

# Q/A Microwave

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Tag	Year 3 Term 2

- **What is microwave? Why microwave is called transverse electromagnetic wave?**
- **Mention the frequency range allocated for microwave communication.**
- **Draw the block diagram of microwave transmitter.**
- **Write the frequency range for C-band and K-band.**

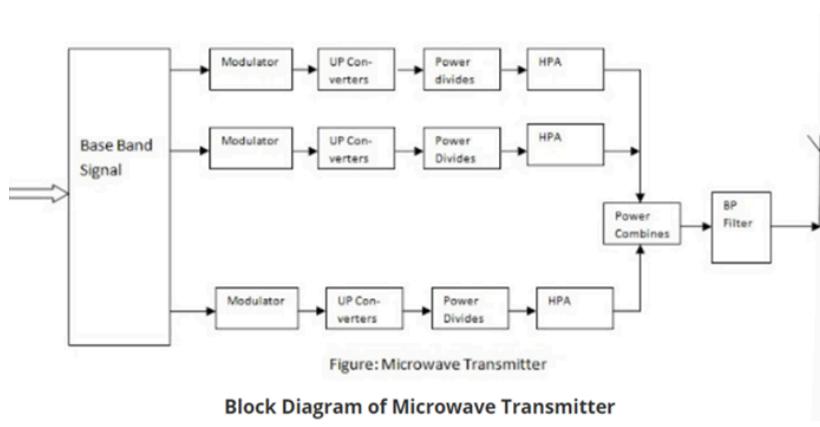
## Solutions:

Microwave is a **line-of-sight wireless communication** technology that uses **high frequency beams** of radio waves to provide **high speed wireless connection** that can **send and receive** voice, video and data information.

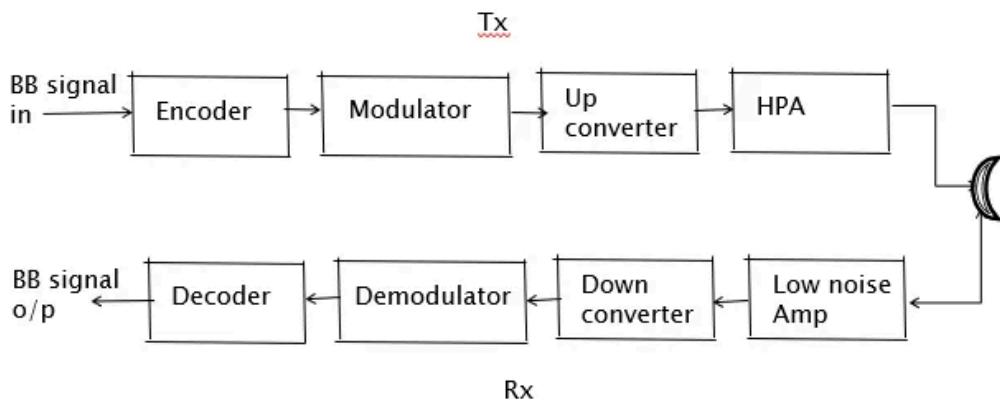
Microwaves are called transverse electromagnetic waves **because the electric and magnetic fields that make up the wave oscillate perpendicular to each other and to the direction the wave travels.**

**Wavelength :** as long as 1 meter as short as 1 millimeter

**Frequency:** 300MHz to 300 GHz



# Microwave Tx/Rx for Satellite



**Microwave frequency bands are designated by specific letters**

Letter	GHz	Q	30-50
L	1-2	U	40-60
S	2-4	V	50-75
C	4-8	E	60-90
X	8-12	W	75-110
Ku	12-18	F	90-140
K	18-26.5	D	110-170
Ka	26.5-40		

- Why Antenna is called transducer? Define Aperture efficiency.
- What is directivity? How can we calculate the directivity?
- Define i) VSWR ii) Directivity iii) Effective aperture iv) Beam width
- What is VSWR? How to calculate VSWR
- A transmission line having 50 impedance is terminated in a load of  $(40+j30)$ . Calculate VSWR
- An antenna that radiates equally in all directions would have effectively zero directionality. What would be its gain (both normal and decibel values).

- "Beam width is the aperture angle from where most of the power is radiated"-Explain.
- Define HPBW and FNBW.
- For a given antenna, electric field is  $E(\theta) = \sin\theta$ . Calculate HPBW and FNBW.
- What is Antenna Efficiency? How to calculate it?
- Write the relationship between antenna length, frequency and wavelength.
- Define ERP with equation.

### Solution:

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An Antenna is a transducer which converts electrical power into electromagnetic waves and vice versa.

An antenna is called a transducer **because it converts electrical energy into electromagnetic (EM) waves and vice versa.**

### Antenna Parameters:

**Directivity:** The ratio of a maximum radiation intensity of the subject antenna to the radiation intensity of an isotropic antenna, radiating the same total power is called directivity.

The ratio of radiation intensity in a given direction from an antenna to the radiation intensity average overall direction is called directivity.

$$\text{Directivity} : D = \frac{\text{maximum radiation intensity of subject antenna}}{\text{Radiation intensity of an isotropic antenna}} = \frac{\phi(\theta, \phi)_{max} (\text{subject antenna})}{\phi_0 (\text{isotropic antenna})}$$

**Gain:** Gain describes how much power is transmitted in the direction of peak radiation to that of an isotropic source.

Antenna gain is calculated by multiplying antenna efficiency with directivity of antenna.

$$G = \eta_e D = \frac{P_{rad}}{P_{input}} \cdot \frac{\phi(\theta, \phi)_{max}}{\phi_0}$$

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)**.

An ideal **isotropic antenna with 0dB or 1(normal) gain**, radiates signal equally in all directions with zero losses .

**Aperture efficiency:** Aperture Efficiency is a term used to describe the effectiveness of an antenna in **converting electrical energy to it into electromagnetic radiation.**

It is the ratio of the effective radiating area to the physical are of the aperture.

$$\epsilon_a = \frac{A_{eff}}{A_p} = \frac{\text{Effective area}}{\text{Physical area}}$$

**Effective aperture (effective area) :** The *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  $\text{W/m}^2$ ). If  $P_t$  represents the power (in Watts) at the antennas terminals available to the antenna's receiver, then:

$$P_t = pA_e$$

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

**Antenna Efficiency:** It is the ratio of the radiated power of the antenna to the input to the input power by the antenna.

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

**VSWR:** VSWR stands for **Voltage Standing Wave Ratio**, and is also referred to as Standing Wave Ratio (SWR).

VSWR is the ratio of the peak amplitude of a standing wave to the minimum amplitude of a standing wave.

$$S = \left| \frac{V_{max}}{V_{min}} \right|, \quad \text{VSWR} = \frac{1+|\tau|}{1-|\tau|}$$

A transmission line having 50 impedance is terminated in a load of  $(40+j30)$  . Calculate VSWR.

$$\text{Reflection Coefficient}, \tau = \frac{Z_L - Z_0}{Z_L + Z_0} = \frac{40+j30-50}{40+j30+50}$$

$$|\tau| = \sqrt{\frac{10}{90}}$$

$$VSWR = \frac{1+|\tau|}{1-|\tau|} = 2$$

### Beam width

Beam width is the aperture angle from where most of the power is radiated.

**"Beam width is the aperture angle from where most of the power is radiated"-Explain.**

**Beam width** is the angular range (aperture angle) over which the majority of an antenna's power is radiated. It is usually measured between the points where the power drops to half (-3 dB) of its maximum value. This defines the main lobe of the radiation pattern, indicating the direction in which the antenna transmits or receives most effectively.

**Half Power Beam Width (HPBW):** **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.  $BW = \frac{70\lambda}{D}$

**First Null Beam Width:** The angular span between the first pattern nulls adjacent to the main lobe, is called as the **First Null Beam Width (FNBW)**.

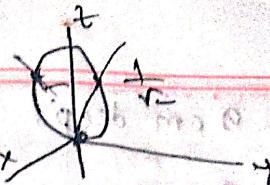
$$FNBW = 2HPBW = \frac{140\lambda}{D} \text{ radian}$$

\* Find HPBW, FNBW

$$(i) E(\theta) = \cos\theta / \sin\theta$$

$$\cos\theta = \frac{1}{\sqrt{2}} \Rightarrow \theta = 45^\circ$$

$$HPBW = 2\theta = 90^\circ$$



$$\cos\theta = 0^\circ$$

$$\Rightarrow M\Phi = 180^\circ$$

$$FNBW = 2\Phi = 180^\circ$$

$$(ii) E(\theta) = \sin^2\theta$$

$$\sin^2\theta = \frac{1}{2}$$

$$\Rightarrow \sin\theta = (\frac{1}{2})^{\frac{1}{2}}$$

$$\Rightarrow \theta = 54.33^\circ$$

$$HPBW = 2(90^\circ - 54.33^\circ)$$

$$= 65.44^\circ$$

$$FNBW = 180^\circ - 0^\circ$$

$$= 180^\circ$$

$$(iii) U(\theta) = \cos^2\theta \cdot \cos^2 3\theta$$

$$\cos^2\theta \cdot \cos^2 3\theta = \frac{1}{2}$$

$$\Rightarrow \cos\theta \cdot \cos 3\theta = \frac{1}{\sqrt{2}}$$

$$\Rightarrow \theta = 14.32^\circ$$

$$HPBW = 2\theta$$

$$= 28.64^\circ$$

$$U = 0$$

$$\cos^2\theta \cdot \cos^2 3\theta = 0$$

$$\theta = 90^\circ, 30^\circ$$

$$FNBW = 2\theta$$

$$= 60^\circ$$

### Relationship between length, frequency, wavelength

The length of the antenna is inversely proportional to the frequency and directly proportional to the wavelength. The higher the frequency and the shorter the

wavelength, the shorter the antenna can be made.

