Q1.1 Explain the following terms i) Antenna gain ii) Radiation Intensity iii) Directivity

i) Antenna Gain

1. Antenna gain represents how well an antenna converts input power into **radio waves in a given direction**, compared to an isotropic antenna.
2. It includes the effect of **directivity + efficiency**.
3. **Formula: $G=\eta\times D$… where, η = antenna efficiency, D= directivity.**
4. **Unit**: dBi (decibels over isotropic).

ii) Radiation Intensity (U)

1. Power radiated **per unit solid angle** in a given direction.
2. Formula: **$U(\theta,\phi)=r^2 x P_{rad}(\theta,\phi)$**
3. Relation with total power: $$P_{rad} = \int_0^{2\pi} \int_0^{\pi} U(\theta, \phi) \sin\theta \, d\theta d\phi$$
4. **Unit**: Watts per steradian (W/sr).
5. It indicates how much power is radiated in a particular angular direction.

iii) Directivity (D)

1. Directivity is the measure of how "focused" an antenna's radiation is in a particular direction compared to an **isotropic radiator**.
2. Formula: **$D = \frac{Umax}{Uavg}$ Where U_{max} = maximum radiation intensity, U_{avg} = average radiation intensity.**
3. **Unit**: dimensionless (often expressed in dB).

Q1.2 Explain : i) Bandwidth ii) Beamwidth iii) Effective area

i) Bandwidth

Definition: The range of frequencies over which an antenna can operate effectively (with acceptable performance).

Usually defined as the frequency range where **VSWR ≤ 2** or **Return Loss ≥ –10 dB**.

Formula:

$BW=f_H-f_L$

Fractional Bandwidth: BW% = $\frac{fH-fL}{fc}$x100

where f_H= higher cutoff freq, f_L = lower cutoff freq, f_c = center freq.

Unit: Hz or %.

ii) Beamwidth

Definition: The angular width of the main lobe of an antenna radiation pattern between two points where the power drops to **half (–3 dB)** of the maximum.

Also called **Half Power Beamwidth (HPBW)**.

Unit: Degrees (°).

Narrow beamwidth → high directivity, Wide beamwidth → low directivity.

iii) Effective Area (Ae)

Definition: The area of an antenna that effectively captures power from an incoming electromagnetic wave.

Relates the **received power** to the **power flux density** of the wave.

Formula: $A_e= (\lambda^2 x G)/4\pi$

where λ = wavelength, G = gain of antenna.

Unit: m^2.

Larger effective area → more power captured → better reception.

Q1.3 Describe various field regions of radiation for antennas

1. Reactive Near-Field Region

1. Closest region to the antenna.
2. Dominated by **stored energy (inductive & capacitive fields)**, not radiated energy.
3. Fields vary rapidly with distance.
4. Extent: $r < 0.62\sqrt{\frac{D^3}{\lambda}}$ where D = largest dimension of antenna, λ= wavelength.
5. Used in **NFC, RFID, inductive coupling**.

2. Radiating Near-Field Region (Fresnel Region)

1. Region where radiation begins but **field distribution still depends on distance**.
2. Used for **antenna measurements and aperture antennas (like horn, parabolic dish)**.
3. Extent: $0.62\sqrt{\frac{D^3}{\lambda}} < r < \frac{2D^2}{\lambda}$

3. Far-Field Region (Fraunhofer Region)

1. The true **radiation region** where the fields form a stable **plane wave pattern**.
2. Angular field distribution is **independent of distance**.
3. Extent: $r > \frac{2D^2}{\lambda}$
4. Most practical antenna applications (broadcasting, communication, radar) work in far field.

Q1.4 Explain the following characteristics of antenna in detail : i) Radiation Pattern ii) Efficiency*

→ **i) Radiation Pattern**: A radiation pattern is a **graphical representation** of the radiation properties of an antenna as a function of space coordinates (angles).

It shows how the antenna radiates energy in different directions.

Types of patterns:

1. **E-plane pattern** → Electric field distribution (vertical plane).
2. **H-plane pattern** → Magnetic field distribution (horizontal plane).
3. **3D Radiation Pattern** → Full spatial radiation.

