Antenna and Wave Propagation (4341106) - Summer 2024 Solution

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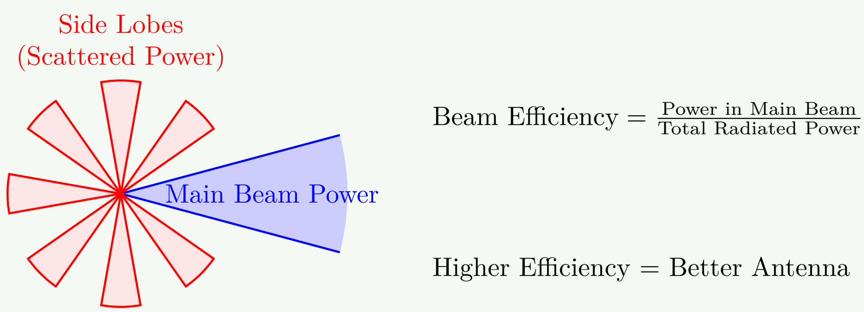
Question 1(a) [3 marks]

Define Beam Area and Beam Efficiency.

Solution

Beam Area: The solid angle through which all of the power radiated by an antenna would flow if the radiation intensity was constant throughout this angle and equal to the maximum value.
Beam Efficiency: The ratio of the power contained in the main beam to the total power radiated by the antenna.

Figure 1. Beam Efficiency Concept



Mnemonic

“”BEAM: Better Efficiency Achieves Maximum performance””

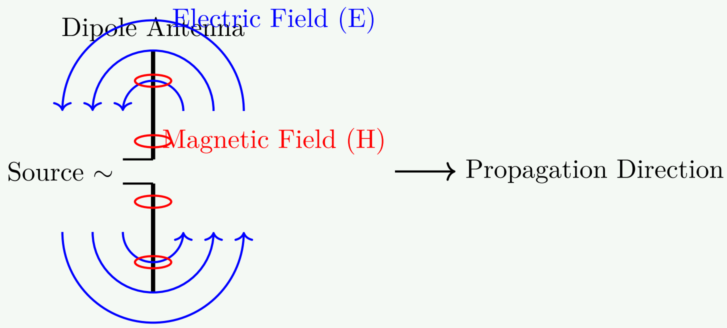
Question 1(b) [4 marks]

What is EM field? Explain its radiation from center fed dipole.

Solution

EM Field: An Electromagnetic (EM) field is a physical field produced by electrically charged objects. It affects the behavior of charged objects in the vicinity of the field.
Radiation from Center-Fed Dipole: When an alternating current flows through the dipole, it creates oscillating electric and magnetic fields that detach and travel outwards.

Figure 2. Fields around a Dipole



- **Electric field (E)**: Lines start from positive charge and end at negative charge.
- **Magnetic field (H)**: Circles around the current carrier (wire).
- **Mechanism**: As current reverses, field lines detach and form closed loops (radiation).
- **Far Field**: E and H are perpendicular to each other and to the direction of propagation.

Mnemonic

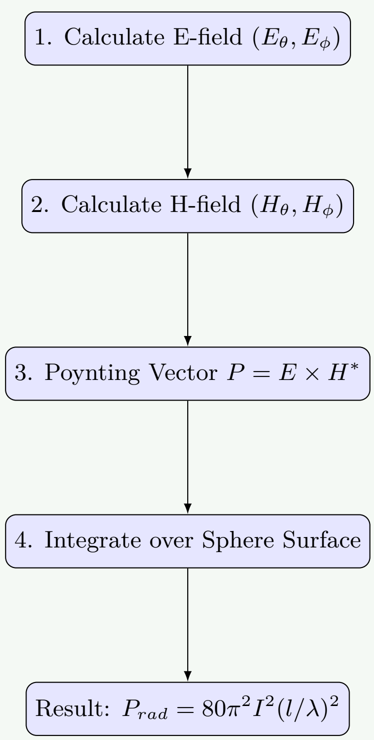
“”CERD: Current Excites Radiating Dipole””

Question 1(c) [7 marks]

Explain Power radiated by elementary dipole using Poynting Vector.

Solution

Power radiated by an elementary dipole is calculated using the Poynting vector, which represents directional energy flux density.



Key Steps:

1. **Fields**:

$$E_\theta = j\frac{\eta I_0 dl}{2\lambda r}\sin\theta e^{-j\beta r}$$

$$H_\phi = j\frac{I_0 dl}{2\lambda r}\sin\theta e^{-j\beta r}$$

2. **Poynting Vector Magnitude** (P_{avg}):

$$P_{avg} = \frac{1}{2}Re(E \times H^*) = \frac{1}{2}\frac{\eta |I_0|^2 (dl)^2}{4\lambda^2 r^2}\sin^2\theta$$

3. **Total Radiated Power** (P_{rad}): Integrate P_{avg} over a closed sphere surface ($ds = r^2 \sin\theta d\theta d\phi$):

$$P_{rad} = \int_0^{2\pi}\int_0^{\pi} P_{avg} r^2 \sin\theta d\theta d\phi$$

$$P_{rad} = \eta\frac{\pi}{3}\left(\frac{I_0 dl}{\lambda}\right)^2$$

Using $\eta = 120\pi \approx 377\Omega$:

$$P_{rad} = 80\pi^2 I_{rms}^2 \left(\frac{dl}{\lambda}\right)^2 \text{ Watts}$$

Mnemonic

“”PEHP: Poynting Explains How Power propagates””

