Propagation and Antenna
Chapter 1.0

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Propagation and Antenna

Course is divided into three parts:

- ❑ EM Wave Propagation Phenomena
- ❑ Types of Antennas and their Functions
- ❑ Optical Communications on brief

Propagation and Antenna

EM Wave Propagation :

- Radio Waves on Move/Travel
- Radiation / Reception of EM Waves
- Means of Radio Communications
- Velocity of EMW Propagation

$$v = c/\sqrt{(\mu_r \varepsilon_r)}$$

Where,

c = Velocity of Light
μ_r = Relative Permeability
ε_r = Relative Permittivity

- Conversion of I and V into EMW and vice-versa
- Propagation based on Basic Transmission Theory

Propagation and Antenna

Properties of Electromagnetic Wave Propagation

- ➢ These waves travel at the speed of light.
- ➢ These waves do not require any medium for propagation.
- ➢ Electromagnetic waves travel in a transverse form.
- ➢ Electromagnetic waves are not deflected by electric or magnetic field.

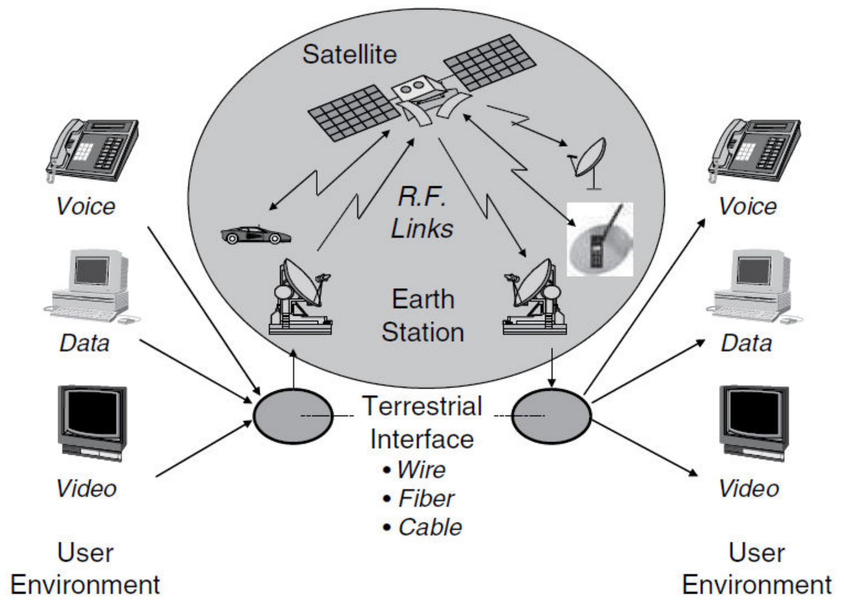
Propagation and Antenna

Properties of Electromagnetic Wave Propagation

- These waves can be polarized.
- Electromagnetic Waves undergo interference and diffraction.
- The wavelength(λ) and frequency (v) of the EM waves can be related as:

  c= v.λ

Radio Wave Propagation in Satellite Communications



Communications via Satellite in the Telecommunications Infrastructure

Birth of Antenna
(In Brief)

- In 1873, James Clerk **Maxwell** (1831 – 1879) Unified Theory of EMW
- In 1887, Heinrich Rudolf **Hertz** (1857 – 1887) First used Metallic Device as an Antenna
- In 1901, Guglielmo **Marconi** (1874 – 1937) Applied Antenna for Long Distance Radio Communication

Historical Advancement
(In some details)

- 1842, First Radiation Experiment, J. Henry
- 1872, Improvement in Telegraphing (patent), M. Loomis
- 1873, Maxwell's Equations
- 1875, Communication System (patent), T. Edison
- 1886, Hertz's Experiment (dipole)
- 1901, Marconi's Success
- 1940, UHF Antennas
- 1960, Modern Antennas

Antenna Types

- Electrically Small (Dipole, Loop)
- Resonant (HW Dipole, Patch, Yagi)
- Broadband (Spiral, Log Periodic)
- Aperture (Horn, Waveguide)
- Reflector and Lens

Chap.1 Radiation & Antenna Fundamentals

Antenna :
- Also Named **Aerial**
- A Device for Radiating and Receiving of EM Waves
- Metallic Device
- Transducer
- Passive Device/Element
- Gateway of Wireless Communications
- Equivalent of Transformer
- Generator & Load Equivalent
- Resonant Device/ Circuit