Main Features:

1. **Main Lobe** → Direction of maximum radiation.
2. **Side Lobes** → Unwanted smaller lobes.
3. **Back Lobe** → Radiation opposite to main lobe.
4. **Nulls** → Directions of zero radiation.

Use: Helps in understanding antenna coverage and directivity.

ii) Antenna Efficiency (η): Antenna efficiency is the ratio of **power radiated by the antenna** to the **total input power supplied** to it.

Formula:

$\eta = P_{rad}/P_{in}$

Factors affecting efficiency:

1. **Conduction losses** (due to finite conductivity of antenna material).
2. **Dielectric losses** (due to nearby materials).
3. **Mismatch losses** (due to impedance mismatch between antenna & transmission line).

Importance:

Higher efficiency → better radiation for given input power.

Q1.5 Explain the details the radiation mechanism of antenna with suitable diagram.

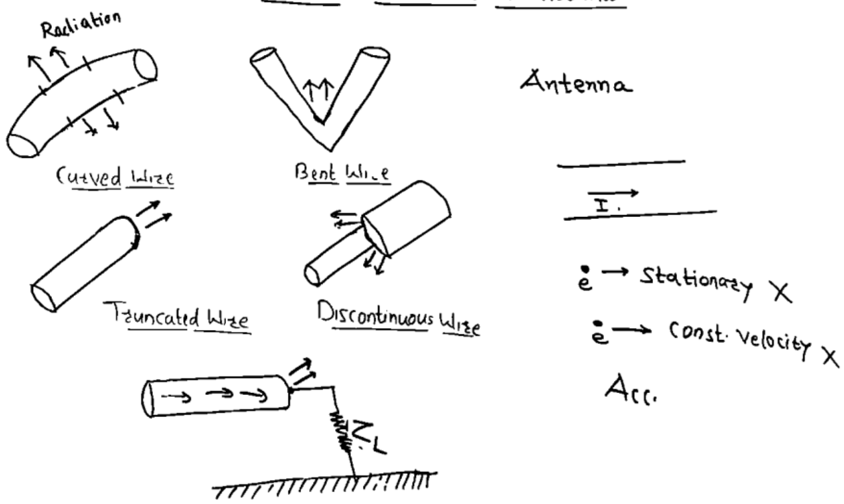
i. The sole functionality of an antenna is **power radiation** or reception. Antenna (whether it transmits or receives or does both) can be connected to the circuitry at the station through a transmission line. The functioning of an antenna depends upon the radiation mechanism of a transmission line.

ii. A conductor, which is designed to carry current over large distances with minimum losses, is termed as a **transmission line**. For example, a wire, which is connected to an antenna. A transmission line conducting current with uniform velocity, and the line being a straight one with infinite extent, **radiates no power**.

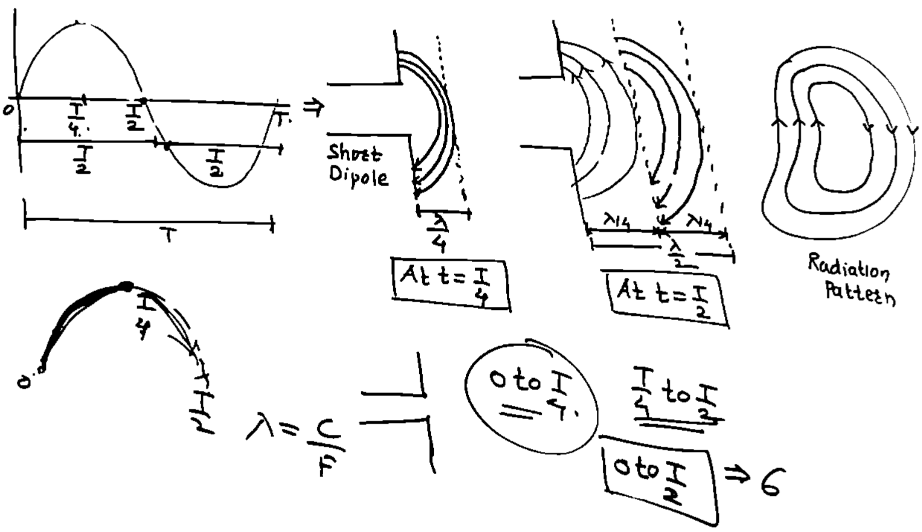
For a transmission line, to become a waveguide or to radiate power, has to be processed as such.

