Antenna & Wave Propagation (4341106) - Winter 2024 Solution

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Question 1(a) [3 marks]

Define: (1) Directivity, (2) Gain, and (3) HPBW

Solution

Parameter	Definition
Directivity	The ratio of radiation intensity in a given direction to the average radiation intensity in all directions.
Gain	The ratio of power radiated in a specific direction to the power that would be radiated by an isotropic antenna with the same input power.
HPBW (Half Power Beam Width)	The angular width of the main lobe where the power falls to half (-3dB) of its maximum value.

Mnemonic

Mnemonic: "DGH: Direction Gets Higher power with narrow beam"

Question 1(b) [4 marks]

List the properties of electromagnetic waves

Solution

Property	Description
Transverse nature	Electric and magnetic fields are perpendicular to each other and to direction of propagation.
Velocity	Travel at speed of light (3×10^8 m/s) in free space.
Frequency range	Vary from few Hz to several THz.
Energy transport	Carry energy from one point to another without need of medium.
Reflection	Can be reflected from conducting surfaces.
Refraction	Change direction when passing between different media.
Diffraction	Can bend around obstacles.
Polarization	The orientation of electric field vector.

Mnemonic

Mnemonic: "TVFERRDP: Travel Very Fast, Energy Reflects Refracts Diffracts Polarizes"

Question 1(c) [7 marks]

Explain physical concept of generation of Electromagnetic wave

Solution

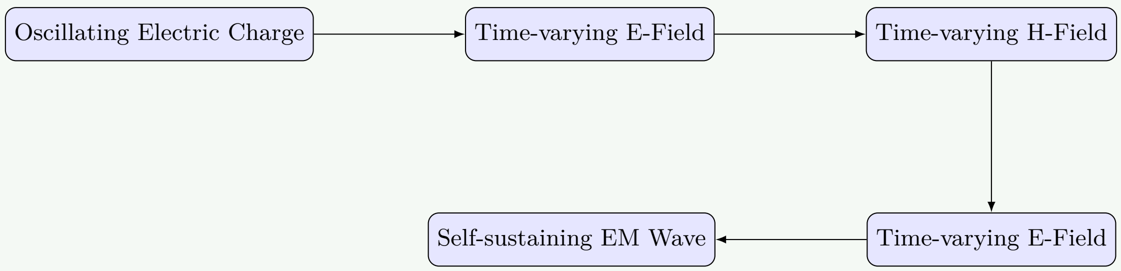

Figure 1. Generation of Electromagnetic Wave

Process of EM Wave Generation:
- **Accelerating charge**: When electric charge accelerates, it produces time-varying electric field.
- **Changing electric field**: This creates a time-varying magnetic field.
- **Changing magnetic field**: In turn creates a time-varying electric field.
- **Self-propagation**: This mutual creation of fields results in self-propagating wave.
- **Energy transfer**: EM waves transfer energy from transmitter to receiver.

Maxwell's Equations: These four equations mathematically describe the generation and propagation of EM waves:
1. Electric field from charges (Gauss's law).
2. No magnetic monopoles exist.
3. Electric fields from changing magnetic fields (Faraday's law).
4. Magnetic fields from currents and changing electric fields (Ampere's law).

Mnemonic

Mnemonic: "CASES: Charges Accelerate, Self-sustaining Electric-Magnetic fields"

Question 1(c) OR [7 marks]

Explain how electromagnetic field radiated from a center fed dipole

Solution

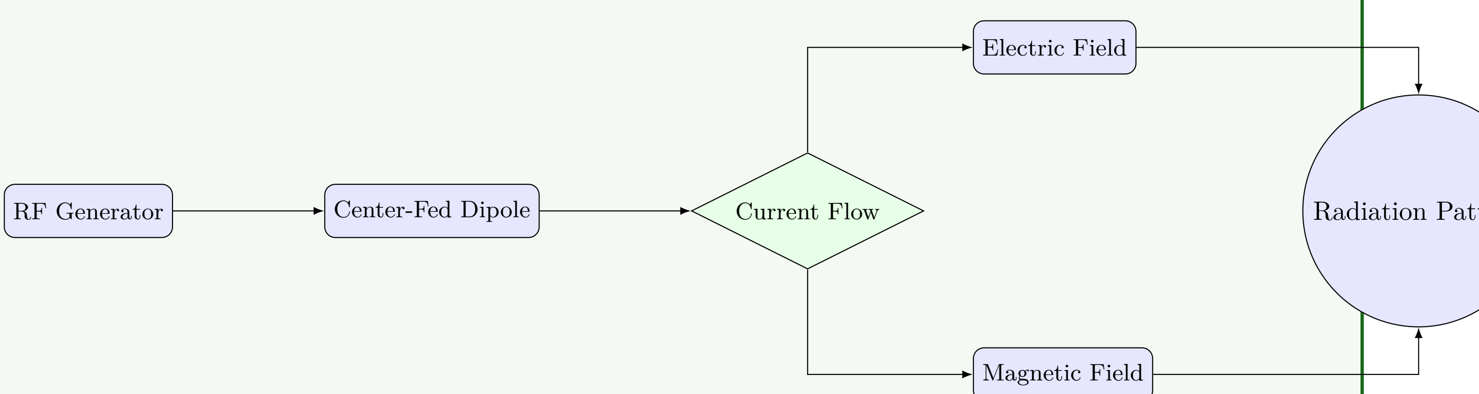

Figure 2. Radiation from Center-Fed Dipole

Radiation Process:

Stage	Process
1. Current excitation	RF signal applied at center of dipole creates alternating current.
2. Current distribution	Sinusoidal current distribution forms along dipole, maximum at center, zero ends.
3. Electric field	Oscillating charges create time-varying electric field perpendicular to dipole.
4. Magnetic field	Current flow creates magnetic field perpendicular to both dipole and electric
5. Near field	Complex field pattern forms close to antenna ($< \lambda/2\pi$).
6. Far field	At distances $> 2\lambda$, radiation stabilizes to form distinctive pattern with main side lobes.