**Equivalent Isotropic Radiated Power:** The amount of power that an isotropic antenna radiates to produce the peak power density observed in the direction of maximum antenna gain, is called as **Equivalent Isotropic Radiated Power**.

### **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)**.

$$\text{ERP(dBW)} = \text{EIRP(dBW)} - 2.15\text{dBi}$$

- If the operating frequency is 1 MHz, then calculate the antenna size for a monopole antenna.
- If the operating frequency is 1 MHz, then calculate the antenna size for a dipole antenna.
- If the operating frequency is 1 MHz, then calculate the antenna size.

### **Solution:**

$$\lambda = \frac{c}{f} = \frac{3 \times 10^8}{10^6} = 300 \text{ meter}$$

Antenna Type	Formula	Size at 1 MHz
Monopole	$\lambda/4$	$300/4=75$
Dipole	$\lambda/2$	$300/2=150$
Full Wavelength	$\lambda$	300

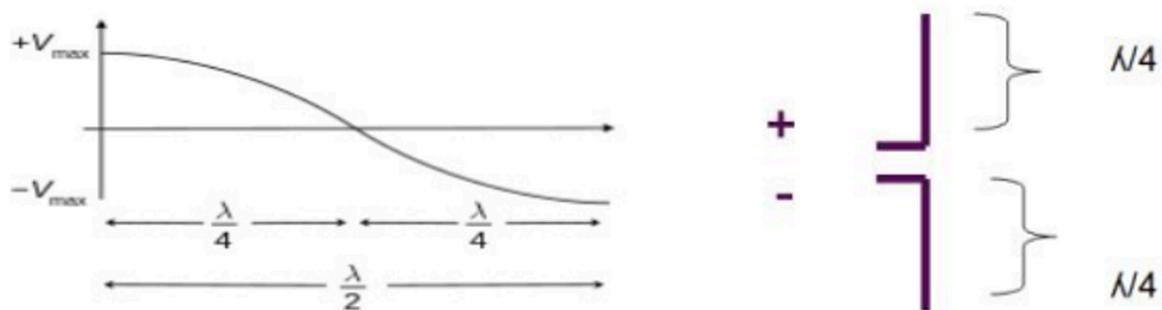
- Explain the half wave dipole antenna.
- What is the impedance of a half wave dipole antenna?
- Define half wave dipole antenna. Write down the features of dipole antenna.
- How do you calculate the size of the dipole antenna in feet? Calculate the size (in feet) of a 30 meter dipole antenna?
- What are the polarization of dipole antenna? Which one-is widely used?

- Draw the 2D radiation pattern of folded dipole antenna.
- What are the advantages and disadvantages of dipole antenna.
- Describe the construction of Yagi-Uda antenna.

**Solution:**

A dipole antenna is defined as a **symmetrical antenna** in which the **two ends are at equal potential** relative to midpoint.

A half wave dipole antenna is the **fundamental radio antenna of metal rod thin wire**, it has a **physical length of half wavelength in free space** of the frequency of operation.



Half-wave dipole antenna (**Hertz antenna**) is the **most widely used antenna** because of its advantages.

**Features of Half wave dipole antenna:**

- Dipole antenna with a **very thin radius** is considered.
- A dipole antenna has **two poles** where RF current flows.
- It **radiates EM signals** due to the current and voltage.
- Current is maximum at the **center and zero at the ends** (sinusoidal).
- Voltage is minimum at the center and maximum at the ends.
- It is usually **fed at the center for low impedance** (easy to match).
- For very short dipoles, input impedance is mainly capacitive (negative reactance).
- As **length increases, both resistance and reactance rise**.

- If the length is close to **one wavelength**, the input impedance becomes **infinite**.
  - At slightly less than **half-wavelength**, the antenna becomes resonant (**no reactance**).
  - At **one wavelength**, input impedance becomes very high.
1. The half-wave dipole antenna is a special case of the dipole antenna, with a length equal to half the **wavelength ( $\lambda/2$ ) of the operating frequency**.
  2. The electric current distribution is maximum at the center and zero at the ends.
  3. It is a **center-fed antenna**.
  4. The typical input impedance of a standard half-wave dipole is approximately  **$Z_{in} = 73 + j42.5 \text{ Ohms}$** .
  5. By slightly shortening the dipole to about  $0.48\lambda$ , the antenna becomes **resonant**, and the impedance becomes purely real:  **$Z_{in} \approx 70 \text{ Ohms}$** , making it well-matched to transmitters or receivers.
  6. The directivity of the half-wave dipole is **1.64** (which is equivalent to **2.15 dB**).
  7. The Half Power Beamwidth (HPBW) of the radiation pattern is approximately **78 degrees**.
  8. **3KHz to 300 GHz**

$$L = \frac{1}{2}k\lambda = \frac{143}{f} \text{ meter} = \frac{468}{f} \text{ feet}, f = MHz$$

$$P_{total} = \frac{1}{2}I_0^2R_{radiation}$$

$R_{radiation} \approx 73.1\Omega$  (73  $\Omega$  resistance and +43  $\Omega$  reactance, )

## Advantages

- Input impedance is not sensitive.
- Matches well with transmission line impedance.
- Has reasonable length.

- Length of the antenna matches with size and directivity.

### **Disadvantages**

- Not much effective due to single element.
- It can work better only with a combination.

A Yagi-Uda antenna is **constructed with a central boom supporting multiple parallel conductive elements: a driven element (usually a half-wave dipole), a reflector (slightly longer), and one or more directors (slightly shorter)**.

To construct a Yagi-Uda antenna, several components come together to create an efficient and directional antenna for transmitting or receiving electromagnetic signals. The central element is called the "boom," which serves as the framework for mounting all other parts. Connected to the transmission line is the primary element, known as the "driven element," responsible for signal transmission or reception. At the far end of the antenna is the "reflector," a longer element that reflects energy towards the antenna's radiation pattern. In front of the driven element, there are multiple strategically placed "directors" with specific lengths and spacings. These directors assist in directing the antenna's radiation pattern for optimal performance.

- **Describe the driven elements for parabolic reflector.**
- **Explain the principle of operation and application of parabolic reflector and its types**
- **Where do we use parabolic antenna. Describe different types of common paraboloids.**
- **Describe the driven elements for parabolic reflector.**

### **Solution:**

A parabolic antenna is a **high-gain reflector antenna** used for **radio, television and data communications**, and also for radio location (radar) on the **UHF and SHF** parts of the electromagnetic spectrum .

### **Why is it used?**

At higher microwave frequencies the physical size of the **antenna becomes much smaller** which in turn **reduces the gain and directivity** of the antenna.

The desired directivity can be achieved using suitably shaped parabolic reflector behind the main antenna which is known as primary antenna or feed .

## Principle Operation

- **Focal Reflection:** When a wave (e.g., light, sound, or microwaves) originates from the focal point of a parabola, it reflects off the parabolic surface and forms a parallel beam directed along the parabola's axis.
- **Converging Waves:** Conversely, parallel incoming waves striking the parabolic surface reflect and converge at the focal point.

## Application of parabolic Reflector:

1. Telecommunication
2. Optics
3. Acoustics
4. Scientific Research

## Types of paraboloid/reflector

Type	Description	Beam Characteristics	Applications
<b>Truncated Paraboloid</b>			
- Horizontal Truncation	<b>Parabolic in horizontal plane</b> , truncated vertically.	<b>Narrow horizontal beam</b> , spreads vertically.	<b>Surface search radar</b> , detects aircraft at varying altitudes.
- Vertical Truncation	<b>Parabolic in vertical plane</b> , truncated horizontally.	<b>Narrow vertical beam</b> , spreads horizontally.	<b>Height-finding systems</b> for precise elevation.
<b>Orange-Peel Paraboloid</b>	Segment of <b>circular paraboloid</b> , <b>narrow horizontally</b> , wide vertically.	<b>Wide horizontal beam</b> , narrow vertically.	<b>Height-finding radar</b> equipment.
<b>Cylindrical Paraboloid</b>	<b>Curved in one dimension, flat in other</b> ; focuses along	<b>Fan-shaped beam</b> , narrow in curved	Radar systems requiring fan-shaped beams.

Type	Description	Beam Characteristics	Applications
	a line using line source.	dimension, wide in flat dimension.	
Corner Reflector	<b>Two flat conductive sheets forming a corner; driven by half-wave radiator.</b>	<b>Simple reflected beam.</b>	<b>Radar and communication</b> systems for wave reflection.

$$G = \frac{4\pi A}{\lambda^2}, A = \frac{\pi d^2}{4}, \text{ Beamwidth } \alpha = \frac{115\lambda}{d}$$

### Types of Microwave feeder/Driven Element

Type	Description	Advantages	Disadvantages
Axial Feed	Feed antenna is <b>placed at the focus</b> , directly in <b>front of the dish</b> , pointing back.	Simple and common design.	Feed and supports <b>block the beam</b> (efficiency 55–60%).
Off-Axis / Offset Feed	<b>Feed is placed to the side</b> of the dish (asymmetrical paraboloid).	<b>No blockage</b> of the beam, better signal reception.	More <b>complex</b> geometry.
Cassegrain	Feed located <b>on or behind the dish</b> ; uses a <b>convex hyperboloidal</b> secondary reflector to <b>reflect waves back</b> to main dish.	Suitable for <b>bulky</b> or complex feeds; efficiency ~65–70%.	Slightly <b>complex</b> design and <b>alignment</b> .
Gregorian	Similar to Cassegrain, but uses a <b>concave (ellipsoidal)</b> secondary reflector.	<b>Very high aperture</b> efficiency (>70%).	Most <b>complex</b> among these; higher <b>cost</b> .