1. If the power has to be radiated, though the current conduction is with uniform velocity, the wire or transmission line should be bent, truncated or terminated.
2. If this transmission line has current, which accelerates or decelerates with a timevarying constant, then it radiates the power even though the wire is straight.
3. The device or tube, if bent or terminated to radiate energy, then it is called as **waveguide**. These are especially used for the microwave transmission or reception.

Radiation Mechanism of antenna.



Radiation Mechanism of antenna.



Q1.6 Derive the fundamental equation for free space propagation.

We Know That,

Isotropic radiator → $P_{avg} = \frac{P_{rad}}{4\pi r^2}$, $G_d\,max = \frac{P_d\,max}{P_{avg}}$

Since, $P_{rec} = P_d\,max\,(A_e)_r$, $(G_d\,max)_r = \frac{4\pi\,(A_e)_r}{\lambda^2}$

$\therefore P_d\,max = (G_d\,max)_t \times P_{avg}$

$\therefore P_d\,max = (G_d\,max)_t \times \frac{P_{rad}}{4\pi r^2}$

$\because \boxed{P_{rec} = P_d\,max \times (A_e)_r}$

$\therefore P_{rec} = (G_d\,max)_t \times \frac{P_{rad}}{4\pi r^2} \cdot (A_e)_r$

$\because \cancel{(A_e)_r = (G_d\,max)_t \cdot \frac{P_{rad}}{4\pi r^2} \times (G_d\,max)_r \cdot \frac{\lambda^2}{4\pi}}$ $\boxed{\because (A_e)_r = (G_d\,max)_r \cdot \frac{\lambda^2}{4\pi}}$

$\therefore P_{rec} = (G_d\,max)_t \cdot \frac{P_{rad}}{4\pi r^2} \cdot (G_d\,max)_r \cdot \frac{\lambda^2}{4\pi}$

$\therefore \boxed{\frac{P_{rec}}{P_{rad}} = (G_d\,max)_t \cdot (G_d\,max)_r \left(\frac{\lambda}{4\pi r}\right)^2}$

Q1.7 Enlist the different types of antennas

According to syllabus, antennas are classified as: **1. Wire Antennas** a) Linear wire antennas (Dipole, Monopole) b) Loop antennas c) Helical antennas **2. Aperture Antennas** (Horn antenna, waveguide aperture) **3. Microstrip Antennas** (Patch antennas **4. Array Antennas** (Yagi-Uda, Phased arrays) **5. Reflector Antennas** (Parabolic dish, Cassegrain) **6. Lens Antennas**

1. Wire Antennas

a) Linear Wire Antennas (Dipole/Monopole)

1. **Structure**: Simple metal rods. Dipole length ≈ λ/2, Monopole length ≈ λ/4 with ground plane.
2. **Radiation**: Figure-8 (dipole), omnidirectional (monopole).
3. **Applications**: Radio, TV, mobile base stations.

b) Loop Antennas

1. **Structure**: Single-turn or multi-turn conducting loop.
2. **Radiation**: Bidirectional, small loop has low efficiency.
3. **Applications**: Direction finding, RFID, AM receivers.

c) Helical Antennas

1. **Structure**: Wire wound in helix shape, operated in normal or axial mode.
2. **Radiation**: Circular polarization (axial mode).
3. **Applications**: Satellite, space communication, GPS.

2. Aperture Antennas

- **Structure**: Flared waveguides or openings (horn antenna is most common).
- **Working**: Provides smooth transition from guided wave to radiated wave.
- **Radiation Pattern**: Highly directive, narrow beam.
- **Advantages**: High gain, less reflection.
- **Applications**: RADAR, satellite communication.

