Antenna & Wave Propagation

(EC0602)

Unit-1

B.Tech. (Electronics and Communication)

Semester-VI

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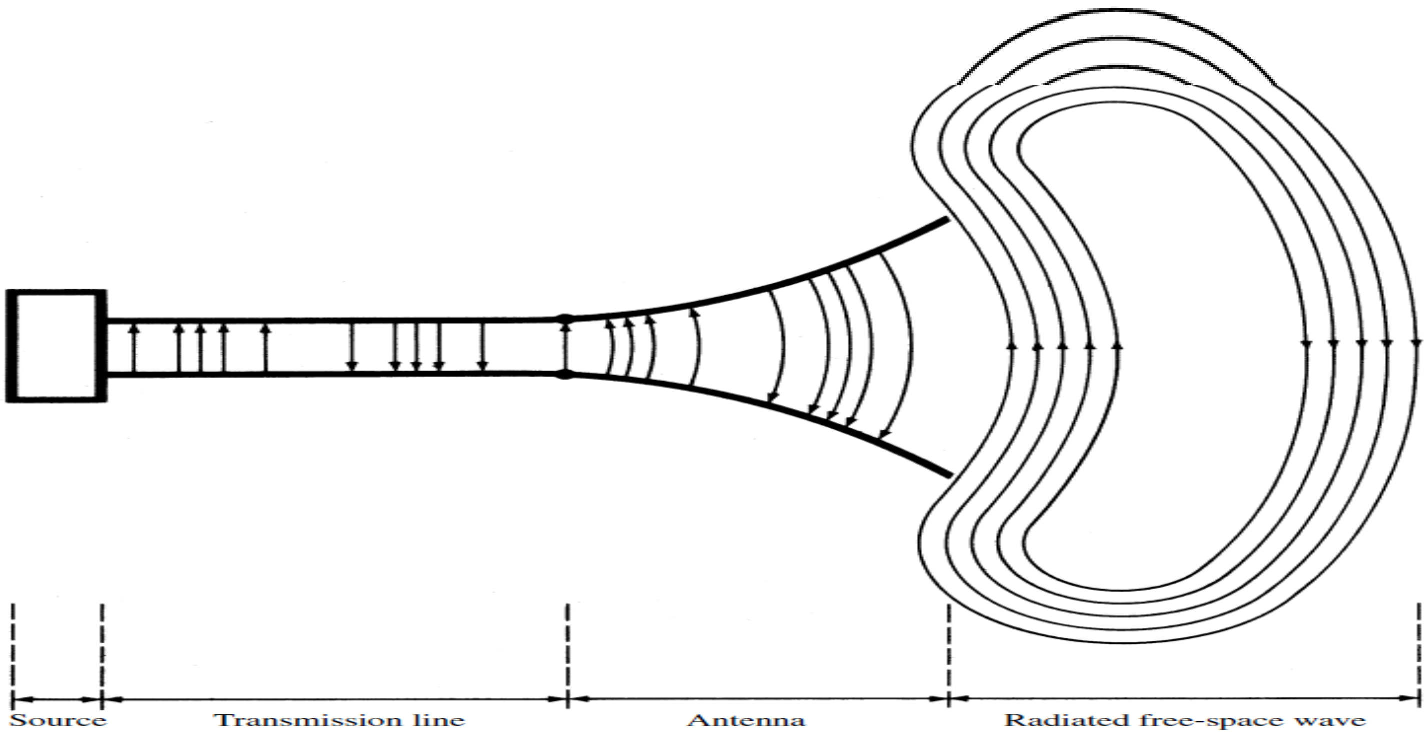
Basic Antenna Concepts

Definitions of Antenna

- **Antenna is a metallic device (as a rod or wire) for radiating or receiving radio waves.**
- As per IEEE, antenna is a device which radiating or receiving radio waves.
- Antenna is a transition device, or transducer, between a guided wave and a free-space wave, or vice-versa.

Definitions

- **Transmitting antenna** convert electrical energy in to RF waves.
- **Receiving antenna** convert RF waves in to electrical signal.

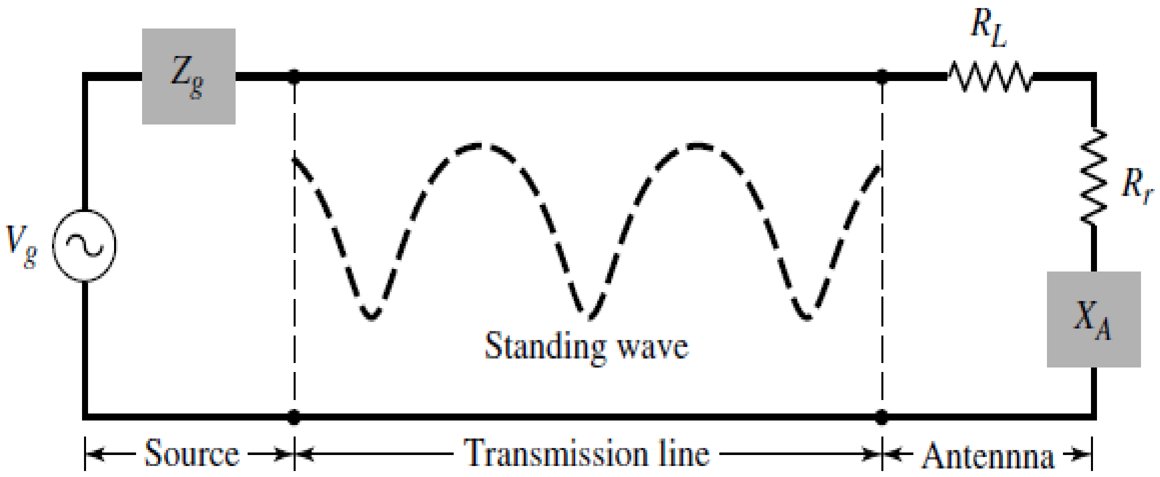


Transmission Line and Antenna

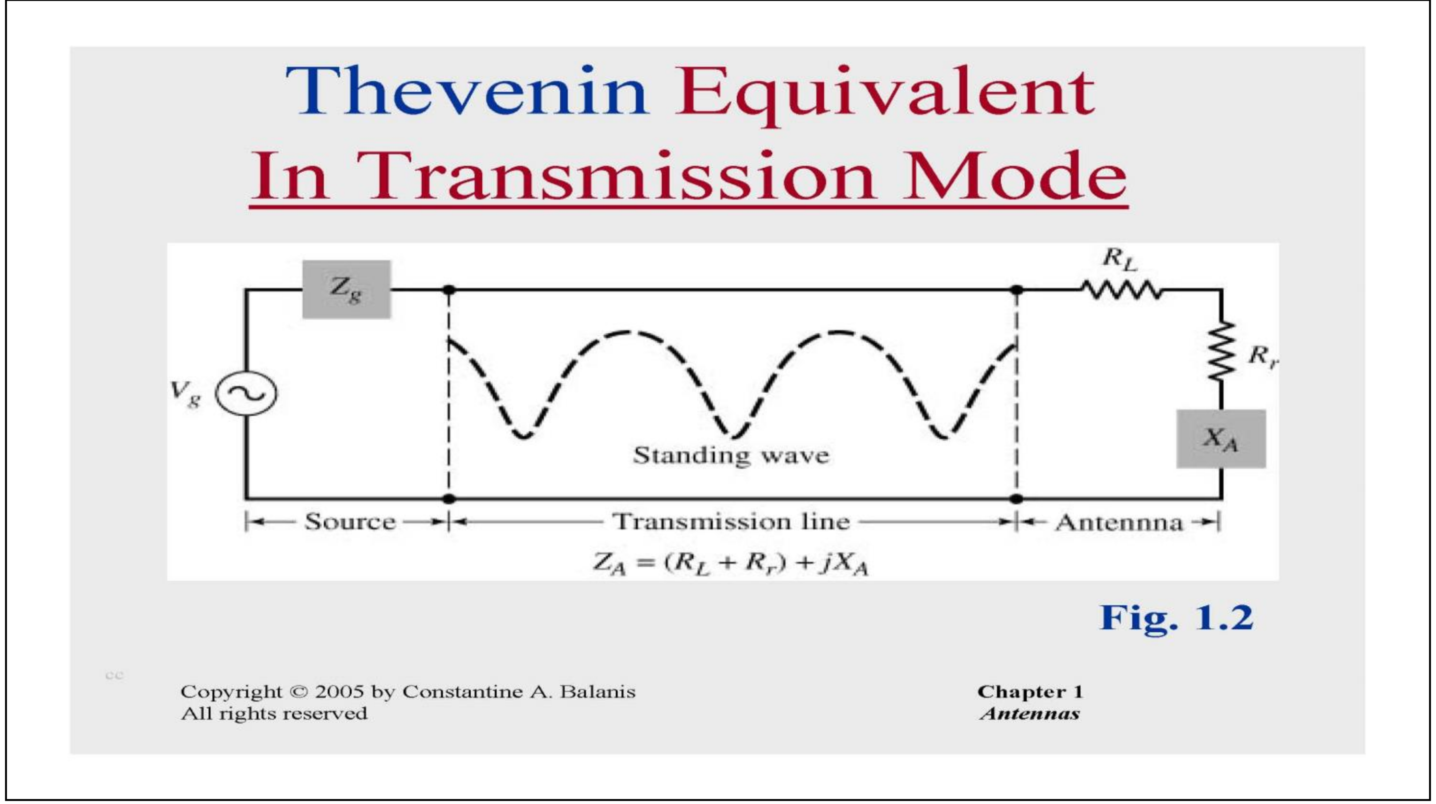
- In transmission line, energy is guided as a plane transverse electromagnetic mode wave with little loss.
- The spacing between wire is assumed to be small fraction of a wavelength.
- As the separation approaches the order of a wavelength or more, the wave tends to be radiated and transmission line becomes antenna.

Continue

- The guiding device or transmission line may take the form of a coaxial line or a hollow pipe (waveguide), and it is used to transport electromagnetic energy from the transmitting source to the antenna, or from the antenna to the receiver.



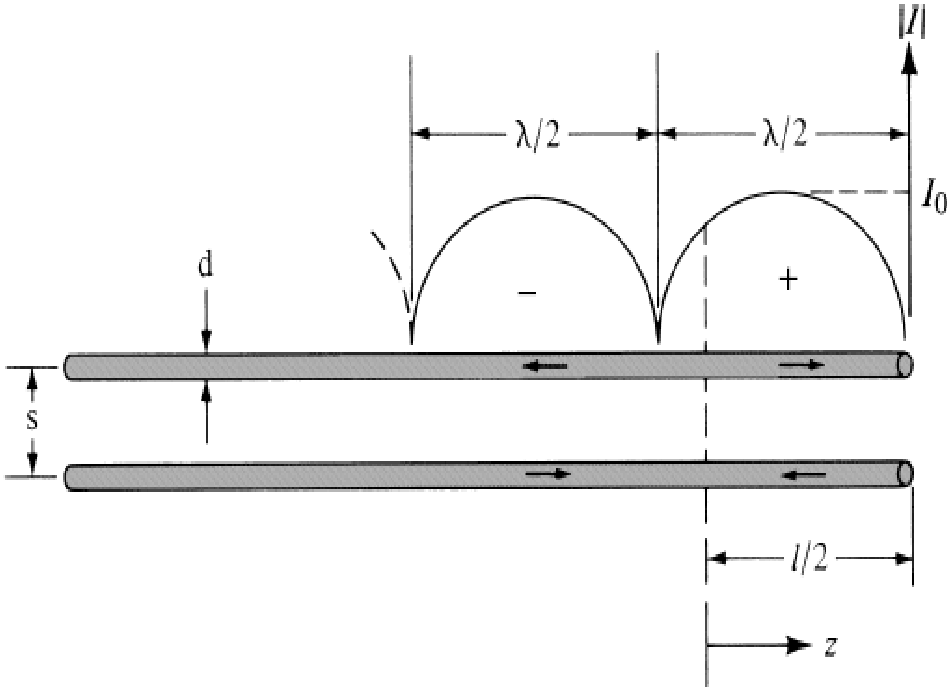
$$Z_A = (R_L + R_r) + jX_A$$



- The transmission line is represented by a line with characteristic impedance Zc, and the antenna is represented by a load ZA [ZA = (RL + Rr) + jXA] connected to the transmission line.
- The load resistance RL is used to represent the conduction and dielectric losses associated with the antenna structure
- Rr , referred to as the radiation resistance, is used to represent radiation by the antenna.