Antenna or Aerial

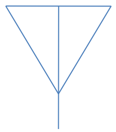
- Major Parts of Transponder
- Radiator / Receptor of EMWs
- Radiates Energy in Specified (Desired) Direction
- Medium Bet^n Guided Wave and EMW
- Maximum Power can be Transferred when
  $\mathbf{Z_g = Z_c = Z_a}$
- Space Impedance Maching Device, $Z_s = 377\ \Omega$
- Interface bet^n EMW and Current Moving in Metal
- Tuned (Matched) Device

Function of Antenna

- Transmitting Antenna : It Converts Electrical Energy into Electromagnetic Energy
- Electric Current Flowing in the Conductor Changes into Radio Waves (EMW) as a Radiation
- Receiving Antenna : It Converts Electro-magnetic Energy into Electrical Energy
- Radio Waves (EMW) Strikes on the Antenna Changes into Corresponding Electric Current

Function of Antenna (Cont…)

- An Antenna should Radiate Energy in Specified Direction rather than other Directions
- Electronic Symbol for an Antenna



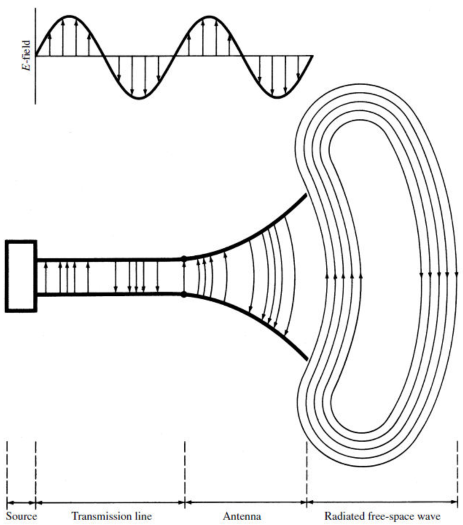
- As RF Signal Current is Applied to an Antenna, the Orbits of the Electrons in the Atoms are Changing as per RF Current on it.

Function of Antenna (Cont…)

- Correspondingly to Each Change of Direction of Orbit, a Quantum of Energy is Released, which Results in **Radiation of RF Energy**

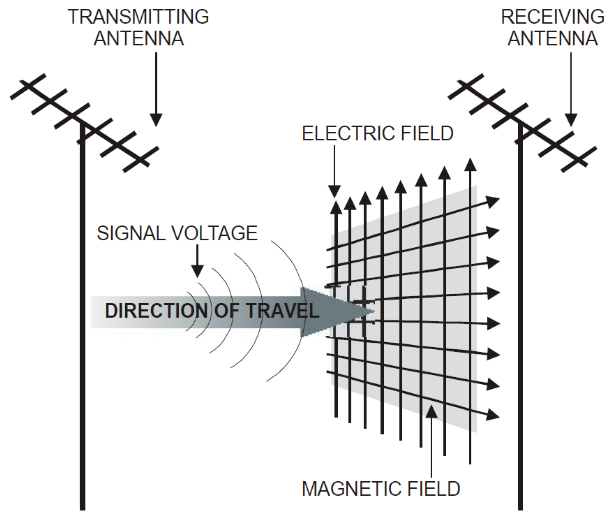
- Transmitting Antenna should Radiate Energy in Specified Direction and Suppress (Stop) the Radiation in Unwanted Directions

Function of Antenna (Cont…)