Q2.1 Give the comparison between co-axial cable and waveguide

Parameter	Co-axial Cable	Waveguide
Structure	Central conductor surrounded by dielectric and outer conductor (like a tube).	Hollow metallic tube (rectangular/circular) without central conductor.
Mode of Propagation	Supports **TEM (Transverse Electromagnetic)** mode.	Supports **TE (Transverse Electric)** and **TM (Transverse Magnetic)** modes.
Frequency Range	Effective for **low to medium frequencies** (up to a few GHz).	Used for **microwave frequencies** (above 3 GHz).
Losses	Higher attenuation at high frequencies due to dielectric & conductor losses.	Very **low loss** at microwave range because no dielectric in propagation path.
Size	Small and flexible, easy to install.	Bulky and rigid, difficult to bend.
Applications	Radio, TV, broadband, general communication links.	RADAR, satellite communication, microwave links.

Q2.2 What are micro waves. Enlighten on advantages and applications of microwave.

What are Microwaves?

- Microwaves are **electromagnetic waves** with frequency range from **1 GHz to 300 GHz** (wavelength from 1 m to 1 mm).
- They lie between **radio waves** and **infrared waves** in the electromagnetic spectrum.
- Due to their **short wavelength and high frequency**, they are widely used in communication and radar.

Advantages of Microwaves

1. **Large Bandwidth** → Can carry huge amount of information compared to radio frequencies.
2. **High Directivity** → Narrow beams possible using small antennas (parabolic dish, horn).
3. **Less Interference** → Operates at higher frequencies, less crowding.
4. **Penetration** → Can penetrate through atmosphere, fog, clouds (useful in satellite & RADAR).
5. **Compact Antennas** → Due to small wavelength, antennas can be very small in size.
6. **High Data Rates** → Supports wireless broadband and high-speed communication.

Applications of Microwaves

1. **Communication** → Satellite links, cellular mobile, Wi-Fi, Bluetooth, TV transmission.
2. **RADAR** → Detection of aircraft, ships, weather monitoring, speed detection.
3. **Medical** → Microwave diathermy (deep tissue heating), cancer treatment.
4. **Industrial** → Microwave ovens, drying, material processing.
5. **Navigation** → GPS, aircraft landing systems.
6. **Military** → Missile guidance, electronic warfare, surveillance.

Q2.3 What is cavity resonator. Explain re-entrant type of cavity resonator

Cavity Resonator

1. A **cavity resonator** is a **hollow metallic enclosure** (usually rectangular or cylindrical) which stores **electromagnetic energy** in the form of standing waves.
2. It works like a **resonant LC circuit** but at **microwave frequencies** (where lumped L & C are not practical).
3. It has **very high Q-factor** → meaning low energy loss and sharp resonance.
4. Used in **oscillators, filters, klystrons, magnetrons** etc.

Re-entrant Cavity Resonator

1. A **re-entrant cavity** is a **modified cavity resonator** where **metal posts (or screws)** are inserted into the cavity.
2. These posts **reduce the effective cavity volume** and **concentrate the electric field** in small gaps.
3. This makes the cavity behave like a **lumped LC circuit** →
4. The **gap** acts like a **capacitor**.
5. The **post/inductor path** acts like an **inductance**.
6. **Resonance frequency can be tuned** by adjusting the gap or depth of the post (like a variable capacitor).

Advantages of Re-entrant Cavity

1. Very **compact size** compared to normal cavity.
2. Easier **frequency tuning**.
3. Can operate at **lower microwave frequencies** where large cavities would otherwise be needed.

Applications

1. Used in **microwave oscillators** (Reflex Klystron).
2. Narrowband **filters**.
3. Frequency stabilization circuits.

Q2.4 Give the comparison between TE Mode and TM Mode

Aspect	**TE Mode (Transverse Electric)**	**TM Mode (Transverse Magnetic)**
Full Form	Transverse Electric	Transverse Magnetic
Definition	No **electric field (E_z)** component in the direction of propagation.	No **magnetic field (H_z)** component in the direction of propagation.
Field Components	Has **$H_z \neq 0$**, but **$E_z = 0$**.	Has **$E_z \neq 0$**, but **$H_z = 0$**.
Nature of Propagation	Electric field is completely transverse; magnetic field has longitudinal component.	Magnetic field is completely transverse; electric field has longitudinal component.
Possible in	Waveguides, but **not in coaxial cable.**	Waveguides only, **not possible in coaxial cable**.
Cut-off Frequency	Each TE mode has a specific cut-off frequency.	Each TM mode also has its own cut-off frequency.

