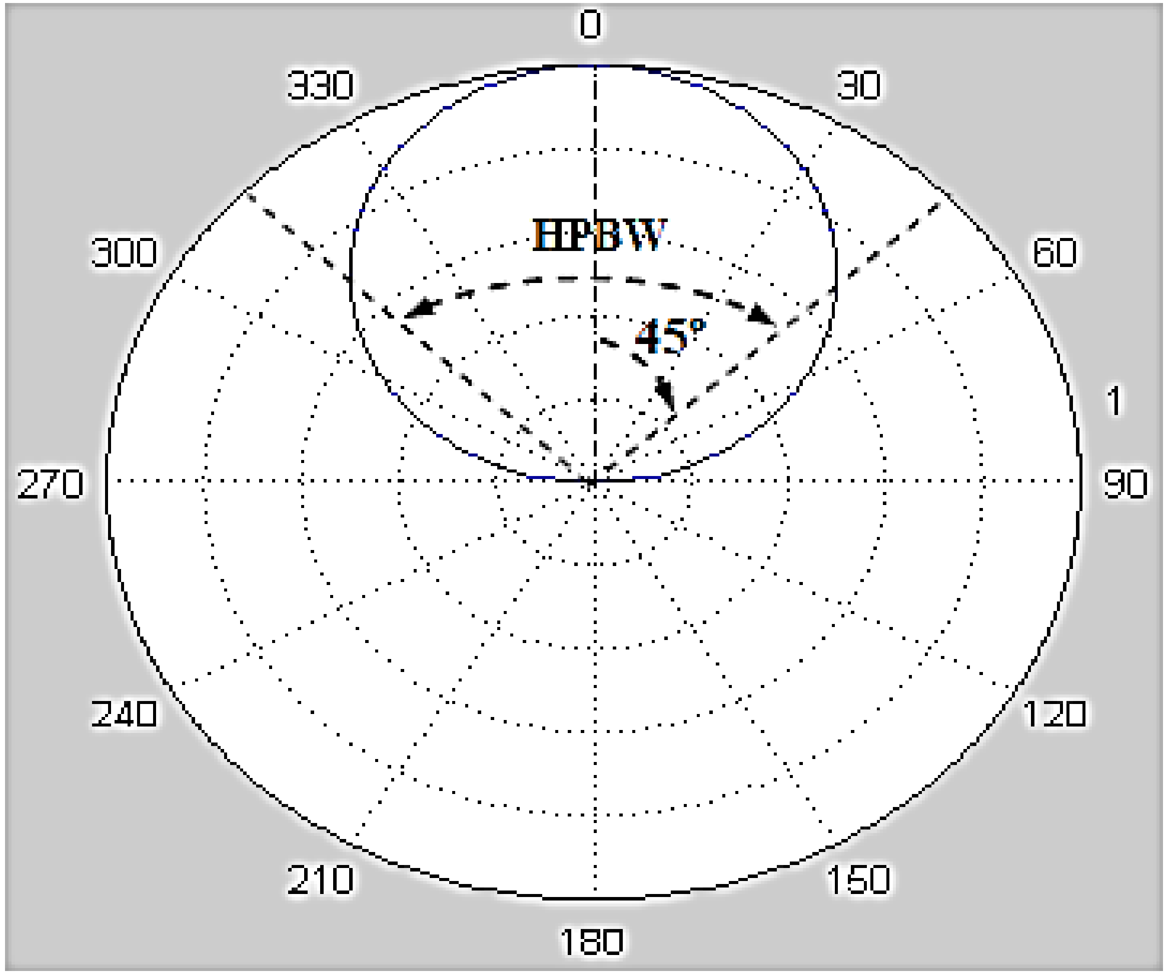

Figure 2. Radiation pattern of the antenna .

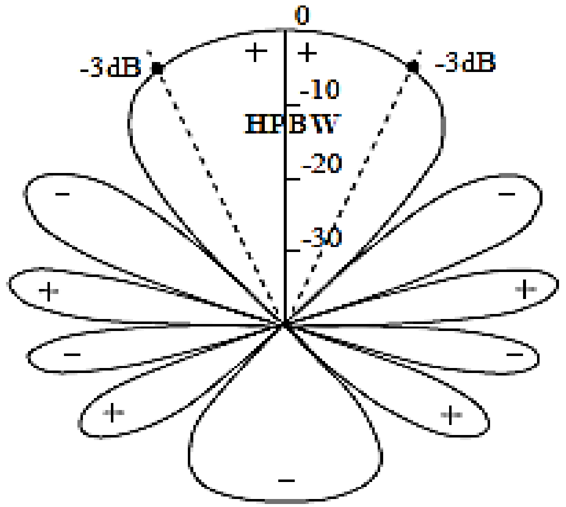

Figure 2 Two dimensional power pattern(in dB).