Antenna as a transition device

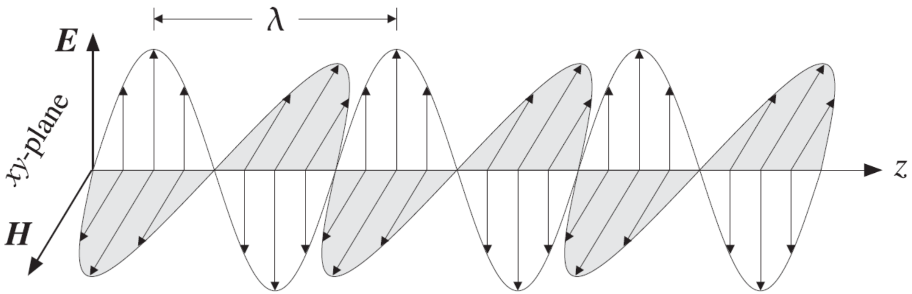
Radiation Fundamentals



Radiation Fields

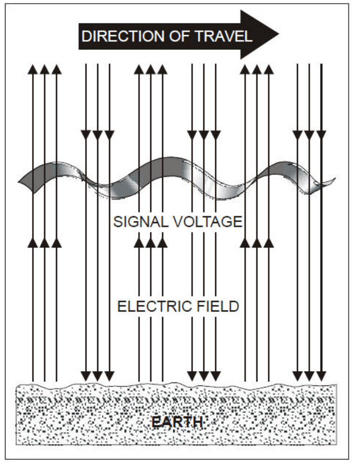
EMW Propagation

Radiation is a Time Varying Phenomena
The Radiated Electric and Magnetic Fields



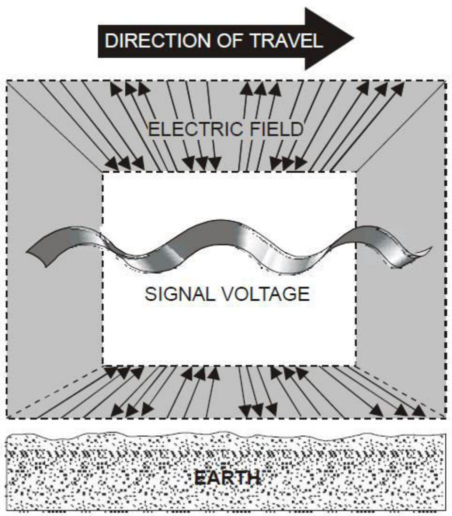
Forward Uniform Plane Wave

Vertical Polarization



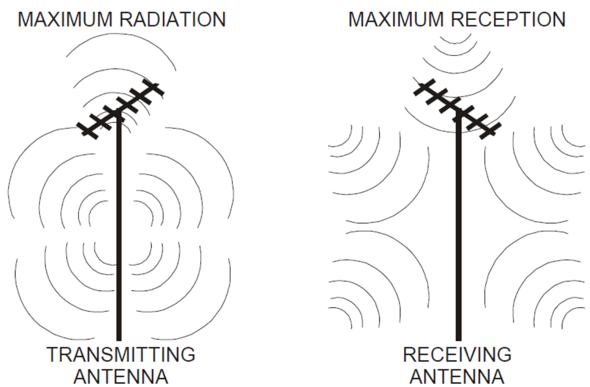
Vertically Polarized Wave

Horizontal Polarization



Horizontally Polarized Wave

Antenna Reciprocity

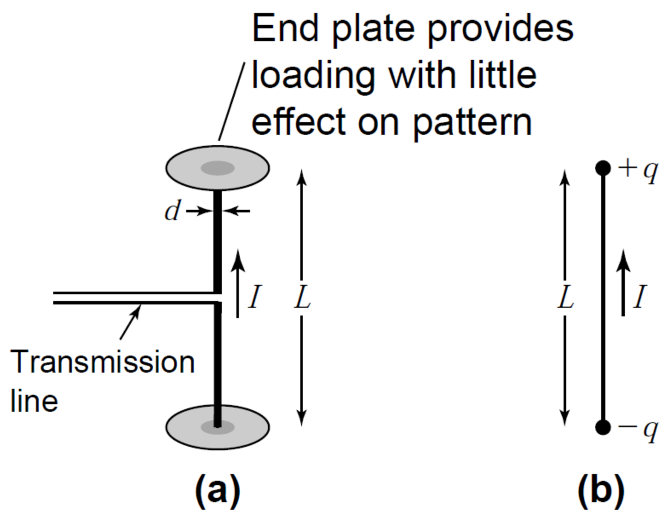


1.1 Retarded Potentials

EM Wave Generation with a Conduction Current

- Propagation Potential at a Distance, r
- Time Varying Potential at a Distance, r
- Radiation is a Time Varying Phenomena
- Potential Developed due to the Field Intensities
  - i.e. due to Electric Field Intensity and Magnetic Field Intensity at any Point, p in the Free Space
  - It is during Transmission of Signal for Propagation Time
  - Propagation Time is also called Retarded Time, $t_r = r/c$

