ANTENNA & RADIO WAVE PROPAGATION

INTRODUCTION LECTURE

ELC 516E SYLLABUS

Course Content:

Antenna theory: Electromagnetic fields and radiation theory; pattern synthesis, near and far field patterns and focused apertures. Properties of Antenna: Antenna Impedance, Radiation Resistance, Radiation Pattern, Beam area and beam efficiency, gain, directivity and Gain, radiation intensity, half power BW, polarization, antenna losses, antenna efficiency, effective aperture, effective length of antenna, effects of antenna height, antenna temperature, front to back ratio, antenna field zones. Antenna synthesis: Fourier transform method; Woodyard method; Problems in antenna design. Basic Antennas and Arrays: Radiation characteristics of wire antennas: Resonant wire antennas (λ, 2λ), Non Resonant (Rhombic) Antenna; Loop antenna; Folded dipole; Yagi-uda antenna; Antenna Arrays-Uniform linear array, Broad side array, End fire array. VHF/UHF antennas: Helical antenna, Parabolic reflector antenna, Horn antenna, Micro strip (patch) antenna, Turnstile and super turnstile antenna, slot antenna. Terrestrial mobile communication antennas: Base station antennas, Mobile station antennas. Smart Antennas. Propagation principles: Friis transmission formula, atmospheric effects, fading, tropospheric scatter, link budget calculation. Ionosphere Layers and Sky wave propagation: Virtual Height, Critical frequency, Maximum usable frequency (MUF), Skip distance, Lowest Usable frequency (LUF), Optimum Usable frequency (OUF) Space Wave propagation: Tropospheric scattered propagation, Duct Propagation. Application: Principles of colour TV transmission and display systems

TEACHING SCHEDULE

1. Antennas:

a) Electromagnetic fields and radiation theory;
b) Thin linear antenna;
Cylindrical antenna;
c) Loop antenna;
d) Antenna arrays;
e) Horn Antenna;
f) Reflector antennas.

2. **Antenna synthesis:**

a) Fourier transform method;
b) Woodyard method;
c) Other methods;

3. **Propagation:**

a) Review of guided and unguided wave propagation;
b) Surface waves;
c) Space wave propagation and atmospheric effects;
d) Sky wave propagation and ionospheric effects;
e) Fading and its effect on communication;
f) Propagation losses in communication links;
g) Scatter propagation.

4. **Diversity-techniques**;

5. **Broadcast and point-to-point system design.**

6. Problems in antenna design.

ELECTROMAGNETIC WAVES & RADIATION THEORY

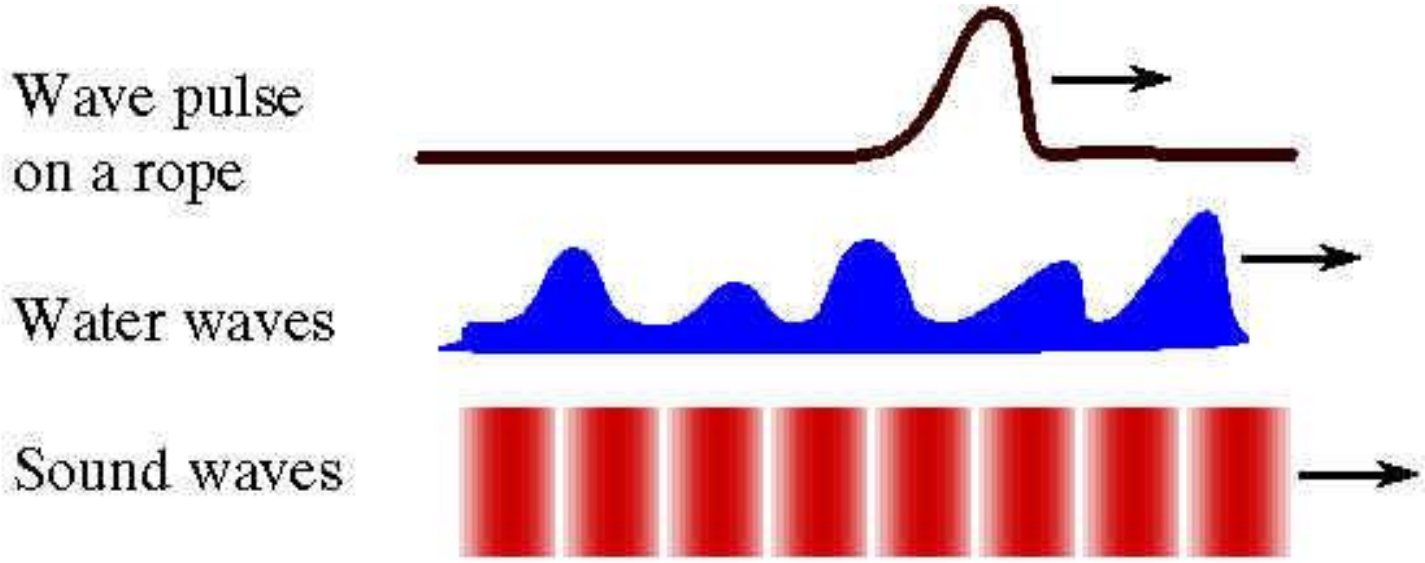
ECE516E – Antenna Engineering and radio Wave Propagation

Thursday, 17 November 2016

ASSUMED KNOWLEDGE

1. A wave is a function of both space and time.

2. Wave motion occurs when a disturbance at point A, at time t_0, is related to what happens at point *B*, at time $t > t_0$.