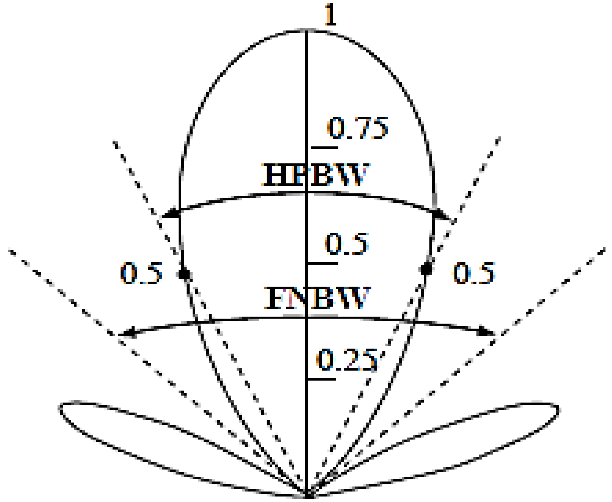

Figure 2 Two dimensional power pattern(in linear scale)

$$U(\theta,\phi) = cos^3\theta$$
$$0.5(max) = U(\theta,\phi)$$
$$0.5(1) = cos^3\theta_h$$
$$cos\theta_h = \sqrt[3]{0.5}$$
$$\theta_h = cos^{-1}\sqrt[3]{0.5} = 37.5^o$$
$$\text{HPBW} = 2|0 - \theta_h|$$
$$\text{HPBW} = 2|0 - 37.5^o|$$
$$\text{HPBW} = 75^o$$

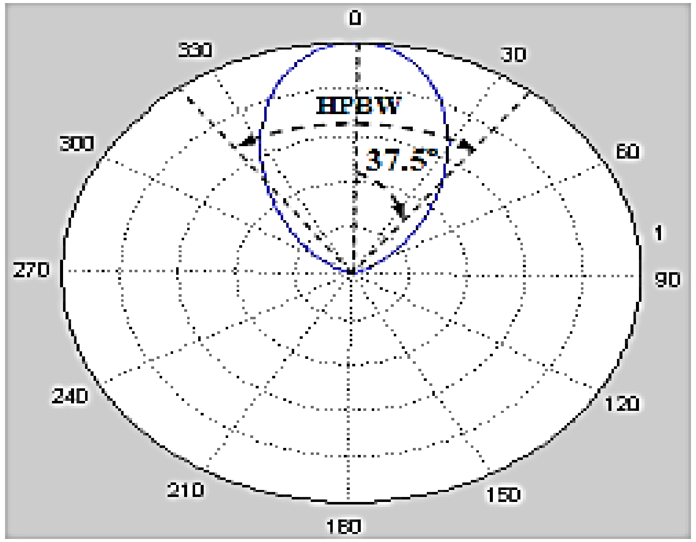

Figure 2. Radiation pattern of the antenna .

Band Width (B.W)

The range of frequency with which the performance of the antenna with respect to some characteristic conforms to a specified standard .

Input Impedance

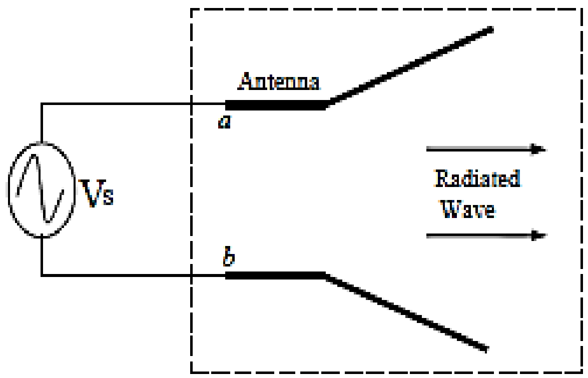

Figure 2.11 transmitting Antenna .

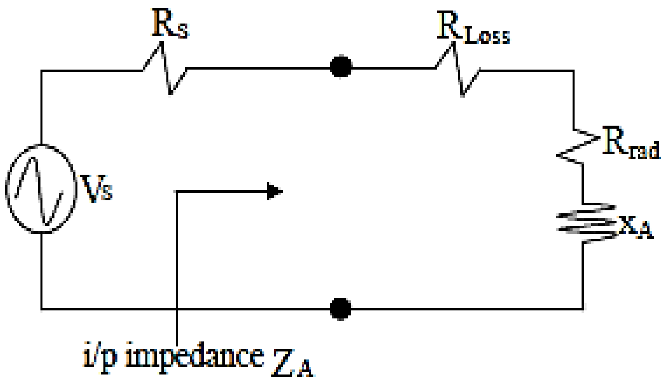

Figure 2.12 Equivalent circuit .