Short Dipole Antenna

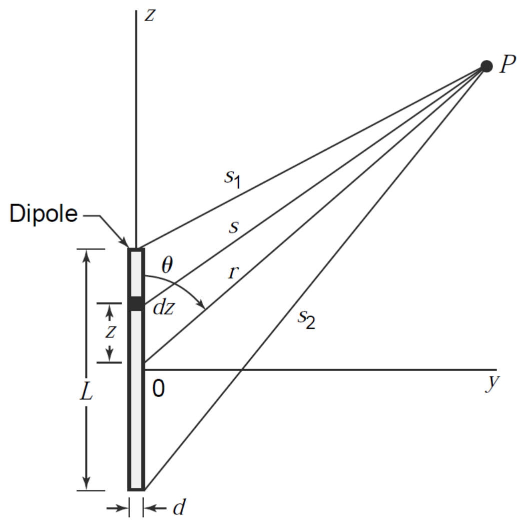


A short dipole antenna *(a) and its equivalent (b).*

Retarded Potentials (Cont..)

- Emf Produced due to the EM Wave, at a Distance, r from the Point Source (i.e. Antenna)
- It can be Scalar and Vector Potentials
- It Takes some Time for the Effect of this Changed Current to be Seen at Point, P
- This time is Retarded Time, r/c (s).
- The Potential Calculated Considering this Effect is Known as <u>Retarded Potential</u>.

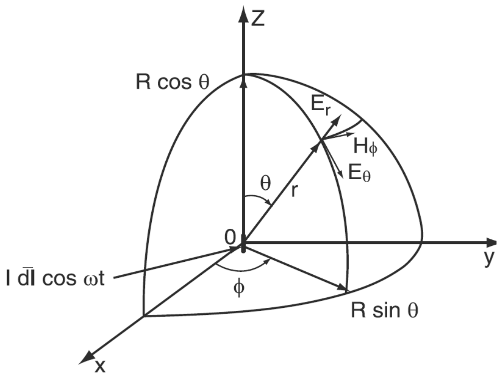
Retarded Potentials (Cont...)



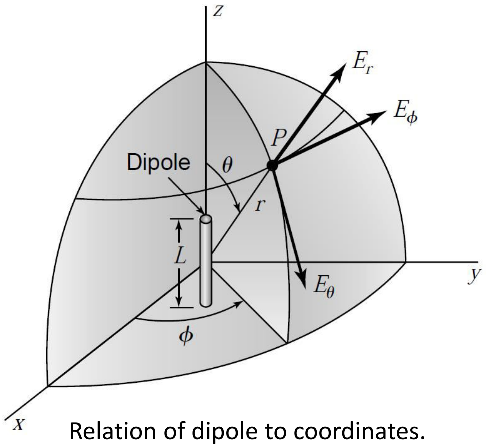
Geometry for short dipole

Retarded Potentials (Cont…)

EM Wave Generation with Short Uniform Current Dipole

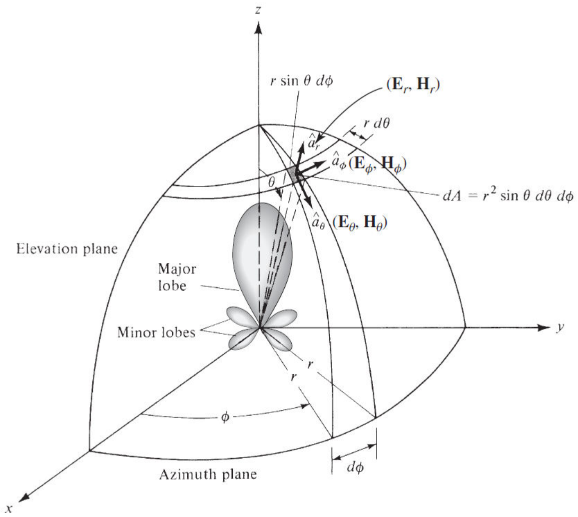


Configuration of filamentary current carrying conductor



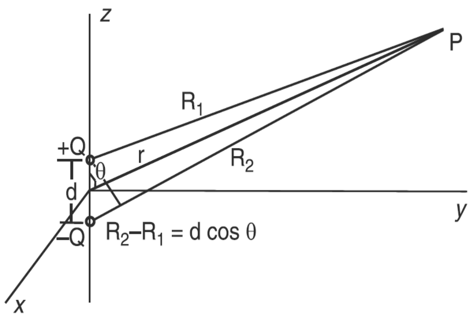
Relation of dipole to coordinates.

