SREENIVASA INSTITUTE OF TECHNOLOGY AND MANAGEMENT STUDIES.
(AUTONOMOUS)
DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

LECTURE NOTES

SUBJECT NAME: **ANTENNAS & WAVE PROPAGATION**
SUBJECT CODE: **23ECE352T**
YEAR & SEM: **III / V**
REGULATION: **R23**
PREPARED BY: ***Dr K YOGAPRASAD & PROF R M SULTHANI***

INSTITUTE VISION

To emerge as a Center of Excellence for Learning and Research in the domains of Engineering, Computing and Management.

INSTITUTE MISSION

IM1: Provide congenial academic ambience with state-of-art resources for learning and research.

IM2: Ignite the students to acquire self-reliance in the latest technologies.

IM3: Unleash and encourage the innate potential and creativity of students.

IM4: Inculcate confidence to face and experience new challenges.

IM5: Foster enterprising spirit among students.

IM6: Work collaboratively with Technical Institutes / Universities / Industries of National, International repute.

DEPARTMENT VISION

To be a center of excellence in Electronics and Communication Engineering by producing globally competent and socially responsible graduates through quality education, innovation, and research.

DEPARTMENT MISSION

M1: To impart quality education in Electronics and Communication Engineering through an excellent academic environment, modern infrastructure, and effective learning resources.

M2: To foster research, innovation, and industry collaboration in emerging technologies for addressing contemporary industrial and societal challenges.

M3: To nurture ethically responsible, self-reliant, and globally competent graduates with teamwork, leadership, and lifelong learning skills.

M4: To cultivate entrepreneurial spirit and creative thinking for sustainable technological and societal development.

PROGRAMMABLE EDUCATIONAL OUTCOMES

PEO1: Graduates will apply mathematical, scientific, and core Electronics and Communication Engineering knowledge to analyse, design, and implement engineering solutions in Signal Processing, VLSI, Embedded Systems, Communication, and Automation to meet industry standards.

PEO2: Career Growth and Leadership: Graduates will demonstrate critical thinking, professional ethics, teamwork, and leadership to achieve career success as practicing engineers, entrepreneurs, or advanced study candidates.

PEO3: Graduates will pursue continuous learning and innovation, contributing to society through research, technology development, patents, startups, or community oriented engineering solutions.

PROGRAM SPECIFIC OUTCOMES

PSO1: Apply core ECE principles and modern tools to analyse, model, and design components and subsystems in Signal Processing, VLSI, Embedded Systems, Communication and validate solutions through simulation and experimental verification.

PSO2: Use creative design methodologies and engineering design cycles to develop prototypes or products that address industrial and societal needs and sustainability considerations.

PROGRAMME OUTCOMES (PO's)

On Successful completion, the graduate will be able to,

PO1: **Engineering Knowledge**: Apply knowledge of mathematics, natural science, computing, engineering fundamentals and an engineering specialization as specified in WK1 to WK4 respectively to develop to the solution of complex engineering problems.

PO2: **Problem Analysis**: Identify, formulate, review research literature and analyze complex engineering problems reaching substantiated conclusions with consideration for sustainable development. (WK1 to WK4)

PO3: **Design/Development of Solutions**: Design creative solutions for complex engineering problems and design/develop systems/components/processes to meet identified needs with consideration for the public health and safety, whole-life cost, net zero carbon, culture, society and environment as required. (WK5)

PO4: **Conduct Investigations of Complex Problems**: Conduct investigations of complex engineering problems using research-based knowledge including design of experiments, modelling, analysis & interpretation of data to provide valid conclusions. (WK8).

PO5: **Engineering Tool Usage**: Create, select and apply appropriate techniques, resources and modern engineering & IT tools, including prediction and modelling recognizing their limitations to solve complex engineering problems. (WK2 and WK6)

PO6: **The Engineer and The World**: Analyze and evaluate societal and environmental aspects while solving complex engineering problems for its impact on sustainability with reference to economy, health, safety, legal framework, culture and environment. (WK1, WK5, and WK7).

PO7: **Ethics**: Apply ethical principles and commit to professional ethics, human values, diversity and inclusion; adhere to national & international laws. (WK9)

PO8: **Individual and Collaborative Team work**: Function effectively as an individual, and as a member or leader in diverse/multi-disciplinary teams.

PO9: **Communication**: Communicate effectively and inclusively within the engineering community and society at large, such as being able to comprehend and write effective reports and design documentation, make effective presentations considering cultural, language, and learning differences

PO10: **Project Management and Finance**: Apply knowledge and understanding of engineering management principles and economic decision-making and apply these to one's own work, as a member and leader in a team, and to manage projects and in multidisciplinary environments.

PO11: **Life-Long Learning**: Recognize the need for, and have the preparation and ability for i) independent and life-long learning ii) adaptability to new and emerging technologies and iii) critical thinking in the broadest context of technological change. (WK8)

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III B.TECH. - V SEMESTER

23ECE352T	**ANTENNAS & WAVE PROPAGATION**	L	T	P	C
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PRE-REQUISITES: **Electromagnetic Waves and Transmission Lines**

COURSE EDUCATIONAL OBJECTIVES:

1.To learn the antennas basic terminology, radiation mechanism of antennas and dipole antennas.
2. To gain knowledge on HF, VHF & UHF antennas, their operation and applications.
3. Analyze the working and applications of Microwave antennas.
4. Understand different techniques involved in the design of antenna arrays and antenna parameter measurements.
5. To study the various types of radio wave propagation methods.

UNIT -1: ANTENNA BASICS & DIPOLE ANTENNAS (9)

Antenna Basics & Dipole antennas: Definition of antenna, Radiation Mechanism – single wire, two wire, dipoles, Antenna Parameters - Radiation Patterns, Main Lobe and Side Lobes, Beam widths, Beam Area, Radiation Intensity, Beam Efficiency, Directivity, Gain and Resolution, Aperture Efficiency, Effective Height and length, Reciprocal Theorem. Radiation-Radiation from Small Electric Dipole, Quarter wave Monopole and Half wave Dipole – Current Distributions, Field Components, Radiated power, Radiation Resistance, Beam width, Illustrative problems.

UNIT- 2: HF, VHF AND UHF ANTENNAS (9)

HF, VHF and UHF Antennas: Loop Antennas - Introduction, Small Loop, Arrays with Parasitic Elements - Yagi - Uda Arrays, Folded Dipoles & their characteristics. Log periodic Antenna, Helical Antennas-Helical Geometry, Helix modes, Helical Antenna in Axial and Normal Modes. Horn Antennas- Types, Fermat‘s Principle, Illustrative Problems.

UNIT – 3: MICROWAVE ANTENNAS (9)

Microwave Antennas : Microstrip Antennas- Introduction, features, advantages and limitations, Rectangular patch antennas- Geometry and parameters, characteristics of Micro strip antennas, Impact of different parameters on characteristics, reflector antennas - Introduction, , parabola reflectors- geometry, pattern characteristics, Feed Methods, Reflector Types - Related Features, Lens Antennas - Geometry of Non-metallic Dielectric Lenses, Zoning, Tolerances, Applications, Illustrative Problems.

UNIT- 4: ANTENNA ARRAYS (9)

Antenna Arrays: Point sources - Definition, Patterns, arrays of 2 Isotropic sources- Different cases, Principle of Pattern Multiplication, Uniform Linear Arrays – Broadside Arrays, End-fire Arrays, BSA with Non-Uniform Amplitude Distributions - General considerations and Binomial Arrays, Illustrative problems. Antenna Measurements: Introduction, Sources of errors, Pattern Measurement Arrangement, Directivity Measurement, Gain Measurements (by comparison, Absolute and 3-Antenna Methods).

UNIT – 5: WAVE PROPAGATION (9)

Wave Propagation: Introduction, Definitions, Characterizations and general classifications, different modes of wave propagation, Ray/Mode concepts, Ground wave propagation (Qualitative treatment) - Introduction, Plane earth reflections, Space and surface waves, wave tilt, curved earth reflections, Space wave propagation - Introduction, field strength variation with distance and height, effect of earth's curvature, absorption and duct propagation, scattering phenomena, tropospheric propagation, fading and path loss calculations, Sky wave propagation - Introduction, structure of Ionosphere, refraction and reflection of sky waves by Ionosphere, Ray path, Critical frequency, MUF, LUF, OF, Virtual height and Skip distance, Illustrative problems.

Total Hours: 45

COURSE OUTCOMES:

On successful completion of the course the student will be able to		POs related to COs
CO1	Understand the antennas basic terminology and radiation mechanism of antennas.	**PO1, PO2**
CO2	Gain knowledge on VHF and UHF antennas, their operation and applications.	**PO1, PO2**
CO3	Design and analyze the working and applications of Microwave antennas.	**PO1, PO2, PO3**
CO4	Analyze different techniques involved in the design of antenna arrays and antenna parameter measurements.	**PO1, PO2**
CO5	Gain a comprehensive knowledge about the types of radio wave propagation methods.	**PO1,PO2**

TEXT BOOKS:

1.John D. Kraus, Ronald J. Marhefka and Ahmad S.Khan, ―Antennas and wave propagation‖, TMH, New Delhi, 4th Ed., 2010.

2. C.A. Balanis, ―Antenna Theory- Analysis and Design‖, John Wiley & Sons, 2nd Edn., 2001.

3. K.D. Prasad and Satya Prakashan, ―Antennas and Wave Propagation‖, New Delhi, Tech. India Publications, 2001.

REFERENCES:

1.E.C. Jordan and K.G. Balmain, ―Electromagnetic Waves and Radiating Systems‖, 2nd Edition, PHI, 2000.

2. G.S.N Raju, ―Antenna and Wave Propagation‖, Pearson Education India, 3rd Edition 2009.

3. R K Shevgaonkar,‖ Electromagnetic Waves‖. Tata McGraw-Hill, 2006

WEB RESOURCE:

1. https://nptel.ac.in/courses/108101092
2. https://www.antenna-theory.com/

CO-PO MAPPING:

CO\PO	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	3	2	-	-	-	-	-	-	-	-	-	-
CO2	3	2	-	-	-	-	-	-	-	-	-	-
CO3	3	2	1	-	-	-	-	-	-	-	-	-
CO4	3	2	-	-	-	-	-	-	-	-	-	-
CO5	3	2	-	-	-	-	-	-	-	-	-	-
CO*	**3**	**2**	**1**	**-**	-	-	-	-	-	-	-	-

Objectives:

The objective of this course is to enable students to:

1. Understand the fundamental concepts of electromagnetic radiation, antenna theory, radiation mechanisms, and antenna performance parameters.
2. Analyze the characteristics and radiation patterns of wire antennas, dipole antennas, monopole antennas, and loop antennas used in communication systems.
3. Study the design, operating principles, and applications of HF, VHF, UHF, and microwave antennas, including Yagi-Uda, log-periodic, helical, horn, microstrip, reflector, and lens antennas.
4. Apply the principles of antenna arrays, pattern multiplication, beamforming, and antenna measurement techniques to evaluate antenna performance.
5. Understand the mechanisms of ground wave, space wave, and sky wave propagation, and analyze propagation phenomena for reliable wireless and satellite communication systems.