A: Antenna

$$Z_A = R_A + jX_A$$

$$R_A = R_{Loss} + R_{rad}$$

$$R_{Loss} = \frac{L}{\sigma A} = \rho \frac{L}{A}$$ For dc resistance

$$R_{Loss} = \frac{L}{2\pi a}\sqrt{\frac{\omega\mu}{2\sigma}}$$ For high frequencies

L: length of antenna .

a: radius of the antenna .

$$\omega = 2\pi F$$

$$\mu = \mu_r \mu_o$$

σ: conductivity of the antenna

Efficiency

$$\eta = \frac{P_{rad}}{P_{in}} \Rightarrow \eta = \frac{R_{rad}}{R_A}$$

$$\eta = \frac{R_{rad}}{R_{rad}+R_{Loss}}$$

$$G_g(\theta,\phi) = 4\pi\frac{U(\theta,\phi)}{P_{rad}}\eta$$

$$G_g(\theta,\phi) = D_g(\theta,\phi)\,\eta \Rightarrow G_o(\theta,\phi) = G_g(\theta,\phi)\big|_{max} = D_o\eta$$

$$\eta = \frac{G_g(\theta,\phi)\big|_{max}}{D_o}$$

Friis Transmission Equation

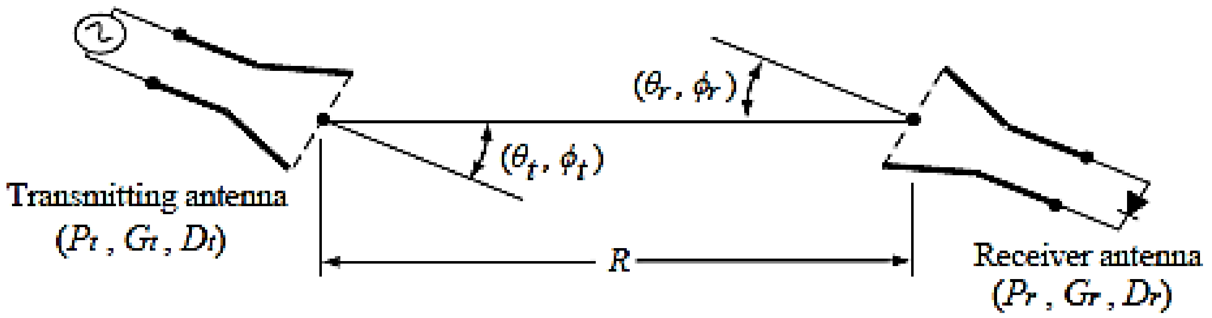

Figure 2.13 Geometrical orientation of transmitting and receiving antennas for Friis transmission equation

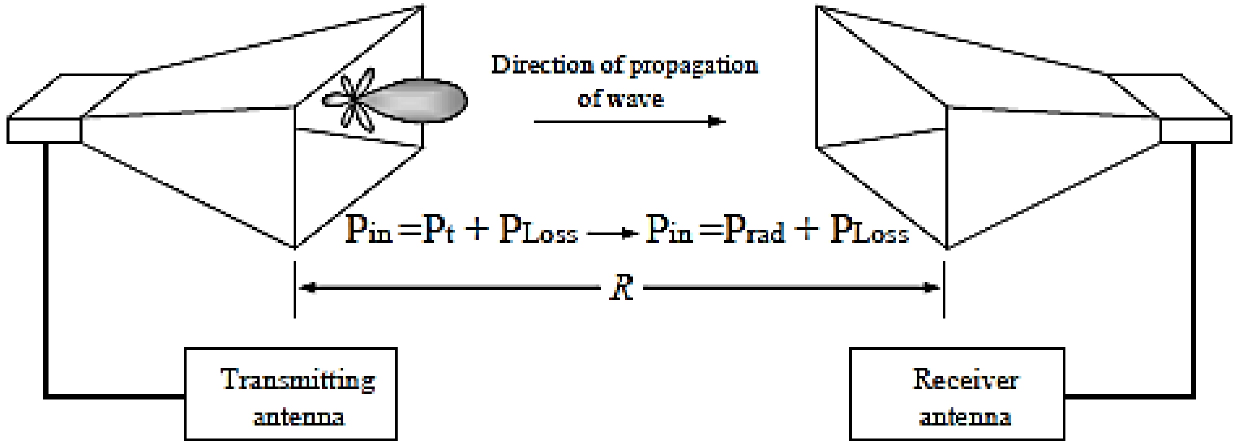

Figure 2.14 Two antennas separated by a distance R.

$$P_r = P_t G_t G_r \left(\frac{\lambda}{4\pi R}\right)^2$$

P_r: received power

Example 2.1 The radiated power density of an antenna is given by:

$$\overrightarrow{W_{av}} = \frac{A_o \, sin\theta}{r^2} \vec{a}_r \ \ \frac{w}{m^2}$$

Determine: 1-The total radiated power.