OR

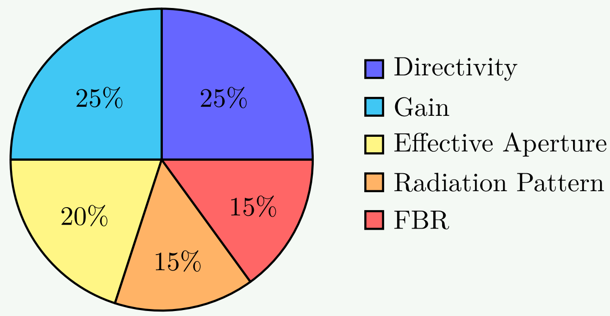
Question 1(c) [7 marks]

Define Antenna, Radiation Pattern, Directivity, Gain, FBR, Isotropic Radiator and Effective Aperture.

Solution

Parameter	Definition
Antenna	A device that converts guided electromagnetic waves to free-space waves and vice versa.
Radiation Pattern	A graphical representation of the radiation properties of the antenna as a function of space coordinates.
Directivity	The ratio of radiation intensity in a given direction to the average radiation intensity.
Gain	The ratio of radiation intensity in a given direction to the radiation intensity that would be obtained if the power accepted by the antenna were radiated isotropically. Takes efficiency into account.
FBR (Front-to-Back Ratio)	The ratio of power radiated in the forward direction (main lobe) to the power radiated in the backward direction.
Isotropic Radiator	A theoretical antenna that radiates electromagnetic energy equally well in all directions.
Effective Aperture	The ratio of the power delivered to the load to the incident power density. Measures how effective an antenna is at receiving power.

Figure 3. Antenna Parameters Overview



Mnemonic

“”DIAGRAM: Directivity Improves Antenna Gain, Radiation And More””

Question 2(a) [3 marks]

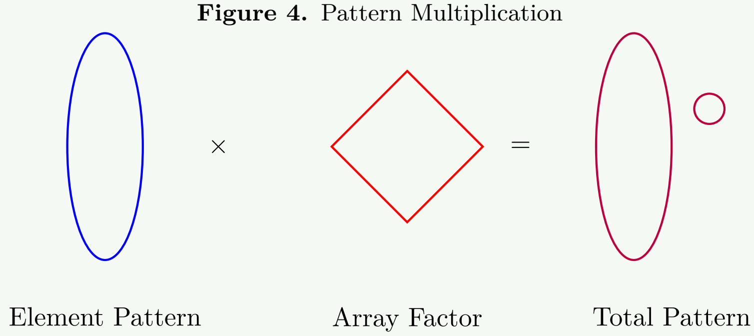
Explain principle of pattern multiplication.

Solution

Principle of Pattern Multiplication: The total field pattern of an array of non-isotropic identical point sources is the product of the individual element pattern and the array factor of the isotropic point sources.

$$\text{Total Pattern} = \text{Element Pattern} \times \text{Array Factor}$$

Figure 4. Pattern Multiplication



It helps in designing arrays with sharper beams and higher directivity without analyzing the complex geometry from scratch.

Mnemonic

“”PEAM: Pattern Equals Array times Element Method””

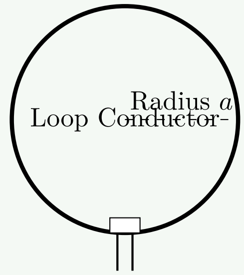
Question 2(b) [4 marks]

Draw & Explain Loop antenna.

Solution

A loop antenna is a radio antenna consisting of a loop or coil of wire, tubing, or other electrical conductor.

Figure 5. Loop Antenna Structure



- **Small Loop** ($C < \lambda/10$): Radiation pattern similar to a magnetic dipole (Figure-8 pattern). Low radiation resistance.
- **Large Loop** ($C \approx \lambda$): Resonant loop. Maximum radiation perpendicular to the loop plane.
- **Applications**: Direction finding (RDF), AM radio reception, RFID tags.

Mnemonic

“”LOOP: Low Output, Orientation Precise””

Question 2(c) [7 marks]

Design a Yagi-uda antenna and explain it.

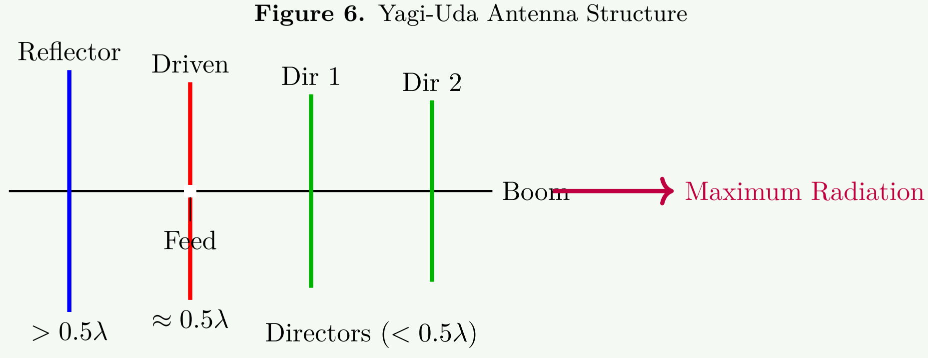
Solution

A Yagi-Uda antenna is a directional antenna consisting of a driven element (usually a dipole) and additional parasitic elements (reflector and directors).