Quote:

"A well-designed antenna does not simply radiate energy—it radiates opportunity for global connectivity."

Expected Outcome:

"Like a perfect mirror, an antenna listens with the same precision and pattern with which it speaks."

INTRODUCTION TO TL

- Maxwell's Equations
- Primary constants.
- Secondary constants.
- TL equation.
- Infinite line
- Distortion less line.
- SC & OC lines.
- UHF Lines.
- Any termination.
- Termination by load.

Maxwell's Equations

- Maxwell’s equations are four fundamental formulas that describe **how electric and magnetic fields interact, propagate, and are generated by charges and currents**.
- Together, they form the **bedrock of classical electromagnetism, optics, and all modern wireless communication**.

$\nabla \cdot \mathbf{D} = \rho$	(1)	Gauss' Law
$\nabla \cdot \mathbf{B} = 0$	(2)	Gauss' Law for magnetism
$\nabla \times \mathbf{E} = -\dfrac{\partial \mathbf{B}}{\partial t}$	(3)	Faraday's Law
$\nabla \times \mathbf{H} = \dfrac{\partial \mathbf{D}}{\partial t} + \mathbf{J}$	(4)	Ampère-Maxwell Law

TABLE 11.2 Transmission Line Characteristics

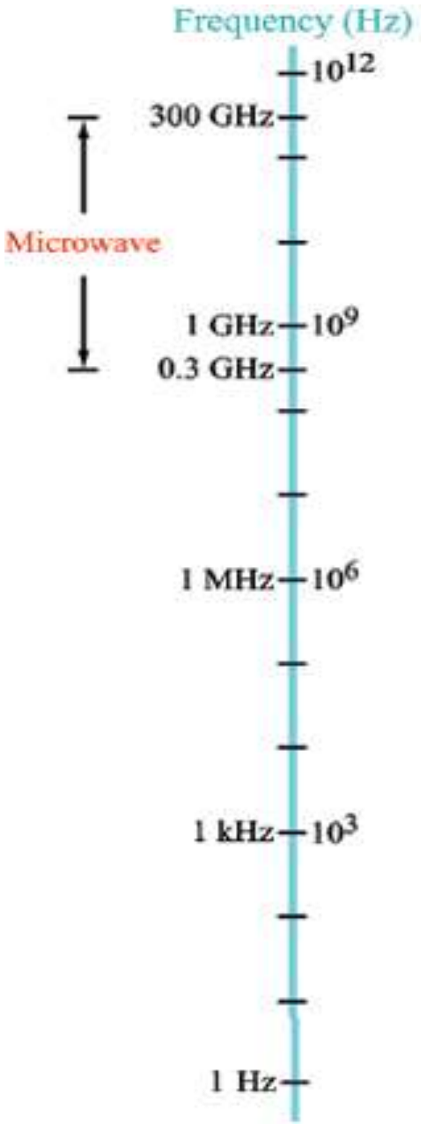
Case	Propagation Constant $\gamma = \alpha + j\beta$	Characteristic Impedance $Z_o = R_o + jX_o$
General	$\sqrt{(R + j\omega L)(G + j\omega C)}$	$\sqrt{\frac{R + j\omega L}{G + j\omega C}}$
Lossless	$0 + j\omega\sqrt{LC}$	$\sqrt{\frac{L}{C}} + j0$
Distortionless	$\sqrt{RG} + j\omega\sqrt{LC}$	$\sqrt{\frac{L}{C}} + j0$

$$Z_o = R_o = \sqrt{\frac{L}{C}}$$

$$\beta = \omega\sqrt{LC} \qquad \frac{R_o}{\beta} = \frac{1}{\omega C} \qquad L = R_o^2 C$$

FREQUENCY SPECTRUM

- ITU-International Telecommunication Union Bands.
- IEEE- Institute of Electrical and Electronics Engineers Association Standard Bands.



Band	Applications
Extremely High Frequency (30–300 GHz)	Radar, advanced communication systems, remote sensing, radio astronomy
Super High Frequency (3–30 GHz)	Radar, satellite communication systems, aircraft navigation, radio astronomy, remote sensing
Ultra High Frequency (300 MHz – 3 GHz)	TV broadcasting, radar, radio astronomy, microwave ovens, cellular telephone
Very High Frequency (30–300 MHz)	TV and FM broadcasting, mobile radio communication, air traffic control
High Frequency (3–30 MHz)	Shortwave broadcasting
Medium Frequency (300 kHz – 3 MHz)	AM broadcasting
Low Frequency (30–300 kHz)	Radio beacons, weather broadcast stations for air navigation
Very Low Frequency (3–30 kHz)	Navigation and position location
Ultra Low Frequency (300 Hz – 3 kHz)	Audio signals on telephone
Super Low Frequency (30–300 Hz)	Ionospheric sensing, electric power distribution, submarine communication
Extremely Low Frequency (3–30 Hz)	Detection of buried metal objects
	Magnetotelluric sensing of the Earth's structure

Frequency Band	Designation	Example uses
3–30 Hz	Extremely low frequency (ELF)	Submarine communication
30–300 Hz	Super low frequency (SLF)	Submarine communication
300–3000 Hz	Ultra low frequency (ULF)	Submarine communication
3–30 kHz	Very low frequency (VLF)	Submarine communication
30–300 kHz	Low frequency (LF)	AM longwave broadcasting, RFID
300–3000 kHz	Medium frequency (MF)	AM (medium-wave) broadcasts
3–30 MHz	High frequency (HF)	Shortwave broadcasts, aviation communications, RFID,
30–300 MHz	Very high frequency (VHF)	FM, television broadcasts
300–3000 MHz	Ultra high frequency (UHF)	TV broadcasts, mobile phones, wireless LAN, Bluetooth
3–30 GHz	Super high frequency (SHF)	microwave devices/communications, wireless LAN
30–300 GHz	Extremely high frequency (EHF)	microwave remote sensing

S.No	Band No.	Abbreviation	Frequency Range	Wavelength
1	4	VLF	3-30KHz	10 to 100Km
2	5	LF	30-300 KHz	1 to 10Km
3	6	MF	300-3000KHz	100 to 1000m
4	7	HF	3-30 MHz	10 to 100m
5	8	VHF	30-300 MHz	1 to 10m
6	9	UHF	300-3000 MHz	10 to 100cm
7	10	SHF	3-30 GHz	1 to 10cm
8	11	EHF	30-300 GHz	1 to 10 mm
9	12	THF	300-3000 GHz	0.1 to 1mm

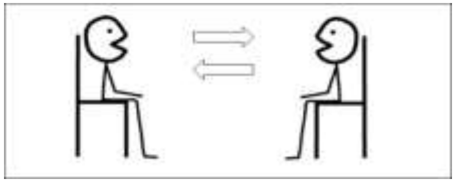
ITU BANDS

S.No	Band Description	Frequency range (GHz)	Abbreviation
1	HF	0.003-0.03	High frequency
2	VHF	0.03-0.3	Very High frequency
3	UHF	0.3-1	Ultra High Frequency
4	L	1-2	Long wave
5	S	2-4	Short wave
6	C	4-8	Compromise between S and L
7	X	8-12	X for cross
8	K_u	12-18	Kurz under
9	K	18-27	Kurz
10	K_a	27-40	Kurz above
11	V	40-75	
12	W	75-110	
13	millimeter	110-300	millimeter

IEEE BANDS

INTRODUCTIO TO ANTENNA

- **voice communication**.

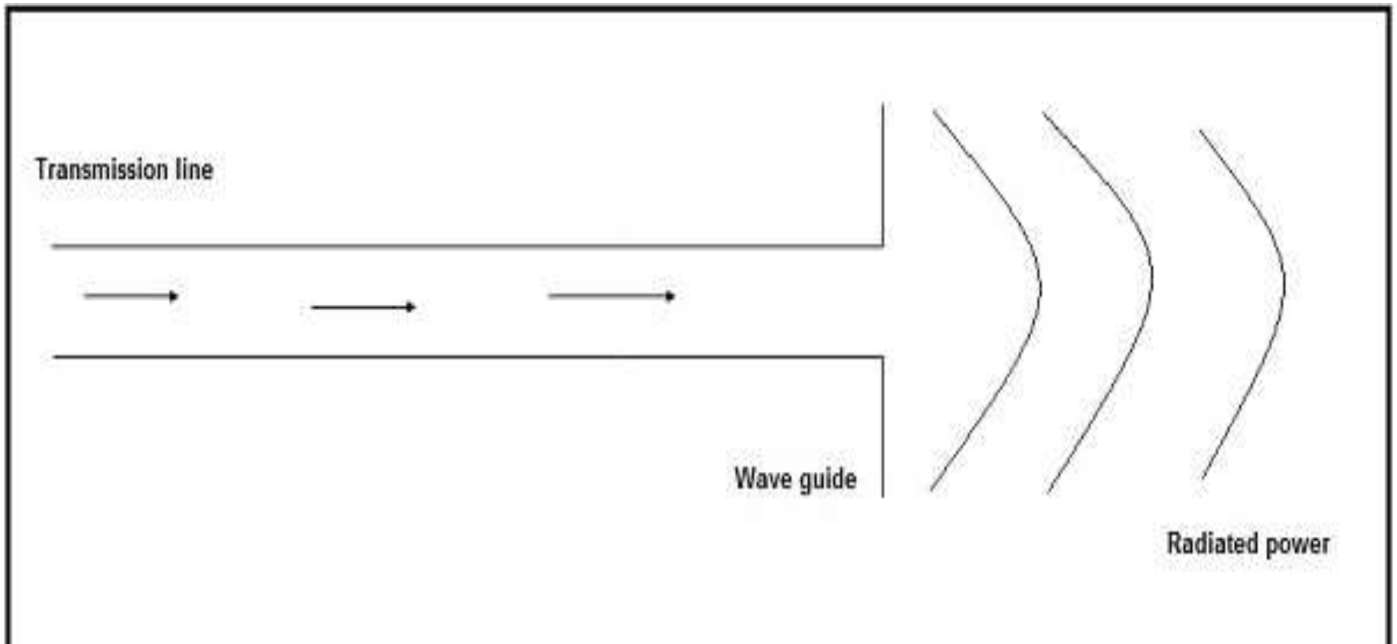


- two individuals communicating with each other. Here, communication takes place through **sound waves**.
- if two people want to communicate who are at longer distances, then we have to convert these sound waves into **electromagnetic waves**.
- The device, which converts the required information signal into electromagnetic waves, is known as an **Antenna**.

