



ECE 516E – ANTENNA ENGINEERING & RADIOWAVE PROPAGATION

ANTENNA THEORY – STUDY GUIDE/REVISION

1. FUNDAMENTAL CONCEPTS

- **What is an Antenna?**

- An antenna is a device that transmits and/or receives electromagnetic waves. It acts as a transducer, converting electrical signals into electromagnetic waves for transmission and vice versa for reception.

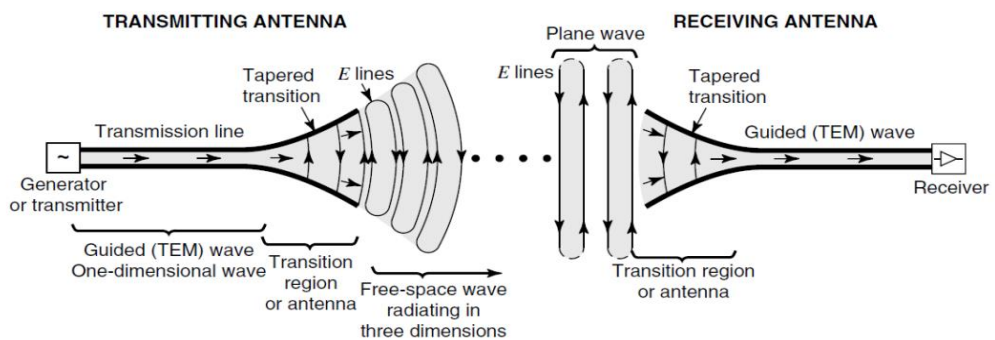


Figure 1. The antenna concept

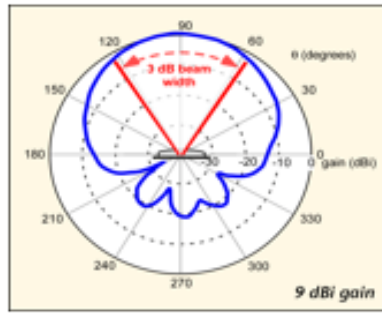
- **Key Functions:**

- **Transmission:** Antennas radiate electromagnetic waves into space, carrying information from a transmitter.
- **Reception:** Antennas capture electromagnetic waves from the air, converting them back into electrical signals for a receiver.
- **Transducer:** An antenna acts as a bridge between the electrical and electromagnetic domains, converting one form of energy to the other.
- **Historical Milestones:** Hertz, Marconi, modern applications (5G, satellite, IoT).

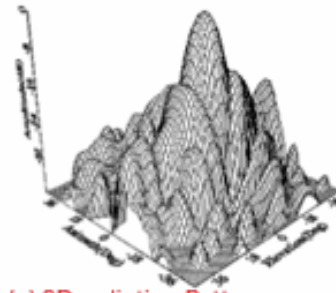
2. ANTENNA PARAMETERS & METRICS

- **Radiation Pattern:**

- 2D/3D plots (polar/cartesian).
- Lobes (main, side, back), beamwidth (HPBW).



(a) Radiation Pattern (Polar form)



(c) 3D radiation Pattern

Figure 1. 2D/3D Radiation patterns

- **Directivity & Gain:**

- $D = \frac{4\pi}{\Omega_A}$ (Solid angle); $G = \epsilon_{rad} D$

- **Efficiency:**

- Radiation efficiency (ϵ_{rad}), losses (ohmic, mismatch).

- **Polarization:**

- Linear, circular, axial ratio, polarization mismatch.

- **Impedance & Bandwidth:**

- Input impedance ($Z_{in}=R_{rad}+jX$), VSWR, impedance bandwidth.

- **Effective Length & Aperture:**

- $A_e = \frac{\lambda^2}{4\pi} G$ (Aperture efficiency)

3. BASIC ANTENNA TYPES

1. **Wire Antennas:**

- **Dipole:** Half-wave ($\lambda/2$), radiation pattern, feed point impedance
(73+j42.5 Ω)

Figure 2. Dipole antenna

- **Monopole:** Quarter-wave ($\lambda/4$), ground plane dependence.

