

THE ELECTROMAGNETIC FIELD THEORY

Dr. A. Bhattacharya

The Underlying EM Fields

- The development of radar as an imaging modality has been based on power and power density
- It is important to understand some of the properties of the electric and magnetic fields that carry the power
- Power radiated towards the Earth's travels as an expanding wavefront
 - If the antenna were isotropic then the wavefront would be spherical with the power density diminishing with the inverse square of distance

Planar approximation of a spherical wave !

The Underlying EM Fields

- The power or power density is carried forward as the result of both an electric field and magnetic field that oscillate at right angles to each other and to the direction of propagation
- The Electric and Magnetic field have four properties that we need to consider
 - The *frequency* with which they oscillate
 - Their *amplitudes*
 - Their *relative phase angles*
 - The *direction* in which they point in space

Electric Field	$\mathbf{E} = E\mathbf{e}$	Vm^{-1} (volts/metre)
Magnetic Field	$\mathbf{H} = H\mathbf{h}$	Am^{-1} (amperes/metre)

The Underlying EM Fields

- There are two ways of writing the magnitudes of the vectors

- *Sinusoidal way*

$$E = E_o \cos(\omega t + \phi_e)$$

$$H = H_o \cos(\omega t + \phi_h)$$

- *Exponential way*

$$E = E_o \exp j(\omega t + \phi_e)$$

$$H = H_o \exp j(\omega t + \phi_h)$$

The Underlying EM Fields

$E_0 \rightarrow$ Electric field magnitude

$H_0 \rightarrow$ Magnetic field magnitude

ϕ_e and ϕ_h are the phase angles

- In **free space** the Electric and Magnetic fields will be in phase with each other so the phase angles are the same
- From the product of the amplitudes of the two fields we get the power density (VAm^{-2})

$$p_p = EH \quad \text{Wm}^{-2}$$

$p_p \rightarrow$ Peak power density

The Underlying EM Fields

- In free space E and H are not independent
 - Related via the **impedance of free space** $\eta = 120\pi = 377\Omega$

$$E = \eta H$$

- *This is the reason behind considering only the Electric field component for all RS applications*

$$p_p = \eta E^2$$

- Since E is a function of time, p_p will fluctuate with time hence the Peak power density is often not used in practice

$$p = \frac{1}{T} \int_0^T p_p(t) dt = \frac{\eta}{T} \int_0^T E^2(t) dt = \frac{1}{2} \eta E_o^2 = \eta E_{rms}^2$$

The Underlying EM Fields

- $E_{rms} = \frac{E_0}{\sqrt{2}}$ is called the Root Mean Square (RMS) value of the field amplitude
 - The field (Electric and Magnetic) strength in applications is normally described in RMS values
 - Expression for fields amplitudes in exponential form are in RMS values

Till here we have only considered the time variations of the fields at a given point in space → No spatial term is involved

The Underlying EM Fields

- The complete expressions for the magnitudes, including how the wave propagate, need to incorporate a dependence on position R (or z axis)