Characteristics:

- **Maximum radiation**: Perpendicular to dipole axis.
- **Null radiation**: Along dipole axis.
- **Omnidirectional**: In azimuth plane (perpendicular to dipole).
- **Polarization**: Same as orientation of dipole.

Mnemonic

Mnemonic: "COME-FR: Current Oscillates, Making Electric-magnetic Fields that Radiate"

Question 2(a) [3 marks]

Differentiate the resonant and non-resonant antennas

Solution

Parameter	Resonant Antennas	Non-Resonant Antennas
Physical length	Multiple of $\lambda/2$ (usually $\lambda/2$ or λ)	Not related to wavelength (typically $> \lambda$).
Standing waves	Strong standing waves present.	Minimal standing waves.
Current distribution	Sinusoidal with maximum at center.	Traveling wave with uniform amplitude.
Input impedance	Resistive (at resonant frequency).	Complex (resistive + reactive).
Bandwidth	Narrow bandwidth.	Wide bandwidth.
Examples	Half-wave dipole, folded dipole.	Rhombic antenna, traveling wave antenna.

Mnemonic

Mnemonic: "SIN-CIB: Size, Impedance, Narrow vs Complex, Impedance, Broad"

Question 2(b) [4 marks]

Explain Yagi antenna and discuss its radiation characteristics

Solution

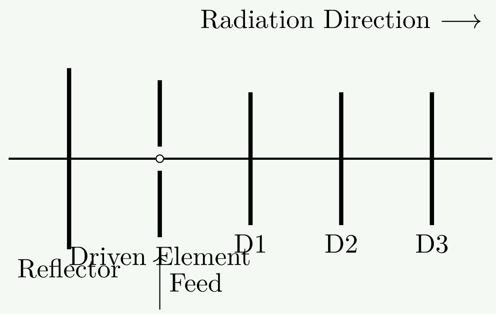

Figure 3. Yagi-Uda Antenna Structure

Yagi Antenna Components:

- **Driven element**: Half-wave dipole connected to transmission line.
- **Reflector**: Slightly longer than driven element, placed behind it.
- **Directors**: Multiple elements shorter than driven element, placed in front.

Radiation Characteristics:

- **Directivity**: High (7-12 dBi) with more directors.
- **Radiation pattern**: Unidirectional, narrow beam along director axis.
- **Front-to-back ratio**: 15-20 dB (good rejection of signals from rear).
- **Bandwidth**: Moderate (around 5% of center frequency).
- **Gain**: Increases with number of directors (typically 3-20 dBi).

Mnemonic

Mnemonic: "DRDU: Directors Radiate, Driven powers, Unidirectional beam"

Question 2(c) [7 marks]

Describe radiation characteristics of resonant wire antennas and draw the current distribution of $\lambda/2, 3\lambda/2$ and $5\lambda/2$ antenna

Solution

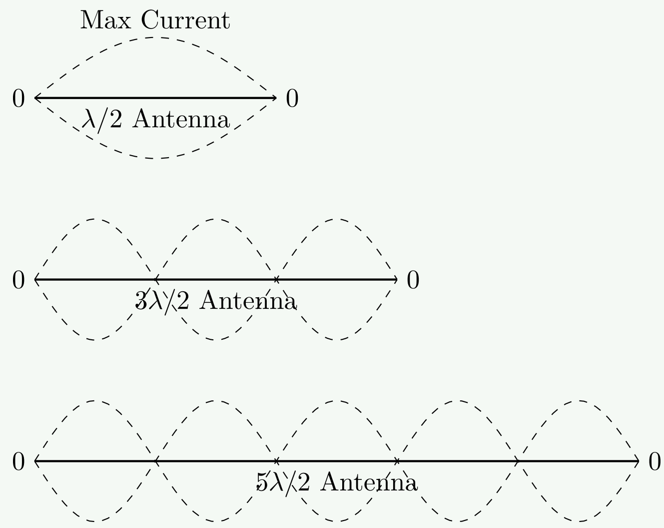

Figure 4. Current Distribution on Resonant Wire Antennas

Radiation Characteristics of Resonant Wire Antennas:

Characteristic	Description
Current distribution	Sinusoidal, with maximum at center f
Input impedance	Approximately 73Ω for $\lambda/2$, varies fo
Radiation pattern	Figure-8 pattern ($\lambda/2$), more complex
Directivity	2.15 dBi for $\lambda/2$, increases with lengt
Polarization	Linear, parallel to wire orientation.
Efficiency	High for properly constructed antenn

Key Points:

- $\lambda/2$ antenna has single current maximum at center.
- $3\lambda/2$ antenna has three half-cycles of current distribution.
- $5\lambda/2$ antenna has five half-cycles of current distribution.
- More half-wavelengths create more radiation lobes.
- Feed point is typically at current maximum for best impedance match.

Mnemonic

Mnemonic: "SIMPLE: Sinusoidal In Middle Produces Lobes Efficiently"

Question 2(a) OR [3 marks]

Differentiate the broad side and end fire array antennas

Solution

Parameter	Broadside Array	End Fire Array
Direction of max radiation	Perpendicular to the array axis.	Along the array axis.
Phase difference	0° (in-phase).	180° or progressive phase.
Element spacing	Typically $\lambda/2$.	Typically $\lambda/4$ to $\lambda/2$.
Radiation pattern	Narrow in plane containing array axis.	Narrow in plane perpendicular to array elements.
Directivity	High, increases with number of elements.	High, increases with number of elements.
Applications	Fixed point-to-point links.	Direction finding, radar.