ONE-DIMENSION WAVE EQUATION

- The scalar wave equation in one dimension takes the form:

$$\frac{d^2E}{dx^2} - u^2\frac{d^2E}{dx^2} = 0 \quad (1)$$

where u is the velocity of the wave.

- Assuming harmonic (or sinusoidal) time dependence $e^{j\omega t}$ the equation becomes:

$$\frac{d^2E_s}{dx^2} + \beta^2 E_s = 0 \quad (2)$$

where $\beta = \frac{\omega}{u}$ and E_s is the phasor form of *E.*

- The possible solution of equation (2) are:

$$E^+ = Ae^{j(\omega t - \beta z)} \quad (3a)$$

$$E^- = Ae^{j(\omega t + \beta z)} \quad (3b)$$

$$E = Ae^{j(\omega t + \beta z)} + Ae^{j(\omega t - \beta z)} \quad (3c)$$

GENERAL ONE DIMENSIONAL WAVE EQUATION

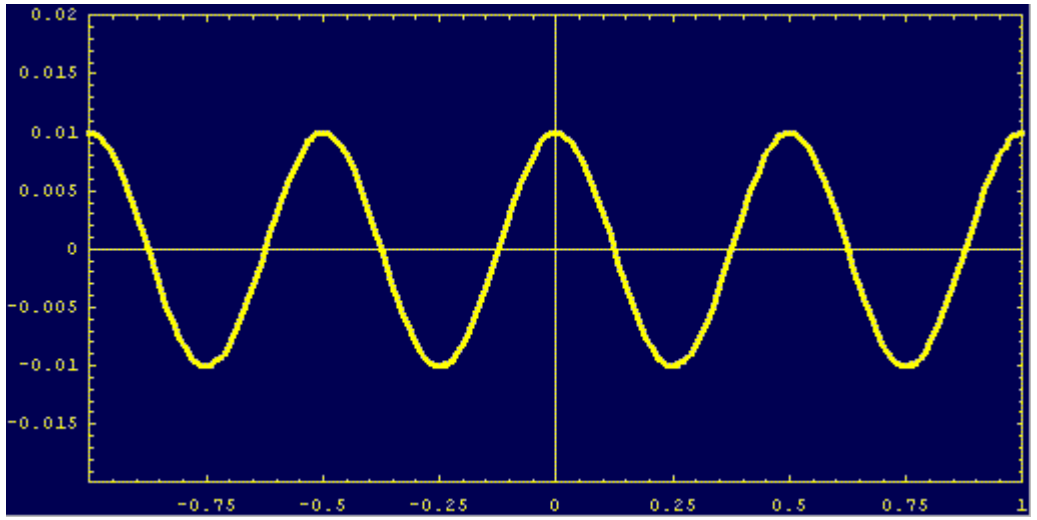
Phase Constant/Wave number

time Amplitude

$$E(z,t) = A \sin(\omega t - \beta z)$$

Displacement

Angular frequency



ELECTROMAGNETIC WAVE SPECTRUM

EM PHENOMENA	FREQUENCY RANGE	APPLICATIONS
1. Cosmic Rays	10^{14} GHz and above	Physics and astronomy
2. Gamma Rays	10^{10} - 10^{13} GHz	Cancer Therapy
3. X-rays	10^{8} - 10^{9} GHz	X-ray examination
4. Ultraviolet Radiation	10^{6} - 10^{8} GHz	Sterilization
5. Visible Light	10^{5} - 10^{6} GHz	Human Vision
6. Infrared Radiation	10^{3} - 10^{4} GHz	Photography in dark or low vision circumstances
7. Microwave Waves	3 - 300 GHz	• Terrestrial high capacity, Communication links, and • Radar and satellite communication links
8. Radio Waves	0.535 – 806 MHz	• Television, • FM radio, and • AM radio

RADIO SPECTRUM

APPLICATION	FREQUENCY RANGE
UHF Television	470 – 806 MHz
VHF Television	54 – 216 MHZ
FM RADIO	88 – 108 MHz
Shortwave Radio	2 – 26 MHz
AM Radio	535 – 1605 KHz