**A parabolic reflector is 9 cm deep and its diameter is 24 cm. How far is its focus from the vertex?**

\* 9 cm deep, diameter 24 cm

$$y^2 = 4ax \rightarrow (i)$$

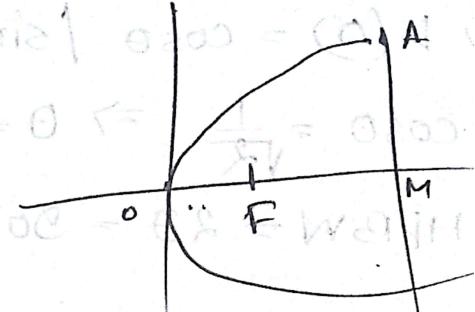
$$OM = 9 \text{ cm} \quad AM = \frac{1}{2} AB \\ \therefore OM = 9 \text{ cm} \quad AM = \frac{1}{2} \times 24 \text{ cm} = 12$$

$$12 \times 12 = 4 \times 9 \times a$$

$$\Rightarrow a = 4$$

$$y^2 = 16x$$

$$F(4, 0)$$



Let the equation of the parabolic shape of the reflector be  $y^2 = 4ax$ . ....(i)

As given, we have  $OM = 9 \text{ cm}$  and  $AB = 24 \text{ cm}$

$\Rightarrow OM = 9 \text{ cm}$  and  $AM = \frac{1}{2} AB = 12 \text{ cm}$ .

$\therefore$  the coordinates of A are  $(9, 12)$ .

Since A lies on equation (i), we have:

$$12^2 = 4 \times a \times 9$$

$$\Rightarrow a = 4.$$

$\therefore$  the equation of the parabola is  $y^2 = 16x$ .

Its focus is  $F(a, 0)$ , i.e.,  $F(4, 0)$ .

Hence, the focus is at a distance of 4 cm from the vertex.

- **What is radiation pattern? What are the common types of radiation patterns?**
- **Compare between near and far field pattern.**
- **What is the simplest antenna design procedure?**

### Solution

Radiation Patterns are **diagrammatical representations of the distribution of radiated energy into space**, as a function of direction.

Radiation Pattern Type	Shape (2D / 3D View)	Description
Omni-directional Pattern	3D: Doughnut shape 2D: Figure-of-eight	<b>Radiates equally</b> in all horizontal directions; <b>non-directional</b> .
Pencil-beam Pattern	Pencil-shaped, narrow and highly directional	Focused beam in a <b>specific direction</b> ; used for <b>long-distance targeting</b> .
Fan-beam Pattern	<b>Fan-shaped</b> (broad in one direction, narrow in the other)	Covers a <b>wide area in one plane</b> , narrow in the perpendicular plane.
Shaped Beam Pattern	<b>Irregular, custom</b> shape	Beam is tailored for <b>specific coverage; no fixed pattern shape</b> .

### Simplest antenna design procedure:

1. **Choose Frequency (f):** Decide the operating frequency (e.g., 100 MHz).
  2. **Calculate Wavelength ( $\lambda$ ):**
  3. **Find Antenna Length (L):**
    - For half-wave dipole:  $L = \lambda/2$
    - For quarter-wave monopole:  $L = \lambda/4$
  4. **Select Material:** Use good conductor (e.g., copper).
  5. **Feed at Center:** For dipole, feed in the middle using coaxial cable.
  6. **Test and Adjust:** Use antenna analyzer or trim for better signal.
- **Calculate the radiation resistance of Hertzian dipole antenna from the total radiated power. If a Hertzian dipole length  $d = 0.11\lambda$  Calculate  $R_{rad}$ ?**

### Solution

The Hertzian dipole is a **theoretical dipole antenna** that consists of an **infinitesimally small current source** acting in free-space.

$$R_{rad} = \frac{2}{I_0^2} P_{total} = \frac{2\pi\mu_0 c_0}{3} (d/\lambda)^2 = \frac{2\pi}{3} z_0 (d/\lambda)^2, Z_0 = 377 \text{ ohm}$$

$$R_{rad} = 80\pi^2 \left(\frac{0.1\lambda}{\lambda}\right)^2 = 7.88 \text{ ohm}$$

A steel rod of length  $d = 1.5$  meters, radius  $a = 1$  mm is used as an antenna for radiation at  $f = 1$  MHz (AM radio).

$$R_{rad} = \frac{2\pi}{3} Z_0 \cdot \frac{d^2}{\lambda^2} = \frac{2\pi}{3} (377\Omega) \left( \frac{1.5}{300} \right)^2 = 0.020\Omega$$

The resistance of a metal wire at high frequency (where the skin depth is much smaller than the wire's radius) is given by:

$$R_{Ohmic} = \sqrt{\frac{\pi f \mu}{\sigma}} \frac{d}{2\pi a}$$

For steel,  $\mu = \mu_0$  and  $\sigma = 2 \times 10^6 \Omega^{-1} m^{-1}$ . Thus  $R_{ohmic} = 0.34\Omega$

The radiation efficiency is therefore:

$$\eta = \frac{R_{rad}}{R_{rad} + R_{Ohmic}} = 0.055$$

(often this is expressed in decibels:  $\eta = -12.6$  dB)

- What are the operational frequencies of horn antenna? Describe different types of horn antenna.

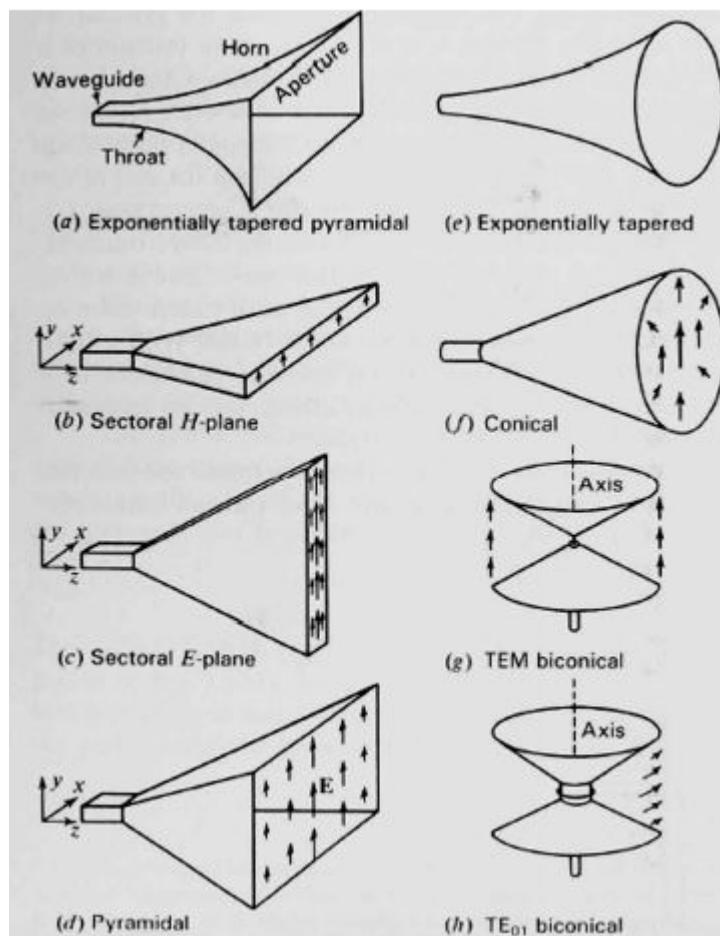
### Solution

A Horn antenna may be considered as a flared out wave guide. To improve the radiation efficiency and directivity of the beam, the waveguide should be provided with an extended aperture to make the abrupt discontinuity of the wave into a gradual transformation.

Operational frequencies 300MHz to 30GHz.

Type of Horn Antenna	Structure / Shape	Flaring Direction	Key Features / Applications
Pyramidal Horn	Truncated pyramid; flaring on both E-plane and H-plane walls of a rectangular waveguide	Both E & H planes	Most common type; used in rectangular waveguides
Sectoral E-plane Horn	Flaring in one direction only (Electric field direction)	E-plane only	Narrow beam in E-plane; wider in H-plane
Sectoral H-plane Horn	Flaring in one direction only (Magnetic field)	H-plane only	Narrow beam in H-plane; wider in E-plane

Type of Horn Antenna	Structure / Shape	Flaring Direction	Key Features / Applications
	direction)		
<b>Conical Horn</b>	Circular flare from a circular waveguide	All around (circularly symmetric)	Used with circular waveguides; good for symmetric beam patterns
<b>Exponential Horn</b>	Curved sides; flare increases exponentially with length	Smooth exponential flare	Minimum reflection, wide bandwidth; used in satellite antennas and radio telescopes



- If aperture length (H-plane) 125mm, aperture width (E-plane) 100mm and operating wavelength 30cm for a horn antenna, then calculate the antenna gain in dB.

$$A = 125 * 100 = 0.0125m^2$$

$$G = \frac{4\pi \times 0.0125}{0.03^2} = \dots$$

$$G_{dB} = 10 \log_{10} G = \dots$$

## Transmission Line

- Contrast between transmission lines and waveguides.

Waveguide	Transmission Line
The waveguide is a <b>hollow metallic structure</b> through which electric and magnetic fields are transmitted.	The transmission line is a conductor which is used to <b>carry electrical signal over a long range</b> .
It has <b>simple</b> to manufactured.	It has <b>complex</b> to manufactured.
In waveguide the <b>power handling is high</b> as compared to transmission line.	In transmission line the <b>power handling is low</b> as compared to waveguide.
The Operating modes are <b>TE or TM mode</b> .	The operating mode are <b>TEM or quasi TEM mode</b> .
In waveguide <b>high power</b> is transmitted.	In transmission line <b>low power</b> is transmitted.
In waveguide the <b>electromagnetic</b> signal is transmitted.	In transmission line the <b>electrical</b> signal is transmitted.
The operating frequency is <b>3 GHZ to 100 GHZ</b> in waveguide.	The operating frequency is <b>up to 18 GHz</b> .