Mnemonic

Mnemonic: "BEPODS: Broadside-End, Perpendicular-Or-Direction, Spacing"

Question 2(b) OR [4 marks]

Explain loop antenna and discuss its radiation characteristics

Solution

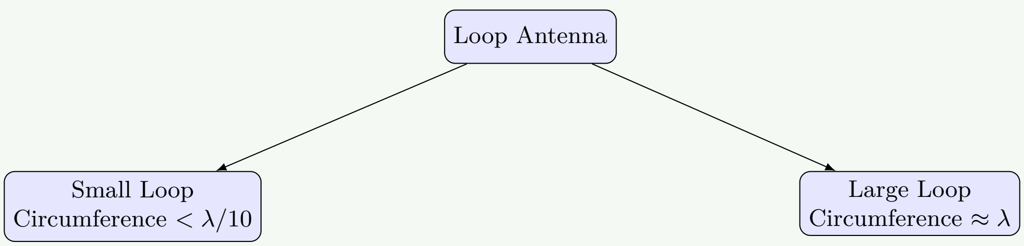

Figure 5. Types of Loop Antennas

Loop Antenna Characteristics:

Parameter	Small Loop	Large Loop
Current distribution	Uniform around loop.	Varies around circumf
Radiation pattern	Figure-8 (perpendicular to loop plane).	More complex with m
Directivity	Low (1.5 dBi).	Higher (3-4 dBi).
Polarization	Magnetic field perpendicular to loop.	Electric field in plane
Input impedance	Very low ($< 10\Omega$).	Higher (50-200Ω).
Applications	Direction finding, AM receivers.	HF communications,

Mnemonic

Mnemonic: "SCALED: Size Changes Antenna's Lobes, Efficiency, and Direction"

Question 2(c) OR [7 marks]

Describe radiation characteristics of non resonant wire antennas and draw the radiation pattern of $\lambda/2, 3\lambda/2$ and $5\lambda/2$ antenna

Solution

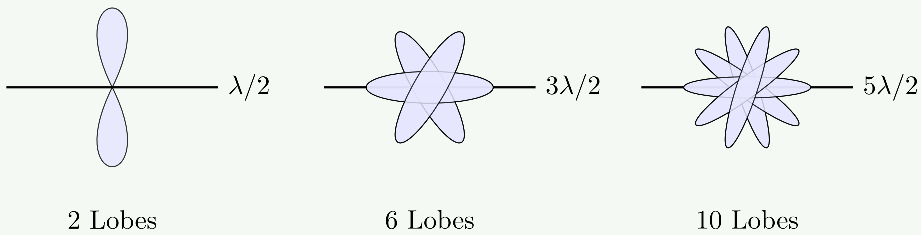

Figure 6. Radiation Patterns of Resonant Wire Antennas (Simplified)

Non-Resonant Wire Antenna Characteristics:

Characteristic	Description
Current distribution	Traveling waves with minimal standing waves.
Termination	Usually terminated with resistive load to preve
Bandwidth	Wide bandwidth operation.
Input impedance	More constant across frequency range.
Radiation pattern	$\lambda/2$: Single main lobe on each side (tilted). $3\lambda/2$: Three main lobes on each side (tilted). $5\lambda/2$: Five main lobes on each side (tilted).
Directivity	Increases with length but divided among multi
Efficiency	Lower than resonant antennas due to resistive

Mnemonic

Mnemonic: "TRIBE-WL: Traveling Resistance Improves Bandwidth, Efficiency Worse, Lobes multiply"

Question 3(a) [3 marks]

Write short note on micro strip (patch) antenna

Solution

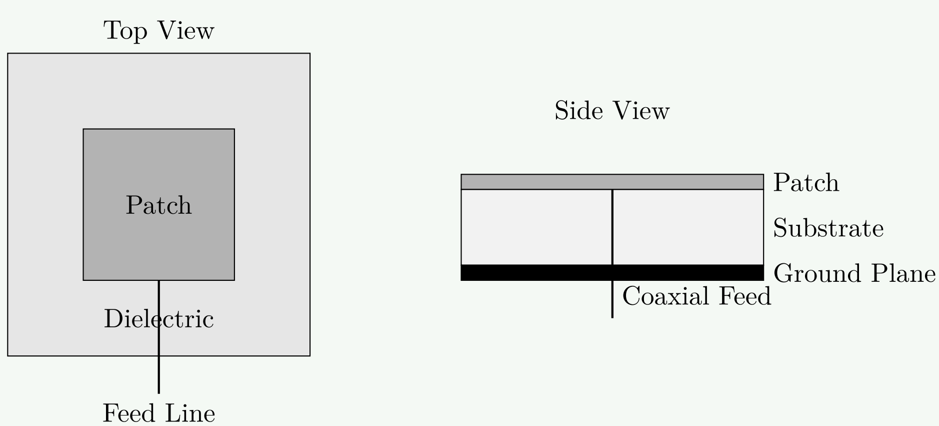

Figure 7. Microstrip Patch Antenna Structure

Microstrip Patch Antenna:

- **Structure**: Metal patch on dielectric substrate with ground plane.

- **Size**: Typically $\lambda/2 \times \lambda/2$ or $\lambda/2 \times \lambda/4$.
- **Feed methods**: Microstrip line, coaxial probe, aperture coupling.
- **Radiation**: From fringing fields at patch edges.
- **Polarization**: Linear or circular depending on patch shape.
- **Bandwidth**: Narrow (3-5% of center frequency).
- **Applications**: Mobile devices, satellites, aircraft, RFID.

Mnemonic

Mnemonic: "SLIM-PCB: Small, Lightweight, Integrable Microwave Printed Circuit Board"

Question 3(b) [4 marks]

Explain helical antenna and discuss its radiation characteristics

Solution

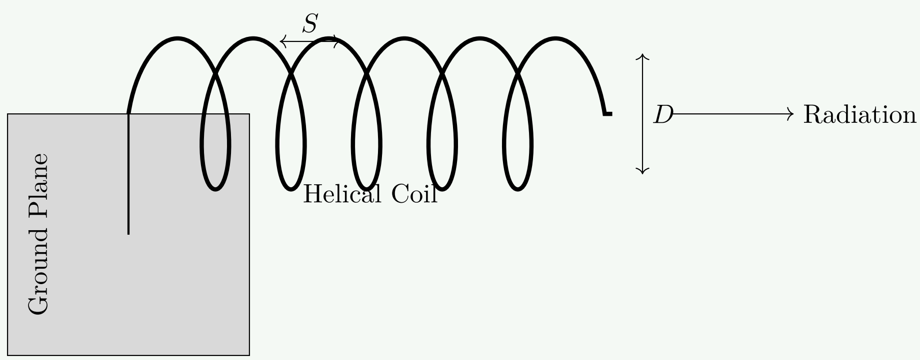

Figure 8. Helical Antenna (Axial Mode)