Design Guidelines:

Element	Length Formula	Typical Spacing
Reflector	$0.5\lambda \times 1.05$ (approx 0.525λ)	$0.15\lambda - 0.25\lambda$ from Driven
Driven Element	0.5λ (resonant length)	Reference (0)
Director 1	$0.5\lambda \times 0.95$	$0.1\lambda - 0.15\lambda$ from Driven
Director 2	$0.5\lambda \times 0.92$	$0.15\lambda - 0.25\lambda$ from D1

Figure 6. Yagi-Uda Antenna Structure



- **Reflector**: Longer than driven element, reflects energy forward.
- **Directors**: Shorter than driven element, guide energy forward.
- **Gain**: High gain (10-20 dB depending on elements).
- **Impedance**: Low input impedance (20-50Ω), often requires a balun.
- **Application**: TV reception, amateur radio, point-to-point links.

Mnemonic

“”YARD: Yagi Achieves Radical Directivity””

OR

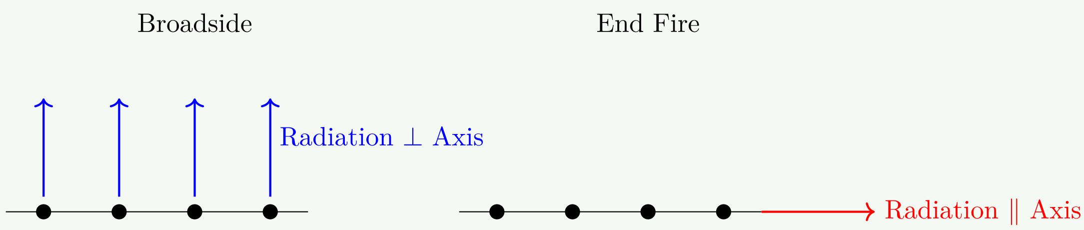
Question 2(a) [3 marks]

Compare broad fire and end fire array antenna.

Solution

Parameter	Broadside Array	End Fire Array
Direction of Max Radiation	Perpendicular to the array axis.	Along the array axis.
Element Phasing	All elements fed in phase (0°).	Progressive phase shift (≈ 180°).
Beamwidth	Narrower main beam.	Wider main beam.
Directivity	Generally higher for same length.	Lower than broadside.
Applications	Broadcasting arrays.	Point-to-point links.

Figure 7. Array Comparison



Mnemonic

“”BEPS: Broadside Emits Perpendicularly, Sideways””

OR

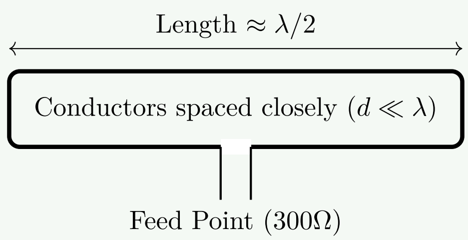
Question 2(b) [4 marks]

Draw & Explain Folded dipole antenna.

Solution

A folded dipole consists of two parallel dipoles connected at both ends, forming a narrow loop. One side is fed at the center.

Figure 8. Folded Dipole



- **Input Impedance**: Approx 300Ω (4 times that of a standard dipole's 73Ω).
- **Bandwidth**: Much wider bandwidth than a simple dipole.
- **Applications**: Standard FM radio antennas, TV reception (uses 300Ω twin-lead cable).
- **Advantage**: Acts as a step-up impedance transformer.

Mnemonic

“”FIBER: Folded Impedance Booster Enhances Reception””

OR

Question 2(c) [7 marks]

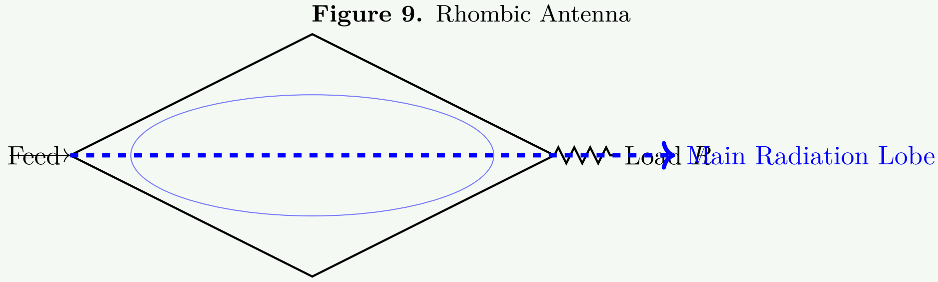
Give names of Non-resonant antennas and explain any one in detail with its radiation pattern.

Solution

Non-Resonant Antennas: 1. Rhombic Antenna 2. V-Antenna 3. Beverage Antenna (Wave antenna) 4. Long Wire Antenna

Rhombic Antenna Explanation: A Rhombic antenna consists of four long wire conductors arranged in a diamond (rhombus) shape. It is a traveling wave antenna terminated in a load resistance R to remove reflection.

Figure 9. Rhombic Antenna



Characteristics:

- **Structure**: Non-resonant due to resistive termination.
- **Radiation Pattern**: Unidirectional (due to termination). Without R, it would be bidirectional.
- **Gain**: High gain (up to 15-20 dB).
- **Bandwidth**: Very wide bandwidth.
- **Applications**: HF point-to-point communication.