ANTENNA BASICS

- An Antenna is a transducer, which converts electrical power into electromagnetic waves and vice versa.
- An Antenna can be used either as a **transmitting antenna** or a **receiving antenna**.

- The power from the transmission line travels through the **waveguide** which has an aperture, to radiate the energy.

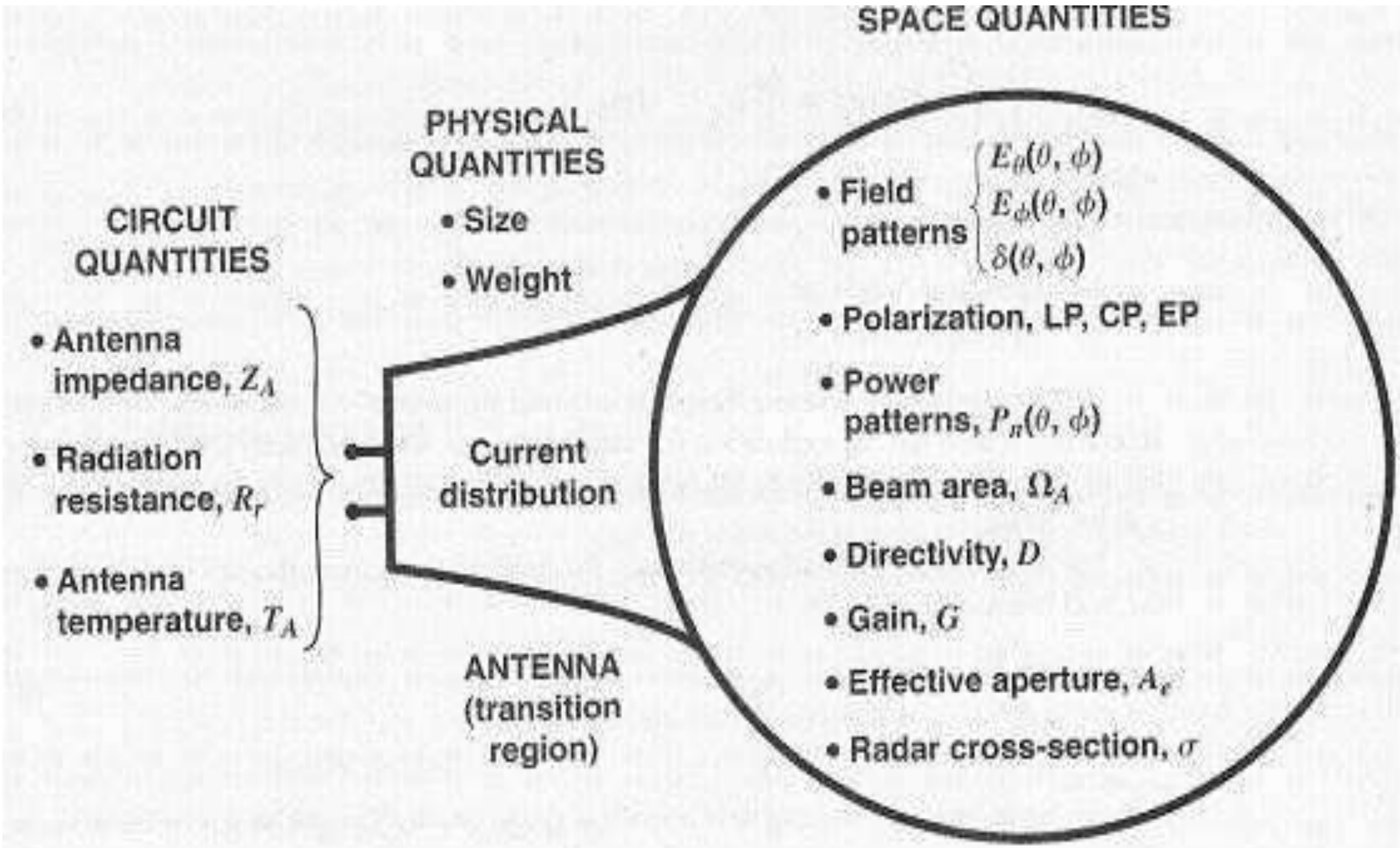


Basic Types of Antennas

- Depending upon –
  - The physical structure of the antenna.
  - The frequency ranges of operation.
  - The mode of applications etc.
  - Physical structure
- Antennas according to the physical structure.
  - Wire antennas
  - Aperture antennas
  - Reflector antennas
  - Lens antennas
  - Micro strip antennas
  - Array antennas

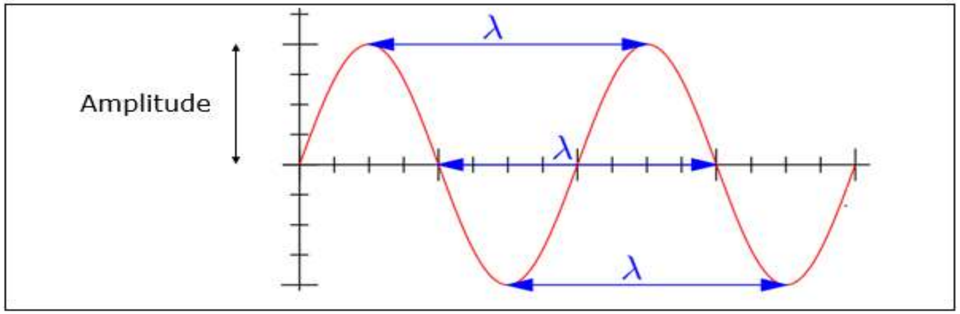
- Frequency of operation
  - Very Low Frequency (VLF)
  - Low Frequency (LF)
  - Medium Frequency (MF)
  - High Frequency (HF)
  - Very High Frequency (VHF)
  - Ultra High Frequency (UHF)
  - Super High Frequency (SHF)
  - Micro wave
  - Radio wave
- Mode of Applications
  - Point-to-point communications
  - Broadcasting applications
  - Radar communications
  - Satellite communications

Antenna Parameters



- Frequency
- Wavelength
- Impedance matching
- VSWR & reflected power
- Bandwidth
- Percentage bandwidth
- Radiation intensity
- Radiation Pattern
- Field Regions
- Directivity
- Antenna Efficiency
- Antenna Gain
- Effective Aperture
- Friis Transmission Equation
- Antenna Temperature

- Frequency - The rate of repetition of a wave over a particular period of time, is called as **frequency**.
- Wavelength - The distance between two consecutive maximum points (crests) or between two consecutive minimum points (troughs) is known as the **wavelength**.
  - The higher the frequency, the lesser will be the wavelength and vice versa.



$$\lambda = \frac{c}{f}$$

- Impedance Matching - The approximate value of impedance of a transmitter, when equals the approximate value of the impedance of a receiver, or vice versa, it is termed as **Impedance matching**.
- Necessity of Matching:
  - The power radiated by an antenna, will be effectively radiated, if the **antenna impedance** matches the free space impedance.
  - For a **receiver antenna**, antenna's output impedance should match with the input impedance of the receiver amplifier circuit.
  - For a **transmitter antenna**, antenna's input impedance should match with transmitter amplifier's output impedance, along with the transmission line impedance.

- VSWR & Reflected Power - The ratio of the maximum voltage to the minimum voltage in a standing wave is known as **Voltage Standing Wave Ratio**.

The key features are :

  – which indicates the impedance mismatch is **VSWR**.
  – The higher the impedance mismatch, the higher will be the value of **VSWR**.
  – The ideal value of VSWR should be 1:1 for effective radiation.
  – Reflected power is the power wasted out of the forward power. Both reflected power and VSWR indicate the same thing.

- Bandwidth - A band of frequencies in a wavelength, specified for the particular communication, is known as **bandwidth**.
  - Bandwidth is the band of frequencies between the higher and lower frequencies over which a signal is transmitted.
  - The bandwidth once allotted, cannot be used by others.
  - The whole spectrum is divided into bandwidths to allot to different transmitters.

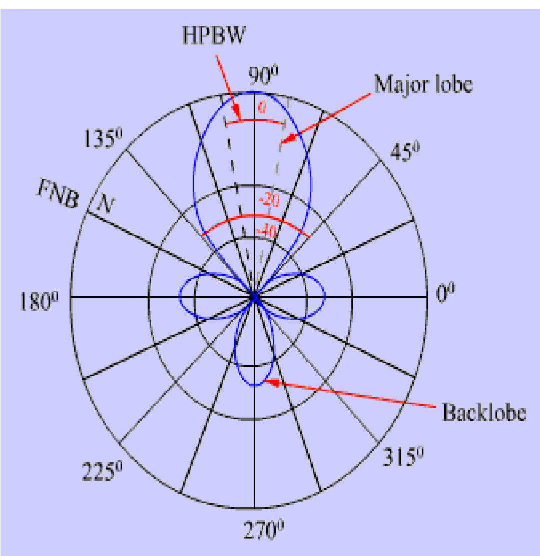
- Percentage Bandwidth - The ratio of absolute bandwidth to the center frequency of that bandwidth can be termed as **percentage bandwidth**.
  - The particular frequency within a frequency band, at which the signal strength is maximum, is called as **resonant frequency**. It is also called as **center frequency (f_C)** of the band.
  - The higher and lower frequencies are denoted as **f_H and f_L** respectively.
  - The absolute bandwidth is given by- **f_H - f_L**.
  - To know how wider the bandwidth is, either **fractional bandwidth** or **percentage bandwidth** has to be calculated.