- ***Sinusoidal way***

$$E = E_o \cos(\omega t - \beta R + \phi_e)$$

$$H = H_o \cos(\omega t - \beta R + \phi_h)$$

- ***Exponential way***

$$E = E_o \exp j(\omega t - \beta R + \phi_e)$$

$$H = H_o \exp j(\omega t - \beta R + \phi_h)$$

β (wavenumber k) is the phase constant measured in rad/m

The Underlying EM Fields

- In *free space*

$$\beta = \frac{\omega}{c} = \frac{2\pi f}{\lambda f} = \frac{2\pi}{\lambda}$$

- At any given point on the Electric field wave

$$\omega t - \beta R + \phi_e = \phi = \text{constant}$$

$$R = \frac{1}{\beta}(\omega t - \phi + \phi_e)$$

- The *phase velocity*

$$v = \frac{dR}{dt} = \frac{\omega}{\beta} = c$$

The Underlying EM Fields

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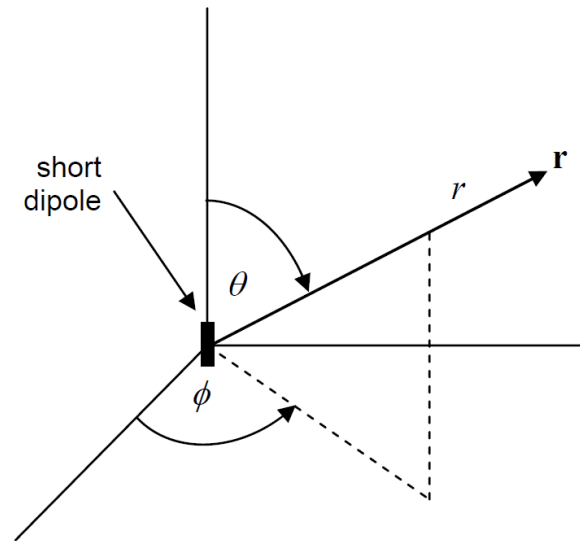
$$v = \frac{dR}{dt} = \frac{\omega}{\beta} = c$$

Near and Far Fields Concept

- In radar remote sensing it is assumed that the transmitted and scattered radiation propagate as Transverse Electro-Magnetic (TEM) waves
- The TEM wave condition does not hold near the antenna and near the vicinity of a radar target
- When we can assume TEM behavior we say that we are in the *far field* otherwise we are in the *near field* of the antenna or the target
- A simplest antenna, the so called short dipole is used to characterize the transition from near to far field

Near and Far Fields Concept

Spherical Coordinates (r, ϕ, θ)



$$E_r = \frac{Ae^{j(\omega t - \beta r)} \cos \theta}{2\pi\epsilon_o} \left(\frac{1}{cr^2} + \frac{1}{j\omega r^3} \right)$$

$$E_\theta = \frac{Ae^{j(\omega t - \beta r)} \sin \theta}{4\pi\epsilon_o} \left(\frac{j\omega}{c^2 r} + \frac{1}{cr^2} + \frac{1}{j\omega r^3} \right)$$

$$H_\phi = \frac{Ae^{j(\omega t - \beta r)} \sin \theta}{4\pi} \left(\frac{j\omega}{cr} + \frac{1}{r^2} \right)$$

Near and Far Fields Concept

- A is a constant and the exponential terms describe propagation outward from the dipole
- (θ, ϕ) are the **Transverse** components of the Electric and Magnetic fields
- r is the **Radial** component of the Electric field → in the direction of propagation
 - The Radial component has a strong inverse dependence on distance than the transverse components → For a large distance it vanishes

Near and Far Fields Concept

$$E_r = 0$$

$$E_\theta = \frac{j\omega A e^{j(\omega t - \beta r)} \sin \theta}{4\pi\epsilon_0 c^2 r}$$

$$H_\phi = \frac{j\omega A e^{j(\omega t - \beta r)} \sin \theta}{4\pi c r}$$

Far Field of the Antenna

- Thus for large distance the wave is TEM
- The far fields are inverse distance dependent

Near and Far Fields Concept

- The transition from near to far field for the short monopole is said to occur when
 - The inverse distance terms in the far field equations are equal to the inverse distance squared terms
 - The cubic terms are assumed to be negligible
- The near field/far field transition for the short monopole case is