Mnemonic

“”RHOMBIC: Reliable High-Output Multi-Band Impressive Communications””

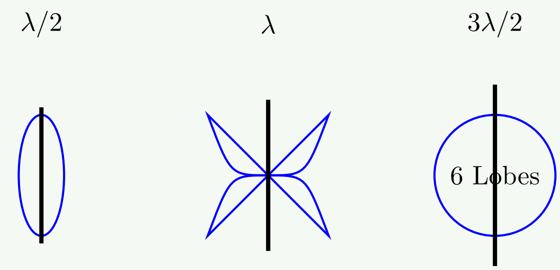
Question 3(a) [3 marks]

Compare radiation pattern of different resonant wire antennas.

Solution

Antenna Type	Pattern Shape	Directivity	Polarization
Half-Wave Dipole ($\lambda/2$)	Figure-8 (donut shape), 2 lobes	2.15 dBi	Linear
Full-Wave Dipole (λ)	Four-lobed (cloverleaf)	3.8 dBi	Linear
$3\lambda/2$ Dipole	Six-lobed	4.2 dBi	Linear
2λ Dipole	Eight-lobed	4.5 dBi	Linear

Figure 10. Resonant Antenna Patterns



Mnemonic

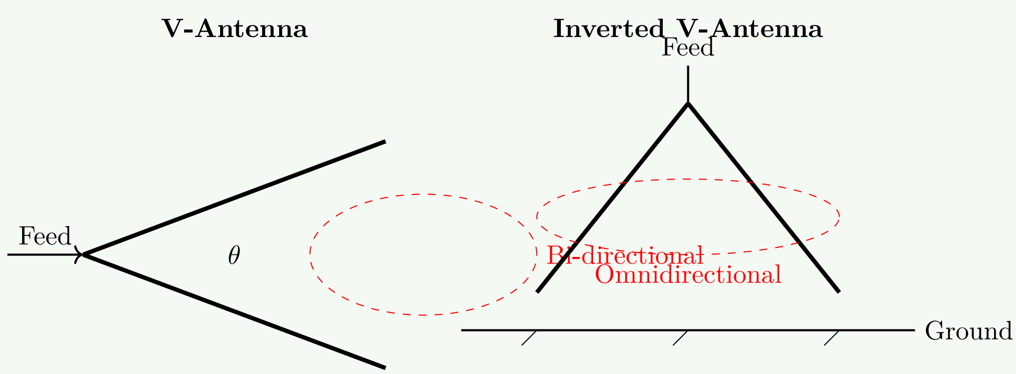
“”MOLD: More wavelengths create Lots of Directivity lobes””

Question 3(b) [4 marks]

Draw V and Inverted V antenna with radiation Pattern.

Solution

Figure 11. V and Inverted-V Antennas



- **V-Antenna**: Two wires forming a V-shape. Main radiation is along the axis of the V (if resonant).
- **Inverted V**: A dipole supported at the center with ends drooping. Pattern is nearly omnidirectional.

Mnemonic

“”VIPS: V-shapes Improve Pattern Selectivity””

Question 3(c) [7 marks]

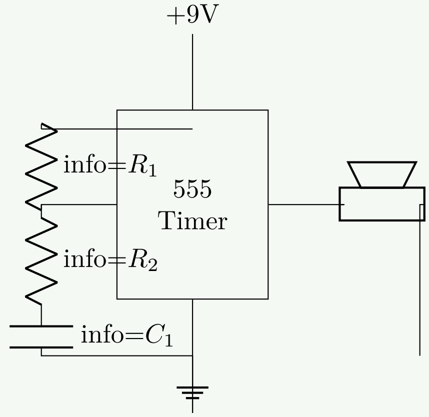
Explain Morse Code and Practice Oscillator.

Solution

Morse Code: A character encoding scheme used in telecommunication that encodes text characters as standardized sequences of two different signal durations, called dots and dashes.

Element	Timing	Sound
Dot (.)	1 Unit	Short Beep
Dash (-)	3 Units	Long Beep
Inter-element space	1 Unit	Silence
Character space	3 Units	Silence
Word space	7 Units	Silence

Figure 12. Morse Code Practice Oscillator using 555 Timer



Operation: The 555 timer is configured as an astable multivibrator. When the key is pressed, the circuit is completed, creating an audio tone (600-800 Hz) driving the speaker.

Mnemonic

“”TEMPO: Timing Elements Make Perfect Oscillation””

OR

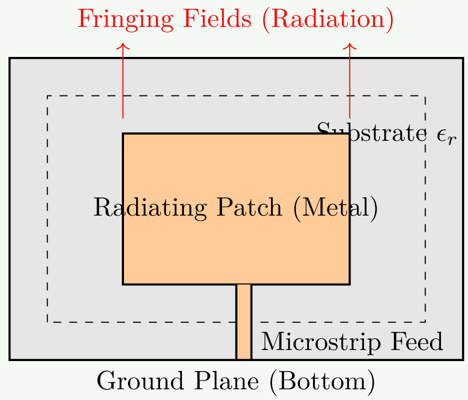
Question 3(a) [3 marks]

Draw and Explain Microstrip Patch antenna.

Solution

A Microstrip Patch Antenna consists of a radiating patch on one side of a dielectric substrate and a ground plane on the other side.

Figure 13. Microstrip Patch Antenna



- **Advantages**: Low profile, lightweight, easy to fabricate, conformable to surfaces.
- **Disadvantages**: Narrow bandwidth, low efficiency.
- **Applications**: Mobile phones, GPS, aircraft, satellites.