- Calculate the input impedance of short circuited quarter wavelength lossless transmission line.

$$\beta l = \frac{2\pi}{\lambda} \frac{\lambda}{4} = \frac{\pi}{2}$$

$$Z_{sc} = jZ_0 \tan \beta l = \infty$$

- If a transmission line is terminated with a resistance equal to its characteristic impedance- what will happen?

Standing wave ratio will be minimum

$$Z_0 = Z_L$$

$$\tau = \frac{Z_0 - Z_L}{Z_0 + Z_L} = 0, \text{ minimum value}$$

$$\text{VSWR} = 1$$

- A transmission line having 50 impedance is terminated in a load of  $(40+j30)$ . Calculate VSWR

VSWR is the ratio of the peak amplitude of a standing wave to the minimum amplitude of a standing wave.

$$S = \left| \frac{V_{max}}{V_{min}} \right|, \quad \text{VSWR} = \frac{1+|\tau|}{1-|\tau|}$$

A transmission line having 50 impedance is terminated in a load of (40+j30) . Calculate VSWR.

$$\text{Reflection Coefficient, } \tau = \frac{Z_L - Z_0}{Z_L + Z_0} = \frac{40+j30-50}{40+j30+50}$$

$$|\tau| = \sqrt{\frac{1}{9}}$$

$$VSWR = \frac{1+|\tau|}{1-|\tau|} = 2$$

- If a transmission line is terminated with a resistance equal to its characteristic impedance then calculate the value of standing wave ratio.**

$$Z_0 = Z_L$$

$$\tau = \frac{Z_0 - Z_0}{Z_0 + Z_0} = 0, \text{ minimum value}$$

$$\text{VSWR} = 1$$

- Using solution of transmission line equation, derive characteristics impedance for transmission line.**
- What will be propagation constant and characteristic impedance for low-loss transmission line?**

$$\beta = \frac{2\pi f}{v}, \text{ f in hertz}$$

$$Z_0 = \sqrt{\frac{L}{C}}$$

- For a 1 volt, 50 MHz signal source with input impedance 75 and load impedance 300 , find i) the characteristics line impedance ii) calculate the transmission line length. If we alter the impedances i.e 75 load and 300 source, is the impedance matches? If yes, explain.**

$$Z_0 = \sqrt{Z_s \cdot Z_L} = \sqrt{300 \cdot 75} = \sqrt{22500} = 150 \Omega$$

$$\lambda = \frac{3 \times 10^8}{50 \times 10^6} = 6 \text{ m}, \quad l = \frac{\lambda}{4} = \frac{6}{4} = 1.5 \text{ m}$$

$$Z_{in} = \frac{Z_0^2}{Z_L} = \frac{150^2}{75} = 300 \Omega$$

Now, since quarter-wave transformers are **symmetric, impedance matching is still achieved** even when source and load are swapped.

- What type of losses occurs due to impedance mismatch?**

Impedance matching in transmission lines is **the practice of ensuring the source, transmission line, and load impedances are equal to minimize signal reflections and maximize power transfer**

The transmission line, if not terminated with a matched load, occurs in losses. These losses are many types such as **attenuation loss, reflection loss, transmission loss, return loss, insertion loss**, etc

- A 100 V peak signal at 1 GHz is applied to a transmission line of characteristic impedance 100 Ω, terminated with an antenna of 75 Ω. Calculate incident current and reflected current. Note that the reflection coefficient at the load is  $\Gamma_L = \frac{Z_L - Z_0}{Z_L + Z_0}$ .

$$\Gamma_L = \frac{75 - 100}{75 + 100} = \frac{-25}{175} = -\frac{1}{7} \approx -0.143$$

$$I_0^+ = \frac{V_0^+}{Z_0} = \frac{100}{100} = 1 \text{ A}$$

$$I_{\text{ref}} = |\Gamma_L| \cdot I_{\text{inc}} = 0.143 \text{ A}$$

- If a section of 300 ohm twin lead has a velocity factor of 0.82. Compare the speed of energy transferred with respect to the vacuum.

$$v_f = \frac{1}{\sqrt{k}} = \frac{v}{c}$$

$$\rightarrow v = v_f \times c = 2.47 \times 10^6 \text{ m/s}$$

The speed of energy transfer in the twin lead is approximately 82% of the speed of light in a vacuum.

- If a transmission desirable VSWR line on a transmission line is (i) 0 (ii) 1 (iii) ½ (iv) infinity.

**Ans : 1**

- a. A 30m long lossless transmission line with  $Z_0 = 50$  operating at 2 MHz is terminated with a load  $Z = 60 + j40$ . If  $v = 0.6C$  on the line. C represents the velocity of light. Find:
  - i. The reflection coefficient r

$$r = \frac{Z_L - Z_0}{Z_L + Z_0} = \frac{(60 + j40) - 50}{(60 + j40) + 50} = \frac{10 + j40}{110 + j40}$$

Simplifying gives us:

$$r = \frac{10 + j40}{110 + j40} = \frac{10 + j40}{110 + j40} \approx 0.0909 + j0.3636$$

## ii. The standing wave ratio

Calculate the magnitude of the reflection coefficient:

$$|r| = \sqrt{(0.0909)^2 + (0.3636)^2} \approx 0.373$$

and then calculate the standing wave ratio:

$$SWR = \frac{1 + |r|}{1 - |r|} = \frac{1 + 0.373}{1 - 0.373} \approx 2.00$$

## iii. The input impedance

Calculate the propagation constant:

$$\beta = \frac{2\pi f}{v} = \frac{2\pi(2 \times 10^6)}{0.6 \times 3 \times 10^8} \approx 0.209 \text{ rad/m}$$

Now calculate the input impedance:

$$Z_{in} = Z_0 \frac{Z_L + jZ_0 \tan(\beta l)}{Z_0 + jZ_L \tan(\beta l)}$$

where  $l = 30m$ . First, calculate  $\tan(\beta l) = \tan(0.209 \times 30) \approx 0.577$  Then substitute into the input impedance formula:

$$Z_{in} = 50 \frac{(60 + j40) + j50(0.577)}{50 + j(60 + j40)(0.577)}$$

Simplifying gives us the final input impedance.

- Define Impedance Matching. Why Impedance Matching are necessary?**

Impedance matching in transmission lines is **the practice of ensuring the source, transmission line, and load impedances are equal to minimize signal reflections and maximize power transfer**

Impedance matching is necessary **to maximize power transfer and minimize signal reflections in electrical circuits**

## Scattering Matrix

It is a square matrix which gives all the combinations of power relationships between the various input and output ports of a Microwave junction. The elements of this matrix are called "**Scattering Coefficients**" or "**Scattering (S) Parameters**".

- **Write the properties of scattering matrix.**

- [S][S] is always a square matrix of order (nxn)

$$[S]_{n \times n}$$

- [S][S] is a symmetric matrix  $S_{ij} = S_{ji}$

- [S][S] is a unitary matrix  $[S][S]^* = I$

- The sum of the products of each term of any row or column multiplied by the complex conjugate of the corresponding terms of any other row or column is zero.

$$\sum_{i=j}^n S_{ik} S_{ik}^* = 0 \quad \text{for } k \neq j$$

- If the electrical distance between some  $k^{\text{th}}$  port and the junction is  $\beta_k I_k$ , then the coefficients of  $S_{ij}$  involving  $k$ , will be multiplied by the factor  $e^{-j\beta_k I_k}$ .

- **Compare among E-plane, H-plane and magic Tee.**

Aspect	E-Plane	H-Plane	Magic Tee
<b>Definition</b>	Plane of electric field	Plane of magnetic field	Hybrid junction of E- and H-planes
<b>Field Orientation</b>	Electric field	Magnetic field	Combines both fields
<b>Structure</b>	Part of waveguide/antenna	Part of waveguide/antenna	Four-port device
<b>Radiation Pattern</b>	Vertical (E-field direction)	Horizontal (H-field direction)	N/A (device, not pattern)
<b>Isolation</b>	No inherent isolation	No inherent isolation	Yes, between specific ports
<b>Power Division</b>	Not applicable	Not applicable	Equal or controlled split

Aspect	E-Plane	H-Plane	Magic Tee
<b>Applications</b>	Antenna pattern analysis	Antenna pattern analysis	Power splitting, mixing
<b>Phase Behavior</b>	Depends on antenna design	Depends on antenna design	180° phase difference possible

- **Find the scattering matrix for the H-plane tee.**
- **What is H-plane Tee? Explain the scattering properties of H-plane Tee with the help of scattering matrix.**

**An H-Plane Tee junction is formed by attaching a simple waveguide to a rectangular waveguide which already has two ports.** The arms of rectangular waveguides make two ports called collinear ports i.e., Port1 and Port2, while the new one, Port3 is called as Side arm or H-arm. This H-plane Tee is also called as Shunt Tee.

The H-plane (Magnetic plane) is the plane containing the magnetic field vector (H-field) and the direction of propagation.

$$(a) V_S = 1V, f = 50 \text{ MHz}, Z_S = 75 \Omega, Z_L = 300 \Omega$$

$$Z_0 = \sqrt{Z_S \cdot Z_L} = 150 \Omega$$

\* H-plane Tee.

1)  $[S]_{3 \times 3}$  Matrix,  $[S] = \begin{bmatrix} \dots & \dots & \dots \\ \dots & \dots & \dots \\ \dots & \dots & \dots \end{bmatrix}$

2)  $S_{13} = S_{23}$ , the junction symmetrical in plane.