Retarded Potentials (Cont..)

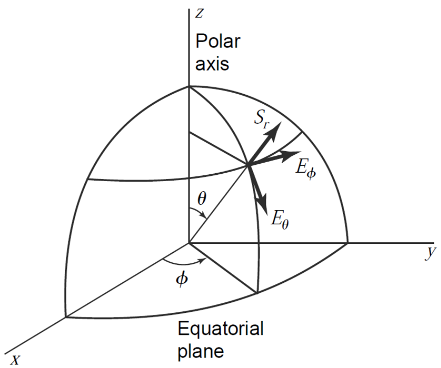


Coordinate system for antenna analysis

The Fields of Short Dipole



Configuration of dipole



Relation of the Poynting vector *S and the two electric field* components of the far field. Where, S_r, E_θ, & E_ϕ –Electric Field Components

Retarded Potentials (Cont..)

By Definition of Electric Current, I

$I = dq/dt$ - - - - - - - - - - - - (1)

The Current Passing the Conductor, I is also

$I = I_0 e^{j\omega t}$ - - - - - - - - - - - - -(2)

Instantaneous Propagation, due the Effect of the Current by Lorentz,

$[\, I\,] = I_0 e^{j\omega\, [t - (r/c)]}$ - - - - - - - - -(3)

Retarded Potentials (Cont..)

Instantaneous Propagation, due to the Effect of the Current,

$[I] = I_0 e^{j\omega [t - (r/c)]}$ - - - - - - - -(3)

Where,

$[I]$ is Retarded (Propagation) Current

(r/c) is Retarded Time, Results in a Phase

Retardation $\omega r/c = 2\pi f r/c$ radians

$= 360^0 f\, r/c$

$= 360^0 t/T$

And, $t = 1/f$ & $t = r/c$

Retarded Potentials (Cont..)

The **Retarded Vector Potential** of the Electric Current,

$A_Z = \mu_0 /4\pi \int_{-L/2}^{+L/2} [I]/s\, dz$ - - - - - (4)

Where,

$[I] = I_0 e^{j\omega [t - (s/c)]}$ - - - - - - - - - - - - -(4a)

z is Distance to a Point on the Conductor

I_0 is Peak Value in Time of Current

μ_0 is Permeability of the Free Space

Retarded Potentials (Cont..)

If $r >> L$ and $\lambda >> L$, then Eqn. (4) becomes,

$A_Z = \mu_0 L I_0 e^{j\omega [t - (r/c)]} /4\pi r$ - - - - - - - - - (5)

This is an Overall **Retarded Vector Potential** of the Electric Current every where surround the Short Dipole

Retarded Potentials (Cont..)

The **Retarded Scalar Potential**, V of a Charge Distribution,

$V = 1 /4\pi\varepsilon_0 \int_V [\rho]/s\, d\tau$ - - - - - - (6)

Where,

$[\rho]$ is the Retarded Charge Density as

$[\rho]= \rho_0 e^{j\omega [t - (s/c)]}$ - - - - - - - - (7)

$d\tau$ is Distance to a Point on the Conductor

ρ_0 is Peak Value in Time of Charge

ε_0 is Permittivity or Dielectric Constant of Free Space.

$\varepsilon_0 = 8.854 \times 10^{-12}$ F/m

Retarded Potentials (Cont..)

The **Retarded Scalar Potential**, V of Eqn. (6) reduces to,

$V = 1/4\pi\varepsilon_0 \{[\rho]/s_1 - [\rho]/s_2\}$ - - - - - (8)

From Eqns. (1) and (4a),

$[\rho] = \int [I]\, dt = I_0 \int e^{j\omega[t-(s/c)]}\, dt = [I]/j\omega$ - - - - (9)

Substituting Eqn. (9) into Eqn. (8),

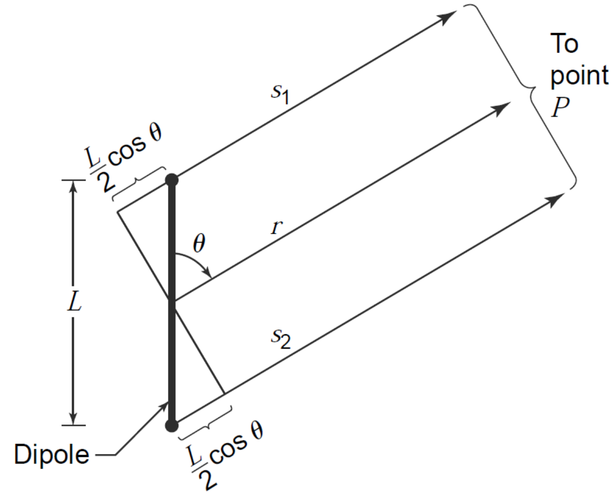
$V = 1/(4\pi\varepsilon_0 j\omega)\{e^{j\omega[t-(s1/c)]}/s_1 - e^{j\omega[t-(s2/c)]}/s_2\}$ - - -(10)