Mnemonic

“”MAPS: Microstrip Antenna Patches are Simple””

OR

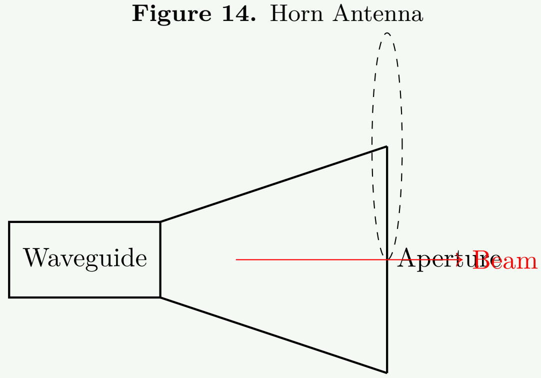
Question 3(b) [4 marks]

Draw and Explain Horn antenna.

Solution

A Horn Antenna is a waveguide flared out at the end to improve radiation efficiency and directivity.

Figure 14. Horn Antenna



- **Function**: Acts as an impedance matching transformer between the waveguide (impedance ≈ characteristic Z) and free space (377Ω).
- **Types**: Sectoral E-plane, Sectoral H-plane, Pyramidal, Conical.
- **Applications**: Standard gain reference, feed for parabolic dishes.

Mnemonic

“”HEWB: Horns Enhance Waveguide Beamwidth””

OR

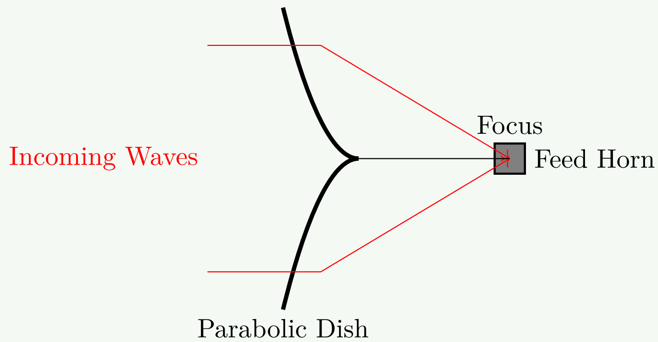
Question 3(c) [7 marks]

List different feed system for Parabolic reflector antenna and explain any one.

Solution

Feed Systems: 1. Front Feed (Primary Feed) 2. Cassegrain Feed 3. Gregorian Feed 4. Offset Feed
Front Feed System Explanation: The primary radiator (feed antenna, usually a horn) is placed at the focal point of the parabolic reflector.

Figure 15. Front Feed Parabolic Reflector



- **Operation**: The parabolic shape reflects incoming parallel rays to a single focal point where the feed collects them. In transmission, the feed radiates to the reflector, which collimates the beam.
- **Advantages**: Simple construction.
- **Disadvantages**: Aperture blockage by feed and supports reduces efficiency.

Mnemonic

“”FACTS: Focused Aperture Captures Transmitted Signals””

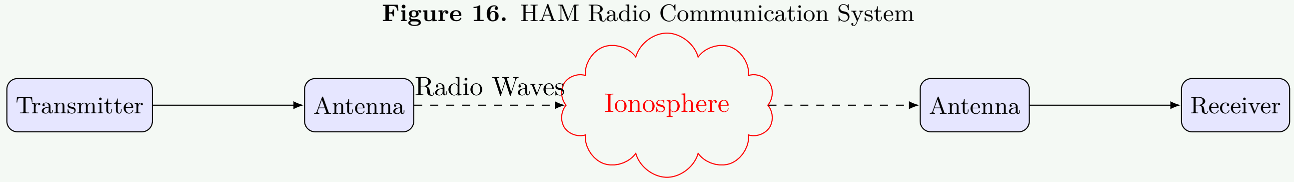
Question 4(a) [3 marks]

Explain working principle of HAM radio.

Solution

HAM radio (Amateur Radio) is a popular hobby and service that brings people, electronics, and communication together.

Figure 16. HAM Radio Communication System



- **Principle**: Users communicate over radio frequencies allocated by regulatory bodies (like WPC in India, FCC in US).
- **Modes**: Voice (AM/FM/SSB), Text (Morse Code), Digital (Packet Radio).
- **Key Feature**: Non-commercial exchange of messages, wireless experimentation, self-training, and emergency communication.

Mnemonic

“”TEAM: Transmission Enables Amateur Messages””

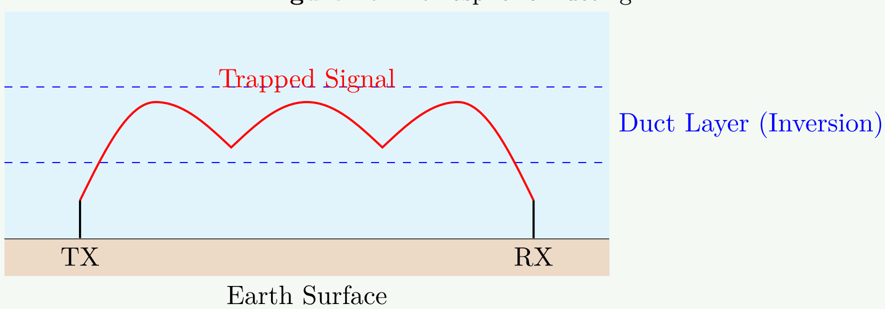
Question 4(b) [4 marks]

Explain Duct Propagation.

Solution

Duct propagation is a phenomenon where radio signals are trapped between two layers of the atmosphere or between a layer and the ground, traveling much further than normal line-of-sight.