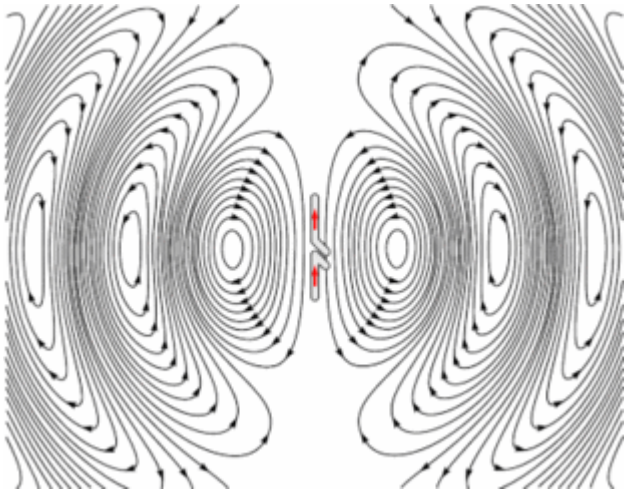
RADAR FREQUENCY BANDS & APPLICATIONS

BAND	ORIGIN	RANGE	WAVE LENGTH	APPLICATION
HF	High Frequency'	3-30 MHz	10 – 100M	**Coastal radar systems, Over-the-horizon (OTH) radars;**
P (VHF)	**'P'** for **'P**revious' (**V**ery **H**igh **F**requency)	30 – 300MHz	1 – 10M	**Applied retrospectively to early radar systems**
UHF	**Ultra High Frequency**	**300 – 1,000 MHz**	**0.3 – 1 M**	**Very long range (e.g. ballistic missile early warning), Ground penetrating, Foliage penetrating**
L	**'L' for 'long'**	**1 – 2.0 GHz**	**15 – 30 cm**	**Long-range air traffic control and surveillance**
S	**'S' for 'short'**	**2 – 4 GHz**	**7.5 – 15 cm**	**Terminal air traffic control, Long-range weather, Marine radar**
C	**Compromise between X and S bands; Hence** C	**4 – 8 GHz**		**Weather radar**
X	**Frequency was kept secret during World War 2, hence 'X'**	**8 – 12 GHz**	**8 – 12 GHz**	**Missile guidance, Marine radar, Weather, Medium-resolution mapping and ground surveillance.**