3) Symmetric property  $S_{ij} = S_{ji}$

$$S_{12} = S_{21}, S_{23} = S_{32} = S_{13} = S_{31}$$

4)  $S_{33} = 0$ , perfectly matched

$$[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{12} & S_{22} & S_{23} \\ S_{13} & S_{23} & 0 \end{bmatrix}$$

$$[S]^* = [S]$$

$$R_{1C_1}: S_{11}^2 + S_{12}^2 + S_{13}^2 = 1 \quad (1)$$

$$R_{2C_2}: S_{12}^2 + S_{22}^2 + S_{23}^2 = 1 \quad (2)$$

$$R_{3C_3}: S_{13}^2 + S_{23}^2 = 1 \Rightarrow S_{13} = \frac{1}{\sqrt{2}} \quad (3)$$

$$R_{3C_1}: S_{13}^2 S_{11}^2 + S_{12}^2 S_{13}^2 = 0 \Rightarrow 0 = 0 \quad (4)$$

$$\Rightarrow S_{11} = S_{12}$$

$$(i) \Rightarrow S_{11} = \cancel{S_{12}} = \frac{1}{2}$$

$$S_{12} = -\frac{1}{2}$$

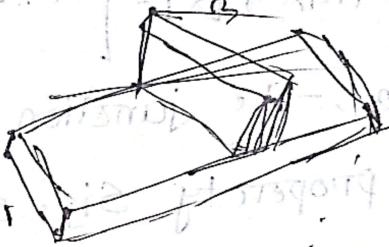
$$(1) - (2), \quad S_{11} = S_{22}$$

$$\begin{vmatrix} \frac{1}{2} & \frac{1}{2} & \frac{1}{\sqrt{2}} \\ -\frac{1}{2} & \frac{1}{2} & \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & 0 \end{vmatrix}$$

$$[B] = [S][A]$$

$$= \boxed{\quad}$$

\* E-plane:



(i)  $[S]_{3 \times 3}$

(ii)  $S_{23} = -S_{13}$  [one out of phase by  $180^\circ$  with an i/p at port 3]

(iii)  $S_{33} = 0$

(iv)  $S_{12} = S_{21}, -S_{13} = S_{31} = S_{23} = S_{32}$

(v)  $[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{bmatrix}$

(vi)  $[S][S]^* = I$

$$R_1 C_1 \div S_{11} + S_{12}^* + S_{13}^* = 1 - (1)$$

$$R_2 C_2 \div S_{12}^* + S_{22}^* + S_{23}^* = 1 - (2)$$

$$R_3 C_3 \div S_{13}^* + S_{23}^* + 0 = 1 - (3) \Rightarrow S_{13} = \frac{1}{\sqrt{2}}$$

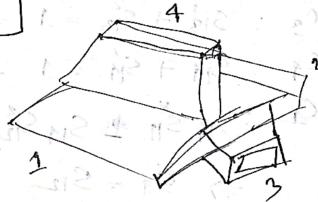
$$R_3 C_4 \div S_{13} S_{11}^* - S_{12}^* S_{13} = 0 \Rightarrow S_{11} = S_{12}$$

$$(1) \Rightarrow S_{11} = \frac{1}{2}$$

$$(1)-(2) \Rightarrow S_{11} = S_{21} \text{ (by Eqn 8)}$$

$$[S] = \begin{bmatrix} \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \\ \frac{1}{2} & \frac{1}{2} & -\frac{1}{2} \\ \frac{1}{2} & -\frac{1}{2} & 0 \end{bmatrix}$$

X E-H plane:



$$(1) [S] 4 \times 4$$

$$(2) S_{23} = S_{13} \quad [\text{H-plane tee section}]$$

$$(3) S_{34} = -S_{14} \quad [\text{E-plane } \rightarrow]$$

(4)  $S_{34} = S_{43} = 0$  [E-term and Ohm's law point out isolated that other won't deliver]

(5) Symmetrical, a port

$$S_{12} = S_{21} \quad S_{23} = S_{13} = S_{32} = S_{31}$$

$$-S_{14} = -S_{41} = S_{24} = S_{42}$$

$$(6) \text{ Perfectly matched, } S_{33} = S_{44} = 0$$

$$(7) [S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{12} & S_{22} & S_{13} & -S_{14} \\ S_{13} & S_{13} & 0 & 0 \\ S_{14} & -S_{14} & 0 & 0 \end{bmatrix}$$

$$(8) [S][S]^* = I$$

$$R_1 C_1 : S_{11}^L + S_{12}^L + S_{13}^L + S_{14}^L = 1 \quad (1)$$

$$R_2 C_2 : S_{12}^L + S_{22}^L + S_{23}^L + S_{24}^L = 1 \quad (2)$$

$$R_3 C_3 : S_{13}^L + S_{23}^L = 1 \Rightarrow S_{13}^L = \frac{1}{r_2}$$

$$R_4 C_4 : S_{14}^L + S_{24}^L = 1 \Rightarrow S_{14}^L = \frac{1}{r_2}$$

$$R_4 C_4 : S_{14}^L S_{11}^* + S_{14}^L S_{12}^* = 0$$

$$\Rightarrow S_{11}^L = S_{12}^L$$

$$(1) - (2), \quad S_{11}^L = S_{22}^L$$

$$S_{11} = S_{22}$$

$$(2), \quad S_{12} = 0 \quad S_{11} = S_{22} = S_{12} = S_{21} = 0$$

With these results full solution

$$[S] = \begin{vmatrix} 0 & 0 & \frac{1}{r_2} & \frac{1}{r_2} \\ 0 & 0 & \frac{1}{r_2} & \frac{1}{r_2} \\ \frac{1}{r_2} & \frac{1}{r_2} & 0 & 0 \\ \frac{1}{r_2} & \frac{1}{r_2} & 0 & 0 \end{vmatrix}$$

- What is directional coupler? Write down the properties of an ideal directional coupler.

- Write the properties of ideal directional coupler.

**Directional coupler** is a four-port device where Port 1 is the incident port, Port 2 is the through port (because it connects via a straight line). Port 4 is the coupled port, and Port 3 is the isolated port.

**Properties:**

- All the terminations are matched to the ports.
- Demo for below: When the power travels from port 1 to port 2, some portion of it gets coupled to port 4 but not to port 3.

Travels	Coupled	not coupled
$1 \rightarrow 2$	4	3
$2 \rightarrow 1$	3	4
Incident through port 3	2	1
Incident through port 4	1	2

- Port 1 and 3 are decoupled as are port 2 and port 4.
- Ideally, the output of port 3 should be zero. But, practically, a small amount of power called back power is observed at port 3.
- **Compare among isolator, circulator and phase shifter.**

Feature	Isolator	Circulator	Phase Shifter
<b>Definition</b>	Allows signal in <b>one direction only</b> , blocks reverse	Routes signal from one port to the <b>next port in a circle</b>	Shifts the <b>phase</b> of signal without changing its magnitude
<b>Type of Device</b>	<b>Non-reciprocal</b> 2-port device	<b>Non-reciprocal</b> 3 or 4-port device	<b>Reciprocal</b> 2-port device
<b>Main Purpose</b>	<b>Protects</b> devices from reflected signals	<b>Routes</b> signals between ports in a defined sequence	<b>Changes</b> the phase angle of a signal
<b>Working Principle</b>	Uses <b>Faraday rotation</b>	Uses <b>Y-junction with magnetized ferrite</b>	Uses <b>delay lines or varactors</b>
<b>Signal Flow</b>	Port A $\rightarrow$ Port B only (blocks B $\rightarrow$ A)	Port 1 $\rightarrow$ 2, 2 $\rightarrow$ 3, 3 $\rightarrow$ 1 (or circular path)	Same signal goes through, but with <b>phase shifted</b>
<b>Ports</b>	2 (3rd port used for termination)	Typically 3 or 4	2
<b>Insertion Loss</b>	$\sim 2$ dB	$\sim 0.5 - 1.5$ dB	Ideally low in all phase states
<b>Key Property</b>	Blocks unwanted <b>reflections</b>	Allows <b>directional signal routing</b>	Provides <b>variable or fixed phase shift</b>

Feature	Isolator	Circulator	Phase Shifter
<b>Reciprocal?</b>	No	No	Yes
<b>Common Use</b>	Between source and load to <b>block reflected power</b>	In <b>radar or duplex communication systems</b>	In <b>phased arrays, beam steering, RF control systems</b>

## Radar

- **What is RADAR? Why it is necessary? Derive radar range equation.**

Radar stands for Radio Detection and Ranging System. It **detects location and distance of objects** using **electromagnetic** energy. It is basically an electromagnetic system used to detect the location and distance of an object from the point where the RADAR is placed.