- The reactance XA is used to represent the imaginary part of the impedance associated with radiation by the antenna.
- Under ideal conditions, energy generated by the source should be totally transferred to the radiation resistance Rr , which is used to represent radiation by the antenna.

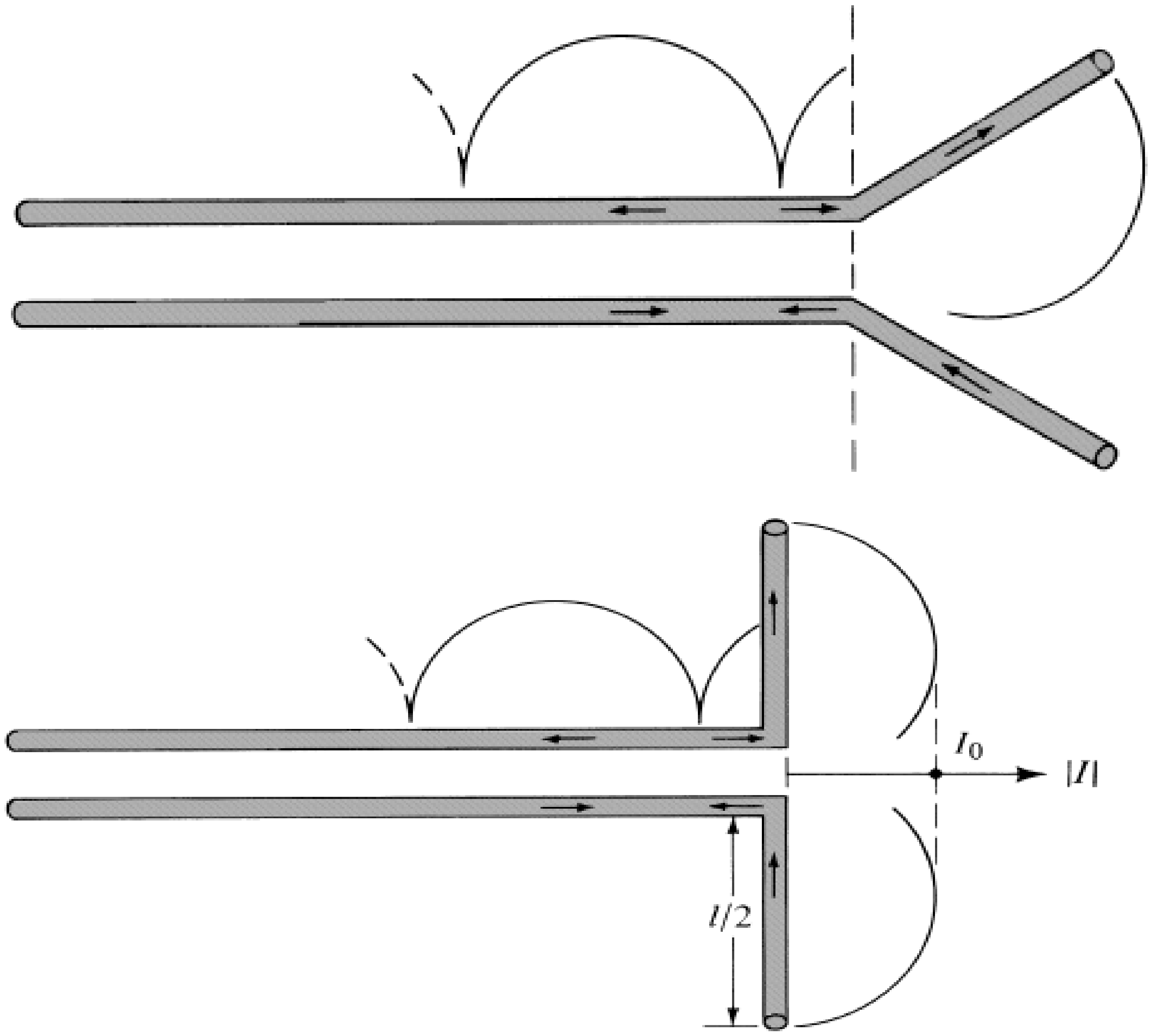
Current Distribution On A Thin Wire Antenna & its radiation Mechanism



- The movement of the charges creates a traveling wave current, along each of the wires. When the current arrives at the end of each of the wires, it undergoes a complete reflection.

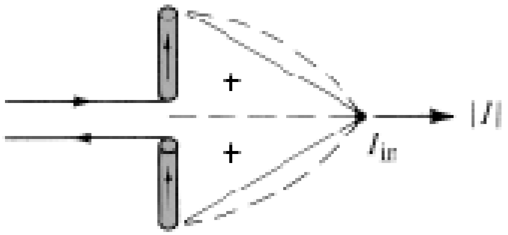
The reflected travelling wave, when combined with the incident travelling wave, forms in each wire a pure standing wave pattern of sinusoidal form.

- For the two-wire balanced (symmetrical) transmission line, the current in a half cycle of one wire is of the same magnitude but 180◦ out-of-phase from that in the corresponding half-cycle of the other wire. If in addition the spacing between the two wires is very small ($s<<\lambda$), the fields radiated by the current of each wire are essentially cancelled by those of the other. The net result is an almost ideal, non radiating transmission line.
- As the section of the transmission line begins to flare, it can be assumed that the current distribution is essentially unaltered uniform in each of the wires. However, because the two wires of the flared section are not necessarily close to each other, the fields radiated by one do not necessarily cancel those of the other. Therefore ideally there is a net radiation by the transmission line system.

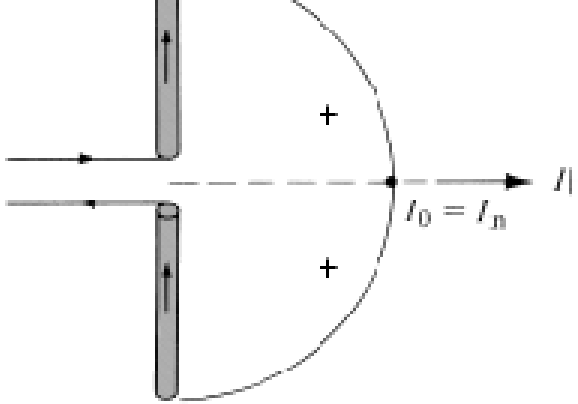


I_0
$|I|$
$l/2$

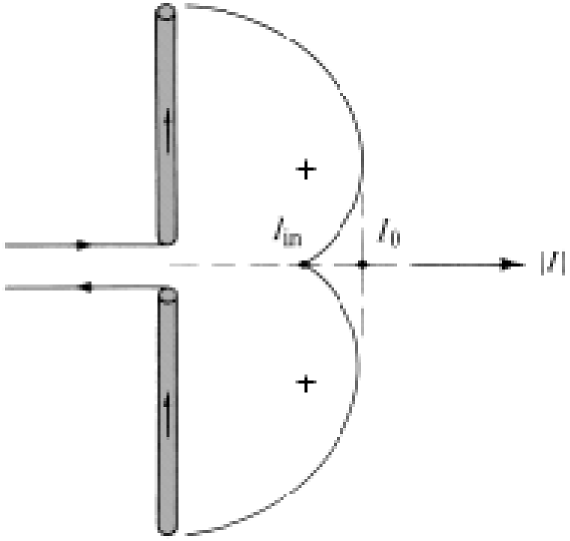
CURRENT DISTRIBUTION ON LINEAR DIPOLES



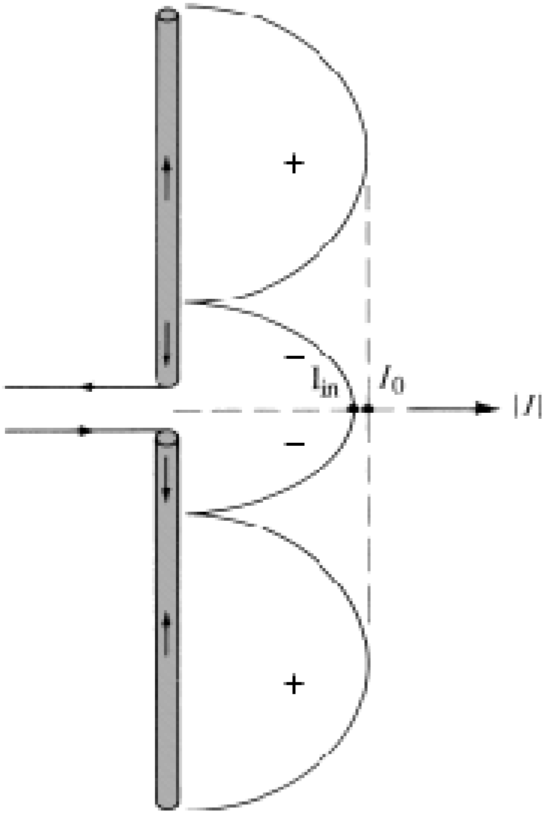
(a) $l << \lambda$



(b) $l = \lambda/2$



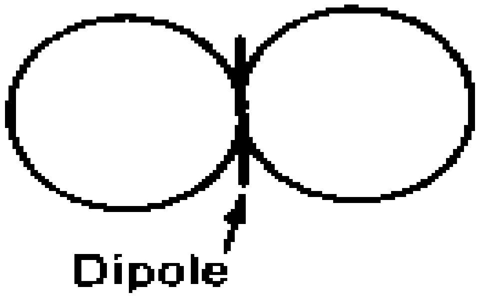
(c) $\lambda/2 < l < \lambda$



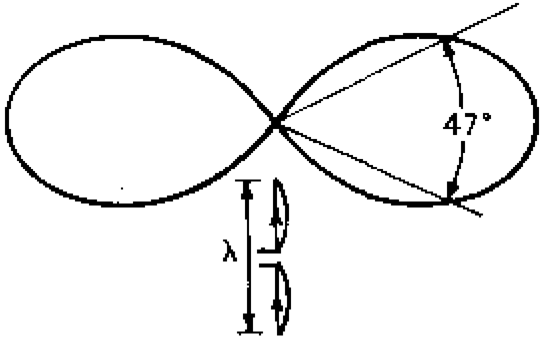
(d) $\lambda < l < 3\lambda/2$

Dipole antenna and its radiation pattern

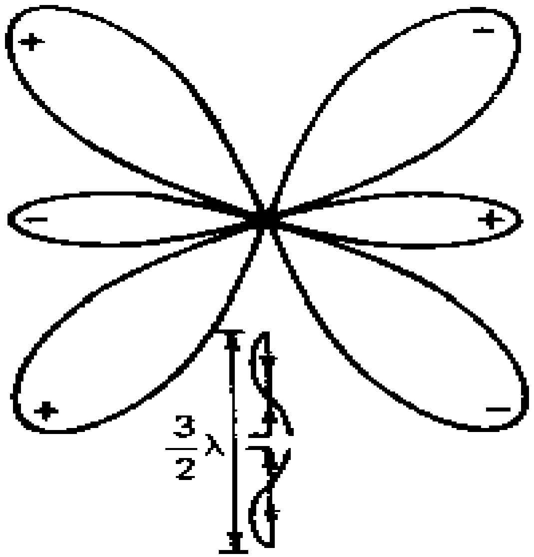
- The radiation pattern of the half wave dipole is as shown in fig.