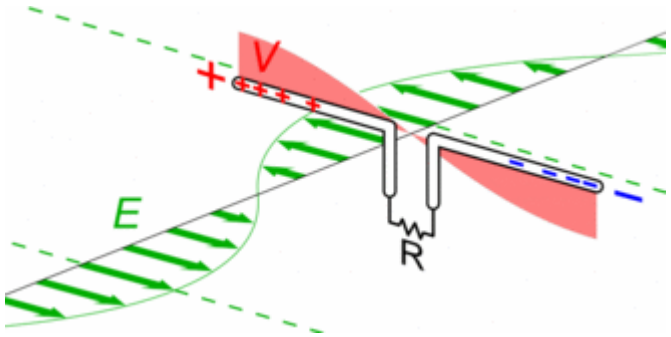
DEFINITION OF ANTENNA

1. Antenna is a device that provides a means for transmitting and receiving radio waves.

2. Antenna provides a transition from a guided wave in a transmission line to a free space wave and vice versa.



(a) Transmitting antenna



(b) Receiving antenna

COMMON TYPES OF ANTENNA



(a) Whip Antenna



(b) Half-wave Dipole



(c) Batwing Antenna



(d) Yagi-Uda Antenna



(e) Rabbit Ears Antenna



(f) Parabolic



(g) Corner



(g) Phased Array



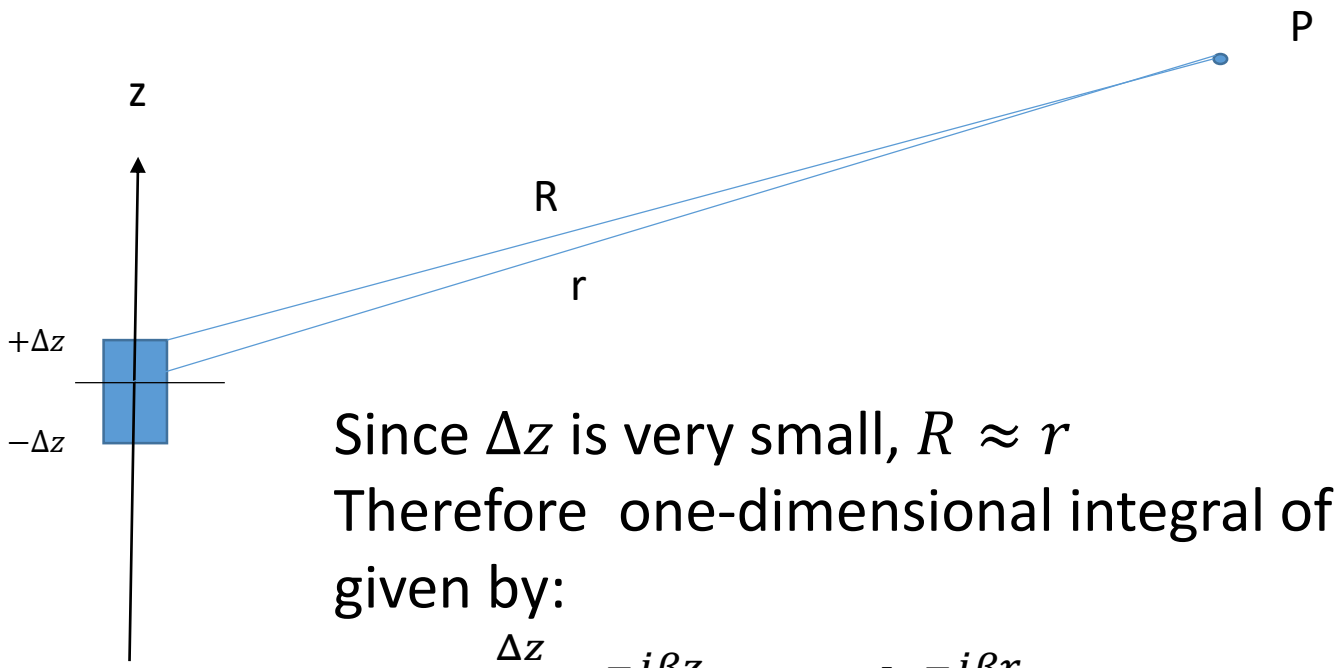
(h) Helical Antenna



(i) MicrowaveHorn Antenna

IDEAL DIPOLE

- **Ideal dipole** refers to an infinitesimal element of current or uniform amplitude current of very small finite length or $\Delta z \ll \lambda$



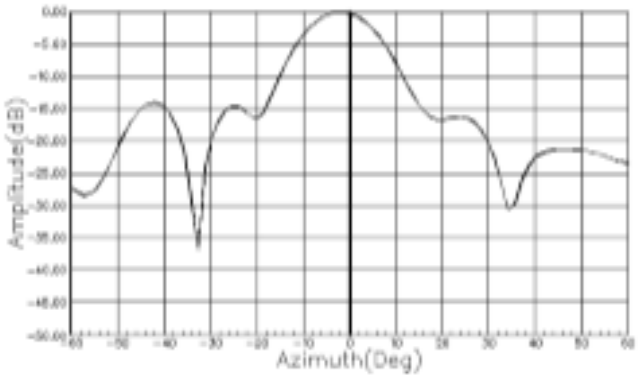
Since Δz is very small, $R \approx r$

Therefore one-dimensional integral of vector potential at point P is given by:

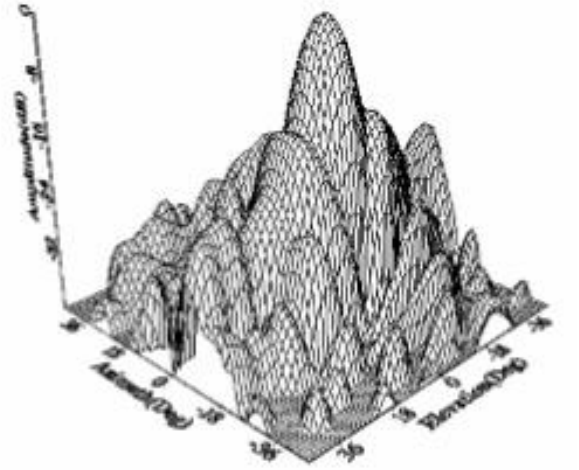
$$A = \int_{-\frac{\Delta z}{2}}^{\frac{\Delta z}{2}} \frac{e^{-j\beta z}}{4\pi r} dz' = \frac{Ie^{-j\beta r}}{4\pi r} \Delta z$$

RADIATION PATTERN

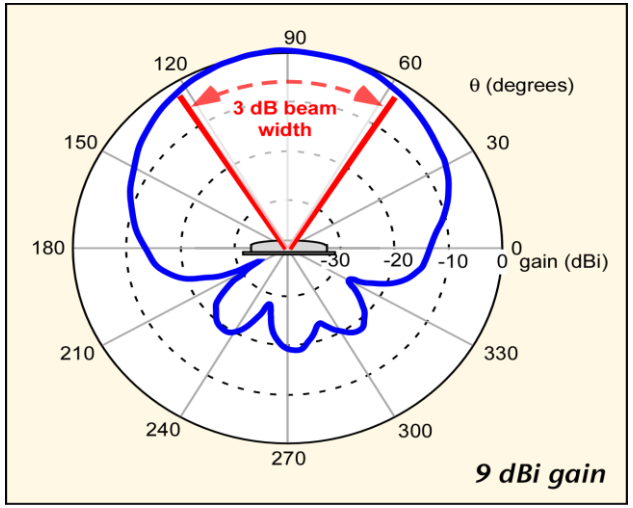
1. **Radiation Pattern** is a graphical representation of the radiation properties of an antenna.
2. **Radiation pattern** is measured by moving a probe antenna round the test antenna.



(a) Radiation Pattern (Rectangular form)