When,

$r >> L$ and $s_1 // s_2 // r$, then, $s_1 = r - L/2\text{Cos}\theta$ - - - - -(11)

$s_2 = r + L/2\text{Cos}\theta$ - - - - (12)

Retarded Potentials (Cont..)



Relations for short dipole when *r >> L.*

Retarded Potentials (Cont..)

Finally the Overall **Retarded Scalar Potential**, V of the Charge Distribution, reduces Equation to

$V = I_0 L \text{Cos}\theta\, e^{j\omega[t-(r/c)]}(1/r + c/j\omega r^2/(4\pi\varepsilon_0 c)$ - - - - - - - - - - - - - - -(13)

[Note: J.D. Kraus, 2nd Edn. pp. 204 (Eqn. 16]

Retarded Potentials (Cont..)

Electric fields of short dipole

$$E_r = \frac{I_0 L \cos\theta\, e^{j\omega[t-(r/c)]}}{2\pi\varepsilon_0}\left(\frac{1}{cr^2} + \frac{1}{j\omega r^3}\right)$$

$$E_\theta = \frac{I_0 L \sin\theta\, e^{j\omega[t-(r/c)]}}{4\pi\varepsilon_0}\left(\frac{j\omega}{c^2 r} + \frac{1}{cr^2} + \frac{1}{j\omega r^3}\right)$$

General case

From J. D. Kraus, 4th Edn. Eqns. (12) & (13) pp.138

1.2 Radiation Patterns & Input Impedance

Radiation Patterns:

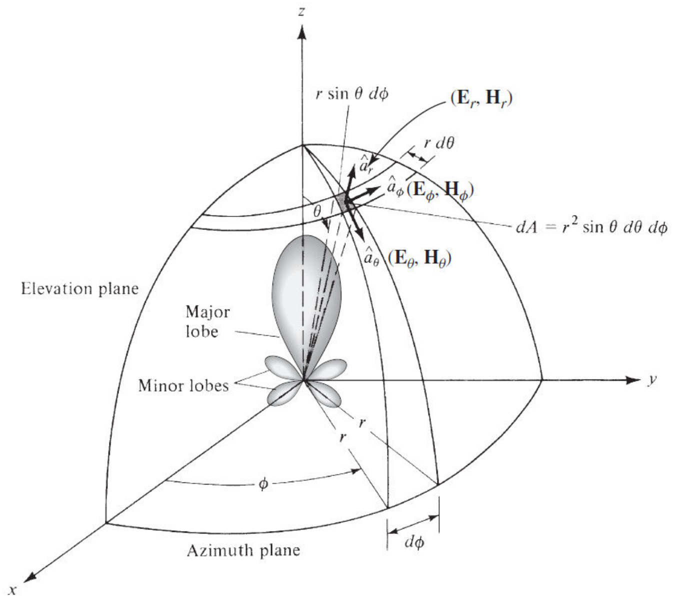
- Mathematical function or a Graphical Representation of the Radiation Properties of the Antenna as a Function of space coordinates.
- It is determined in the far field region
- It is represented as a function of the directional coordinates.
- Radiation properties include power flux density, radiation intensity, field strength, directivity, phase or polarization.

Radiation Patterns

Radiation Patterns:

- 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.*
- Often the *field and power patterns are normalized with respect to their maximum* value, yielding *normalized field and power patterns.*
- *Also, the power pattern is usually* plotted on a logarithmic scale or more commonly in decibels (dB).