Q2.5 Explain the Structural details, types and applications of Striplines

Structural Details

1. A **stripline** is a **planar transmission line** used at microwave frequencies.
2. It consists of:
   a. A **thin conducting strip** placed between **two parallel ground planes**.
   b. The strip is embedded inside a **dielectric substrate**.
   c. The dielectric completely surrounds the strip → giving **TEM mode propagation**.
3. Cross-section looks like a **sandwich**:Ground plane (top), Dielectric., Strip conductor (center), Dielectric, Ground plane (bottom)

Types of Striplines

1. **Conventional Stripline**: Symmetric structure → strip is at the center between two ground planes.
2. **Asymmetric Stripline**
   - Strip is **off-centered** (not at exact middle).
   - Used when fabrication tolerances or desired field distribution differ.
3. **Multiple Stripline**
   - More than one strip placed between ground planes.
   - Allows **multiline coupling** → used in directional couplers, filters.

Applications of Stripline

1. **Microwave Integrated Circuits (MICs)** → compact RF/microwave circuits.
2. **Filters** → bandpass/bandstop filters at GHz frequencies.
3. **Couplers & Power Dividers** → due to controlled impedance.
4. **Phase Shifters** → in phased array radars.

Q2.6 Explain various types of coupling methods

Types of Coupling Methods

1. Direct (or Resistive) Coupling

- Components are **physically connected** (conductor-to-conductor).
- Simple but **lossy** at microwave frequencies.
- Not commonly used at very high frequencies.

2. Magnetic (or Inductive) Coupling

- Achieved by placing a **loop of wire or stripline** near the magnetic field region of the resonator/waveguide.
- Works because of **mutual inductance**.
- Example: loop coupling in **cavity resonators**.

3. Electric (or Capacitive) Coupling

- A **probe or small rod** is inserted into the electric field region of the cavity or waveguide.
- Energy transfer takes place due to **capacitance effect**.
- Example: probe coupling in **waveguides & cavities**.

4. Aperture (or Iris) Coupling

- An **opening (slot/aperture)** is made in the common wall between two waveguides or cavities.
- Energy couples through this aperture due to **field interaction**.
- Widely used in **waveguide filters & cavities**.

5. Hybrid/Directional Coupling

- Uses special structures (like **hybrid junctions or directional couplers**) to **split or combine microwave power** in a controlled way.
- Example: **magic tee, directional coupler**.

Q2.7 With the help of suitable filed pattern diagram, explain TE10 mode in rectangular waveguide

TE10 Mode in Rectangular Waveguide

1. Basics

- **TE (Transverse Electric) Mode** → No electric field component in the direction of propagation (**E_z = 0**).
- In $\mathbf{TE_{mn}}$ mode:
  - m = number of half-wave variations of the **E-field along broad dimension (a)**.
  - n = number of half-wave variations along **narrow dimension (b)**.

So, for $\mathbf{TE_{10}}$**:**

- m=1, n=0.
- One half-wave variation along **'a'** (broad wall).
- Zero variation along **'b'** (narrow wall).

2. Field Pattern

- **Electric Field (E_y):**
  - Maximum at the center of the broad wall.
  - Zero at conducting walls (satisfies boundary conditions).
  - Pattern: **one half-sine curve along width (a)**, uniform along height (b).
- **Magnetic Field (H_x, H_z):**
  - Exists in transverse + longitudinal directions.
  - Complements the electric field distribution.

4. Cutoff Frequency

For $\mathbf{TE_{10}}$: $\mathbf{f_c = c \backslash 2a}$

where

- c = velocity of light
- a = broad dimension of waveguide

Since cutoff depends only on a, $\mathbf{TE_{10}}$ mode is the **dominant mode** in rectangular waveguides (lowest cutoff frequency).

5. Applications

- Used in most practical waveguide systems because it's the **dominant & lowest-loss mode**.
- Common in **radar, satellite communication, microwave links**.