Helical Antenna Characteristics:

Parameter	Normal Mode	Axial Mode
Helix circumference	Small ($< \lambda/\pi$).	About λ.
Radiation pattern	Omnidirectional (like dipole).	Directional (end-fire).
Polarization	Linear, perpendicular to helix axis.	Circular (RHCP or LHC
Input impedance	High (120-200Ω).	100-200Ω.
Bandwidth	Narrow.	Wide (up to 70%).
Applications	Mobile phones, FM radio.	Satellite comms, space t

Mnemonic

Mnemonic: "NASA-CP: Normal Axial Spacing Affects Circular Polarization"

Question 3(c) [7 marks]

Explain horn antenna and discuss its radiation characteristics

Solution

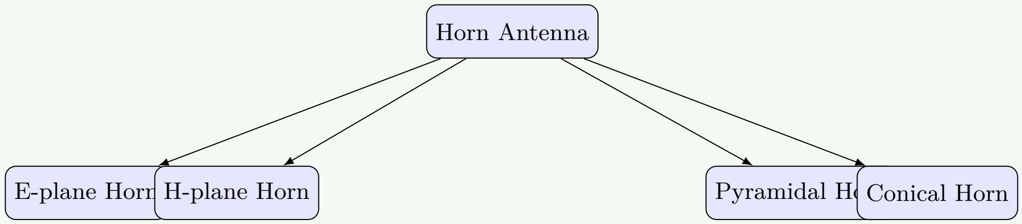

Figure 9. Types of Horn Antennas

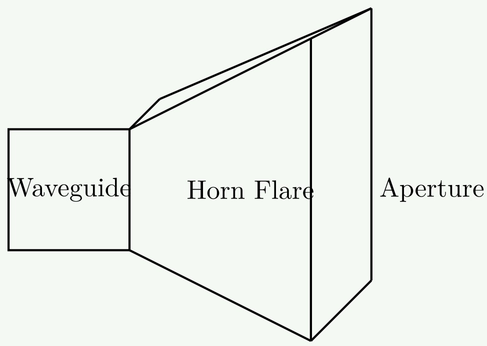

Figure 10. Pyramidal Horn Antenna Structure

Horn Antenna Characteristics:

Characteristic	Description
Operating principle	Gradual transition from waveguide to free space.
Frequency range	Microwave and mm-wave (1-300 GHz).
Directivity	Medium to high (10-20 dBi).
Radiation pattern	Directional with main lobe in forward direction.
Beamwidth	E-plane: 40-50°, H-plane: 40-50°.
Polarization	Linear (matches waveguide).
Bandwidth	Very wide ($>$ 100%).
Efficiency	Very high ($>$ 90%).
Applications	Radar, satellite communications, EMC testing.

Mnemonic

Mnemonic: "POWER-HF: Pyramidal Or Waveguide Extended, Radiates High Frequencies"

Question 3(a) OR [3 marks]

Write short note on slot antenna

Solution

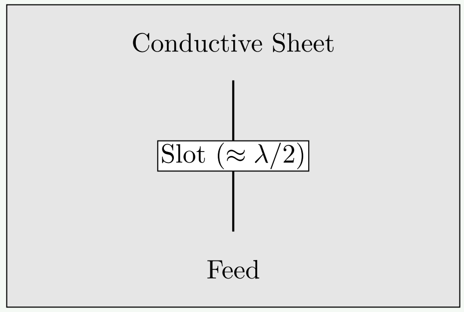

Figure 11. Slot Antenna

Slot Antenna:

- **Structure**: Narrow slot cut in conductive sheet/plane.
- **Size**: Typically $\lambda/2$ long for resonance.
- **Feed method**: Across the slot at center or offset.
- **Radiation pattern**: Similar to dipole but rotated 90° (Babinet's principle).
- **Polarization**: Linear, perpendicular to slot length.
- **Impedance**: High (several hundred ohms).
- **Applications**: Aircraft, satellites, base stations.

Mnemonic

Mnemonic: "SCRAP: Slot Cut Radiates Alternating Polarization"

Question 3(b) OR [4 marks]

Explain parabolic reflector antenna and discuss its radiation characteristics

Solution

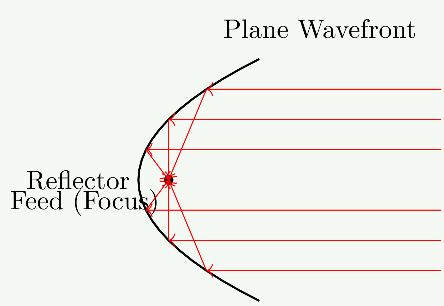

Figure 12. Parabolic Reflector Ray Tracing

Parabolic Reflector Antenna Characteristics:

Characteristic	Description
Operating principle	Focuses parallel incoming waves to focal point (r
Frequency range	From UHF to millimeter waves (300 MHz - 300 G
Directivity	Very high (30-40 dBi for large dishes).
Radiation pattern	Highly directional, narrow main beam.
Beamwidth	Inversely proportional to diameter ($\theta \approx 70\lambda/D$ d
Feed types	Prime focus, Cassegrain, Gregorian, offset.
Efficiency	50-70% depending on feed design and blockage.