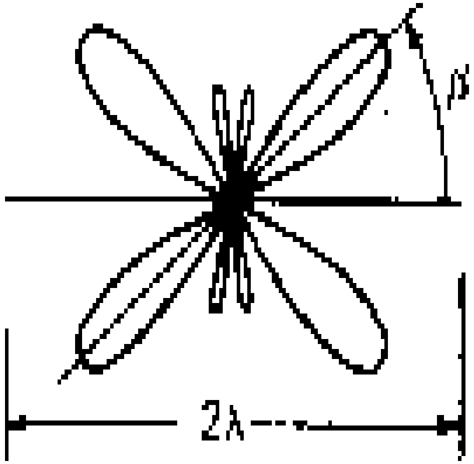
- The radiation pattern of full wave dipole is as shown in fig.



- The radiation pattern of the 3λ/2 dipole is as shown in fig.

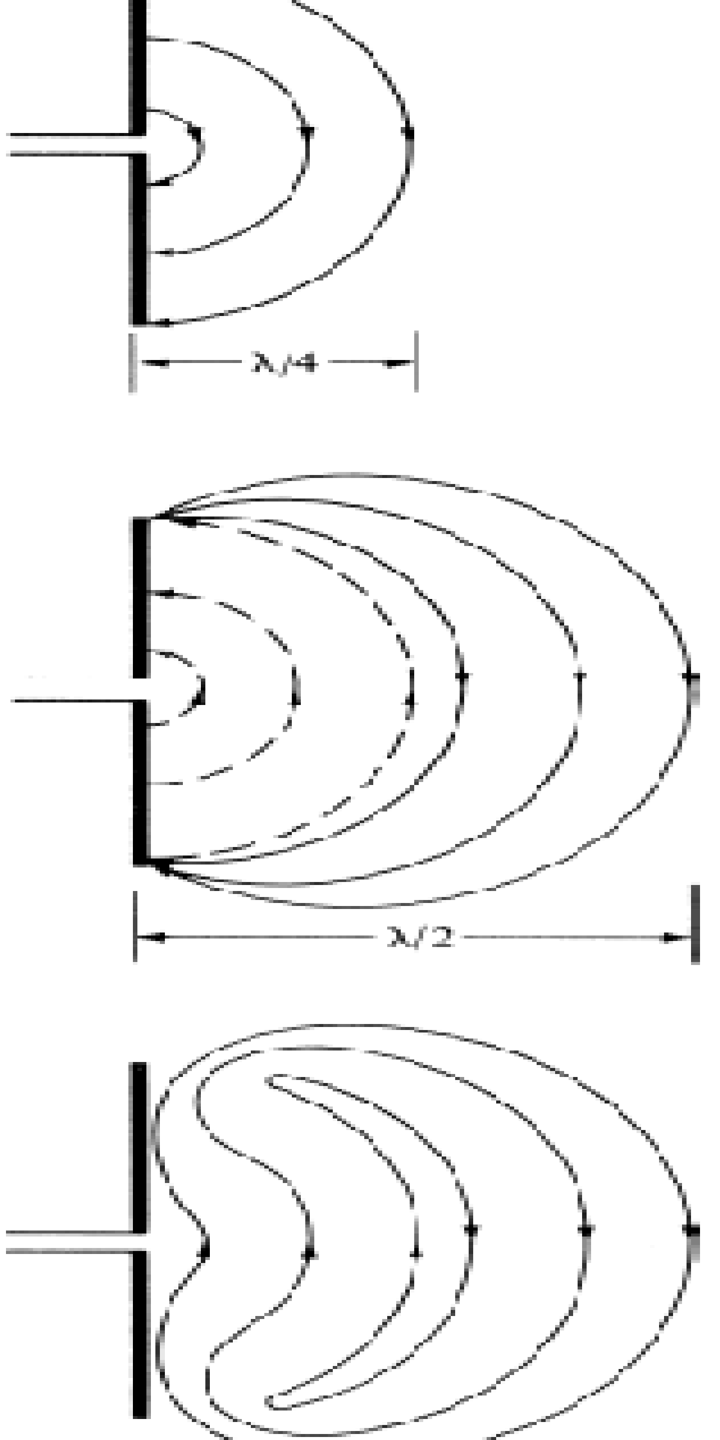


- The radiation pattern of 2 λ dipole is as shown in fig.



How the electric lines of force are detached from the antenna to form the free-space waves.
Example: Dipole

- Figure 1.14(a) displays the lines of force created between the arms of a small center-fed dipole in the first quarter of the period during which time the charge has reached its maximum value (assuming a sinusoidal time variation) and the lines have traveled outwardly a radial distance *λ/4.*
- During the next quarter of the period, the original three lines travel an additional *λ/4 (a total of λ/2 from the* initial point) and the charge density on the conductors begins to diminish.



(a) $t = T/4$ (T = period)

(b) $t = T/2$ (T = period)

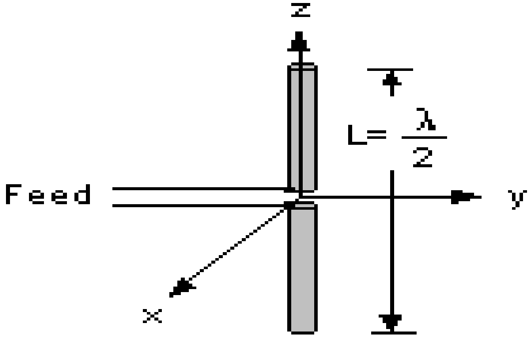
(c) $t = T/2$ (T = period)

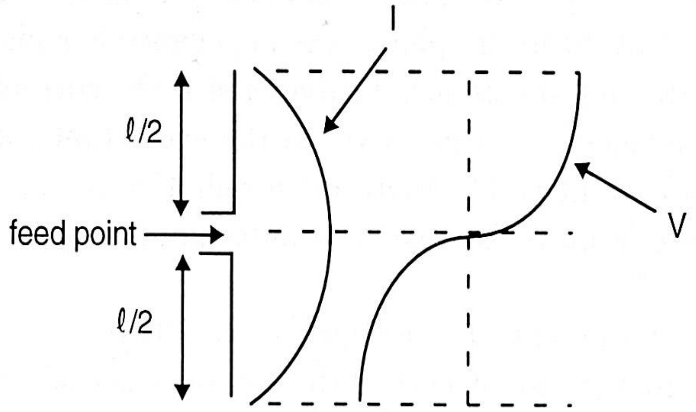
Continue

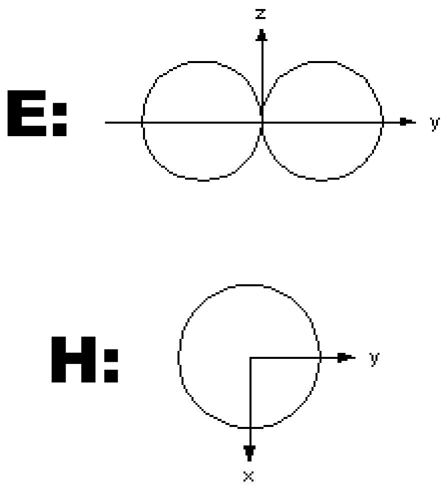
- The lines of force created by the opposite charges are three and travel a distance *λ/4 during* the second quarter of the first half, and they are shown dashed in Figure 1.14(b).
- Since there is no net charge on the antenna, then the lines of force must have been forced to detach themselves from the conductors and to unite together to form closed loops.
- In the remaining second half of the period, the same procedure is followed but in the opposite direction. After that, the process is repeated and continues indefinitely and electric field patterns.

Types of Antenna: 1. Wire Antennas

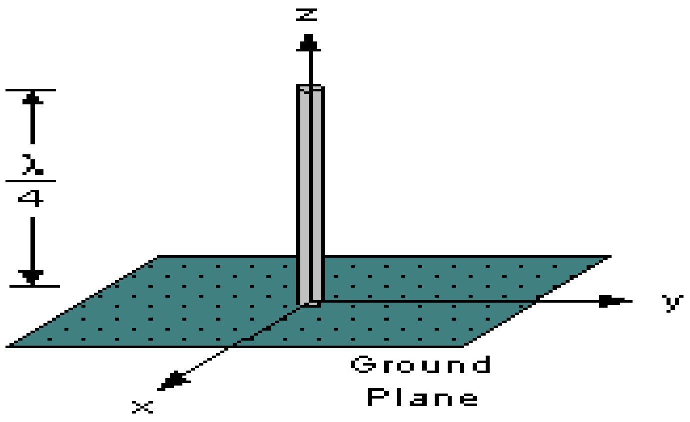
½ Wave Dipole

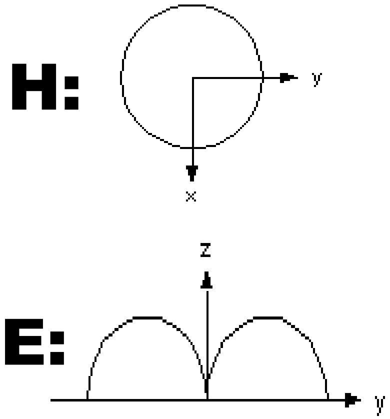






¼ Wave Monopole





Continue

- The world's most popular antenna is the half-wave dipole. This means that the total length of the antenna is equal to half of the wavelength of the signal you're trying to transmit or receive.
- The dipole is fed by a two wire line where the two currents are equal in amplitude but opposite in direction.
- This shows the current distribution; the ends are essentially an open circuit, so most of the energy is radiated out the center of the antenna. The electric field radiates in a donut shaped pattern around the dipole axis, and the magnetic field radiates in a circle outward from the antenna.
- The quarter-wave monopole is very similar; it basically consists of one-half a dipole plus a perfectly conducting plane. Most of the parameters are halved, including the total power radiated.