Coordinate system for antenna analysis



Radiation Patterns & Input Impedance

Radiation Patterns:

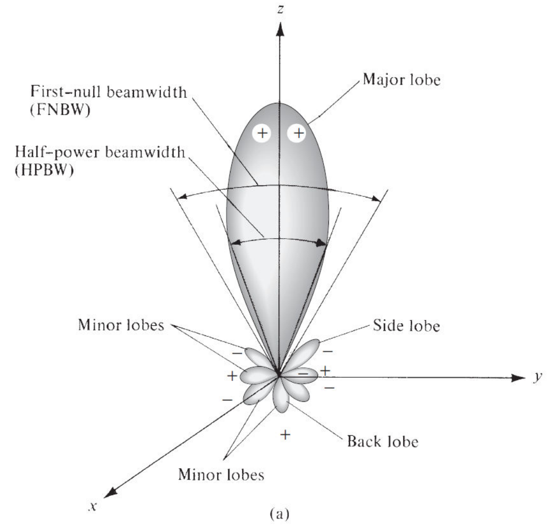
- Mathematical function or a Graphical Representation of the Radiation Properties of the Antenna as a Function of Space Coordinates.
- It is Determined in the Far Field Region
- It is Represented as a Function of the Directional Coordinates.

Radiation Patterns & Input Impedance

Radiation Properties Include

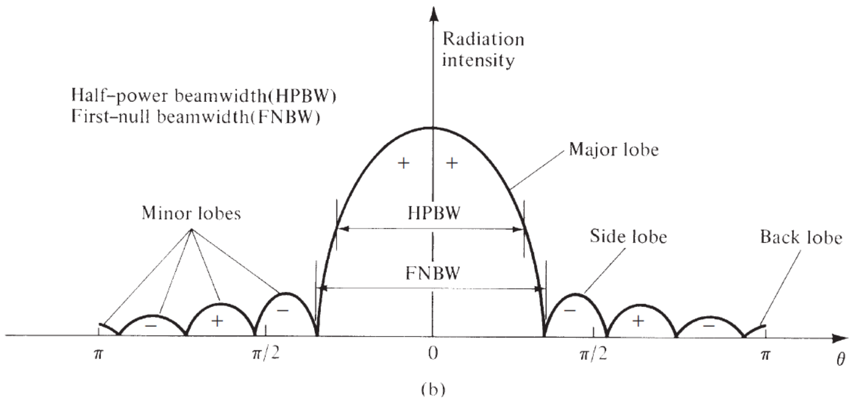
- Power Flux Density (PFD),
- Radiation Intensity,
- Field Strength,
- Directivity,
- Phase, or
- Polarization.

Radiation Pattern



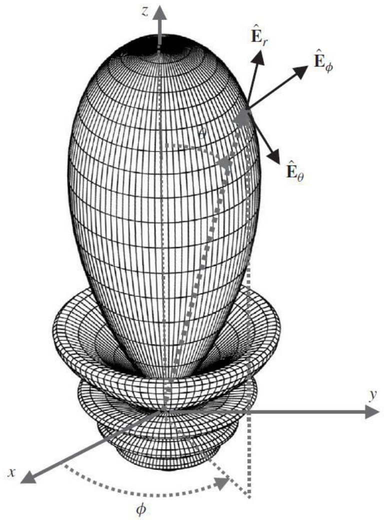
Radiation lobes and beam widths of an antenna pattern

Radiation Patterns



Linear plot of power pattern and its associated lobes and beam widths.

3D Radiation Patterns



Normalized three-dimensional amplitude *field pattern (in linear scale)*

Radiation Patterns & Input Impedance

Radiation Patterns can be

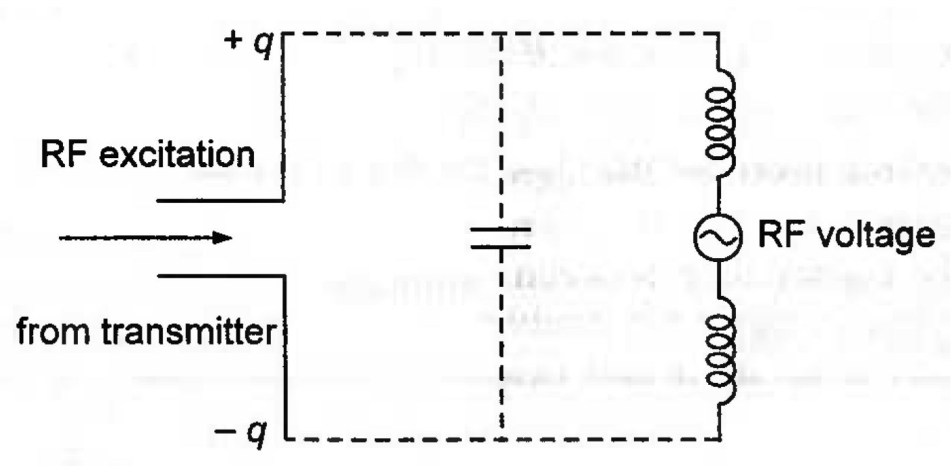
1. Isotropic Radiation Pattern
2. Omni-directional Radiation Pattern
3. Directional Radiation Pattern