**Operating range:** UHF and microwave frequencies (**400 MHz to 40 GHz**).

\* Radar derive,

\* Radar range equation

$$\text{Power density equation, } P_{ai} = \frac{P_t}{4\pi R^2} \text{ Wm}^{-2} \dots (1)$$

$P_t$  = Amount of power transmitted by Radar transmitter

$$\text{Power density due to directional antenna, } P_{dd} = \frac{P_t G_r}{4\pi R^2} \text{ W} \dots (2)$$

Power density of echo signal,

$$P_{de} = P_{dd} \cdot \frac{\sigma}{4\pi R^2} \text{ W} \dots (3)$$

$\sigma$  : Radar cross section of the target

Power received by radar,  $P_r = P_{de} A_e$ .  $A_e$  : Effective aperture

$$P_r = P_{de} \cdot A_e$$

$$= \frac{P_t G_r \sigma}{(4\pi R^2)^2} A_e$$

$$\Rightarrow R = \left( \frac{P_t G_r \sigma A_e}{(4\pi)^2 P_r} \right)^{\frac{1}{4}}$$

$$R = R_{\max} \Rightarrow P_r = S_{\min}$$

$$R_{\max} = \left( \frac{P_t G_r \sigma A_e}{(4\pi)^2 S_{\min}} \right)^{\frac{1}{4}}$$

$$\text{Modified: } G_r = \frac{4\pi}{\lambda^2} A_e \quad | \quad A_e = \frac{\lambda^2}{4\pi} G_r$$

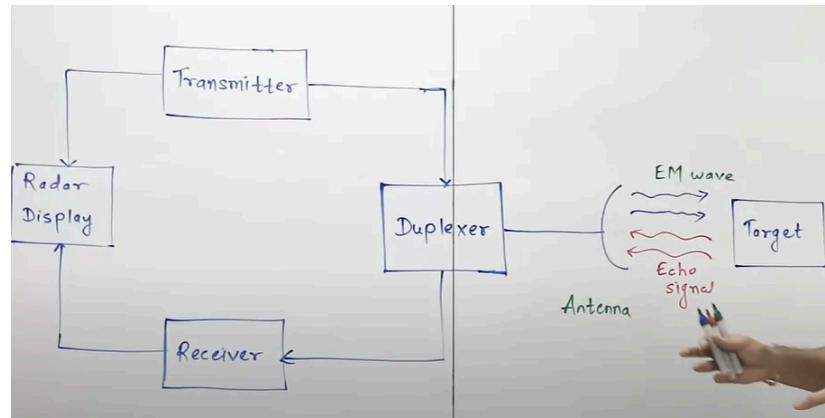
$$R_{\max} = \boxed{\quad}$$

$$R_{\max} = \boxed{\quad}$$

- What is RADAR? Write down the functions of Radar?

- Purpose : Detect, track, locate and identify object

- **Capabilities:** Determines distance, velocity, shape, size
- **Comparison with other sensors:** Superior for detecting faraway targets
- Draw RADAR block diagram.



- Describe the working procedure of a moving target indicator radar system..

### 1. Pulse Transmission

The radar system transmits a train of short radio frequency (RF) pulses toward the surveillance area.

### 2. Echo Reception

Echo signals are received from both stationary and moving objects after reflecting off targets.

### 3. Doppler Shift Detection

Moving targets introduce a Doppler shift (change in frequency) in the received signal, which is a key indicator of motion.

### 4. Phase Comparison

The radar compares the phase of echo signals from **successive pulses** to detect whether a target has moved between transmissions.

### 5. Clutter Rejection

Using delay lines or filters, the radar cancels out echoes from stationary objects (like buildings or trees), known as clutter.

### 6. Output Signal Extraction

After filtering, only the signals from **moving targets** remain and are processed further.

## 7. Display

The radar display shows only the **moving targets**, while stationary objects are suppressed, providing a clear view of moving objects.

- Calculate the maximum range of Radar for the following specifications.  
Operating frequency  $f=10\text{GHz}$ , peak power transmitted by the Radar  $400\text{KW}$ , effective aperture for the receiving antenna  $A=5\text{m}^2$ , Radar cross-section of the target  $\sigma=30\text{m}^2$ , power of minimum detectable signal  $S_{min}=10^{-10}\text{W}$ .

$$R_{max} = \left( \frac{P_t \cdot G_r \cdot A_e \cdot \sigma}{(4\pi)^2 \cdot S_{min}} \right)^{\frac{1}{4}}$$

$\lambda = \frac{c}{f} = \frac{3 \times 10^8}{10 \times 10^9} = 0.03$

$\therefore 127.62 \text{ km}$

- Calculate the maximum range of the radar when power transmitted by the radar is  $250\text{KW}$ , transmitting antenna gain is  $4000$ , effective aperture of the receiving antenna is  $4 \text{ m}^2$ , radar cross section of the target is  $25 \text{ m}^2$  and power of the minimum detectable signal is  $10^{-12} \text{ W}$ .

$$R_{max} = \left( \frac{P_t \cdot G_t \cdot A_e \cdot \sigma}{(4\pi)^2 \cdot S_{min}} \right)^{\frac{1}{4}}$$

$\therefore 158.63 \text{ km}$

- Discuss how the target is tracked using any one of the angular tracking methods.

[ Extra : Radar, which is used to track the path of one or more targets is known as **Tracking Radar**.

The pencil beams of Radar Antenna perform tracking in angle. The axis of Radar Antenna is considered as the reference direction. If the direction of the target and reference direction is not same, then there will be **angular error**, which is nothing but the difference between the two directions. ]

### 1. Sequential Lobing

- Antenna beams are switched alternately between two directions (beam positions) to track a target.
- Radar alternates beam between **Position 1** and **Position 2**.
- Compares received signal strength from both positions.
- Difference in signal strength indicates direction and magnitude of angular error.

### 2. Conical Scanning

- Antenna beam **continuously rotates** around the boresight axis to track a target.
- The rotating beam traces a **cone-shaped path** (hence "conical").
- This rotation causes the **echo signal to be modulated** at the same frequency as the beam rotation.
- The **amplitude** of the modulation depends on how far the target is from the beam center.

## Satellite

A communication satellite is an **orbiting artificial earth satellite** that receives a **communications signal** from a transmitting ground station, **amplifies and possibly processes** it, then **transmits it back to the earth** for reception by one or more receiving ground stations.

- **Define: Eccentricity, vernal equinox, right accession of ascending node, line of nodes. Mention them with appropriate figures.**

Eccentricity defines the shape of the satellite orbit. It is the ratio of the distance between the foci of the ellipse to the length of its major axis. For a perfect circle, eccentricity is zero.

The Vernal Equinox is the point where the **Sun crosses the Earth's equatorial** plane moving from the southern to the northern hemisphere. It is used as a reference point in the celestial coordinate system.

Right Ascension of Ascending Node is the angle measured from the vernal equinox to the ascending node of the satellite orbit, measured in the equatorial plane.

The line of nodes is the line joining the **ascending and descending nodes through the centre of Earth.**

- **Define: i) look angle ii) sub satellite point iii) apogee and perigee**

Look angle is the angle between the direction of the satellite from the **Earth station** and the **local horizontal** at the Earth station.

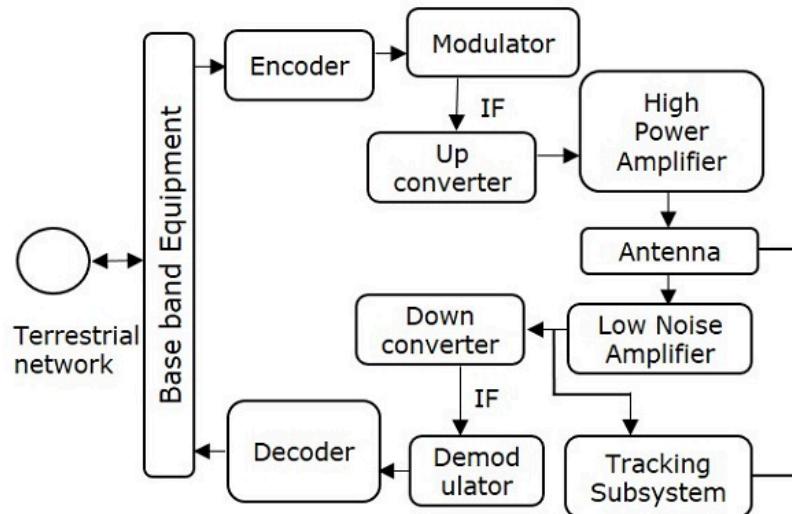
- The angle between **local horizontal plane and the plane passing through earth station**, satellite and center of earth is called as **azimuth angle**.
- The angle between **vertical plane and line pointing to satellite** is known as Elevation angle.

The sub-satellite point is the point on the **Earth's surface directly beneath the satellite** at any given time.

**Apogee** is the farthest point of the satellite from the Earth in its orbit.

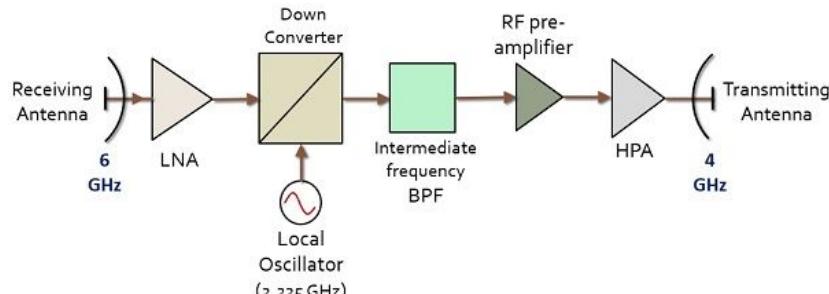
**Perigee** is the closest point of the satellite to the Earth in its orbit.

- **Write down the functional block diagram of an earth station and explain how signal is processed for transmission and reception.**



- **What is transponder? Explain the block diagram of single conversion transponder.**

A transponder is **an electronic device that transmits and receives radio signals**.



Block Diagram of Transponder for 6/4 GHz band

Electronics Desk

- Explain the block diagram of typical FDMA satellite system.
- Write a short note on SPADE.
- Shortly explain AOC and TTCM subsystem.