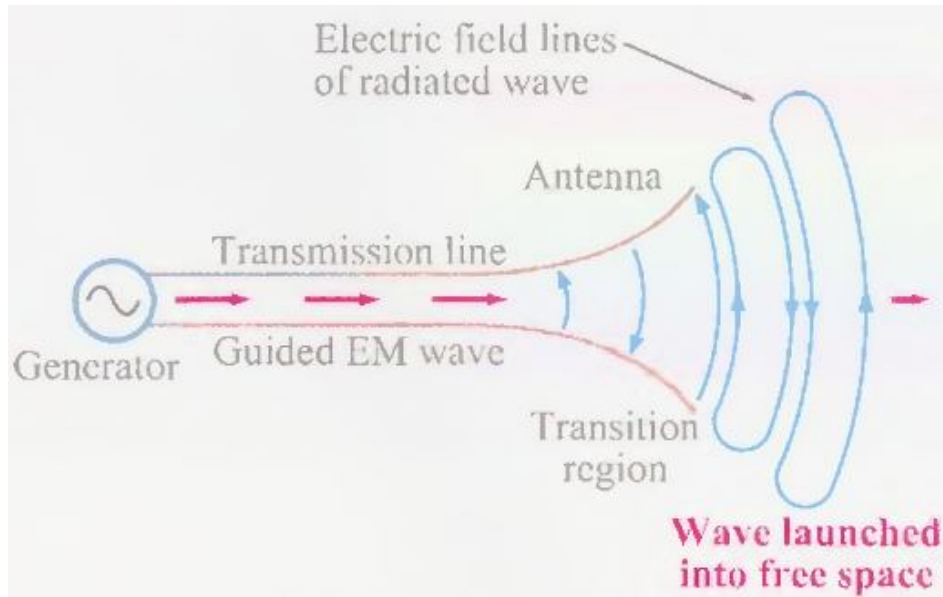
$$\left| \frac{\omega}{cr} \right| = \left| \frac{1}{r^2} \right| \Rightarrow r \approx \frac{\lambda}{6}$$

Antenna Basics

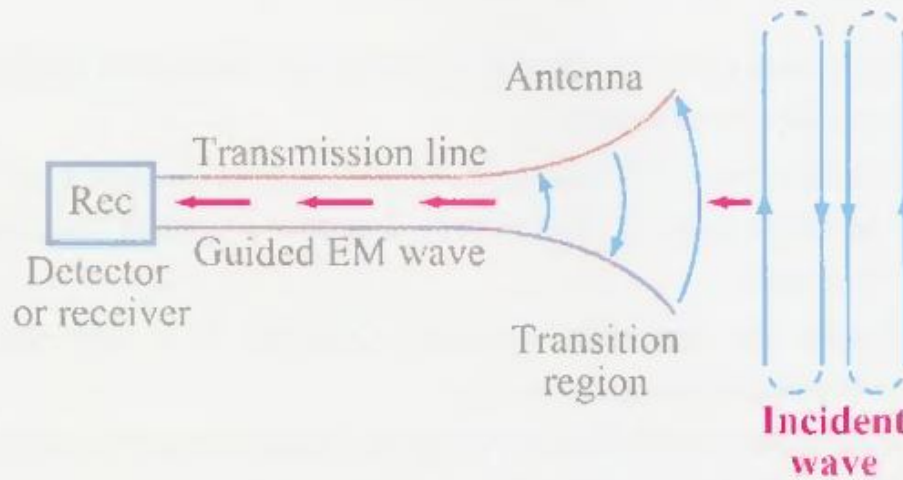
- The radiation and impedance properties of an antenna are governed by its shape, size material properties
- The dimension of an antenna are usually measured in terms of the wavelength of the wave it is transmitting or receiving
 - 1 m long dipole antenna operating at wavelength 2 m exhibits the same properties as a 1 cm long dipole antenna operating at wavelength 2 cm