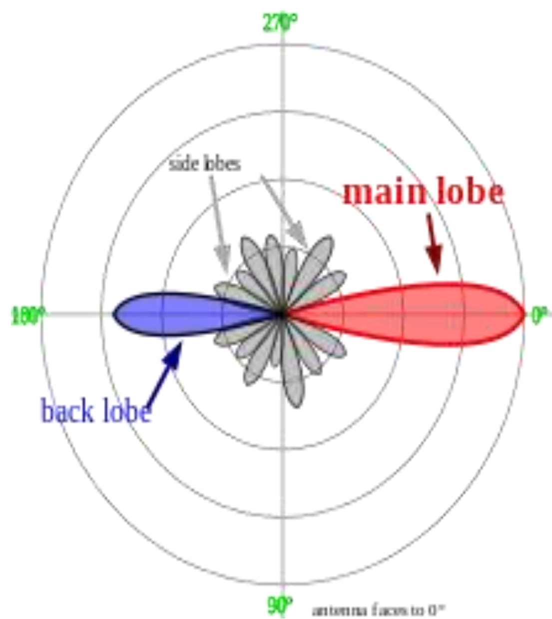
$$Percentage\ bandwidth = \frac{absolute\ bandwidth}{center\, frequency} = \frac{f_H - f_L}{f_c}$$

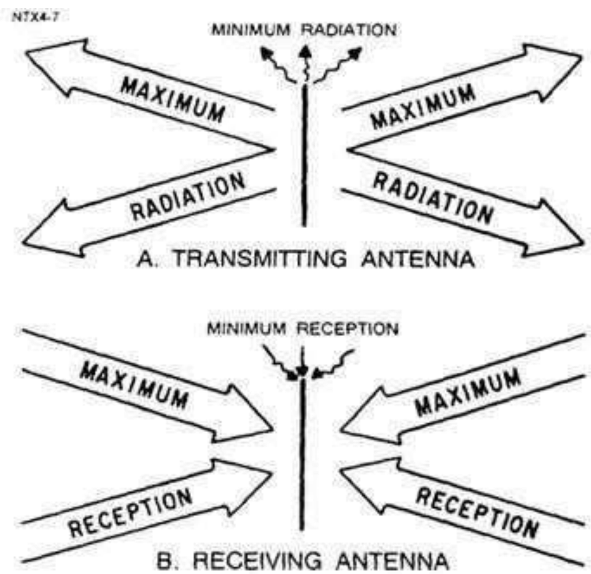
- Radiation Intensity - the power per unit solid angle.
  - Radiation emitted from an antenna which is more intense in a particular direction, indicates the maximum intensity of that antenna.
  - The emission of radiation to a maximum possible extent is nothing but the radiation intensity.

$$U = r^2 \times W_{rad}$$

- **Radiation Pattern** - the variation of the power radiated by an antenna as a function of the direction away from the antenna.
  - This power variation as a function of the arrival angle is observed in the antenna's far field.
  - An antenna's normalized radiation pattern can be written as a function in spherical coordinates F(θ,ø).



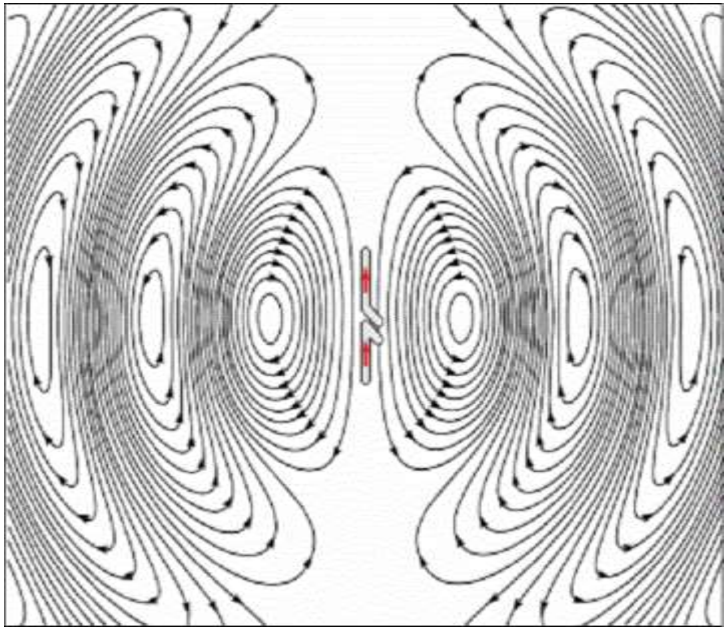




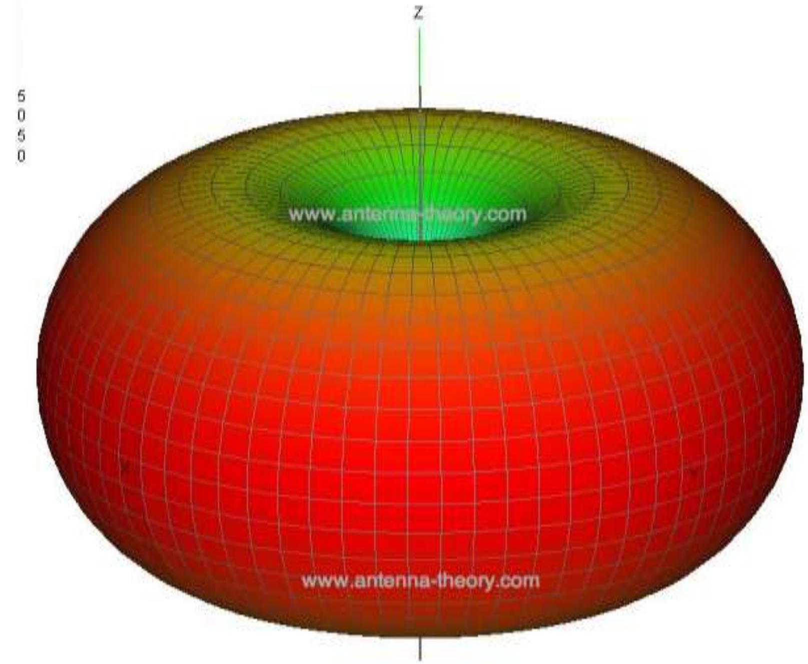
Radiation Pattern

- Radiation is the term used to represent the emission or reception of wave front at the antenna, specifying its strength.
- The sketch drawn to represent the radiation of an antenna is its **radiation pattern**.
- One can simply understand the function and directivity of an antenna by having a look at its radiation pattern.
- The power when radiated from the antenna has its effect in the near and far field regions.
  - Graphically, radiation can be plotted as a function of **angular position** and **radial distance** from the antenna.
  - This is a mathematical function of radiation properties of the antenna represented as a function of spherical co-ordinates, E (θ, Ø) and H (θ, Ø).

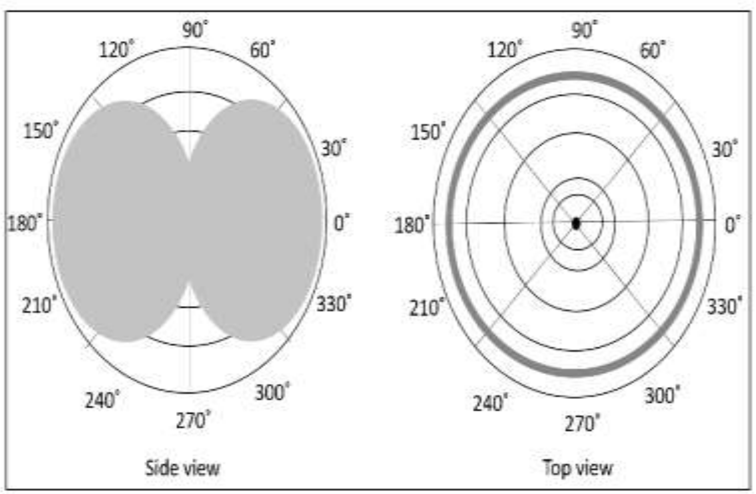
- The radiation patterns can be field patterns or power patterns.
  - The **field patterns** are plotted as a function of electric and magnetic fields. They are plotted on logarithmic scale.
  - The **power patterns** are plotted as a function of square of the magnitude of electric and magnetic fields. They are plotted on logarithmic or commonly on dB scale.



RP of DIPOLE ANTENNA



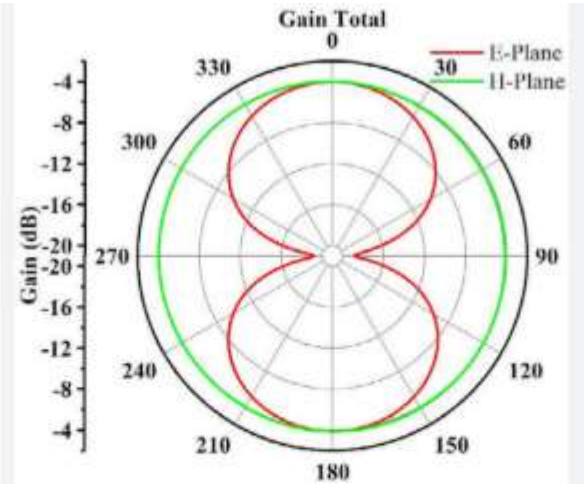
3-D RP

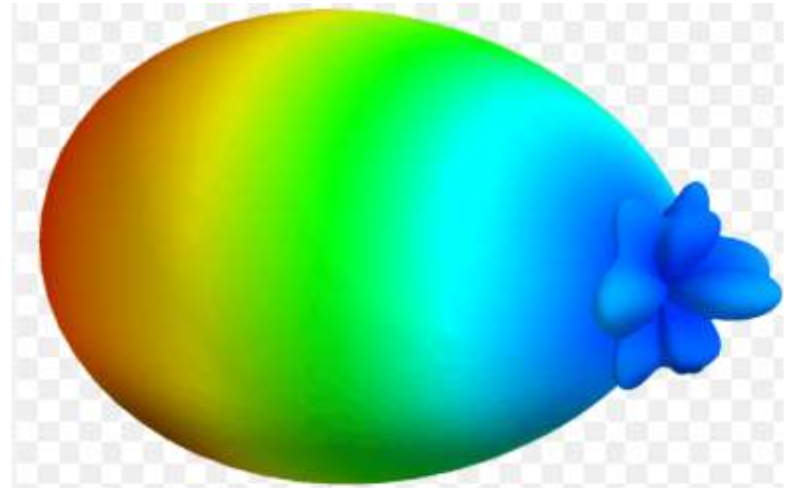


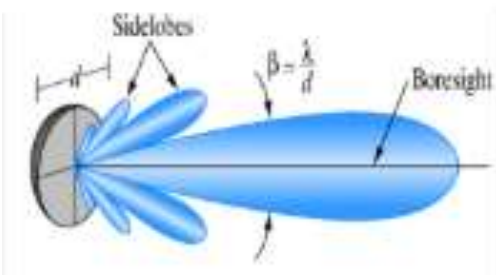
2-D RP

Types of Radiation patterns

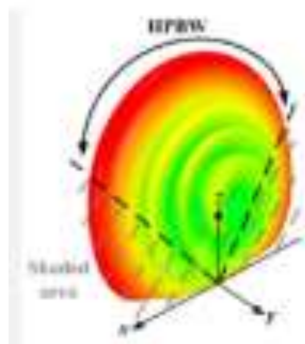
- The common types of Radiation patterns are –
  - Omni-directional pattern (also called non-directional pattern): The pattern usually has a doughnut shape in three-dimensional view. However, in two-dimensional view, it forms a figure-of-eight pattern.
  - Pencil-beam pattern – The beam has a sharp directional pencil shaped pattern.
  - Fan-beam pattern – The beam has a fan-shaped pattern.
  - Shaped beam pattern – The beam, which is non-uniform and patternless is known as shaped beam.
- A referential point for all these types of radiation is the isotropic radiation.
- It is important to consider the isotropic radiation even though it is impractical.