Mnemonic

Mnemonic: "FIND-SHF: Focused, Intense Narrow Directivity for Super High Frequencies"

Question 3(c) OR [7 marks]

Describe V and inverted V antenna

Solution

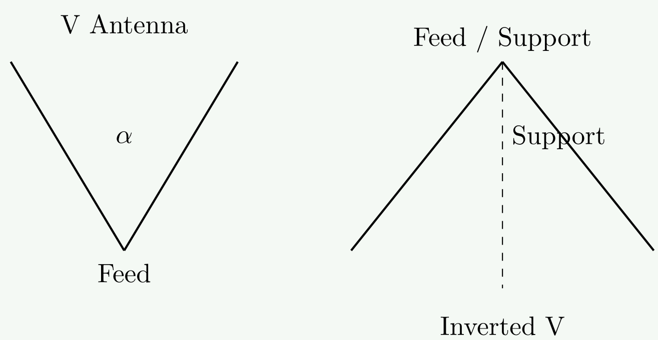

Figure 13. V and Inverted V Antennas

Comparison:

Characteristic	V Antenna	Inverted V Antenna
Construction	Two equal length wires in V-shape.	Bent dipole in inverted V-shape.
Angle	10-90° (affects directivity).	90-120° typically.
Leg Length	Multiple wavelengths ($1 - 6\lambda$).	$\lambda/4$ each (total $\lambda/2$).
Pattern	Bidirectional/Unidirectional.	Omnidirectional (mostly).
Impedance	300-900Ω.	Lower ($\approx 50\Omega$).
Mounting	Horizontal.	Vertical (single center support).

Mnemonic

Mnemonic: "VOVO: V Outward (radiation), V One-support (inverted)"

Question 4(a) [3 marks]

Define: (1) Reflection, (2) Refraction and (3) Diffraction

Solution

Phenomenon	Definition
Reflection	The bouncing back of electromagnetic waves when they strike a boundary between two different media without penetrating the second medium.
Refraction	The bending of electromagnetic waves when they pass from one medium to another due to change in wave velocity.
Diffraction	The bending of electromagnetic waves around obstacles or through openings, allowing waves to propagate into shadowed regions.

Mnemonic

Mnemonic: "RRD: Rays Rebound, Redirect, Disperse"

Question 4(b) [4 marks]

List HAM radio application for communication

Solution

Application Category	Specific Applications
Emergency communications	Disaster relief, emergency response, weather reporting.
Public service	Community events, search and rescue, traffic monitoring.
Technical experimentation	Antenna design, propagation studies, digital modes testing.
International goodwill	DX communication, contesting, international friendship.
Personal recreation	Casual conversations, hobby groups, radio clubs.
Educational outreach	School programs, STEM activities, training new operators.
Space communication	Satellite operation, ISS contact, EME (moon bounce).
Digital communication	APRS, packet radio, FT8, RTTY, PSK31.

Mnemonic

Mnemonic: "EPTIPS-D: Emergency, Public, Technical, International, Personal, Space, Digital"

Question 4(c) [7 marks]

Explain ionosphere's layers and sky wave propagation

Solution

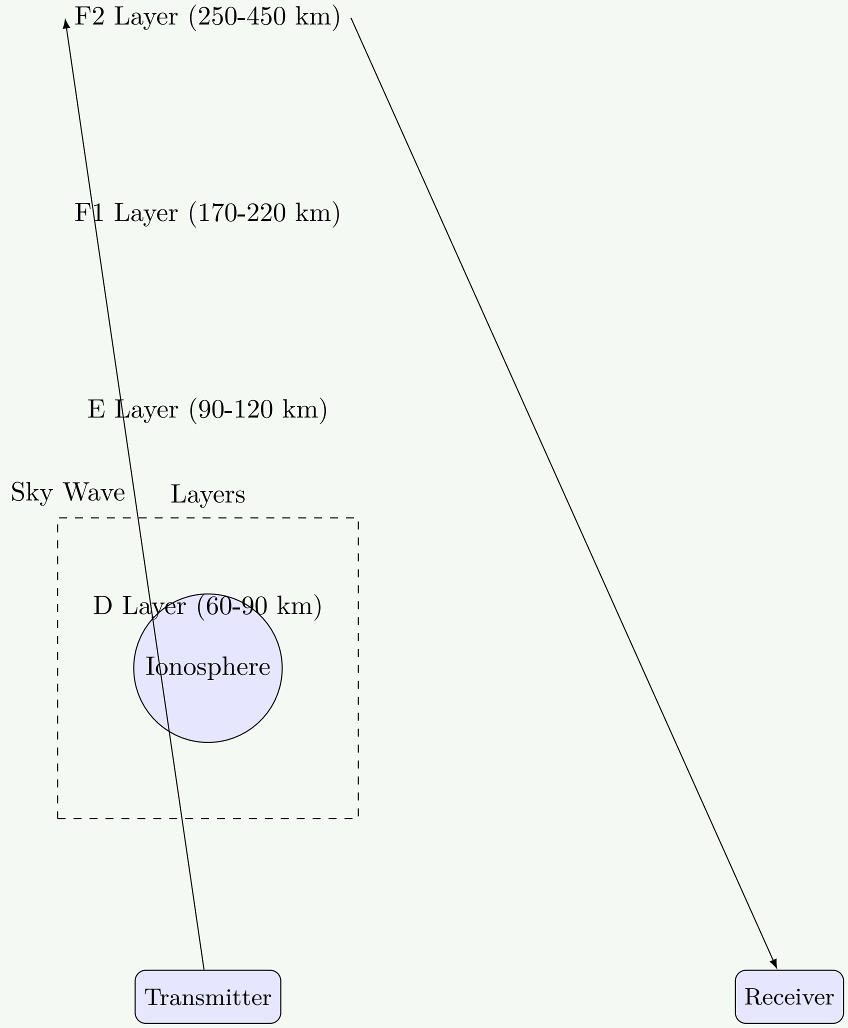

Figure 14. Ionospheric Layers and Sky Wave Propagation

Ionospheric Layers:

Layer	Altitude	Characteristics	Effect on Radio Waves
D Layer	60-90 km	Low ionization, exists only during daylight.	Absorbs LF/MF signals, minimal refraction.
E Layer	90-120 km	Medium ionization, stronger during day.	Refracts HF waves up to 5 MHz.
F1 Layer	170-220 km	Present only during day, merges with F2 at night.	Refracts higher HF frequencies.
F2 Layer	250-450 km	Highest ionization, present day and night.	Main layer for long-distance HF communication.