Figure 17. Atmospheric Ducting



Mnemonic

“”TRIP: Trapped Rays In atmospheric Paths””

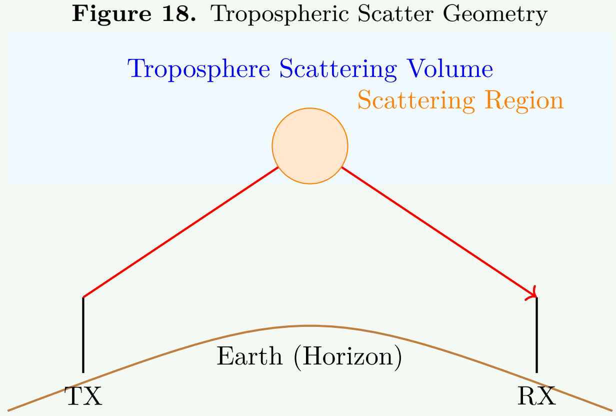
Question 4(c) [7 marks]

Explain Tropospheric Scattered Propagation in detail.

Solution

Tropospheric Scatter (Troposcatter) is a method of communicating with microwave radio signals over considerable distances (often up to 300 km or more) by exploiting the scattering properties of the troposphere.

Figure 18. Tropospheric Scatter Geometry



Mechanism Characteristics:

Feature	Description
Principle	Forward scattering due to turbulence, irregularities in refractive index, or dus troposphere (lower atmosphere).
Frequency	Typically UHF and SHF (300 MHz - 10 GHz).
Region	Common Scattering Volume: The intersection of the transmit and receive ant
Requirements	High gain antennas and high power transmitters are needed due to high path
Reliability	Fairly reliable, unaffected by ionospheric disturbances, but subject to fading.

Mnemonic

“”STARS: Scatter Tropospheric Allows Range beyond Sight””

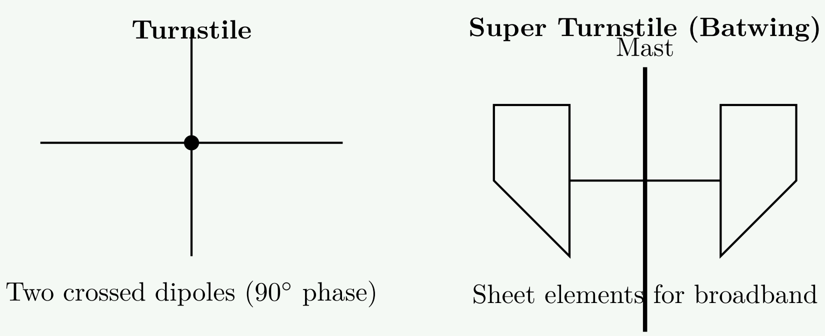
OR

Question 4(a) [3 marks]

Draw turnstile and super turnstile antenna.

Solution

Figure 19. Turnstile and Super Turnstile (Batwing)



- **Turnstile**: Provides omnidirectional horizontal pattern. Used in VHF/UHF.
- **Super Turnstile**: Broad bandwidth adaptation, commonly used in TV broadcasting.

Mnemonic

“”TACO: Turnstile Antennas Create Omnidirectional patterns””

OR

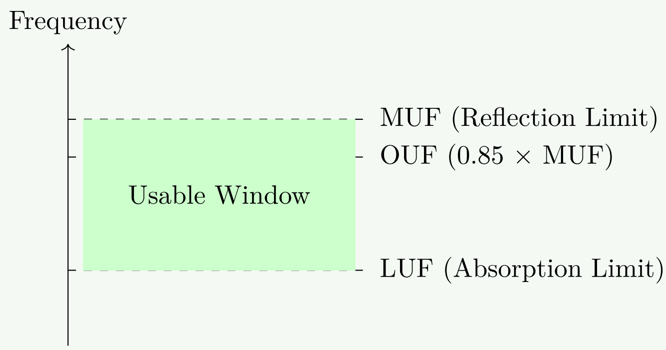
Question 4(b) [4 marks]

Give full form of MUF, LUF and OUF.

Solution

Abbreviation	Full Form	Description
MUF	Maximum Usable Frequency	The highest frequency that can be used for skywave communication between two specific points at a specific time. $f_{MUF} = f_c \sec\theta$.
LUF	Lowest Usable Frequency	The lowest frequency that provides satisfactory signal-to-noise ratio for a given circuit. Below this, absorption is too high.
OUF (or OWF)	Optimum Usable Frequency (Optimum Working Freq)	A frequency chosen for reliable communication, typically 85% of the MUF to account for ionospheric variations.

Figure 20. Frequency Selection



Mnemonic

“”MLO: Maximum and Lowest determine Optimum””

OR

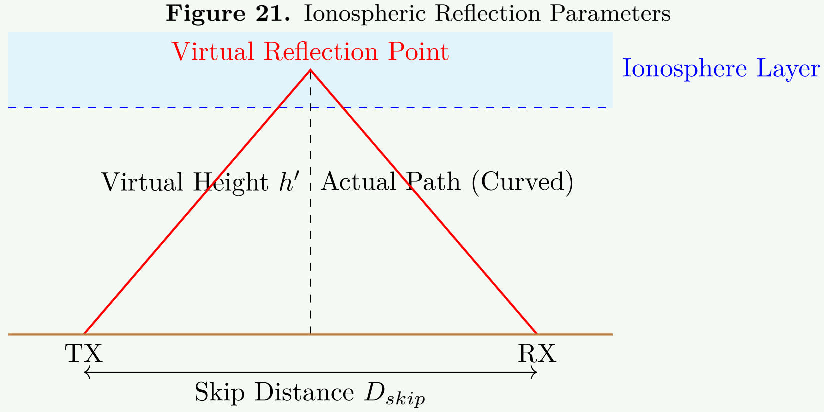
Question 4(c) [7 marks]

Explain virtual height, critical frequency and skip distance in detail.