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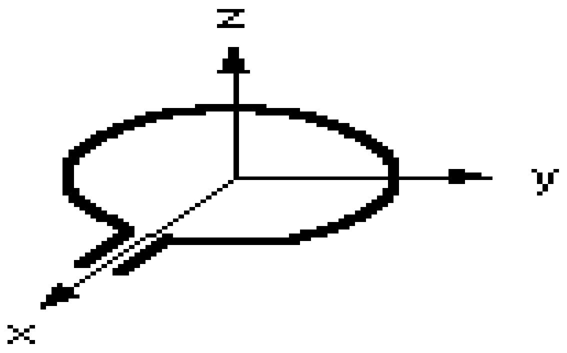
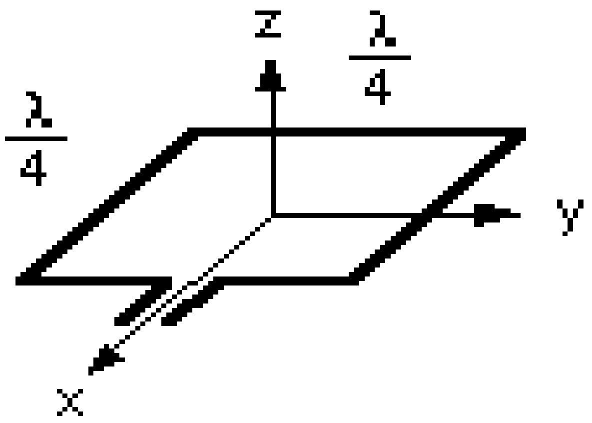
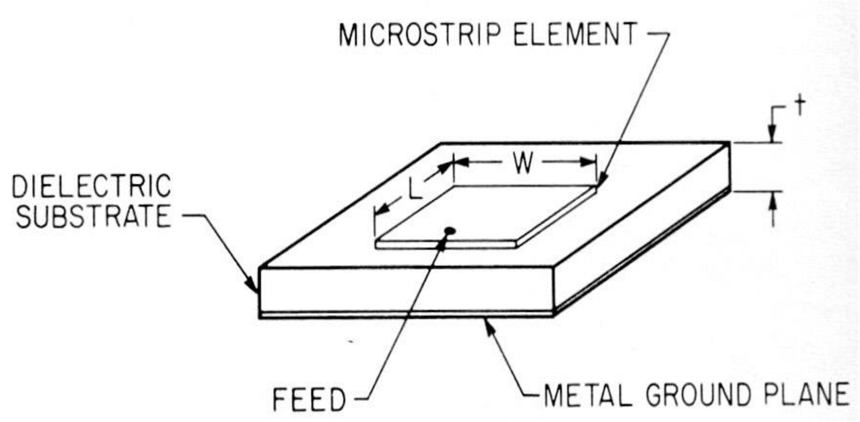
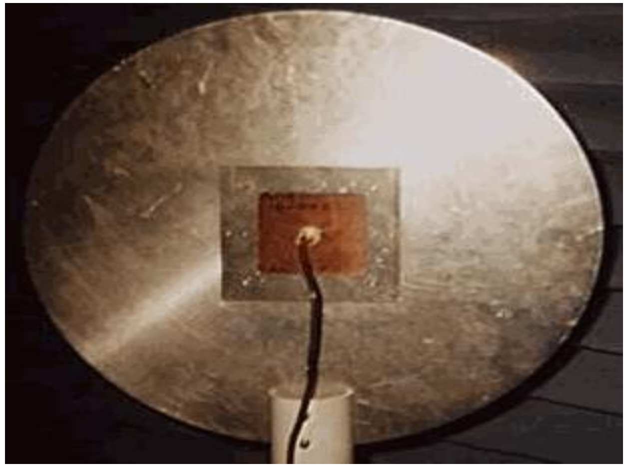
Loop Antennas





Micro-strip Antennas





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- A third type of antenna is the loop antenna. These are very useful as receivers, especially for low frequencies when dipoles would become very large.
- Microstrip or patch antennas are often manufactured directly on a printed circuit board. The dielectric between the two rectangular conductors is simply the printed-circuit substrate. These antennas are generally built for devices that require small antennas, leading to frequencies usually in the gigahertz.

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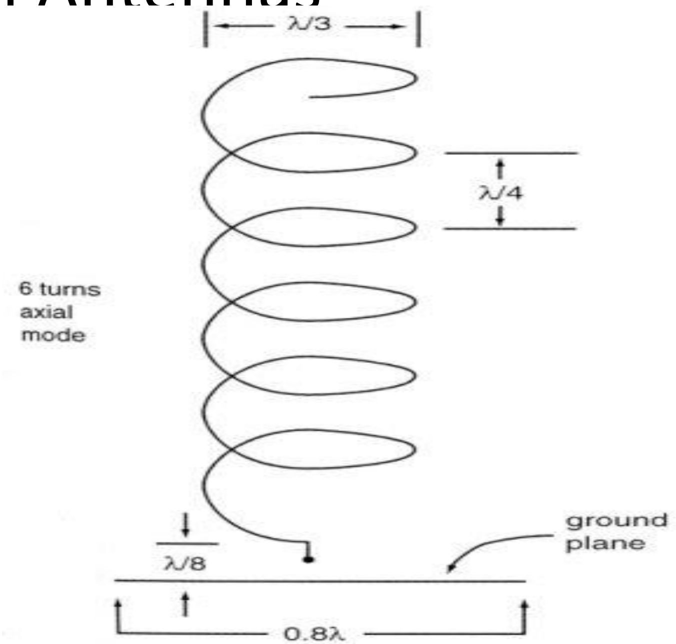
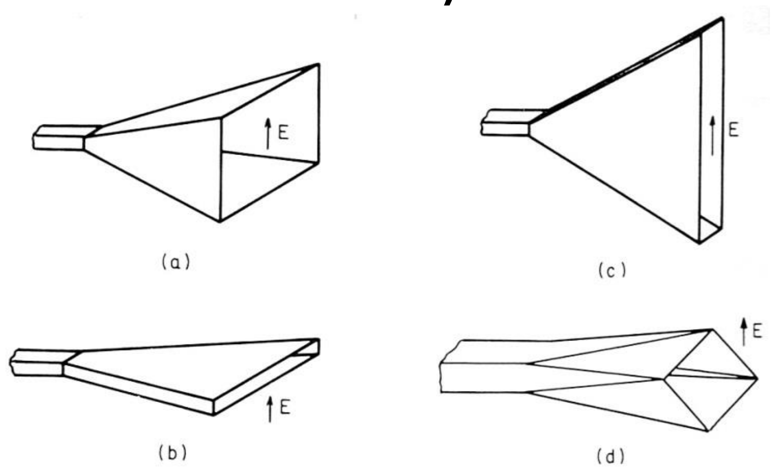
Helical Antennas



Horn Antennas Antennas)



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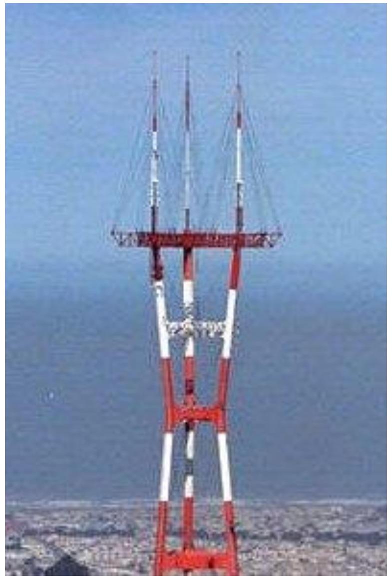
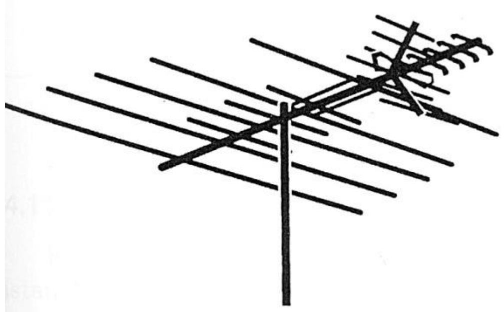
- Helical antennas are used because they are circularly polarized. This means that they radiate in both the vertical and horizontal directions, unlike the dipole which only radiates normal to its axis.
- Horn antennas are obviously very directional. The shape of the horn determines if the electric or magnetic fields are maximized. The gain is very high in the direction of the horn’s axis.

Antenna Applications

VHF and UHF Antennas



Transmitting Tower



UHF/VHF/FM
Receiving Antenna

Continue

- Another application for antennas is VHF and UHF antennas, which stand for Very High Frequency and Ultra High Frequency.
- You've all seen the tall transmitting towers. They need to be large enough to achieve the desired frequency and provide a large range of coverage. VHF and UHF covers frequencies from 3 MHz to 3000 MHz and includes television and FM radio broadcasting.
- The most common type of receiving antenna is called a Yagi array antenna. The array has different size conductors to receive different frequencies. Yagi arrays are highly directional, so they should always be pointed towards the transmitter tower.

Antenna Applications

Wireless Communications

¼ Wave Helical

¼ Wave 2-in-1

¼ Wave Whip

Continue

- Antennas have lots of applications in wireless communications. Many different types of antennas can be used, and they all have their own advantages. Two common antennas are the quarter wave helical and quarter wave whip antennas.

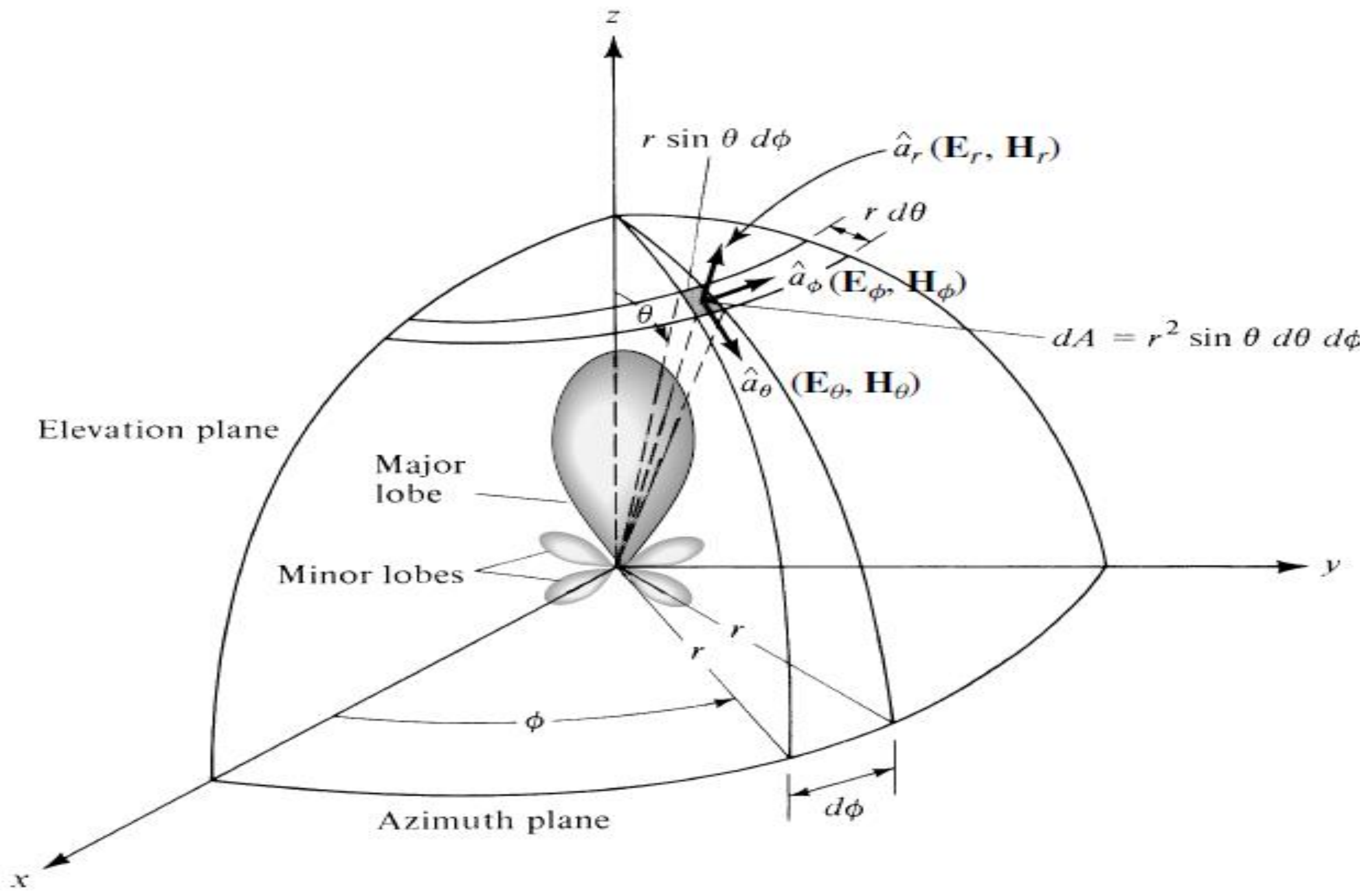
- The whip, which is the same as a monopole, is the most common antenna for cellular phones, and is typically used in the 400 to 500 MHz range. The quarter wave helical antenna is smaller than the whip and has similar performance. Lately it is used in the 800 to 1000 MHz bands. Another antenna you've probably seen is the retractable antenna.