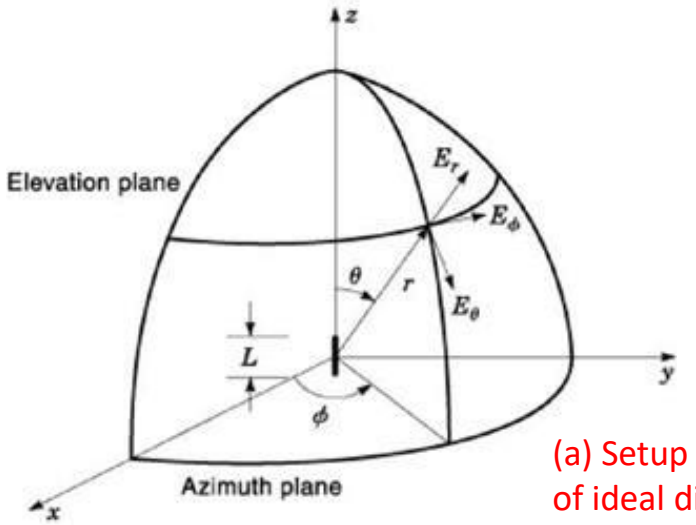


(c) 3D radiation Pattern



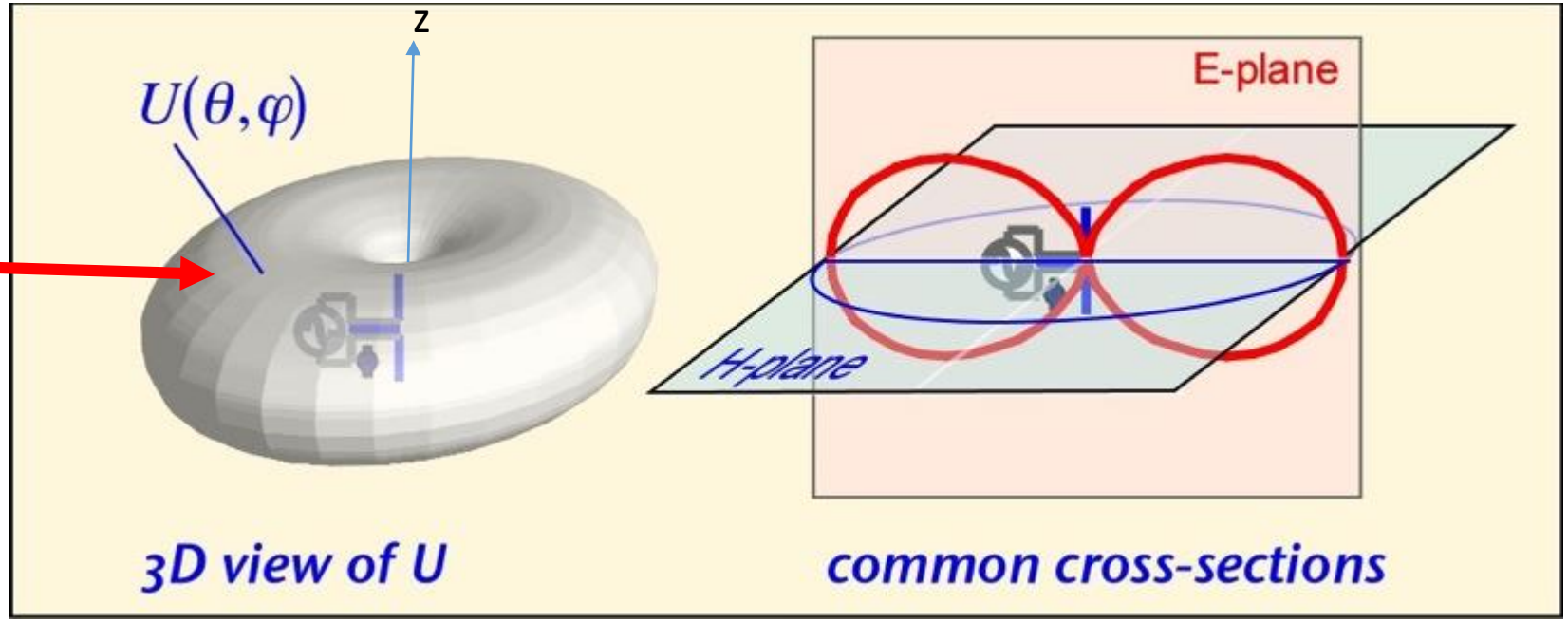
(b) Radiation Pattern (Polar form)