2. **Loop Antennas:**

- Small loop (magnetic dipole), radiation resistance

$$R_r \propto \left(\frac{C}{\lambda}\right)^4$$

3. **Aperture Antennas:**

- Horn antennas reflector antennas (parabolic).

$$G \approx \frac{4\pi}{\lambda^2} A_{phys}$$

4. Microstrip Patch Antennas:

- Rectangular patch low-profile (PCB integration).

$$f_r \approx \frac{c}{2L\sqrt{\epsilon_r}}$$

4. ANTENNA ARRAYS

1. Array Factor (AF):

- Linear arrays:
- $AF = \sum I_n e^{jn(kd \cos \theta + \beta)}$

2. Beam Steering:

- Phase shifters (β), scanning angle (θ_0).

3. Array Types:

- Broadside ($\beta=0$), endfire ($\beta=\pm kd$), uniform/non-uniform excitation.

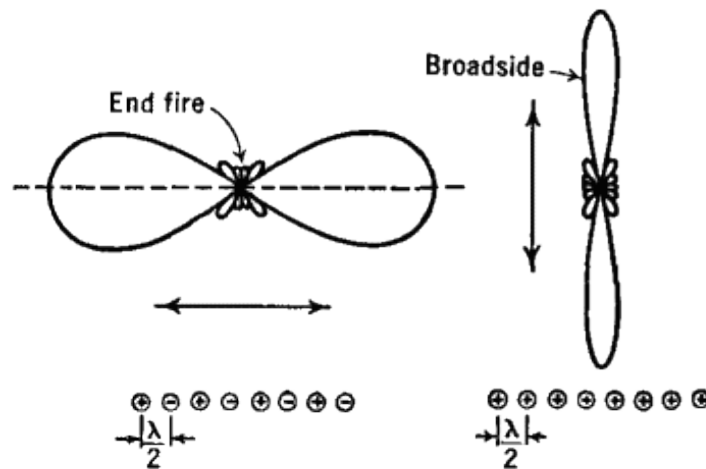


Figure 3. Broadside and end-fire array antennas

4. Pattern Multiplication:

- Total pattern = Element pattern × Array Factor.

5. ANTENNA MEASUREMENTS

• Test Environments:

- Anechoic chambers (reflection minimization).

• Key Measurements:

- Radiation patterns (far-field distance $r > \frac{2D^2}{\lambda}$)
- Gain (comparison method), impedance (VNA).

III. KEY FORMULAS

Parameter	Formula
Frequency-Wavelength	$f = \frac{c}{\lambda}$
Directivity	
Gain	
Beamwidth (approx.)	
VSWR	
Radiation Resistance	

SOFTWARE TOOLS:

- **Simulators:** ANSYS HFSS, CST Studio, FEKO (design/optimization).
- **Open-Source:** NEC-2, Qucs (basic modeling).

Online Resources:

- Antenna-Theory.com - Tutorials & calculators.
- IEEE Xplore - Research papers (e.g., *IEEE Transactions on Antennas and Propagation*).
- MIT OpenCourseWare (OCW) - Lecture notes/videos.

V. STUDY TIPS

1. Visualize Concepts:

- Sketch radiation patterns, current distributions.
- Use EM simulators to model dipoles/patches.

2. Derive Equations:

- Practice deriving E -field for Hertzian dipole.
- Master pattern multiplication for arrays.

3. Solve Problems:

- Calculate gain, beamwidth, and impedance for given antennas.
- Design a $\lambda/2$ dipole at 2.4 GHz ($\lambda=12.5\text{ cm}$).

4. Relate to Real World:

- Identify antenna types in smartphones (PIFA), Wi-Fi routers (MIMO arrays).

5. Review EM Fundamentals:

- Revisit wave equations, Poynting vector, boundary conditions.

VI. PRACTICE PROBLEMS

1. A dipole antenna has a radiation resistance of $73\ \Omega$. If ohmic losses are $5\ \Omega$, calculate its radiation efficiency.
2. Design a linear array of 4 isotropic sources spaced $\lambda/2$ apart. Plot the array factor for broadside and endfire cases.
3. A parabolic dish has a diameter of 1 m and operates at 10 GHz. Estimate its gain (assume 60% aperture efficiency).
4. Explain why a monopole antenna requires a ground plane.

VII. FURTHER EXPLORATION

- **Hot Topics:** MIMO, mmWave antennas (5G), reconfigurable antennas.
- **Projects:**
 - Simulate a patch antenna in HFSS/CST.
 - Build a simple Yagi-Uda antenna for FM radio reception.
- **Career Paths:** RF engineering, satellite communications, radar systems.