Antenna Parameters and Definitions

Antenna Parameters

- Radiation Pattern & lobes
- HPBW & FNBW
- Beam Area
- Radiation density & radiation intensity
- Beam efficiency
- Directivity & gain (antenna efficiency)
- Antenna Aperture
- Polarization
- Antenna effective height

Radiation Pattern of Antenna Field



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- 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.
- Radiation properties include power flux density, radiation intensity, field strength, directivity, phase or polarization.

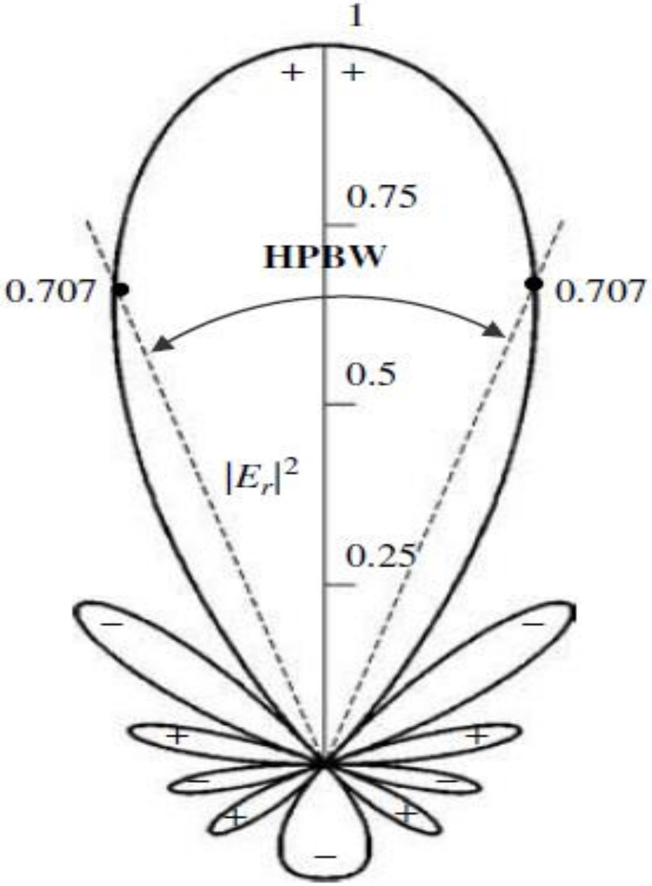
Continue

- 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.
- Various parts of a radiation pattern are referred to as lobes, which may be sub classified into major or main, minor, side, and back lobes.

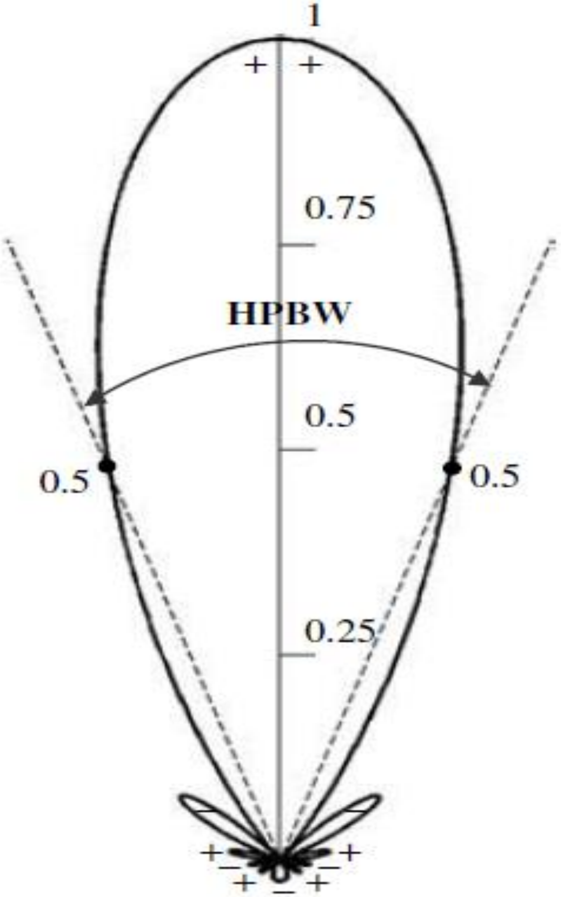
Radiation lobes

- Radiation lobe: portion of radiation pattern bounded by regions of relatively weak radiation intensity
- Major lobe: radiation lobe in the direction of maximum radiation (θ=0)
- Minor lobe: other lobes except major lobe
- Side lobe: radiation lobe in any other direction than intended lobe
- Back lobe: radiation lobe whose axis makes an angle of 180° w.r. to beam of antenna. (θ=π)

HPBW & FNBW

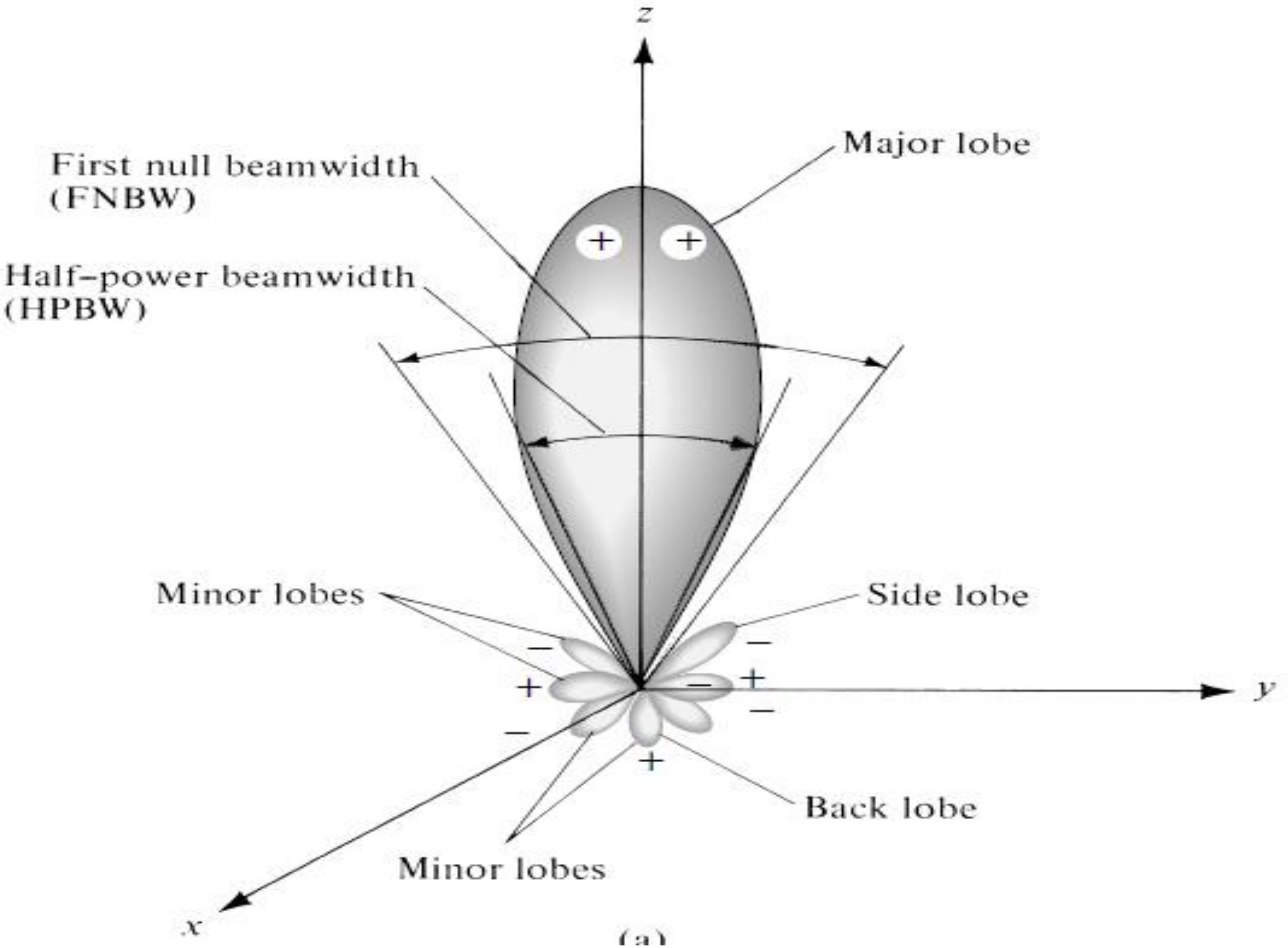


Field pattern



power pattern

HPBW & FNBW



z
Major lobe
First null beamwidth
(FNBW)
Half-power beamwidth
(HPBW)
Minor lobes
Side lobe
y
Back lobe
Minor lobes
x

(a)