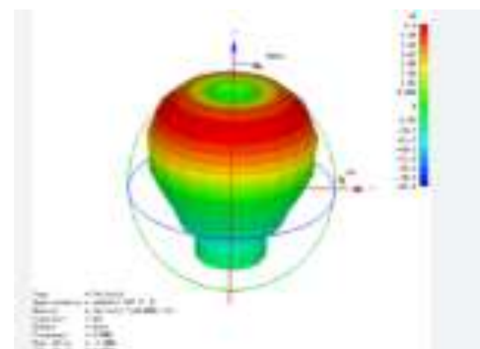




(a) Pencil beam



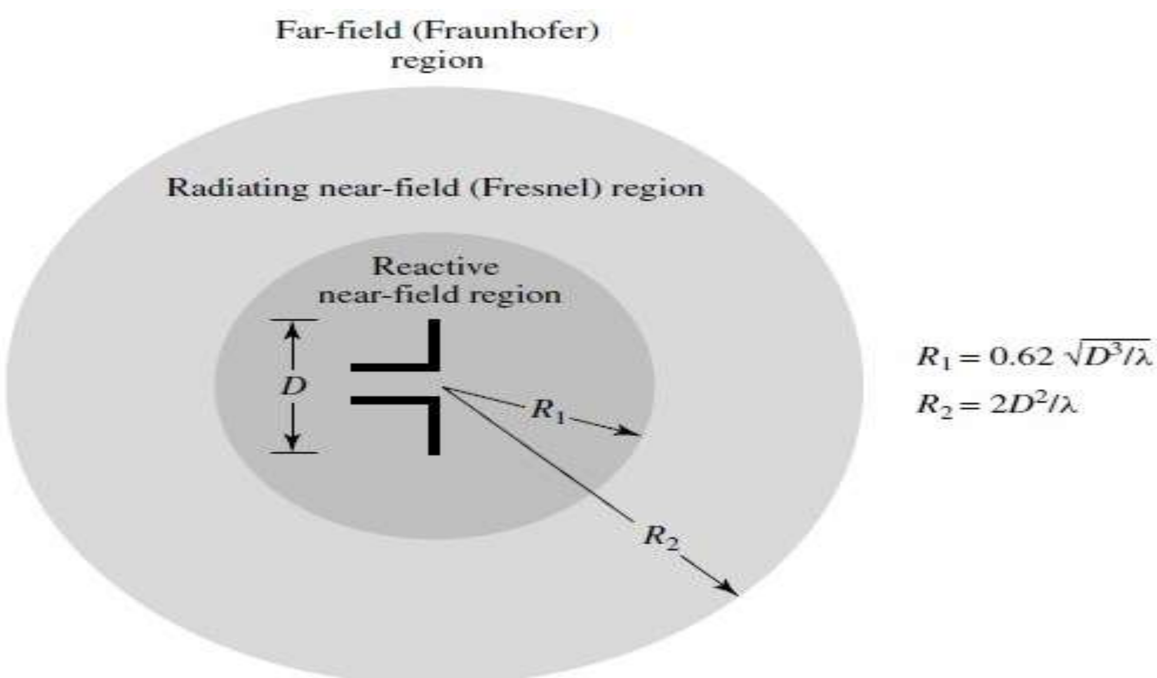
(a)



Isotropic Radiation

- The radiation from a point source, radiating uniformly in all directions, with same intensity regardless of the direction of measurement.
- The improvement of radiation pattern of an antenna is always assessed using the isotropic radiation of that antenna.
- If the radiation is equal in all directions, then it is known as **isotropic radiation**.
- The point source is an example of isotropic radiator.
- However, this isotropic radiation is practically impossible, because every antenna radiates its energy with some directivity.
- The isotropic radiation is nothing but **Omni-directional radiation**.

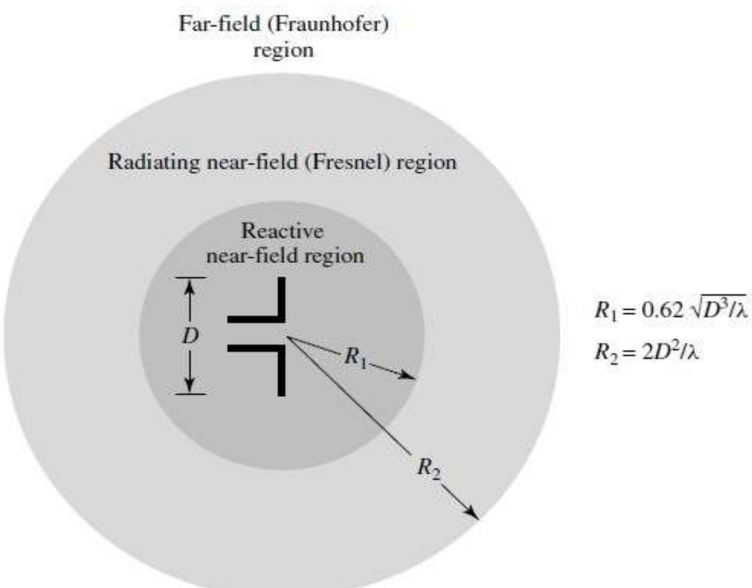
- Field Regions - this **determines the antenna's radiation pattern**.
  - Since antennas are used to communicate wirelessly from long distances, this is the region of operation for most antennas.

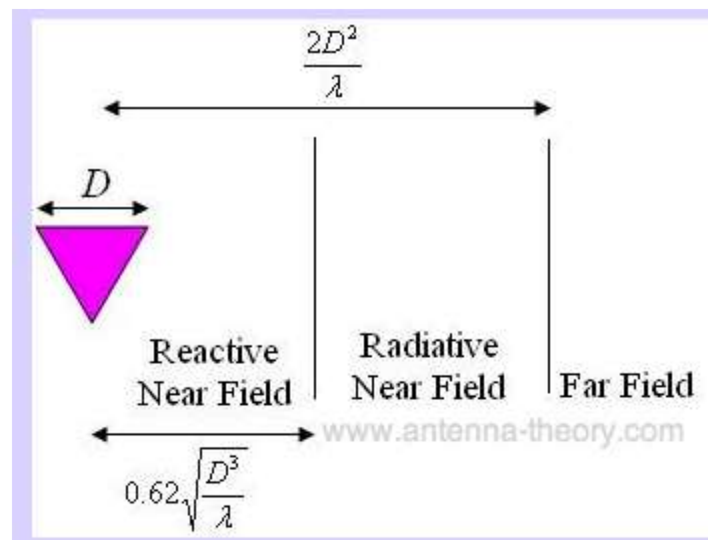


Field Regions

- The fields surrounding an antenna are divided into 3 primary regions:
  – Reactive Near Field
  – Radiating Near Field or Fresnel Region
  – Far Field or Fraunhofer Region
- The far field region is the most important, as this determines the antenna's radiation pattern.
- Since antennas are used to communicate wirelessly from long distances, this is the region of operation for most antennas.

- It is also called as **radiation field**, as the radiation effect is high in this area. Many of the antenna parameters along with the antenna directivity and the radiation pattern of the antenna are considered in this region only.





Far Field (Fraunhofer) Region

- the region far from the antenna, as you might suspect. In this region, the radiation pattern does not change shape with distance (R).
- Although the E- and H- fields still die off as 1/R, the power density dies off as 1/R^2.
- The far field is dominated by radiated fields, with the E- and H-fields orthogonal to each other and the direction of propagation, as with plane waves.

- If the maximum linear dimension of an antenna is *D* and the wavelength is , then the following 3 conditions must all be satisfied to be in the far field region:

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

$$R >> D$$

$$R >> \lambda$$

Reactive Near Field Region

- In this region, the fields are predominately reactive fields, which means the E- and H- fields are out of phase by 90 degrees to each other (recall that for propagating or radiating fields, the fields are orthogonal (perpendicular) but are in phase).

$$R < 0.62\sqrt{\frac{D^3}{\lambda}}$$

Radiating Near Field (Fresnel) Region

- The radiating near field or Fresnel region is the region between the near and far fields.
- In this region, the reactive fields are not dominate; the radiating fields begin to emerge.
- However, unlike the Far Field region, here the shape of the radiation pattern may vary appreciably with distance.

$$0.62\sqrt{\frac{D^3}{\lambda}} < R < \frac{2D^2}{\lambda}$$

- Directivity: fundamental antenna parameter.
- “The ratio of maximum radiation intensity of the subject antenna to the radiation intensity of an isotropic or reference antenna, radiating the same total power is called the **directivity**.”
- It is a measure of how 'directional' an antenna's radiation pattern is. An antenna that radiates equally in all directions would have effectively zero directionality, and the directivity of this type of antenna would be 1 (or 0 dB).

$$Directivity = \frac{Maximum\ radiation\ intensity\ of\ subject\ antenna}{Radiation\ intensity\ of\ an\ isotropic\ antenna}$$

$$D = \frac{\phi(\theta,\phi)_{max}(from\ subject\ antenna)}{\phi_0(from\ an\ isotropic\ antenna)}$$

Where

- $\phi(\theta,\phi)_{max}\phi$- is the maximum radiation intensity of subject antenna.
- Φ_0- is the radiation intensity of an isotropic antenna (antenna with zero losses).