Solution

These are key parameters in skywave propagation via the ionosphere.

Figure 21. Ionospheric Reflection Parameters



1. **Virtual Height (h')**: The apparent height of the ionized layer as determined from the time interval between the transmitted pulse and the ionospheric echo at vertical incidence, assuming the wave travels at the speed of

light c.

2. **Critical Frequency (f_c)**: The highest frequency that is returned to earth by a layer when the wave is transmitted vertically ($\theta_i = 0$).
$$f_c = 9\sqrt{N_{max}}$$
where N_{max} is maximum electron density.
3. **Skip Distance (D_{skip})**: The minimum distance from the transmitter at which a sky wave of a given frequency (greater than f_c) can be returned to earth.
$$D_{skip} = 2h\sqrt{\left(\frac{f}{f_c}\right)^2 - 1}$$
Or via secant law: $D = 2h\tan(\cos^{-1}(f_c/f))$.

Mnemonic

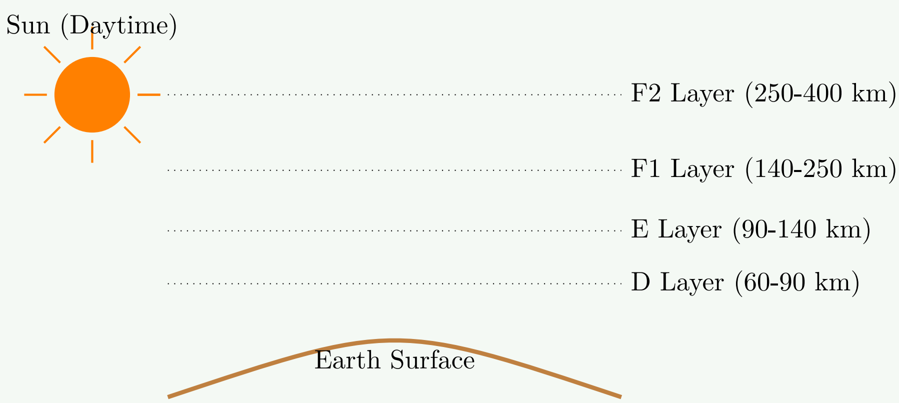
“”VCS: Virtual height Controls Skip distance””

Question 5(a) [3 marks]

With neat figure show different Ionosphere layers.

Solution

Figure 22. Ionospheric Layers



- **D Layer**: Absorbs HF waves, disappears at night.
- **E Layer**: Reflects some HF waves, sporadic E.
- **F1/F2 Layers**: Main reflecting layers for long-distance skywave communication. F1/F2 merge at night.

Mnemonic

“”DEAF: Down to up - D, E, And F layers””

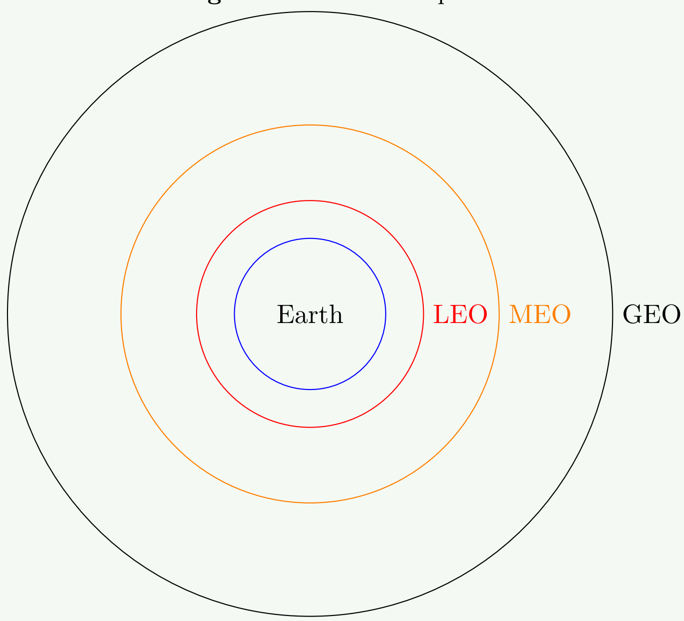
Question 5(b) [4 marks]

Give names of different types of satellite communication systems and compare it.

Solution

System	Orbit	Characteristics
GEO (Geostationary)	35,786 km (Equatorial)	Stationary relative to earth. High latency (~240ms). Wide coverage (3 sats for global). TV, Weather.
MEO (Medium Earth)	2,000 - 35,000 km	Lower latency than GEO. Used for GPS, GLONASS.
LEO (Low Earth)	160 - 2,000 km	Low latency (~20ms). Moving fast relative to earth. Requires constellation for coverage. Iridium, Starlink.
HEO (Highly Elliptical)	Elliptical	Molniya orbit. High dwell time over high latitudes (Polar regions).