RADIATION PATTERN OF IDEAL DIPOLE



(a) Setup for measuring parameters of ideal dipole

Toroid

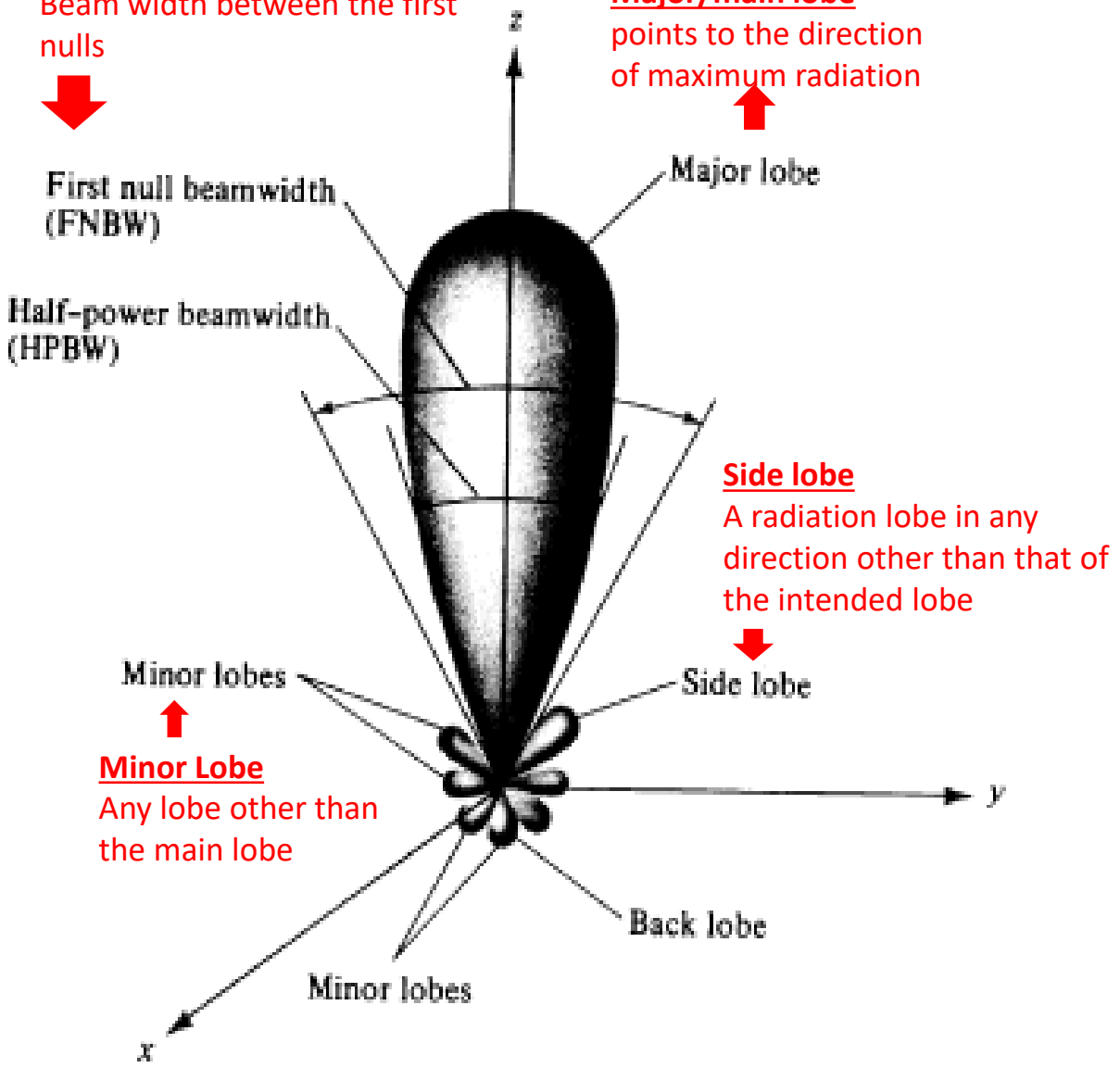


RADIATION PATTERN PARAMETERS

First Null Beam width
Beam width between the first nulls

Major/main lobe
points to the direction of maximum radiation

Half-power Bandwidth
Angular separation of points where the maximum main lobe power is reduced to half.



Side lobe
A radiation lobe in any direction other than that of the intended lobe

Minor Lobe
Any lobe other than the main lobe

SIDE LOBE LEVEL

- Side lobe Level (SLL) is a measure of how power is concentrated in the main lobe.