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Antenna Basics



(a) Transmission mode



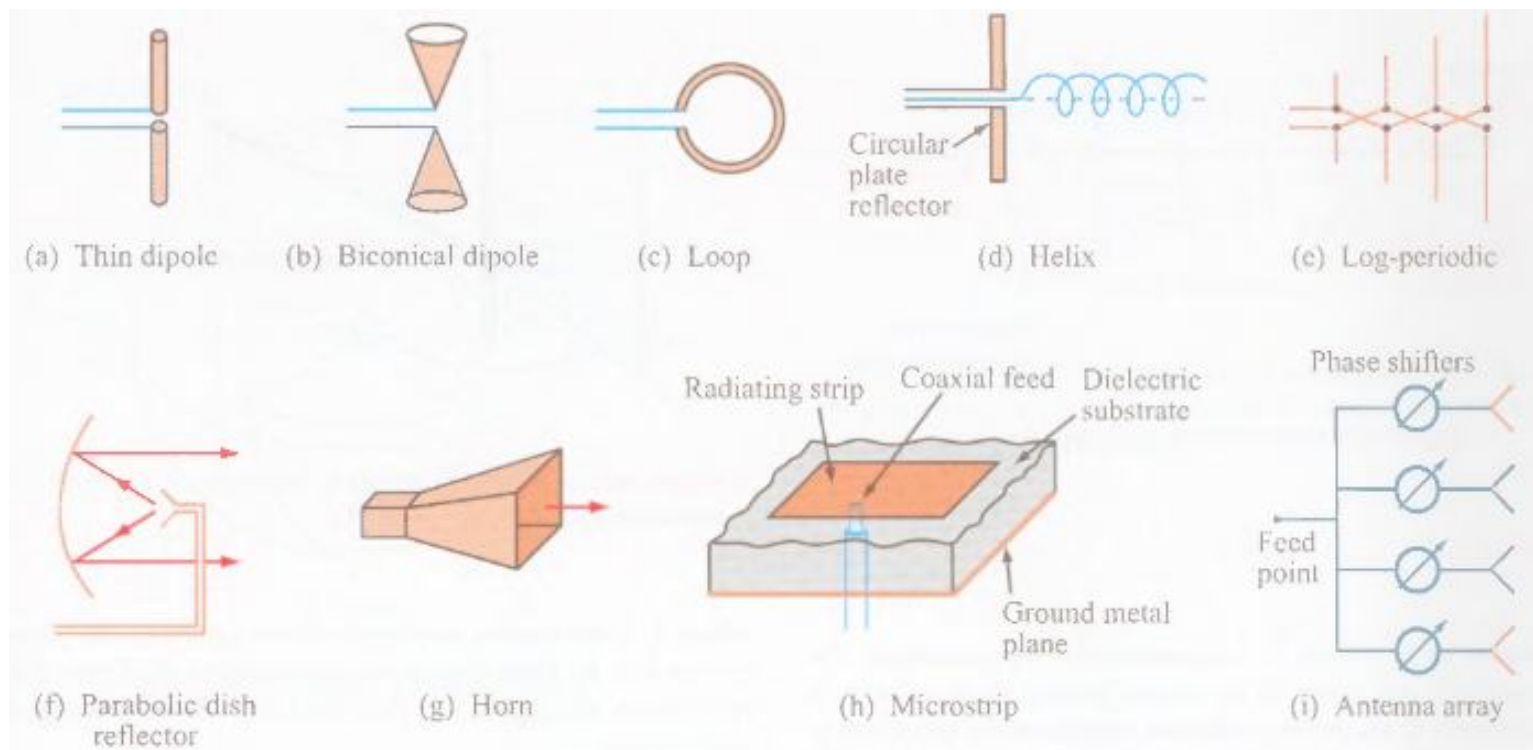
(b) Reception mode

Antenna Basics

- The directional function characterizing the relative distribution of power radiated by an antenna is known as the *antenna radiation pattern*
- An *isotropic* antenna is a hypothetical antenna that radiates equally in all directions. It is often used as a reference radiator when describing the radiation properties of real antennas
- Most antennas are *reciprocal* devices exhibiting the same radiation pattern for transmission as for reception

Antenna Basics

- The radiation properties of an antenna include
 - Its directional radiation pattern
 - The associated **polarization** state of the radiated wave when the antenna is used in the transmission mode → **Antenna Polarization**



Antenna Basics