Figure 23. Orbit Comparison



Mnemonic

“”TBDMN: Telecom, Broadcasting, Data, Military, Navigation””

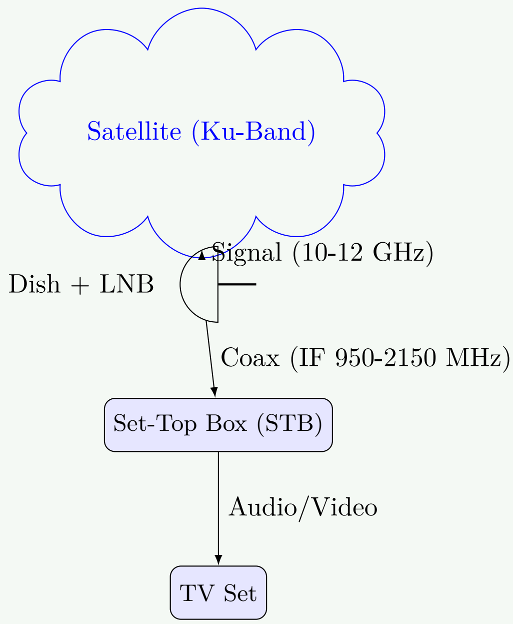
Question 5(c) [7 marks]

Draw and explain DTH receiver system.

Solution

DTH (Direct-To-Home): A satellite television broadcasting system where TV programs are transmitted directly to the subscriber’s premises using Ku-band satellites.

Figure 24. DTH System Block Diagram



Components:
1. **Parabolic Dish**: 60-90 cm offset dish to collect weak satellite signals.
2. **LNBF (Low Noise Block Feedhorn)**: Amplifies the weak Ku-band signal and downconverts it to IF (Intermediate Frequency) range for transmission over cable.
3. **Coaxial Cable**: RG-6 cable transmits IF signal to STB.
4. **Set-Top Box (STB)**: Contains tuner, demodulator (QPSK/8PSK), and decoder (MPEG-2/4) to convert digital signals into video/audio for TV.
5. **Smart Card**: For conditional access (decrypting paid channels).

Mnemonic

“”DOCS: Dish Obtains, Converts and Shows signals””

OR

Question 5(a) [3 marks]

What is the Need of Smart Antennas? Write its applications.

Solution

Smart Antenna: An array of antennas with smart signal processing algorithms used to identify spatial signal signatures and calculate beamforming vectors to track the desired user.

Need:
- **Capacity Increase**: Allows spatial division multiple access (SDMA), serving more users.
- **Range Extension**: High directive gain extends cell coverage.
- **Interference Rejection**: Nulls can be steered towards interferers.
- **Power Efficiency**: Directs energy only where needed.

Applications:
- 4G/5G Cellular Networks (MIMO).
- Radar Systems.
- Wi-Fi (Beamforming routers).
- Satellite Communications.

Mnemonic

“”SAFE: Smart Antennas For Efficiency””

OR

Question 5(b) [4 marks]

Explain Kepler’s 3rd law.

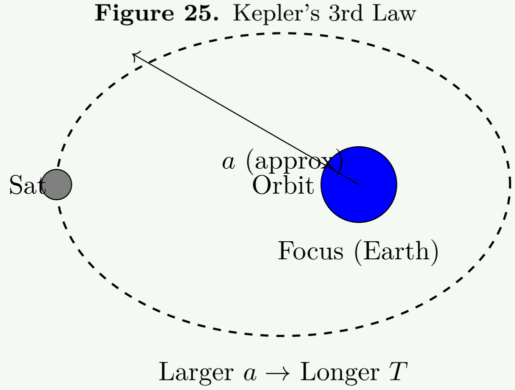
Solution

Kepler’s 3rd Law (Law of Periods): The square of the orbital period (T) of a planet or satellite is directly proportional to the cube of the semi-major axis (a) of its orbit.

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

Where:
- T: Orbital period (seconds)
- a: Semi-major axis (meters) - radius for circular orbit.
- G: Gravitational constant ($6.67 \times 10^{-11} Nm^2/kg^2$)
- M: Mass of the central body (Earth).

Figure 25. Kepler’s 3rd Law



Mnemonic

“”CAP: Cube of Axis equals Period squared””

OR

Question 5(c) [7 marks]

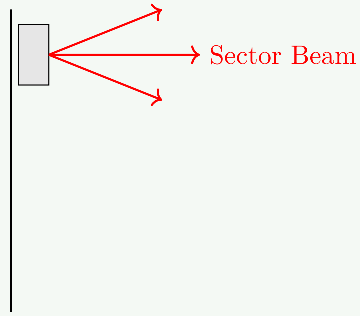
Identify the different types of Antennas for Terrestrial Mobile communication and explain in detail.

Solution

Detailed explanation of Base Station and Mobile Station antennas.

Type	Example	Feature
Base Station	Sectoral Panels	Directional (120°), High Gain, Vertical Array.
Mobile Station	PIFA, Monopole	Omnidirectional, Compact, Multi-band.
MIMO	Multiple Elements	Spatial diversity, Multiplexing.

Figure 26. Base Station Sector Antenna



Explanation:

1. **Base Station Antennas**:
   - Typically Collinear Dipole Arrays inside a radome.
   - Used to cover a specific sector (e.g., 3 sectors of 120 degrees each).
   - Provide high gain in horizontal direction and narrow beam vertical direction.
   - Supports electrical or mechanical downtilt to contain coverage.
2. **Mobile Antennas**:
   - **PIFA (Planar Inverted-F Antenna)**: Very common in phones. Compact, built onto PCB.
   - **Monopole/Whip**: Used on vehicles.
   - Features: Omnidirectional in azimuth plane to allow reception from any direction.

Mnemonic

“”BEST: Base-stations Employ Sector Technology””