Effective Area @ Effective Aperture

- useful parameter calculating the receive power of an antenna.
- Assume that a plane wave with the same polarization as the receive antenna is incident upon the antenna.
- Further assume that the wave is travelling towards the antenna in the antenna's direction of maximum radiation.

- *effective aperture* parameter describes how much power is captured from a given plane wave.
  - Let *p* be the power density of the plane wave (in W/m^2).
  - If *P_t* represents the power (in Watts) at the antennas terminals available to the antenna's receiver,
    - $P_t = p\ A_e$
- the effective area simply represents how much power is captured from the plane wave and delivered by the antenna. This area factors in the losses intrinsic to the antenna (ohmic losses, dielectric losses, etc.).
- A general relation for the effective aperture in terms of the peak **antenna gain** (**G**) of any antenna is given by:

$$\boxed{A_e = \frac{\lambda^2}{4\pi} G}$$

Effective Length & Effective Area

- Among the antenna parameters, the effective length and effective area are also important.
- **Effective length :** Antenna Effective length is used to determine the polarization efficiency of the antenna.
- **Definition**– "The **Effective length** is the ratio of the magnitude of voltage at the open terminals of the receiving antenna to the magnitude of the field strength of the incident wave front, in the same direction of antenna polarization."
- When an incident wave arrives at the antenna's input terminals, this wave has some field strength, whose magnitude depends upon the antenna's polarization.
- This polarization should match with the magnitude of the voltage at receiver terminals.

$$l_e = \frac{V_{oc}}{E_i}$$

- Where
  - le is the effective length.
  - Voc is open-circuit voltage.
  - Ei is the field strength of the incident wave.

Effective area (Aeff)

- **Definition** – "**Effective area** is the area of the receiving antenna, which absorbs most of the power from the incoming wave front, to the total area of the antenna, which is exposed to the wave front."
- The whole area of an antenna while receiving, confronts the incoming electromagnetic waves, whereas only some portion of the antenna, receives the signal, known as the **effective area**.
- Only some portion of the received wave front is utilized because some portion of the wave gets scattered while some gets dissipated as heat.
- Hence, without considering the losses, the area, which utilizes the maximum power obtained to the actual area, can be termed as **effective area**.

ANTENNA PARAMETERS

- **Aperture Efficiency**:
  - the ratio of the effective radiating area (or effective area) to the physical area of the aperture.”
- An antenna has an aperture through which the power is radiated.
- This radiation should be effective with minimum losses.
- The physical area of the aperture should also be taken into consideration, as the effectiveness of the radiation depends upon the area of the aperture, physically on the antenna.

- where
  - εA is Aperture Efficiency.
  - Aeff is effective area.
  - Ap is physical area.

$$\varepsilon_A = \frac{A_{eff}}{A_p}$$

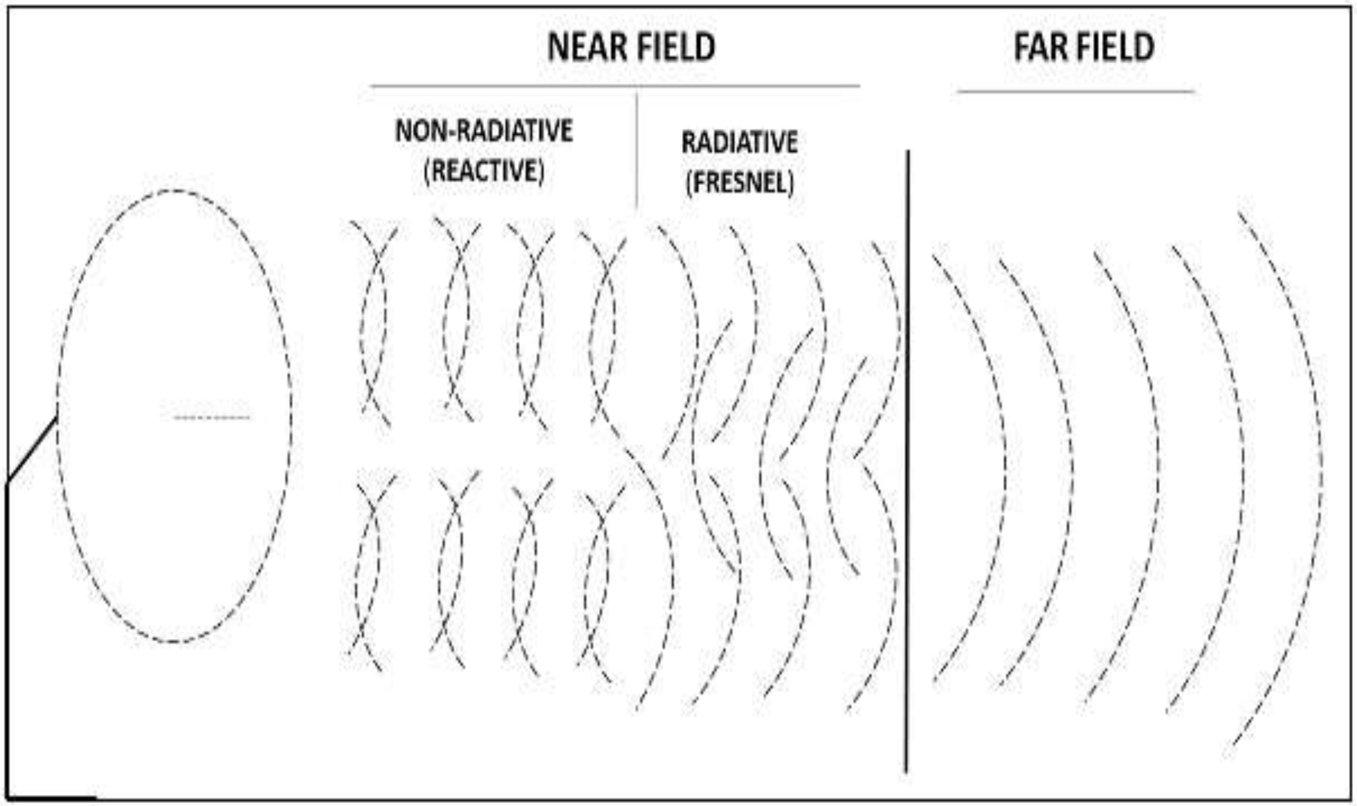
- **Antenna Efficiency**:
  - "the ratio of the radiated power of the antenna to the input power accepted by the antenna."
- Simply, an Antenna is meant to radiate power given at its input, with minimum losses.
- The efficiency of an antenna explains how much an antenna is able to deliver its output effectively with minimum losses in the transmission line.
- This is otherwise called as **Radiation Efficiency Factor** of the antenna.

- Where
  - ηe is the antenna efficiency.
  - Prad is the power radiated.
  - Pinput is the input power for the antenna.

$$\eta_e = \frac{P_{rad}}{P_{input}}$$

- Antenna Gain:
  - a measure of power radiated in a particular direction (typically the peak direction of radiation).
  - ratio of the radiation intensity in a given direction to the radiation intensity that would be obtained if the power accepted by the antenna were radiated isotropically.”
- Simply, gain of an antenna takes the directivity of antenna into account along with its effective performance. If the power accepted by the antenna was radiated isotropically (that means in all directions), then the radiation intensity we get can be taken as a referential. $G = \eta_e D$
- The term **antenna gain** describes how much power is transmitted in the direction of peak radiation to that of an isotropic source & measured in **dB**.
- Unlike directivity, antenna gain takes the losses that occur also into account and hence focuses on the efficiency.

- Beam width and Side lobe:
  - The **main beam** is the region around the direction of maximum radiation (usually the region that is within 3 dB of the peak of the main beam). The main beam in Figure 2 is centered at 90 degrees.
  - The **sidelobes** are smaller beams that are away from the main beam. These sidelobes are usually radiation in undesired directions which can never be completely eliminated. The sidelobes in Figure 2 occur at roughly 45 and 135 degrees.
  - The **Half Power Beamwidth (HPBW)** is the angular separation in which the magnitude of the radiation pattern decrease by 50% (or -3 dB) from the peak of the main beam.


NEAR FIELD
FAR FIELD
NON-RADIATIVE
(REACTIVE)
RADIATIVE
(FRESNEL)

Effective Radiated Power

- If the radiated power is calculated by taking half-wave dipole as the reference, rather than an isotropic antenna, then it can be termed as **ERP (Effective Radiated Power)**.
  - $ERP(dBW) = EIRP(dBW) - 2.15\,dBi$

Beam Area

- “Beam area (W) is the solid angle through which all the power radiated by the antenna would stream if P (θ, Ø) maintained its maximum value over Ω_A and was zero elsewhere.”
- The radiated beam of the antenna comes out from an angle at the antenna, known as solid angle, where the power radiation intensity is maximum.
- This **solid beam angle** is termed as the **beam area**. It is represented by $\boldsymbol{\Omega_A}$.
- The radiation intensity P (θ, Ø) should be maintained constant and maximum throughout the solid beam angle Ω_A, its value being zero elsewhere.
  - Power radiated=$P(\theta,\Phi)\Omega A$ watts

$$\Omega_A = \int_0^{2\pi} \int_0^{\pi} P_\pi(\theta, \Phi) d\Omega \; wattts$$

$$d\Omega = \sin\theta \; d\theta \; d\Phi \; watts$$

Where

- Ω_A is the solid beam angle.
- θ is the function of angular position.
- Φ is the function of radial distance.

Beam Efficiency

- States that the ratio of the beam area of the main beam to the total beam area radiated.”
- The energy when radiated from an antenna, is projected according to the antenna’s directivity.
- The direction in which an antenna radiates more power has maximum efficiency, while some of the energy is lost in side lobes.
- The maximum energy radiated by the beam, with minimum losses can be termed as **beam efficiency**.