Input Impedance (Z_{in})

- Impedance Presented by Antenna at itsTerminals
- The Ratio of the Voltage to Current at a Terminals
- Ratio of the Appropriate Components of
- The Electric to Magnetic Fields at a Point Impedance
- Input Impedance is Measured at a pair of Terminals
- That is Input Terminals of the Antenna
- It is Measured as:

$$Z_{in} = R_A + jX_A$$

Antenna Equivalent



Elementary Dipole Oscillator

Input Impedance (Z_{in})

- Input Impedance:

$$Z_A = R_A + jX_A$$

Where,

Z_A is Antenna Imepedance at Terminals a-b

R_A is Antenna Resistance at Terminals a-b

X_A is Antenna Reactance at Terminals a-b

And, $R_A = R_r + R_L$

R_r = Radiation Resistance of the Antenna

R_L = Loss Resistance of the Antenna

Input Impedance (Cont…)

Radiation Resistance

- Fictitious Resistance
- Equivalent to Same Amount of Power When actually Radiating
- Not actually Measured the Resistance from Antenna
- Rr is Subject to the power that it converts into EMW
- Ratio of power radiated to the square of current at the feed point

Loss Resistance

- Ohmic or Load Resistance
- For Efficient Radiation, R_r must be very Higher than R_L
- Loss Resistance gives Rise to Power Loss

Input Impedance (Cont…)

Radiation Resistance

Radiating Antenna Power (P) = $R_r * I^2_{RMS}$

Radiation Resistance (R_r) for Half Wave Dipole

$$R_r = 80\pi^2(l_e/\lambda)^2 \text{ - - - - - -(i)}$$

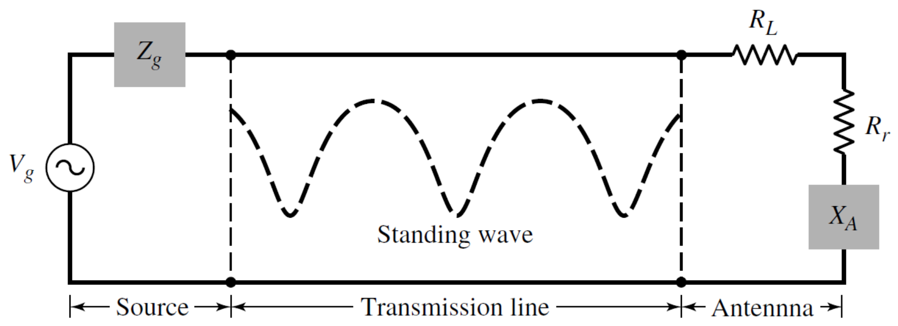
Radiation Resistance (R_r) for Short Dipole

$$R_r = 40\pi^2(l_e/\lambda)^2 \text{ - - - - - (ii)}$$

Radiation Resistance (R_r) for monopole

$$Rr = 20\pi^2(h/\lambda)^2 \text{ - - - - - (iii)}$$

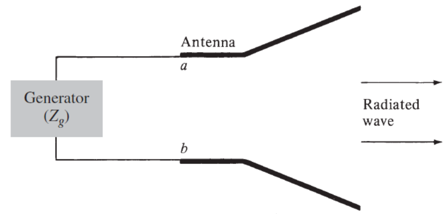
Input Impedance (Z_{in})



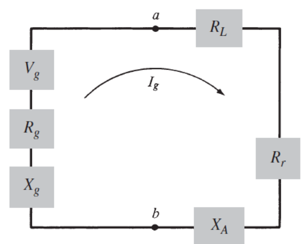
$$Z_A = (R_L + R_r) + jX_A$$

Transmission-line Thevenin equivalent of antenna in transmitting mode

Input Impedance



(a) Antenna in transmitting mode



(b) Thevenin equivalent

Thank You
for Your Present!

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