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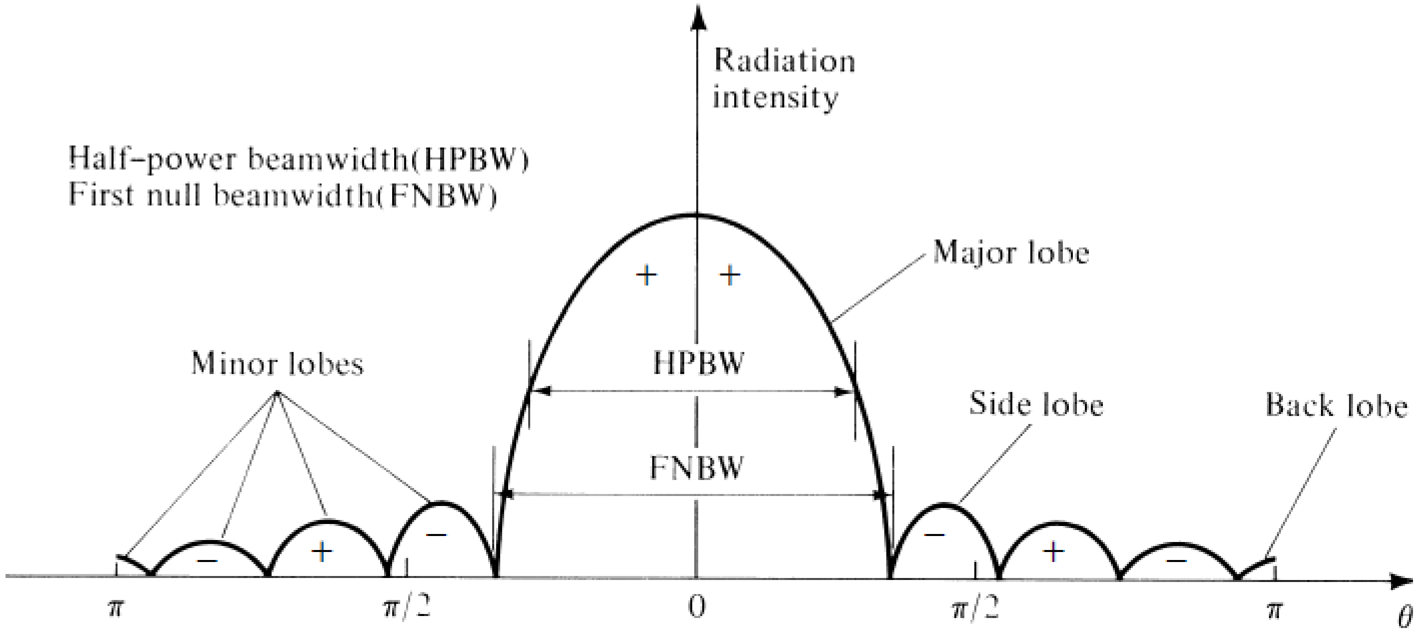
- The angular beam width at the half-power level or half power beam width (HPBW) or -3 dB beam width and beam width between first nulls (FNBW) are shown in figure.

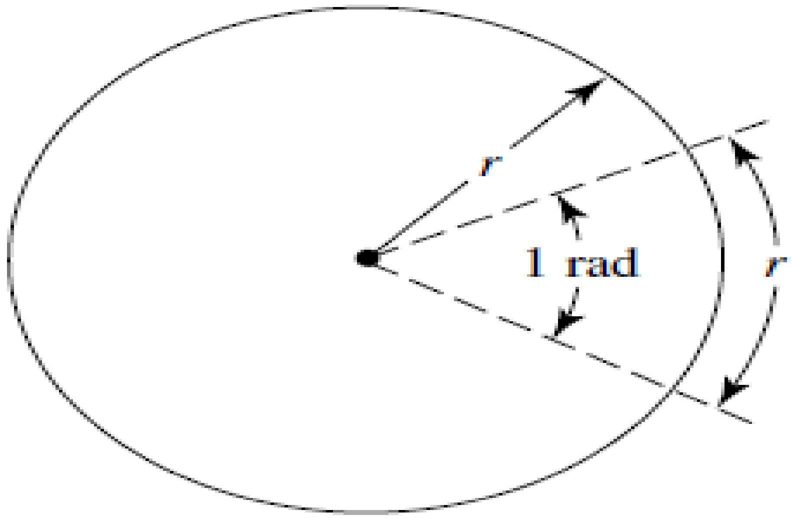


Type of Radiators

- Isotropic Radiator: “lossless antenna having equal radiation in all directions”
- Directional antenna: “having the property of radiating or receiving EM waves more effectively in some directions than in others”
- Sp. Case: Omni directional Antennas: “having directional pattern in orthogonal plane and non directional pattern in other plane”

Plane Angle & Solid Angle

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



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- The measure of a solid angle is a steradian.
- One steradian is defined as the solid angle with its vertex at the centre 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 = 4πr, there are 4π sr (4πr/r) in a closed sphere.

2 2 2

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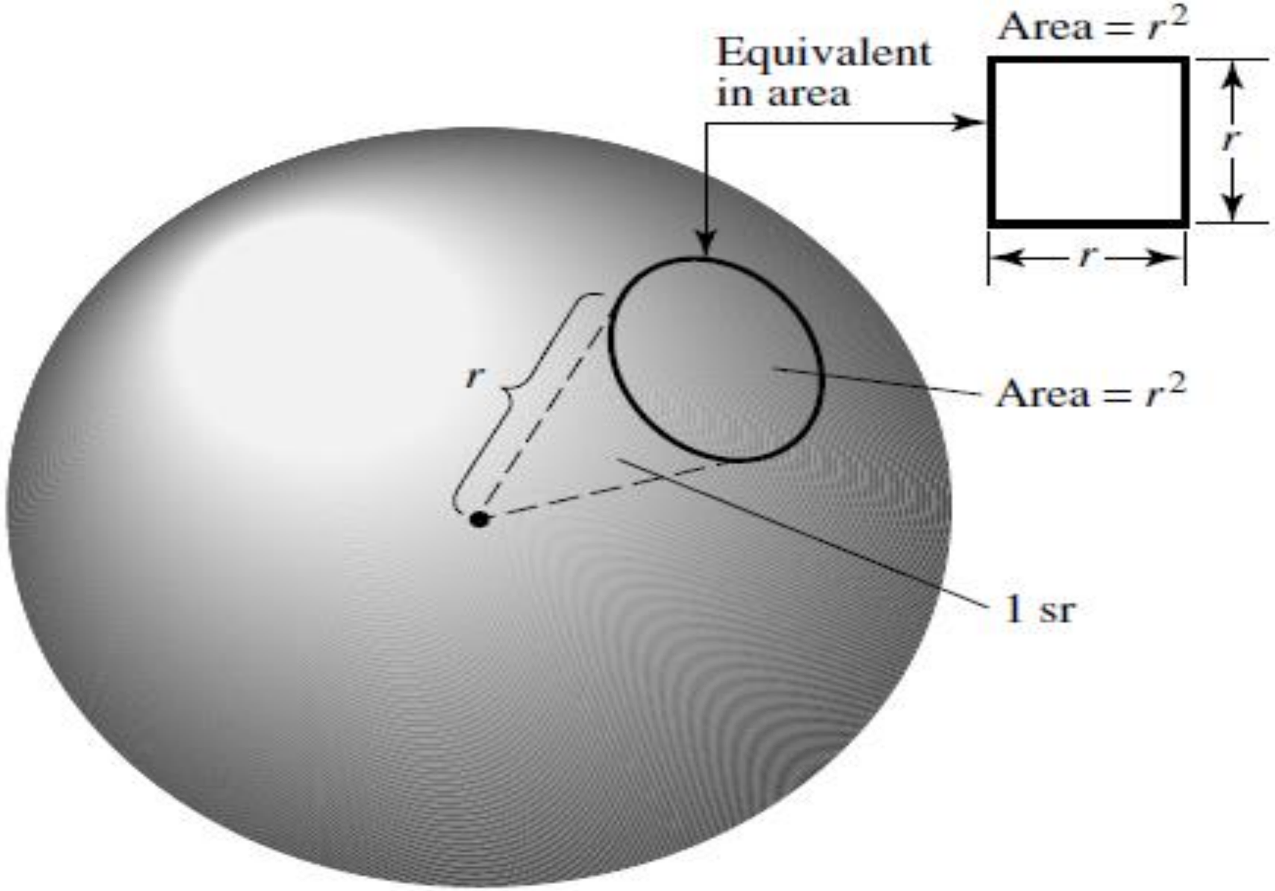

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- The infinitesimal area dA on the surface of a sphere of radius r, shown in Figure ,is given by

$$dA = r^2 \sin\theta \, d\theta \, d\phi \ (m^2)$$

- Therefore, the element of solid angle dΩ of a sphere can be written as

$$d\Omega = dA/r^2 = \sin\theta \, d\theta \, d\phi \ (sr)$$

Radiation Density (W)

- Instantaneous Poynting vector (power density)
- Average Power density for time varying fields
  (W_{av})
- Average Power radiated by antenna (P_{av})

Radiation Intensity (U)

- The power radiated from antenna per unit solid angle is called the radiation intensity U (Watt/Sr).
- The radiation intensity is a far-field parameter, and it can be obtained by simply multiplying the radiation density by the square of the distance. In mathematical form it is expressed as

$$U = r \quad W_{rad}$$

2

Continue

- The radiation intensity is also related to the far-zone electric field of an antenna as

$$U(\theta,\phi) = r^2/2\eta \; |E(r, \theta, \phi)|^2$$

- The total power is obtained by integrating the radiation intensity over the entire solid angle

$$P_{rad} = \int_0^{2\pi} \int_0^{\pi} U \sin\theta \, d\theta \, d\phi$$

Directive gain

$$G_d = \frac{\text{Radiation Intensity of antenna in given direction}}{\text{Radiation Intensity of Isotropic antenna}}$$

- Maximum Directivity: It is a **relative figure of merit which gives an indication of directional properties of an antenna** compare to those of isotropic antenna (D=1).

Directivity and Gain

- The directivity is also the ratio of the area of a sphere (4π sr) to the beam area (Ω_A) of the antenna.
- Beam Area/Beam solid angle : It is the solid angle through which all the power of the antenna would flow if its radiation intensity is maximum over beam solid angle and zero elsewhere.

Beam Area/ Beam solid angle (Ω_A)

- Beam solid angle is approximately equal to the product of the half-power beam widths in two perpendicular planes.

- Antennas for cell phones should have **a low directivity** because the signal can come from any direction, and the antenna should pick it up.

- In contrast, satellite dish antennas have a very **high directivity**, because they are to receive signals from a fixed direction. As an example, if you get a direct TV dish, they will tell you where to point it such that the antenna will receive the signal.

Beam Efficiency

- The beam efficiency (BE) is defined by

$$BE = \frac{\text{power transmitted (received) within cone angle } \theta 1}{\text{power transmitted (received) by the antenna}}$$

- where θ_1 is the half-angle of the cone within which the percentage of the total power is to be found.

$$BE = \int_0^{2\pi}\int_0^{\theta_1} U(\theta,\varphi) \sin\theta \, d\theta \, d\varphi$$

Beam efficiency

- If θ_1 is chosen as the angle where the first null or minimum occurs, then the beam efficiency will indicate the amount of power in the major lobe compared to the total power.
- **Beam efficiency is the ratio of main beam area to the total beam area.**
- Total beam area consists of major plus minor lobe areas.

Antenna Efficiency

- Reflection efficiency
- Conduction efficiency
- Dielectric efficiency

Gain of antenna

- The gain G of an antenna is an actual or realized quantity which is less than the directivity D due to ohmic losses in the antenna.
- directivity will always be greater than unity, and it is a relative “figure of merit” which gives an indication of the directional properties of the antenna as compared with those of an isotropic source
- $D = G_{d\,(max)}$
- The ratio of gain to the directivity is the antenna efficiency factor. G= k D.

where k= Efficiency factor.