2-radiation intensity.

3-Directivity.

The solution:- $P_{rad} = \int\int \overrightarrow{W}_{av} \ . \overrightarrow{ds}$, $\overrightarrow{ds} = r^2 sin\theta \ d\theta d\phi \vec{a}_r$

1- $$P_{rad} = \int_0^{2\pi} \int_0^{\pi} \frac{A_o \, sin\theta}{r^2} \vec{a}_r \ . r^2 sin\theta \ d\theta d\phi \vec{a}_r = 2\pi A_o \int_0^{\pi} sin^2\theta = \pi^2 A_o \text{ watt}$$

2- $U(\theta, \phi) = r^2 W_{av}$

$$U(\theta, \phi) = r^2 \frac{A_o \, sin\theta}{r^2} = A_o sin\theta$$

3- $$D_o = 4\pi \frac{U(\theta,\phi)|_{max}}{\int\int U(\theta,\phi) \ d\Omega} = 4\pi \frac{A_o}{\int_0^{2\pi} \int_0^{\pi} A_o sin\theta \, sin\theta \ d\theta d\phi} = \frac{4\pi}{2\pi \int_0^{\pi} sin^2\theta \ d\theta}$$

$$D_o = \frac{4\pi}{2\pi \frac{\pi}{2}} = \frac{4}{\pi} = 1.27$$

Example 2.2 The radiated power density of an antenna is given by:

$$\overrightarrow{W_{rad}} = \frac{A_o \sin^2\theta}{r^2}\vec{a}_r \ \frac{\text{w}}{m^2}$$

Determine: 1-The total radiated power.

2- radiation intensity.

3-Directivity. note: $\int_0^{\pi} \sin^3\theta = \frac{4}{3}$

The solution:- $P_{rad} = \int\int \overrightarrow{W_{av}} \ . \overrightarrow{ds}$

1- $P_{rad} = \int_0^{2\pi}\int_0^{\pi} \frac{A_o \sin^2\theta}{r^2}\vec{a}_r \ . r^2 \sin\theta \ d\theta d\phi \vec{a}_r = 2\pi A_o \int_0^{\pi} \sin^3\theta = \frac{8\pi}{3} A_o \text{watt}$

2- $U(\theta,\phi) = r^2 W_{av}$

$$U(\theta,\phi) = r^2 \frac{A_o \sin^2\theta}{r^2} = A_o \sin^2\theta$$

3- $D_o = 4\pi \frac{U(\theta,\phi)|_{max}}{\int\int U(\theta,\phi) \ d\Omega} = 4\pi \frac{A_o}{\int_0^{2\pi}\int_0^{\pi} A_o \sin^2\theta \sin\theta \ d\theta d\phi} = \frac{4\pi}{2\pi \int_0^{\pi} \sin^3\theta \ d\theta}$

$$D_o = \frac{4\pi}{2\pi \frac{4}{3}} = \frac{3}{2} = 1.5$$

Example 2.3 An antenna has a field pattern given by $E(\theta) = \cos\theta \cos 2\theta$ for $0 \le \theta \le 90^o$ Find HPBW .

The solution:- $0.707(\max) = \cos\theta \cos 2\theta$

$0.707(1) = \cos\theta \cos 2\theta$

$\cos\theta_h = \frac{0.707}{\cos 2\theta}$

$\theta_h = \cos^{-1}\left(\frac{0.707}{\cos 2\theta}\right)$

$\theta_h = 20.5^o$

HPBW= $2 \times 20.5^o = 41^o$

θ	$E(\theta)$
0	1
30°	0.75
45°	0.5
60°	0.25
90°	0

Example 2.4 The radiation intensity of an antenna is represented by: $U(\theta) = \cos^2\theta \cos^2 3\theta$ for $0 \le \theta \le 90^o$ Find HPBW .

The solution:- $0.5(\max) = \cos^2\theta \cos^2 3\theta$

$0.5 = \cos^2\theta \cos^2 3\theta$

$0.707 = \cos\theta \cos 3\theta$

$\cos\theta_h = \frac{0.707}{\cos 3\theta}$

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

$\theta_h = 14.375^o$

HPBW= $2 \times 14.375^o = 28.75^o$

θ	$E(\theta)$
0	1
30°	0.75
45°	0.5
60°	0.25
90°	0

Thank You