Aspect	AOC Subsystem	TTCM Subsystem
Full Form	Attitude and Orbit Control	Telemetry, Tracking, Commanding, and Monitoring
Main Function	Controls the <b>orientation (attitude)</b> and <b>orbit position</b> of the satellite	Handles <b>communication and control</b> between satellite and Earth station

Aspect	AOC Subsystem	TTCM Subsystem
Purpose	Ensures satellite points in correct direction (e.g., antennas towards Earth, solar panels to Sun)	Ensures satellite's <b>health, position, and commands</b> are transmitted, received, and monitored
Methods Used	- <b>Spin stabilization</b> (rotating body)- <b>Three-axis stabilization</b> (using momentum wheels)	- <b>Telemetry</b> (sends sensor data to Earth)- <b>Tracking</b> (finds satellite location)- <b>Commanding</b> (sends control signals)
Key Components	- Spinning drum- De-spin mechanism- Momentum wheels for 3-axis control	- Sensors and encoders- RF transmitters for telemetry- Antennas and command receivers
Satellite Stability	Keeps satellite stable and correctly oriented in orbit	Keeps satellite <b>communicating</b> and <b>under control</b> from ground
Example of Use	Making antennas continuously face Earth despite satellite motion	Sending temperature, pressure data to Earth; commanding thrusters to adjust orbit

- **State and explain Kepler's law. Derive differential equation for the motion of a satellite.**
1. *The orbit of a satellite around the Earth is an ellipse, with the center of mass of the Earth located at one of the two foci of the ellipse.*
  2. *A line joining a satellite and the Earth sweeps out equal areas in the orbital plane in equal intervals of time.*
  3. *The square of the orbital period of a satellite is directly proportional to the cube of the semi-major axis of its orbit.*

$$T^2 = \left( \frac{4\pi^2}{\mu} \right) a^3; \mu = 3.986004 \times 10^5 \text{ km}^3/\text{s}^2$$

### Distinguish between Active and Passive satellite.

Aspect	Passive Satellite	Active Satellite
Definition	A satellite that only <b>reflects signals</b> from Earth without amplification or modification.	A satellite that <b>receives, amplifies, and retransmits</b> signals back to Earth using onboard electronics.

Aspect	Passive Satellite	Active Satellite
<b>Function</b>	Reflects incoming signals from Earth.	Amplifies and retransmits received signals.
<b>Power Supply</b>	No onboard power; relies entirely on external transmitted energy.	Contains onboard power sources to operate internal electronics.
<b>Earth Station Requirement</b>	Needs <b>high power</b> transmitters and large tracking facilities.	Needs <b>lower power</b> Earth stations due to onboard amplification.
<b>Control from Ground</b>	Cannot be controlled once in orbit.	Can be actively controlled and monitored from ground.
<b>Signal Strength</b>	Signal weakens significantly (high attenuation) due to long travel path and no amplification.	Signal strength is maintained or enhanced due to onboard amplification (low attenuation).
<b>User Access</b>	Open to random users	Controlled access
Example	Echo-I (NASA, 1960)	Most modern communication satellites
<b>Tracking Facility</b>	Needs large tracking stations	Compact and efficient ground stations possible
Amplification	No	Amplifies the received signals
<b>Power Generation</b>	Cannot generate or transmit power	Can generate and transmit power

- **Describe the orbit of a satellite.**

The path a **Satellite follows around a planet** is defined as an orbit.

Aspect	Non-Geostationary Orbit (NGSO)	Geostationary Orbit (GSO)
<b>Definition</b>	Satellites that orbit the Earth at <b>lower altitudes</b> and <b>do not remain fixed</b> relative to a point on Earth.	A circular orbit directly above the equator where the satellite <b>appears stationary</b> from Earth because it rotates at the same speed as Earth.
<b>Orbit Altitude</b>	Low Earth Orbit (LEO) or Medium Earth Orbit (MEO), generally <b>below 35,786 km</b>	Fixed at <b>35,786 km above the equator</b>
<b>Tracking Requirement</b>	<b>Complex tracking</b> needed; satellite moves relative to Earth	<b>Simple tracking</b> ; satellite appears fixed in the sky

Aspect	Non-Geostationary Orbit (NGSO)	Geostationary Orbit (GSO)
Signal Handover	Requires <b>handover</b> of signal between satellites due to motion	No handover needed; signal from a single satellite is continuous
Lifetime & Replacement	<b>Shorter satellite life</b> , requires <b>frequent replacement</b>	<b>Longer life</b> , fewer replacements needed
Transmission Delay	<b>Lower delay</b> due to shorter distance	<b>Higher delay (~250 ms)</b> due to long distance
Coverage Area	Can provide <b>global or polar coverage</b>	<b>No coverage at poles</b> ; best suited for equatorial and mid-latitudes
Free Space Loss	<b>Lower</b> , due to closer distance to Earth	<b>Higher</b> , due to larger distance

Aspect	GEO (Geostationary Earth Orbit)	MEO (Medium Earth Orbit)	LEO (Low Earth Orbit)
Definition	Satellite appears <b>stationary</b> from Earth; orbits at <b>36,000 km</b> above equator.	Satellite orbits Earth at <b>8,000–20,000 km</b> altitude; slower movement than LEO.	Satellite orbits at <b>500–2,000 km</b> altitude; fast-moving with frequent Earth passes.
Orbit Type	<b>Circular</b> orbit above equator, 0° inclination.	Can have <b>varied inclinations</b> ; often circular.	<b>Inclined or polar</b> orbits; moves across Earth quickly.
Coverage	<b>Covers 1/3 of Earth</b> per satellite; 3 satellites cover almost entire Earth.	Fewer satellites needed than LEO, but more than GEO.	Needs <b>many satellites</b> for full Earth coverage (e.g., 50–200).
Latency (Delay)	<b>High</b> (~250 ms); not ideal for real-time data or voice.	<b>Moderate</b> latency; better than GEO but not as good as LEO.	<b>Low latency</b> (~10 ms); ideal for data and voice communications.
Footprint	<b>Very large</b> ; allows wide area coverage.	<b>Medium</b> footprint; good balance between coverage and resolution.	<b>Small</b> footprint; allows for high frequency reuse like cellular networks.
Tracking Requirement	<b>Minimal</b> ; appears stationary, so simple ground tracking.	<b>Moderate</b> tracking needed; satellites	<b>High</b> tracking required; fast movement requires

Aspect	GEO (Geostationary Earth Orbit)	MEO (Medium Earth Orbit)	LEO (Low Earth Orbit)
		move slowly relative to Earth.	continuous tracking and handovers.
Lifetime	<b>Long</b> (up to 15 years or more).	<b>Moderate</b> lifetime.	<b>Short</b> (5–8 years); affected by atmospheric drag.
Use Cases	TV, radio broadcast, weather, global telephone backbone.	GPS, navigation, communication systems.	Mobile communication, remote sensing, Earth observation, internet (e.g., Starlink).
Advantages	- Constant view of same area - Ideal for broadcasting - Minimal Doppler shift	- Fewer satellites than LEO - Good regional coverage - Less complex than LEO	- Low delay - Good for mobile & polar regions - Better signal strength due to proximity

- **What are the conditions required for an orbit to Geostationary?**
  - The satellite should be placed **35,786 kms** (approximated to 36,000 kms) above the surface of the earth.
  - These satellites must travel in the **rotational speed of earth**, and in the direction of motion of earth, that is **eastward**.
  - The **inclination** of satellite with respect to earth must be **0°**.
- **Derive the standard mathematical equation for the radius of the satellite's orbit r.**

\* Gravitational force = Centrifugal force

$$m \frac{GME}{r^2} = m \times \frac{\mu}{r^2} = \frac{mv^2}{r}$$

$$r = \frac{H}{vL}$$

$$r = \frac{GME}{v^2}$$

- Write down the equation of power received by an earth station from a satellite transmitter and convert the equation into dBW.

$$P_r = \frac{P_t G_t A_{er}}{4\pi R^2} = \frac{P_t G_t G_r}{(\frac{4\pi R}{\lambda})^2} = \frac{EIRP \times G_r}{Pathloss}$$

$$\begin{aligned} Pr_{dB} &= 10 \log EIRP + 10 \log G_r - 10 \log l_p \\ &= (EIRP)_{dB} + (G_r)_{dB} - 20[\log 4\pi + \log R - \log \lambda] \end{aligned}$$

## \* Derivation

$$\text{Flux density, } \Phi = \frac{P_t G_t}{4\pi R^2} \text{ W m}^{-2}$$

$$\text{Power Received (By ideal antenna), } P_R = \frac{P_t G_t A}{4\pi R^2} \text{ W}$$

$$= \frac{P_t G_t G_r}{4\pi R^2} \text{ W} \quad [G_r = \frac{4\pi}{\lambda^2} A]$$

$$A_e = \eta_A A_r \quad \text{Path Loss}$$

$$P_R = EIRP + G_r - LP - L_o - L_{tag} - L_{ta}$$

↓  
Tx Antenna Rx Antenn  
Attenuation

$$EIRP = P_t G_t$$

$$\text{Path Loss} = \left( \frac{4\pi R}{\lambda} \right)^2$$

$$P_R = 10 \log EIRP + 10 \log G_r - 10 \log L_p$$

- The period of the moon is 27.2 days. Determine the radius of the moon's orbit and the orbital speed of the moon (Given  $M_{\text{earth}} = 5.98 \times 10^{24} \text{ kg}$  and  $R_{\text{earth}} = 6.37 \times 10^6 \text{ m}$ ).

$$\Rightarrow T = 2\pi \sqrt{\frac{R^3}{GM}} \quad T = 27.2 \times 60 \times 24 \times 2 \pi \text{ s}$$

$$\Rightarrow R = \left( \frac{T^2 GM}{4\pi^2} \right)^{1/3} \quad GM = 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-1} \text{ s}^{-2}$$

$$= 3.82 \times 10^8 \text{ m}$$

- A satellite is orbiting in the equatorial plane with a period from perigee to perigee of 12 hours. Given that the eccentricity is 0.002, calculate the semi major axis. The earth's equatorial radius is 6378.1414 Km.

$$* T = 2\pi \sqrt{\frac{R^3}{GM_E}} = 2\pi \sqrt{\frac{a^3}{M}} \rightarrow \text{semimajor axis}$$