Antenna Aperture (Effective Area)

- The physical aperture A_P is the actual area of the mouth of antenna.
- But the field response of the horn is not uniform across the aperture A because E at the sidewalls must equal zero.
- Thus, the effective aperture A_e of the horn is less than the physical aperture A_p.
- The aperture efficiency is $\varepsilon_{ap} = Ae / A_p$.

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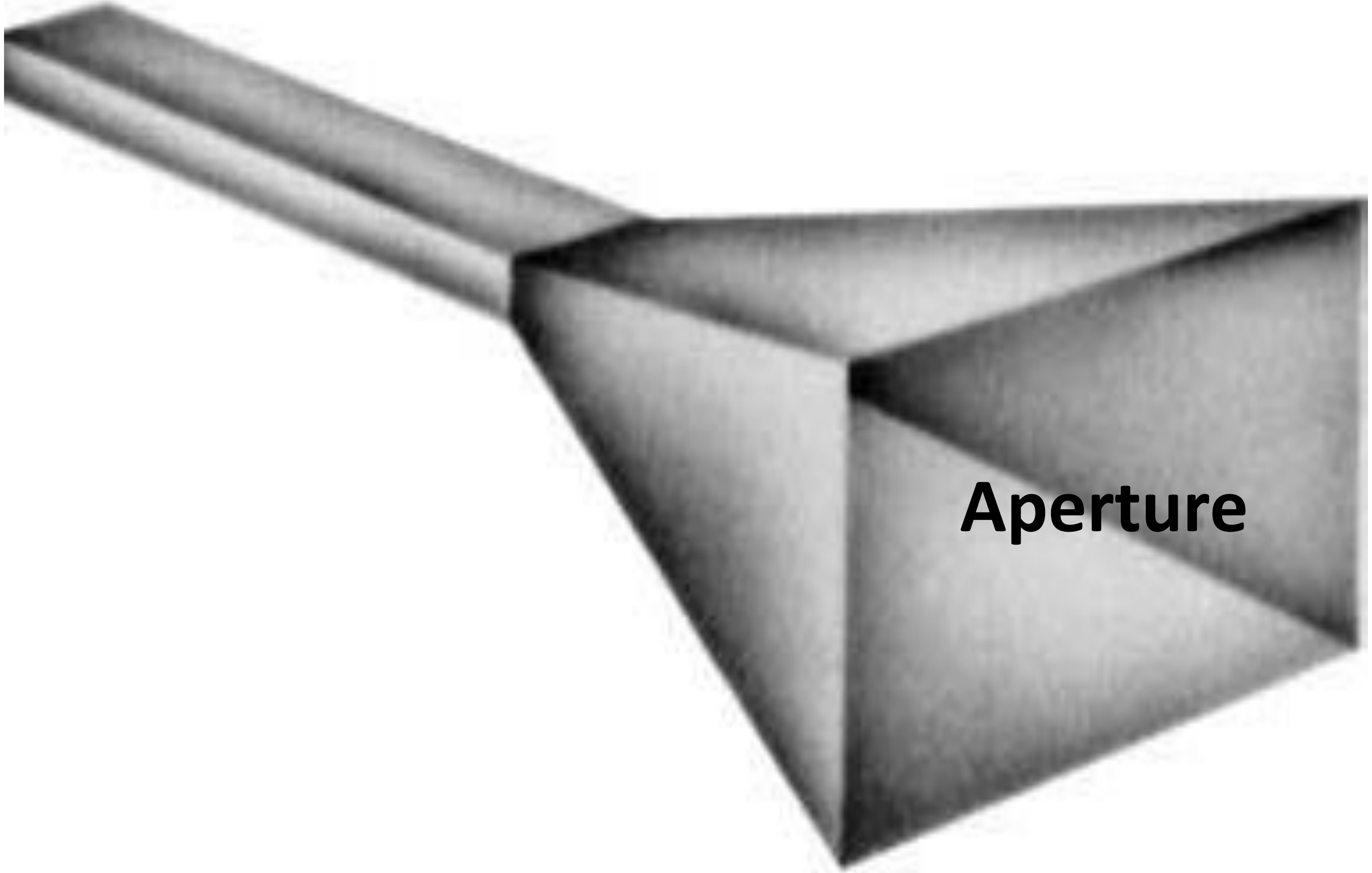

Relation between maximum directivity and maximum effective area

- Derivation
- Both are in direct proportion.

Friis Transmission equation

- It relates the power delivered to the receiver load and input power of transmitting antenna.

Effective Height

- The effective height may be defined as the ratio of the induced voltage to the incident field. h = V/E (m).
- Another way of defining effective height is to consider the transmitting case and equate the effective height to the physical height multiplied by the normalized average current,

$$h_e = \frac{1 \int I(z)\,dz}{I_0} = \frac{I_{av}\,h_p}{I_0}$$

Antenna Field Zones

- The field around an antenna may be divided into two principal regions,

➢ Near field or Fresnel zone

➢ Far field or Fraunhofer zone

- The near field is also divided into two regions,

➢ Reactive near field

➢ Radiating near field (Fresnel zone)

- The boundaries separating these regions are not unique.

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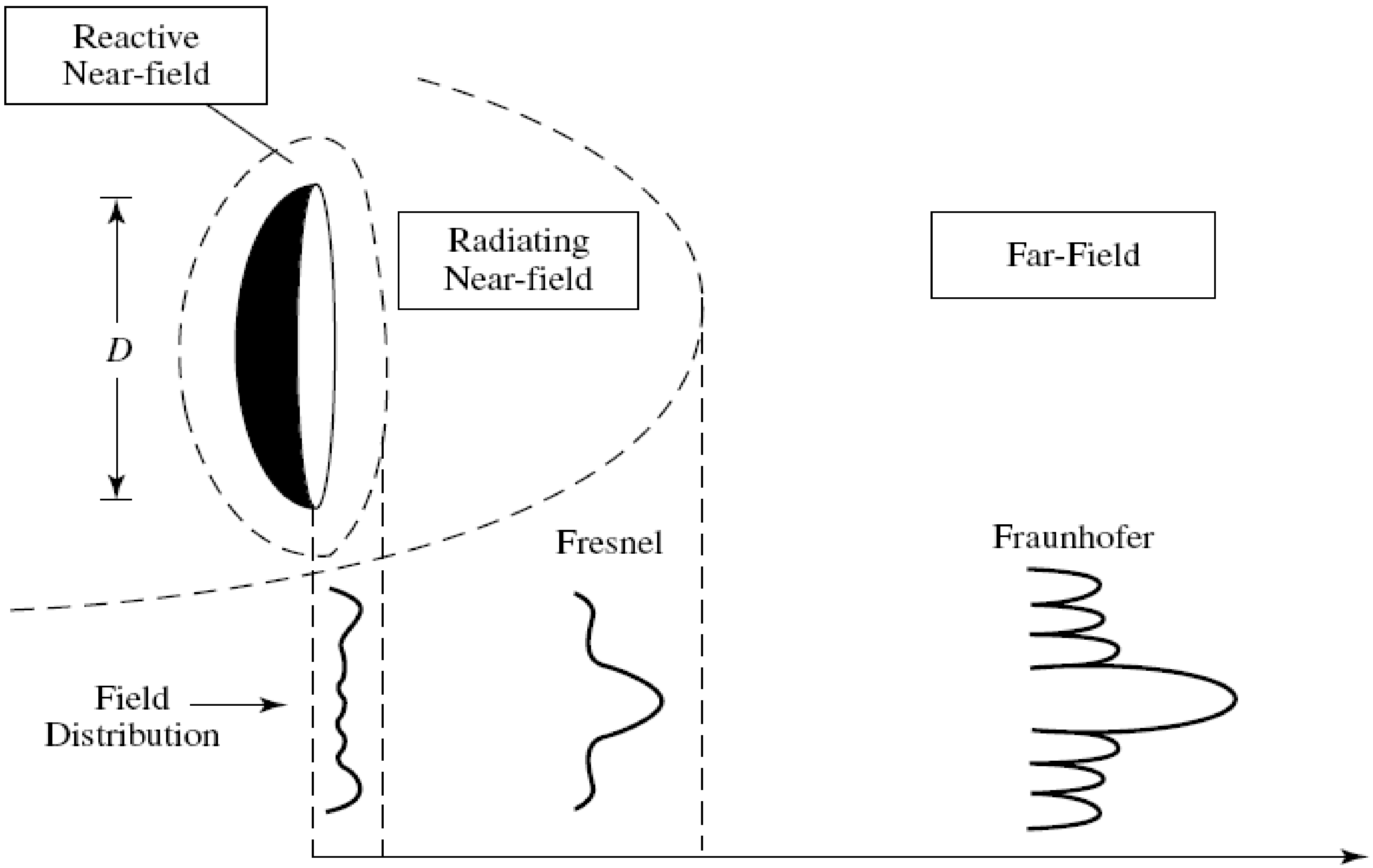


Reactive
Near-field
D
Radiating
Near-field
Far-Field
Fresnel
Fraunhofer
Field
Distribution

Continue

- <u>Reactive near field</u>: The portion of the near-field region immediately surrounding the antenna wherein the <u>**reactive field predominates**</u>. For most antennas, the outer boundary of this region is commonly taken to

  exist at a distance $R < 0.62\left(\frac{D^3}{\lambda}\right)^{\frac{1}{2}}$ from the antenna surface

Continue

- Radiating near field (Fresnel zone) : The 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.
- If the antenna has a maximum overall dimension which is very small compared to the wavelength, this field region may not exist.

Continue

- The inner boundary is taken to be the distance $R \geq 0.62 \left(\frac{D^3}{\lambda}\right)^{\frac{1}{2}}$ and the outer boundary the distance $R < 2\left(\frac{D^2}{\lambda}\right)$, where D is the largest dimension of the antenna.
- In this region the field pattern is a function of the radial distance and radial field component may be appreciable.

Continue

- <u>Far field zone </u>(Fraunhofer zone): The region of the field of an antenna where the angular field distribution is essentially **<u>independent of the distance from the antenna</u>**. In this region all power flow is directed radially outward.
- The far-field region is commonly taken to exist at distances greater than 2(   ) from the antenna.

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

Polarization in Antenna

- Polarization of a radiated wave is defined as that property of an electromagnetic wave describing the time-varying direction and relative magnitude of the electric-field vector.
- There are three types of polarization in antenna,

➢ Linear polarization

➢ Circular polarization

➢ Elliptical polarization

Continue

- The figure that the electric field traces is an ellipse, and the field is said to be elliptically polarized.
- Linear and circular polarizations are special cases of elliptical, and they can be obtained when the ellipse becomes a straight line or circle, respectively.