Sky Wave Propagation Parameters:

- **Virtual Height**: Apparent height where reflection seems to occur (higher than actual due to gradual refraction).
- **Critical Frequency**: Maximum frequency that can be reflected when transmitted vertically.
- **Maximum Usable Frequency (MUF)**: Highest frequency that can be used for communication between two points.
- **Skip Distance**: Minimum distance from transmitter where sky waves return to Earth.
- **Lowest Usable Frequency (LUF)**: Minimum frequency that provides reliable communication.
- **Optimum Working Frequency (OWF)**: Typically 85% of MUF, provides most reliable communication.

Mnemonic

Mnemonic: "DEFMSL: During day, Every Frequency Makes Somewhat Longer paths"

Question 4(a) OR [3 marks]

Define: (1) MUF, (2) LUF and (3) Skip distance

Solution

Term	Definition
MUF (Maximum Usable Frequency)	The highest frequency that can be used for reliable communication between two specific points via ionospheric reflection.
LUF (Lowest Usable Frequency)	The minimum frequency that provides adequate signal strength for reliable communication despite D-layer absorption.
Skip Distance	The minimum distance from a transmitter at which a sky wave of a specific frequency returns to Earth.

Mnemonic

Mnemonic: "MLS: Maximum frequency Leaps, Lowest frequency Seeps, Skip distance Spans"

Question 4(b) OR [4 marks]

List HAM radio digital modes of communication

Solution

Digital Mode	Description	Typical Frequency Bands
FT8	Low power, narrow bandwidth, automated exchange.	HF bands (especially 20m, 40m, 80m).
PSK31	Phase Shift Keying, keyboard-to-keyboard.	HF bands (especially 20m, 40m).
RTTY	Radio Teletype, oldest digital mode.	HF bands.
APRS	Automatic Packet Reporting System, position reporting.	VHF (typically 144.39 MHz in US).
SSTV	Slow Scan Television, image transmission.	HF bands (especially 20m).
JT65/JT9	Weak signal modes for EME and DX.	HF and VHF bands.
WINLINK	Email over radio.	HF and VHF bands.
DMR	Digital Mobile Radio, voice digital mode.	VHF and UHF bands.

Mnemonic

Mnemonic: "PRAW-JDW: PSK, RTTY, APRS, WINLINK, JT65, DMR"

Question 4(c) OR [7 marks]

Explain space wave propagation

Solution

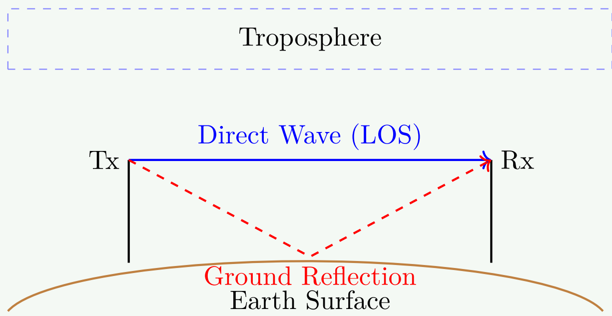

Figure 15. Space Wave Propagation Mechanisms

Space Wave Propagation: Space wave propagation refers to radio waves that travel through the troposphere (lower atmosphere) rather than via ionospheric reflection. It includes:

1. **Direct wave**: Travels in straight line from transmitter to receiver (line-of-sight).
2. **Ground-reflected wave**: Reflects off Earth's surface before reaching receiver.
3. **Surface wave**: Follows Earth's curvature due to diffraction.

Types of Space Wave Propagation:

- **Tropospheric Scatter Propagation**:
  - **Mechanism**: Signal scattering by irregularities in troposphere.
  - **Frequency range**: VHF, UHF, SHF (100 MHz - 10 GHz).
  - **Distance**: 100-800 km (beyond horizon).
- **Duct Propagation**:
  - **Mechanism**: Trapping of waves in atmospheric ducts (layers with abnormal refractive index).
  - **Distance**: Up to 2000 km (far beyond horizon).

Factors Affecting Space Wave Propagation:

- **Height of antennas**: Higher antennas increase range.
- **Frequency**: Higher frequencies experience less diffraction.
- **Terrain**: Obstacles block signals (Fresnel zone clearance needed).
- **Weather**: Temperature inversions, humidity affect ducting.
- **Earth's curvature**: Limits line-of-sight distance.

Mnemonic

Mnemonic: "DRIFT-SD: Direct Routes, Irregular Formations of Troposphere, Scatter and Ducts"

Question 5(a) [3 marks]

Define: (1) Beam area (2) Beam efficiency, and (3) Effective aperture

Solution

Parameter	Definition
Beam Area	The solid angle through which all of the power radiated by the antenna would pass if the radiation intensity was constant at its maximum value.
Beam Efficiency	The ratio of power radiated in the main beam to the total power radiated by the antenna.
Effective Aperture	The ratio of power received by the antenna to the power density of the incident wave.

Mnemonic

Mnemonic: "BEA: Beam area Encloses, efficiency Excludes sidelobes, Aperture Extracts power"

Question 5(b) [4 marks]