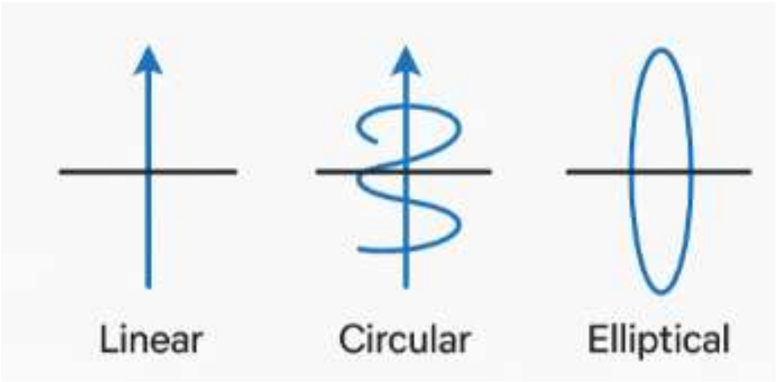
$$\eta_B = \frac{\Omega_{MB}}{\Omega_A}$$

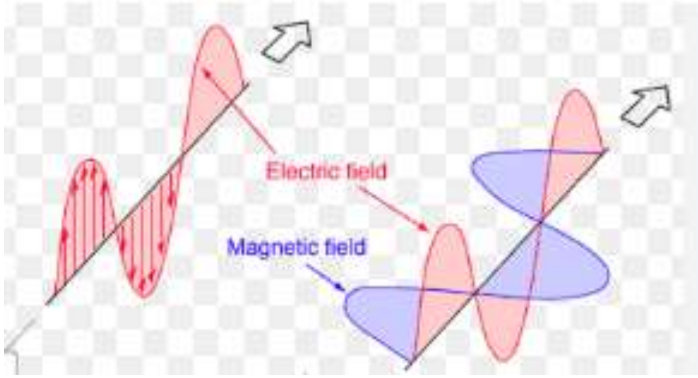
Where,

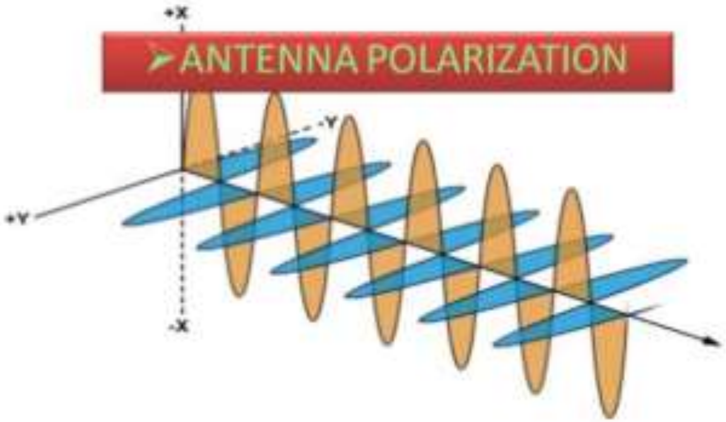
- η_B is the beam efficiency.
- Ω_{MB} is beam area of the main beam.
- Ω_A is total solid beam angle (beam area).

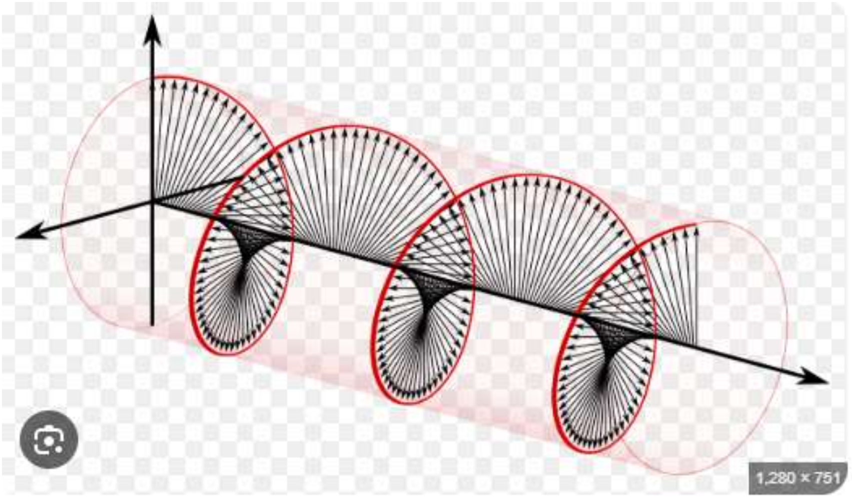
Antenna Polarization

- An Antenna can be polarized depending upon our requirement.
- It can be linearly polarized or circularly polarized.
- The type of antenna polarization decides the pattern of the beam and polarization at the reception or transmission.
  - Linear polarization
  - Circular polarization
  - Elliptical polarization


Linear
Circular
Elliptical


Electric field
Magnetic field


+X
➤ANTENNA POLARIZATION
-Y
+Y
-X


1,280 × 751

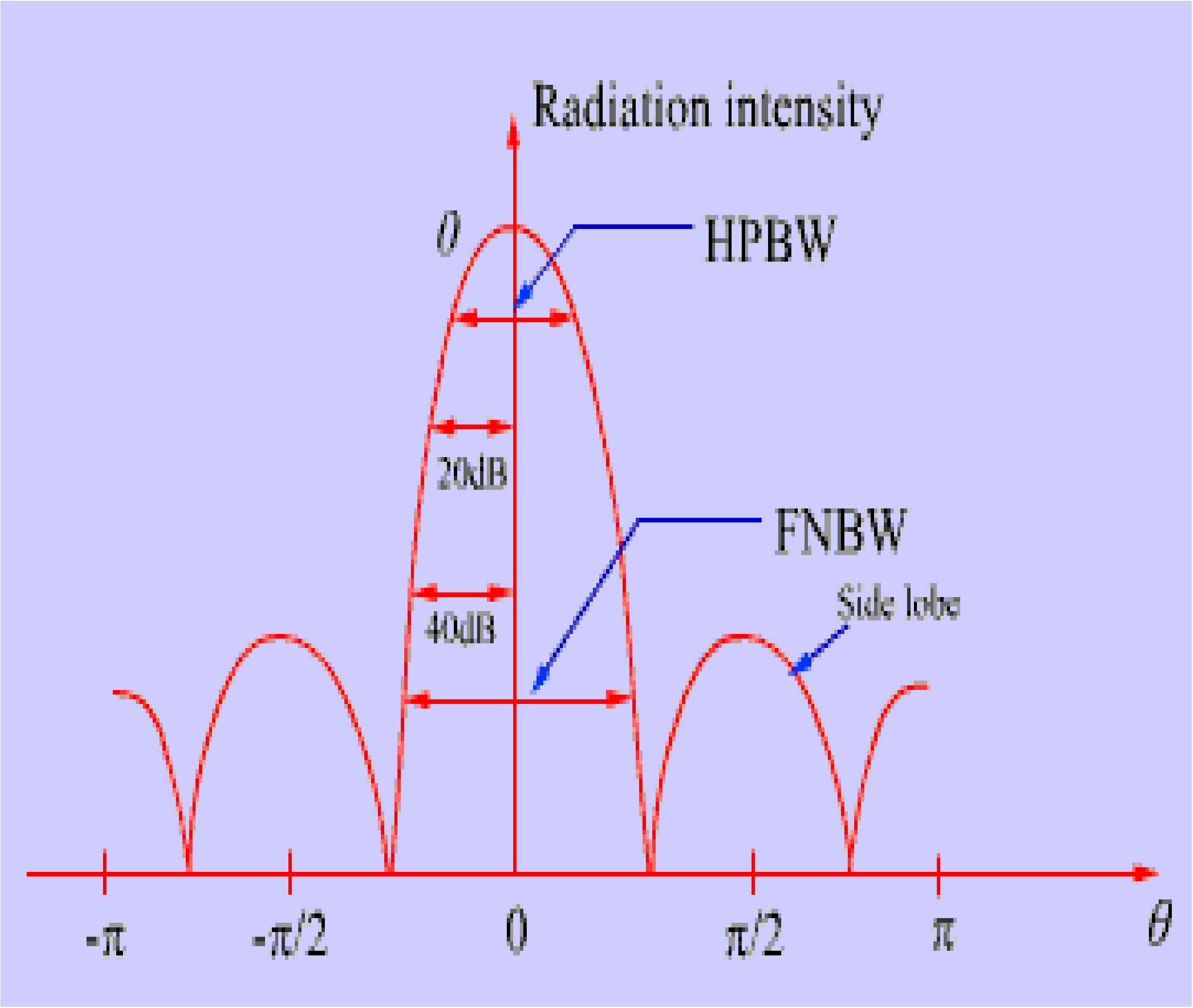
- **Linear polarization**
  - When a wave is transmitted or received, it may be done in different directions. The **linear polarization** of the antenna helps in maintaining the wave in a particular direction, avoiding all the other directions. Hence, we use this linear polarization to improve the **directivity** of the antenna.
- **Circular polarization**
  - When a wave is circularly polarized, the electric field vector appears to be rotated with all its components loosing orientation. The mode of rotation may also be different at times. However, by using **circular polarization**, the effect of multi-path gets reduced and hence it is used in satellite communications such as **GPS**.

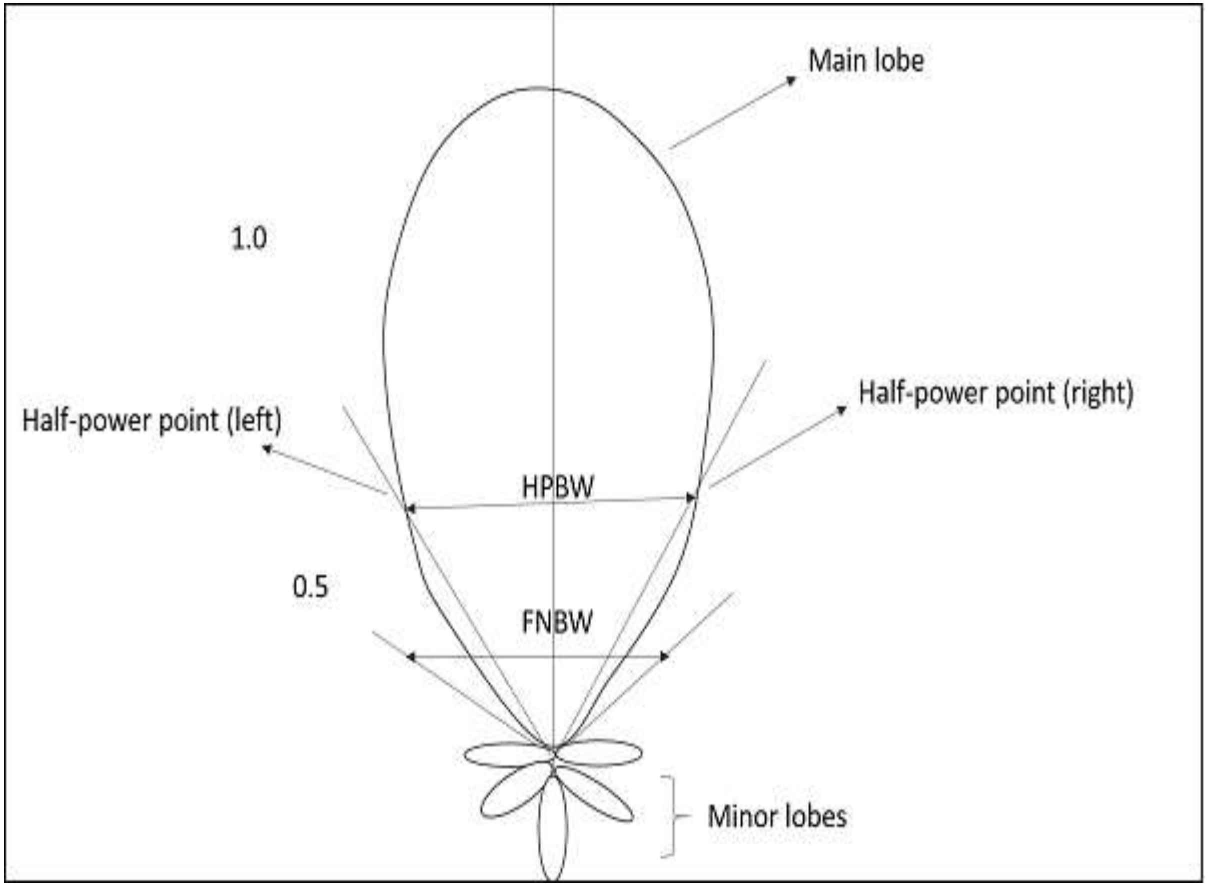
- **Elliptical polarization**:
- It is a fundamental property of electromagnetic waves (like light or radio waves) where **the tip of the electric field vector traces out an ellipse over time in any fixed plane intersecting the direction of propagation**. It serves as the most general form of wave polarization.