Continue

- **<u>Linear polarization</u>:** A time-harmonic wave is linearly polarized at a given point in space if the **<u>electric-field vector at that point is always oriented along the same straight line at every instant of time.</u>** This is accomplished if the field vector (electric) possesses:

➢ Only one component

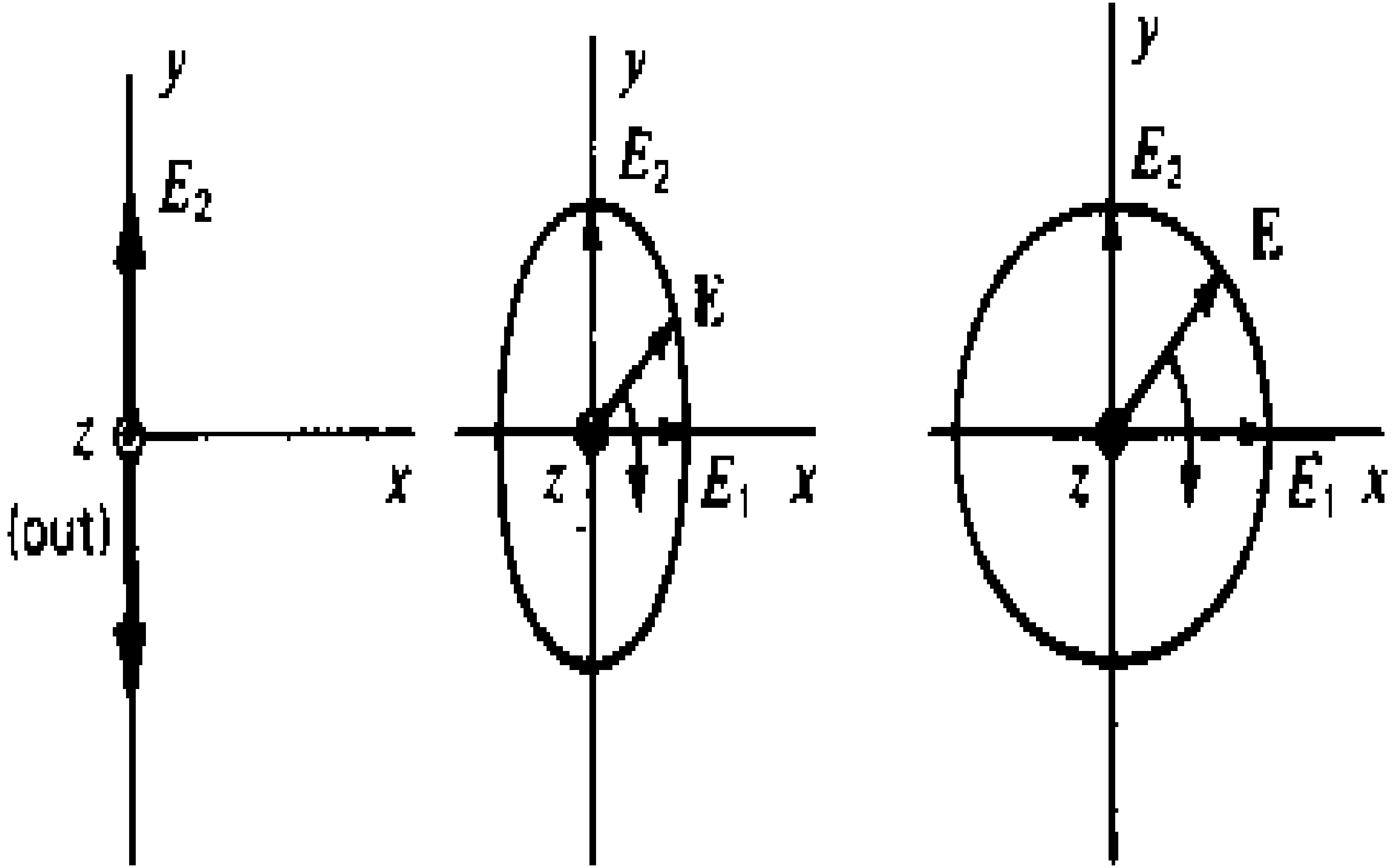
➢ Two orthogonal linear components that are in time phase or 180◦ out-of- phase.

Continue

- Circular polarization: A time-harmonic wave is circularly polarized at a given point in space if the **electric field vector at that point traces a circle as a function of time**. This is accomplished if the field vector (electric) possesses:

- ➢ The field must have two orthogonal linear components
- ➢ The two components must have the same magnitude
- ➢ The two components must have a time-phase difference of odd multiples of 90◦.

Continue



Linear polarization Elliptical polarization Circular polarization

Continue

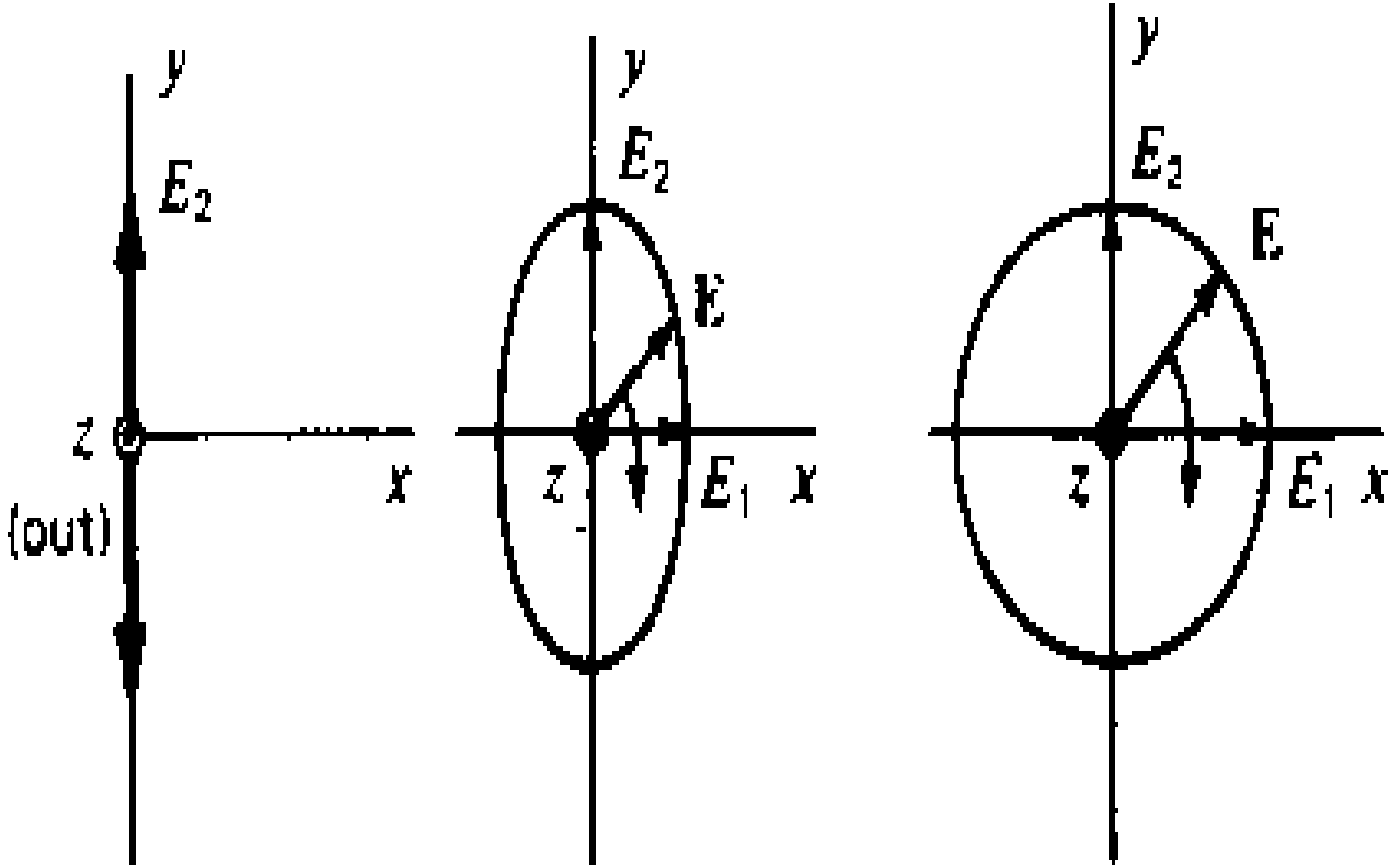
- The sense of rotation is always determined by **rotating the phase-leading component toward the phase-lagging** component. If the rotation is clockwise, the wave is right-hand circularly polarized; if the rotation is counterclockwise, the wave is left-hand circularly polarized.
- **Elliptically polarization**: A time-harmonic wave is elliptically polarized if the **tip of the field vector (electric)traces an elliptical locus in space**.

Continue

- The necessary and sufficient conditions to accomplish this are if the field vector (electric) possesses all of the following:

- The field must have two orthogonal linear components
- The two components can be of the same or different magnitude
- (1) If the two components are not of the same magnitude, the time-phase difference between the two components must not be 0° or multiples of 180°. (2) If the two components are of the same magnitude, the time-phase difference between the two components must not be odd multiples of 90°.

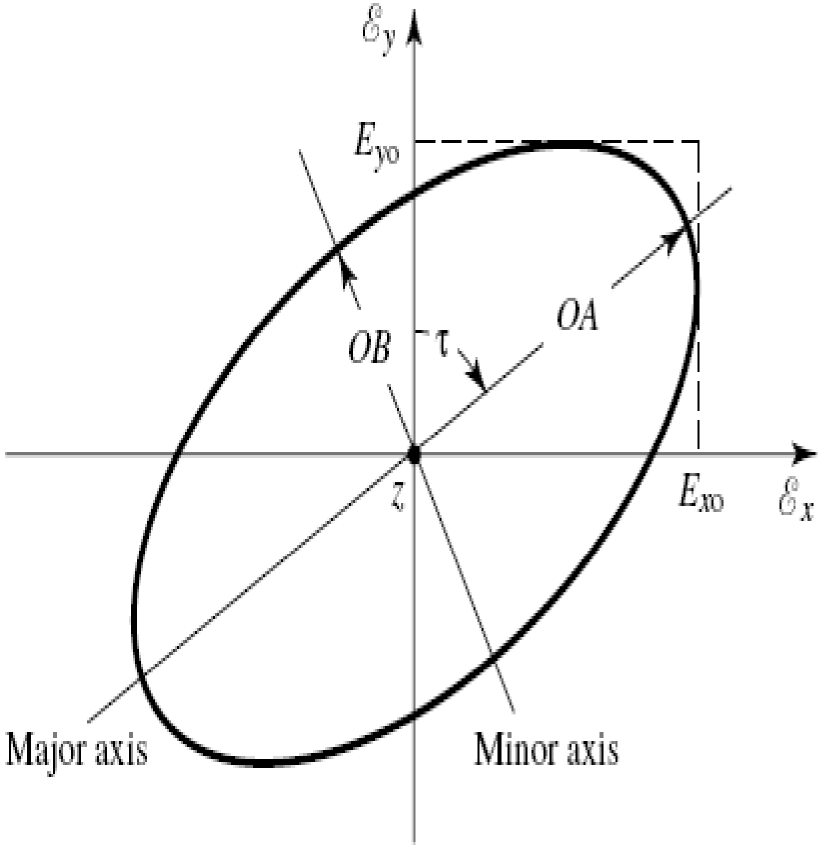
Continue



Linear polarization Elliptical polarization Circular polarization

Continue

- Co-polar & cross polar components
- Axial ratio for elliptical polarization



Polarization Ellipse

Antenna Bandwidth

- It is defined as “the **range of frequencies , on either side of center frequency,** within which the performance of the antenna characteristics (such as radiation pattern, beamwidth, gain ,polarization, SLL, radiation efficiency) are within an acceptable value of those at center frequency.”