$\rightarrow \text{Kepler constant}$   
 $3.99 \times 10^{14} \text{ m}^3/\text{s}^2$

$$a = \left( \frac{T^2 M}{4\pi^2} \right)^{\frac{1}{3}}$$

$$= 26612 \text{ km}$$

- A satellite downlink at 12 GHz operates with a transmit power of 6 W and an antenna gain of 48.2dB. Calculate the EIRP in dBW

$$EIRP_{db} = 10 \log P_t + Gt_{dB} = 10 \log 6 + 48.2 = 7.78 + 48.2 = 55.98$$

- The orbital period of a Geo stationary satellite is T=23h56min409sec. Calculate the distance of the satellite from earth surface. What will be the linear velocity?

$$* R = \left( \frac{T^2 GM_E}{4\pi^2} \right)^{\frac{1}{3}}$$

$T = 86165 \text{ s}$

$$G = 6.67 \times 10^{-11} \text{ m}^3 \text{ kg}^{-1} \text{ s}^{-2}$$

$$M = 6 \times 10^{24}$$

$$\text{From Surface: } 42220 - 6400 = 35820 \text{ km}$$

$$v^2 = \frac{\mu}{R} \Rightarrow v = \sqrt{\frac{3.99 \times 10^{12}}{42220 \times 1000}} = 307.42 \text{ m/s}$$

- Q.a) For the design of a Receiving C – band earth station, the downlink frequency is 4 GHz. The receiver devices have the following gains and noise temperatures:  $G_{rf} = 20$  dB,  $G_m = 0$  dB,  $T_{in} = 25$  K,  $T_{rf} = 50$  K,  $T_m = 500$  K and  $T_{ir} = 1000$  K (i) Calculate the system noise temperature. (ii) If  $G_m=8$  dB loss then re-calculate the system noise temperature. (iii) How can the noise temperature of the receiver be minimized when  $G_m=8$  dB loss?  
 b) For the noise figure of 1 dB. Find out the corresponding noise temperature.  
 c) A satellite has an antenna with a gain of 22 dB, maintaining a distance of 39,000 km from the earth station, transmitting a power of 20 W. Calculate the flux density at the receiver earth station.

a)

$$(i) T_s = T_{in} + T_{rf} + \frac{T_m}{G_{rf}} + \frac{T_{ir}}{G_{rf} \times G_m}$$

$$= 25 + 50 + \frac{500}{10^{-8/10}} + \frac{1000}{10^{-8/10} \times 10^0}$$

$$= 90 \text{ K}$$

$$(ii) G_{rm} = 10^{-8/10} = 0.16$$

$$T_s = T_{in} + T_{rf} + \frac{T_m}{G_{rf}} + \frac{T_{ir}}{G_m \times G_{rf}}$$

$$= 25 + 50 + \frac{500}{100} + \frac{1000}{100 \times 0.16}$$

$$= 84.58 \text{ K}$$

(iii) Lower system temperature are obtained by using a higher gain LNA. Suppose we increase the LNA gain in this example  $G_{rf} = 50$  dB =  $10^5$

$$T_s = 50 + 25 + \frac{500}{10^5} + \frac{1000}{10^5 \times 10^{-8/10}}$$

$$= 75.07 \text{ K}$$

$$(b) NF = 1 \text{ dB} = 10^{\frac{1}{10}} = 1.26$$

$$\begin{aligned} T_n &= T_0 (\cancel{1.26} \cdot NF - 1) \\ &\cancel{=} 80 (1.26 - 1) \\ &= 290 (1.26 - 1) \\ &\approx 175.4 \end{aligned}$$

$T_0$ : Reference  
noise  
temperature  
 $= 290\text{K}$

### (c)

Data and conversion:

Satellite antenna gain = 22 dB =  $10^{22/10} = 158.5$  W;

Satellite signal wavelength

$$\lambda = \frac{c}{f} = \frac{3 \times 10^8}{11 \times 10^9} = 0.0273 \text{ m}$$

where  $c$  – speed of light;

Earth station to satellite distance,  $R = 39,000 \text{ km} = 3.9 \times 10^7 \text{ m}$

a) Substituting the given values into (1), we have:

$$\varphi = \frac{20 \times 158.5}{4 \times \pi \times (3.9 \times 10^7)^2} = 1.66 \times 10^{-13} \text{ W/m}^2$$

Using the decibel notation:

$$\begin{aligned} \varphi &= 10 \log(P_s G_s) - (20 \log R + 10 \log(4\pi)) \\ &= 10 \log(20 \times 158.5) - (20 \log 3.9 \times 10^7 + 10 \log 12.57) \\ &= 35.01 - 151.82 - 10.99 \\ &= -127.8 \text{ dBW/m}^2 \end{aligned}$$

Note that

$$= 10 \log(1.66 \times 10^{-13}) = -127.8 \text{ dBW/m}^2$$

- c) A satellite at a distance of 39,000 km from the EIE departmental building radiates the power of 20 W from an antenna with a gain of 22 dB in the direction of a VSAT at the EIE building with an effective aperture area of  $10 \text{ m}^2$ .  
 Calculate

- i) The flux density at the departmental building
- ii) The power received by the VSAT antenna.

If the satellite operates at a frequency of 11 GHz and the Earth Station antenna has a gain of 52.3 dB

- iii) Determine the received power.

### Solution

RWF 1

Data and conversion:

$$\text{Satellite antenna gain} = 22 \text{ dB} = 10^{22/10} = 158.5 \text{ W};$$

Satellite signal wavelength

$$\lambda = \frac{c}{f} = \frac{3 \times 10^8}{11 \times 10^9} = 0.0273 \text{ m}$$

where  $c$  – speed of light;

Earth station to satellite distance,  $R = 39,000 \text{ km} = 3.9 \times 10^7 \text{ m}$

- a) Substituting the given values into (1), we have:

$$\varphi = \frac{20 \times 158.5}{4 \times \pi \times (3.9 \times 10^7)^2} = 1.66 \times 10^{-13} \text{ W/m}^2$$

Using the decibel notation:

$$\begin{aligned} \varphi &= 10 \log(P_i G_i) - (20 \log R + 10 \log(4\pi)) \\ &= 10 \log(20 \times 158.5) - (20 \log 3.9 \times 10^7 + 10 \log 12.57) \\ &= 35.01 - 151.82 - 10.99 \\ &= -127.8 \text{ dBW/m}^2 \end{aligned}$$

Note that

$$= 10 \log(1.66 \times 10^{-13}) = -127.8 \text{ dBW/m}^2$$

- b) The power received with an effective collecting antenna of  $10 \text{ m}^2$  aperture is:

$$P_r = \varphi \times A_e = 1.66 \times 10^{-13} \times 10 = 1.66 \times 10^{-12} \text{ W}$$

In decibels:

$$P_r = [\varphi] + [A] = -127.8 + 10 = -117.8 \text{ dBW}$$

Note that

$$-117.8 \text{ dBW} = 10^{-11.78} \text{ W} = 1.66 \times 10^{-12} \text{ W}$$

- c) Working in decibels using equation (9) we have:

$$\begin{aligned} L_p &= 20 \log(4\pi R / \lambda) \\ &= 20 \log(4 \times \pi \times 3.9 \times 10^7 / 0.0273) \\ &= 205.08 \text{ dB} \\ &\therefore \end{aligned}$$

$$\begin{aligned} P_r &= EIRP + G_r - L_p \\ &= 35.01 + 52.3 - 205.08 \\ &= -117.77 \text{ dBW}. \end{aligned}$$

**✓ Example B:** 

A satellite at a distance of 39,000 km from the EIE departmental building radiates a power of 20 W from an antenna with a gain of 22 dB in the direction of a VSAT at the EIE building with an effective aperture area of  $10 \text{ m}^2$ .

Find:

- The flux density at the departmental building
- The power received by the VSAT antenna

c. If the satellite operates at a frequency of 11 GHz and the Earth Station (ES) antenna has a gain of 52.3 dB. Determine the received power.

 P(10)/10

Solution

Data and conversion:

$$\text{Satellite antenna gain} = 22 \text{ dB} = 10^{22/10} = 158.5 \text{ W};$$

Satellite signal wavelength

$$\lambda = \frac{c}{f} = \frac{3 \times 10^8}{11 \times 10^9} = 0.0273 \text{ m}$$

where  $c$  – speed of light;

Earth station to satellite distance,  $R = 39,000 \text{ km} = 3.9 \times 10^7 \text{ m}$

- Substituting the given values into (1), we have:

$$\varphi = \frac{20 \times 158.5}{4 \times \pi \times (3.9 \times 10^7)^2} = 1.66 \times 10^{-13} \text{ W/m}^2$$

Using the decibel notation:

$$\begin{aligned} \varphi &= 10 \log(P_i G_i) - (20 \log R + 10 \log(4\pi)) \\ &= 10 \log(20 \times 158.5) - (20 \log 3.9 \times 10^7 + 10 \log 12.57) \\ &= 35.01 - 151.82 - 10.99 \\ &= -127.8 \text{ dBW/m}^2 \end{aligned}$$

Note that

$$= 10 \log(1.66 \times 10^{-13}) = -127.8 \text{ dBW/m}^2$$

- The power received with an effective collecting antenna of  $10 \text{ m}^2$  aperture is:

$$P_r = \varphi \times A_e = 1.66 \times 10^{-13} \times 10 = 1.66 \times 10^{-12} \text{ W}$$

In decibels:

$$P_r = [\varphi] + [A] = -127.8 + 10 = -117.8 \text{ dBW}$$

Note that

$$-117.8 \text{ dBW} = 10^{-11.78} \text{ W} = 1.66 \times 10^{-12} \text{ W}$$

- Working in decibels using equation (9) we have:

$$L_p = 20 \log(4\pi R / \lambda)$$

$$= 20 \log(4 \times \pi \times 3.9 \times 10^7 / 0.0273)$$

$$= 205.08 \text{ dB}$$

∴

$$\begin{aligned} P_r &= EIRP + G_r - L_p \\ &= 35.01 + 52.3 - 205.08 \\ &= -117.77 \text{ dBW}. \end{aligned}$$

Q/A