- **Horizontal polarization**
  - Horizontal polarization makes the wave weak, as the reflections from the earth surface affect it. They are usually weak at low frequencies below 1GHz. **Horizontal polarization** is used in the transmission of **TV signals** to achieve a better signal to noise ratio.
- **Vertical polarization**
  - The low frequency vertically polarized waves are advantageous for ground wave transmission. These are not affected by the surface reflections like the horizontally polarized ones. Hence, the **vertical polarization** is used for **mobile communications**.
- Each type of polarization has its own advantages and disadvantages.
- A RF system designer is free to select the type of polarization, according to the system requirements.

Beam width

- **Beam width** is the aperture angle from where most of the power is radiated.
- The two main considerations of this beam width:
  - Half Power Beam Width **(HPBW)** and
  - First Null Beam Width **(FNBW)**.
- **HPBW :** "The angular separation, in which the magnitude of the radiation pattern decreases by 50% (or -3dB) from the peak of the main beam, is the **Half Power Beam Width**."
- In other words, Beam width is the area where most of the power is radiated, which is the peak power.
- **Half power beam width** is the angle in which relative power is more than 50% of the peak power, in the effective radiated field of the antenna.

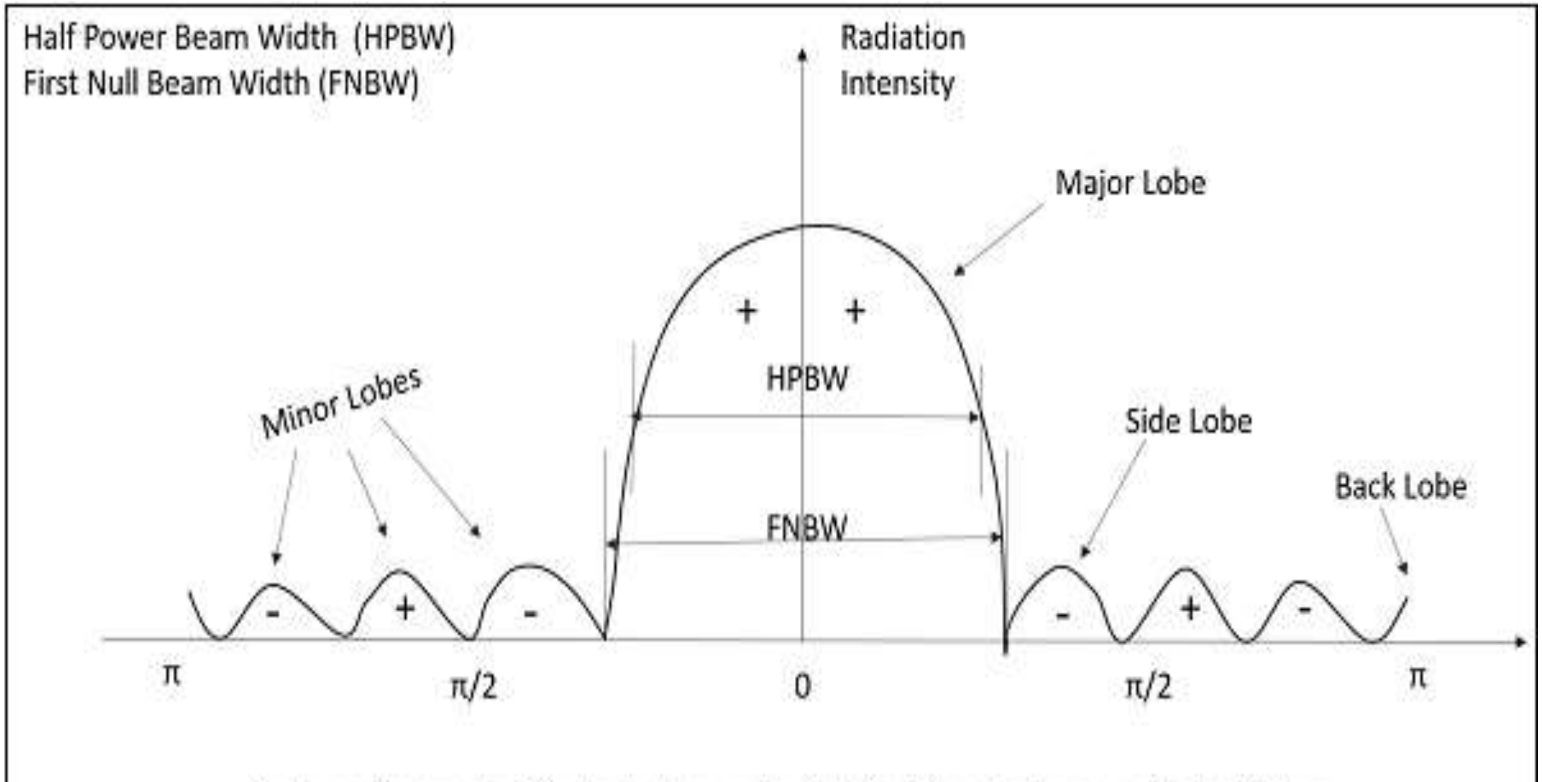

Radiation intensity
0
HPBW
20dB
40dB
FNBW
Side lobe
-π
-π/2
0
π/2
π
θ


Main lobe
1.0
Half-power point (right)
Half-power point (left)
HPBW
0.5
FNBW
Minor lobes

- Where
  - λ is wavelength (λ = 0.3/frequency).
  - **D** is Diameter.

$$Half\ power\ Beam\ with = 70\lambda_{/D}$$

- The units - **radians** or **degrees**.
- **FNBW:** “The angular span between the first pattern nulls adjacent to the main lobe, is called as the **First Null Beam Width**.”
- Simply, FNBW is the angular separation, quoted away from the main beam, which is drawn between the null points of radiation pattern, on its major lobe.



Antenna Parameters illustrated over a typical directional antenna radiation Pattern

$$FNBW = 2HPBW$$

$$FNBW\ 2\left(70\lambda/D\right) = 140\lambda/D$$

Reciprocity

- one of the most useful (and fortunate) property of antennas.
- Reciprocity states that the receive and transmit properties of an antenna are identical.
- Hence, antennas do not have distinct transmit and receive radiation patterns.
- If you know the radiation pattern in the transmit mode then you also know the pattern in the receive mode.
- This makes things much simpler, as you can imagine.

Properties under Reciprocity

- The properties of transmitting and receiving antenna that exhibit the reciprocity are:
  - Equality of Directional patterns.
  - Equality of Directivities.
  - Equality of Effective lengths.
  - Equality of Antenna impedances.

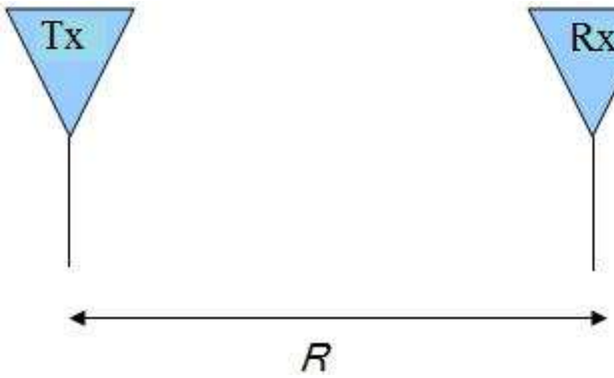
Poynting Vector

- It describes the energy of the EM Wave per unit time per unit area at any given instant of time.
- **John Henry Poynting** first derived this vector in 1884 and hence it was named after him.
- **Definition** – "Poynting vector gives the rate of energy transfer per unit area" or "The energy that a wave carries per unit time per unit area is given by the Poynting vector."
- Poynting vector is represented by **"Ŝ"**.

- Where $\hat{S} = \hat{E} \times \hat{H}$ $\hat{S} = \frac{1}{\mu_0}(\hat{E}\hat{H})$
  - S^ is the instantaneous Poynting vector **(W/m^2)**.
  - E^ is the instantaneous electric field intensity **(V/m)**.
  - H^ is the instantaneous magnetic field intensity **(A/m)**.
- The important point to be noted here is that the magnitude of E > H within an EM wave.
- However, both of them contribute the same amount of energy.
- Ŝ is the vector, which has both direction and magnitude.
- The direction of Ŝ is same as the velocity of the wave.
- Its magnitude depends upon the E and H.

The Friis Equation

- The most fundamental equation of antenna theory.
- This equation relates transmit power, antenna gains, distance and wavelength to received power.
- is used to calculate the power received from one antenna (with gain *G1*), when transmitted from another antenna (with gain *G2*), separated by a distance *R*, and operating at frequency *f* or wavelength.



$$P_R = \frac{P_T G_T G_R \lambda^2}{(4\pi R)^2}$$

$$P_R = \frac{P_T G_T G_R c^2}{(4\pi R f)^2}$$

www.antenna-theory.com