$$SLL_{dB} = 20Log_{10}\left(\frac{|F_{SLL}|}{|F_{max}|}\right)$$

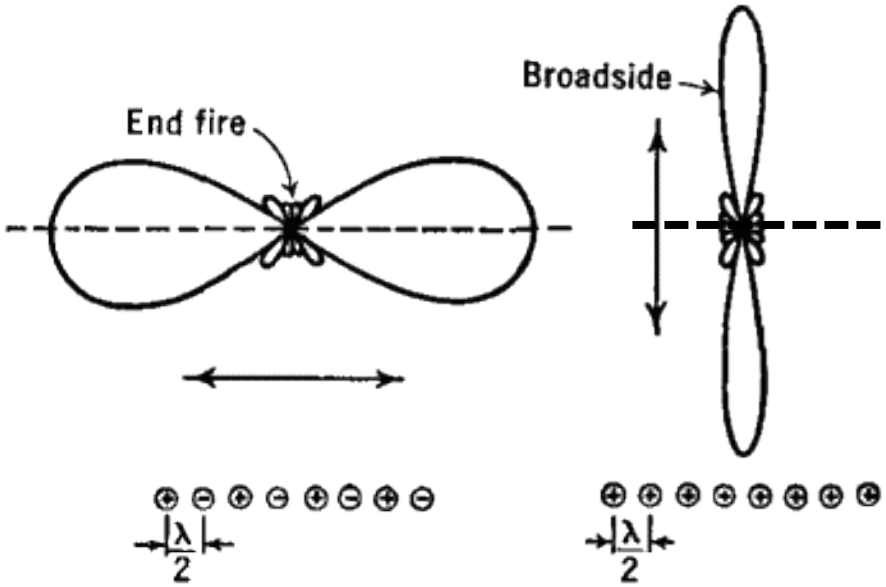
Where

F_{SLL} is the maximum value of the highest side lobe, and

F_{max} is the maximum value of the major (main) lobe

BROADSIDE /END FIRE ANTENNA

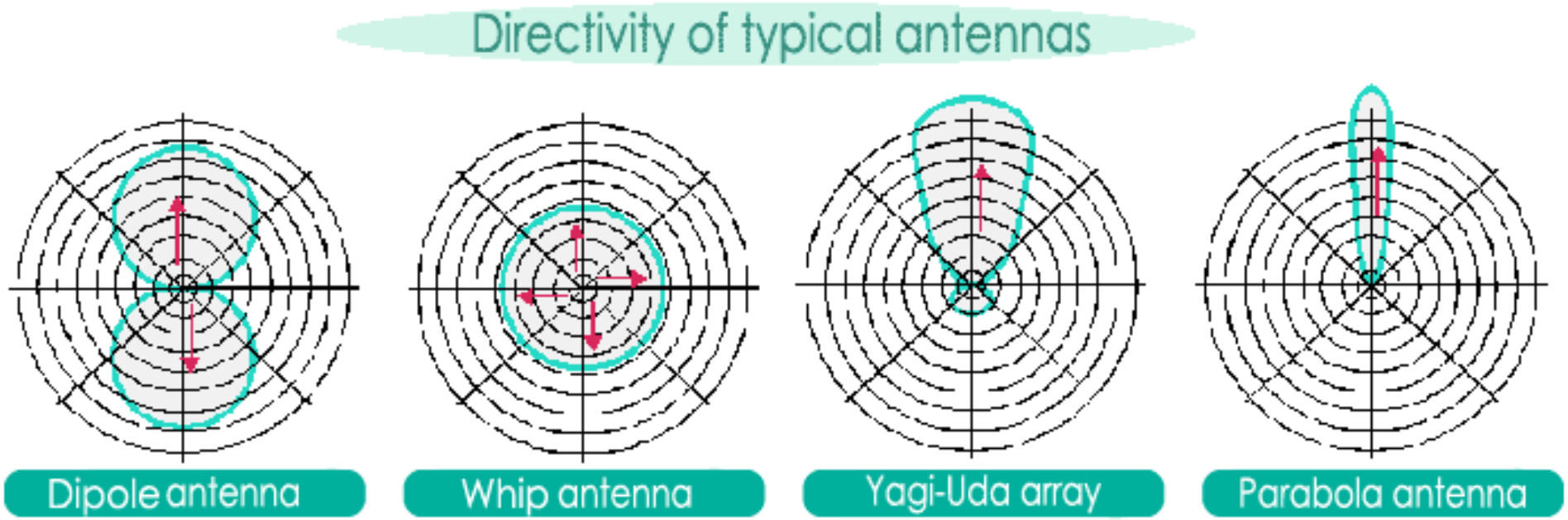
1. **A broadside antenna** has the main beam in the direction normal to the plan containing the antenna.



2. **End fire Antenna** has the main beam in a direction parallel to the plane containing the antenna

ANTENNA DIRECTIVITY

- **Directivity** is a measure of how an antenna concentrates power in one direction in preference to other directions.



DIRECTIVE GAIN

- **Directive Gain** is the ratio of radiation intensity in a certain direction to the average power intensity.

$$D(\theta, \varphi) = \frac{U(\theta, \varphi)}{U_{ave}}$$

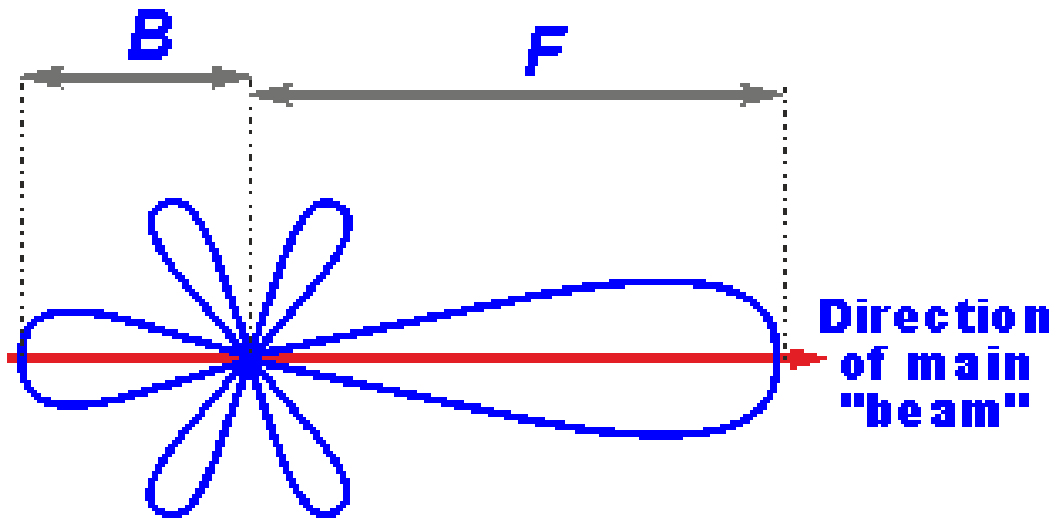
Directivity is the maximum value of Directive Gain, i.e

$$Directivity = \frac{U_m}{U_{ave}}$$

FRONT-BACK (FB) RATIO

- **Front back (FB)** ratio is the ratio of the front lobe to the back lobe, or

$$FB\ Ratio = 20\ log\left(\frac{Main\ lobe\ (Max)}{Back\ Lobe(Max)}\right)$$



ANTENNA GAIN

1. **Antenna Gain** is 4π times the ratio of the radiation intensity in a given direction to the net power entering the antenna from the transmitter.

$$G(\theta, \varphi) = 4\pi \frac{U(\theta, \varphi)}{U_{in}}$$

The maximum value of the power gain is:-

$$G = \frac{4\pi U_m}{P_{in}}$$

Where Um refers to the main lobe

INPUT IMPEDANCE OF ANTENNA

- The input impedance is the antenna impedance at its terminals.
- Input Impedance is affected by other objects near the antenna.