Describe need of smart antenna

Solution

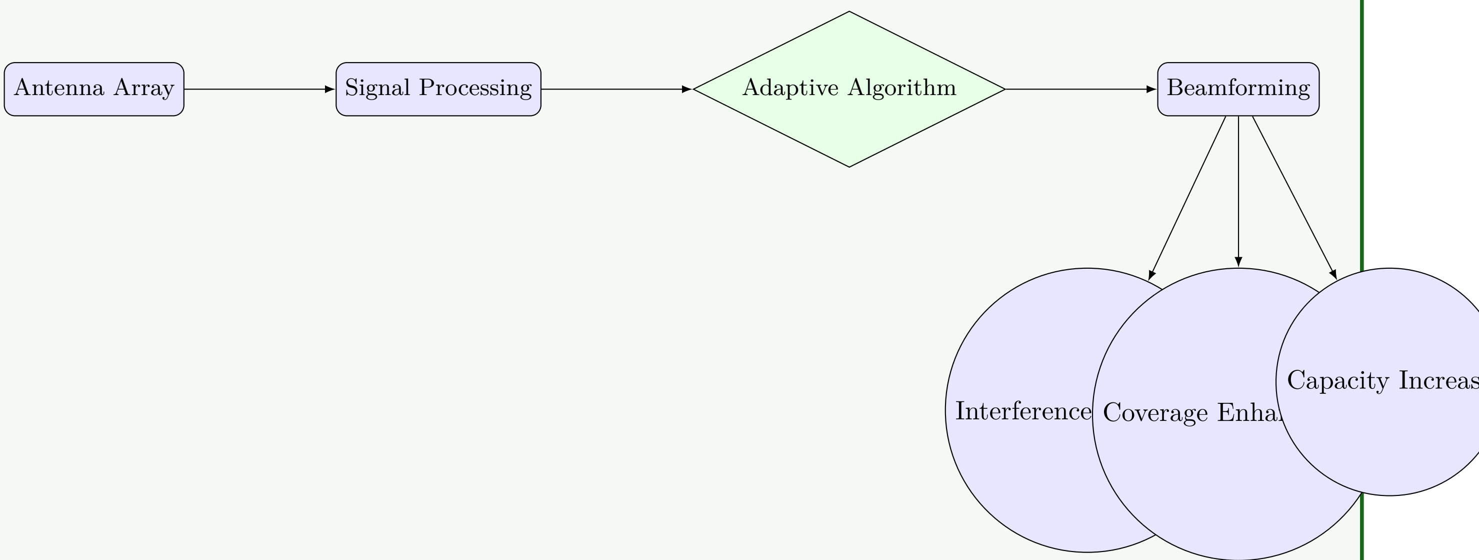

Figure 16. Smart Antenna System Concept

Need for Smart Antennas:

Need	Description
Spectrum efficiency	Reuse frequencies more effectively in same geographic area.
Capacity enhancement	Support more users in same bandwidth through spatial separation
Coverage extension	Increase range by focusing energy in desired directions.
Interference reduction	Minimize effects of co-channel interference and jammers.
Energy efficiency	Reduce transmitted power by focusing energy only where needed.
Multipath mitigation	Reduce fading by selecting optimal signal paths.
Location services	Enable direction finding and positioning applications.
Signal quality	Improve SNR through spatial filtering.

Mnemonic

Mnemonic: "SLIM-ACES: Spectrum efficiency, Location services, Interference reduction, Multipath mitigation, Adaptive beams, Capacity, Energy, Signal quality"

Question 5(c) [7 marks]

Draw the DTH Receiver indoor and outdoor black diagram and discuss its functions

Solution

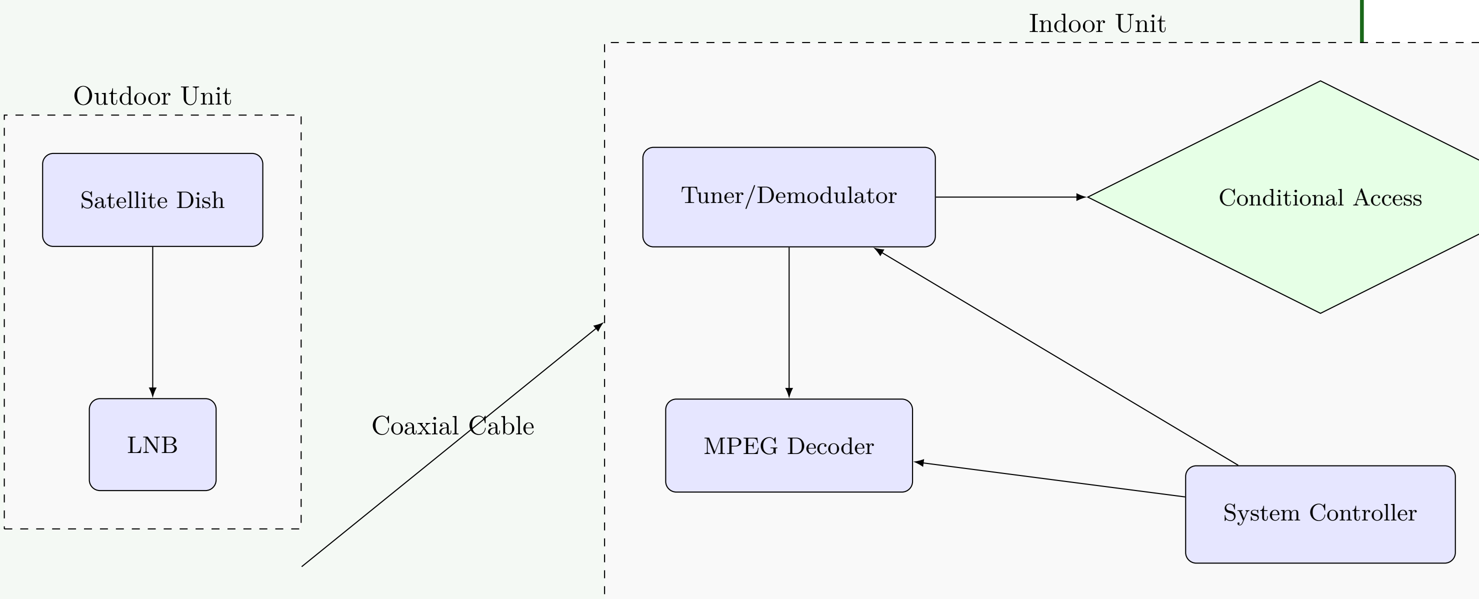

Figure 17. DTH Receiver System Block Diagram

DTH Receiver System Components and Functions:

Outdoor Unit Components:

- **Satellite Dish**: Collects and reflects weak satellite signals to focal point.
- **LNB (Low Noise Block)**: Receives signals from dish, amplifies them with minimal noise addition, and converts high frequency (10-12 GHz) to lower IF frequency (950-2150 MHz).

Indoor Unit Components:

- **Tuner/Demodulator**: Selects desired channel frequency, demodulates signal to extract digital data stream.
- **MPEG-2/4 Decoder**: Decodes compressed video/audio signals into viewable/audible content.
- **Conditional Access Module**: Provides security and decryption for subscribed channels.
- **System Controller/CPU**: Manages overall operation, processes user commands, updates software.
- **User Interface**: Provides on-screen display, receives remote control inputs.

Signal Flow Process:

1. Satellite dish collects signals and focuses them to LNB.
2. LNB amplifies, filters and converts signals to lower frequency.
3. Coaxial cable carries IF signals to indoor unit.
4. Tuner selects channel and demodulates signal.
5. Conditional access module decrypts authorized content.

Mnemonic

Mnemonic: "SALT-DCU: Satellite dish And LNB Transmit, Demodulator Converts and Unscrambles"

Question 5(a) OR [3 marks]

Define: (1) Antenna, (2) Folded dipole, and (3) Antenna array

Solution

Term	Definition
Antenna	A device that converts electrical signals into electromagnetic waves for transmission or electromagnetic waves into electrical signals for reception.
Folded Dipole	A dipole antenna modified by adding a second conductor connected at both ends to the first, forming a narrow loop with feed point at the bottom center.
Antenna Array	A system of multiple antenna elements arranged in a specific geometric pattern to achieve desired radiation characteristics.

Mnemonic

Mnemonic: ”AFD: Antenna Feeds, Folded Doubles impedance, Directivity increases with Arrays”

Question 5(b) OR [4 marks]

Describe application of smart antenna

Solution

Application Area	Specific Applications
Mobile Communications	Base stations for 4G/5G networks, capacity enhancement, coverage improvement.
Wi-Fi Systems	MIMO routers, extended range access points, interference mitigation.
Radar Systems	Phased array radars, target tracking, electronic warfare, weather radars.
Satellite Communications	Adaptive beamforming, tracking earth stations, interference rejection.
Military/Defense	Jammers, secure communications, reconnaissance, surveillance.
IoT Networks	Low-power wide-area networks, directional coverage for sensors.
Vehicle Communications	V2X communications, autonomous vehicles, collision avoidance.
Indoor Positioning	Location-based services, asset tracking, emergency services.

Mnemonic

Mnemonic: ”SWIM-MIV: Satellite, Wireless, IoT, Military, Mobile, Indoor positioning, Vehicles”

Question 5(c) OR [7 marks]

Explain Terrestrial mobile communication antennas and also discuss about base station and mobile station antennas

Solution

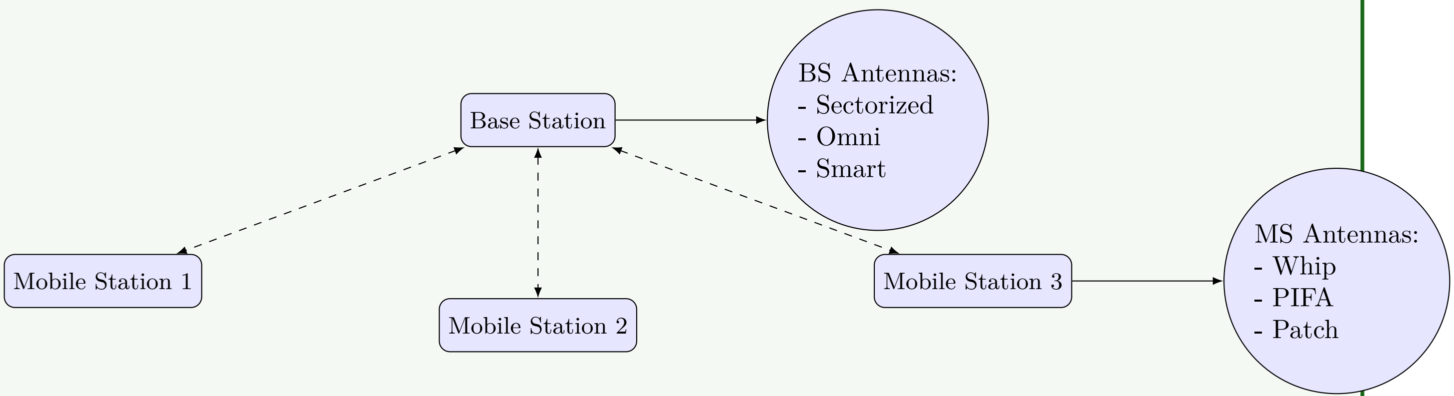

Figure 18. Terrestrial Mobile Communication System

Base Station Antennas:

Antenna Type	Characteristics	Applications
Omnidirectional	360° horizontal coverage, 6-12 dBi gain.	Rural areas, low traffic den
Sectorized	65-120° sector coverage, 12-20 dBi gain.	Urban/suburban areas, fre reuse.
Diversity Antennas	Multiple elements, space/polarization diversity.	Multipath environments, h reliability.
Smart Antennas	Adaptive beamforming, 15-25 dBi gain.	High capacity areas, 4G/5

Mobile Station Antennas:

Antenna Type	Characteristics	Applications
Whip/Monopole	External, $\lambda/4$, omnidirectional.	Vehicle-mounted phones,
Helical	Compact, good bandwidth, flexible.	Portable radios, early mo
PIFA (Planar Inverted-F)	Internal, compact, multiband.	Modern smartphones, tal
Patch/Microstrip	Low profile, directional, dual pol.	Data cards, fixed termina

Key Considerations:

- **Base Station**: High gain, focused beams, interference control (downtilt).
- **Mobile Station**: Small size, multiband, SAR compliance, design integration.

Mnemonic

Mnemonic: "BOMBS-WHIP: Base Omni/Multi-Beam/Smart, Whip/Helical/Inverted-F/Patch"