Represents power stored in the near field of the antenna

$$Z_{in} = R_{in} + jX_{in}$$

Represents dissipation of power through heating (ohmic losses) and radiation (radiation losses)

OHMIC LOSSES

- The average power dissipated in the antenna is given by:

$$P_{in} = \frac{1}{2} R_{in} |I_{in}|^2$$

- Where I_{in} is the current flowing through the input terminals

$$P_{in} = P_r + P_{Ohmic}$$
$$= \frac{1}{2} R_r |I_{in}|^2 + \frac{1}{2} R_{Ohmic} |I_{in}|^2$$

- We can therefore define antenna radiation impedance Rr as

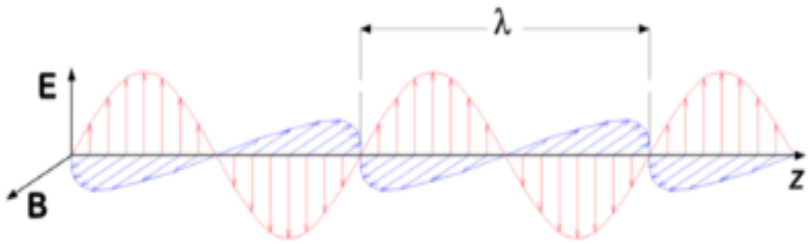
$$R_r = \frac{2P_r}{|I_{in}|^2}$$

- We can also define Ohmic resistance as:

$$R_O = \frac{2(P_{in} - P_r)}{|I_{in}|^2}$$

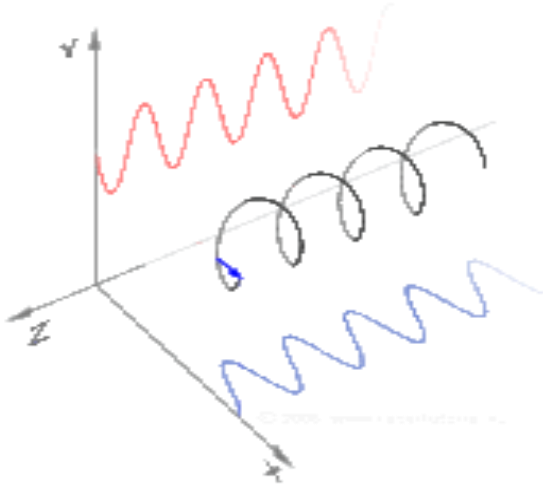
PLANE POLARIZED WAVE

- **Plane polarized wave** have the electric and the magnetic fields lying in fixed planes.



(a) Linearly polarized EM wave

- **Plane polarized waves** can be linearly polarized or circularly polarized.



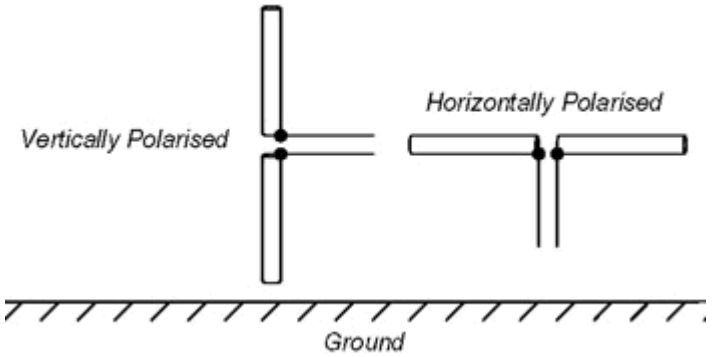
(b) Circularly polarized wave as a sum of two linearly polarized waves

ANTENNA POLARIZATION

1. **Antenna polarization** refers to the polarization of the wave radiated by the antenna in a given direction.
2. An antenna is said to **be vertically polarised (linear)** when its electric field is perpendicular to the Earth's surface.

   An example of a vertical antenna is a broadcast tower for AM radio or the "whip" antenna on an auto-mobile.
3. **Horizontally polarised (linear) antennas** have their electric field parallel to the Earth's surface.

   An example of horizontal polarisation antenna is the TV aerial.



CIRCULAR POLARISATION

- **Circular polarisation** is most often used in satellite communications.

- Since the polarisation of a linear polarised radio wave may be rotated as the signal passes through any anomalies (such as Faraday rotation) in the ionosphere, circular rotation is desirable in satellite communication.



(a) Circularly polarised helical antenna